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Toward an Intelligent Long-Term Assistance for People with Dementia In the Context of Navigation in Indoor Environments

Intelligente Langzeit-Unterstützung für Menschen mit Demenz im Kontext der Navigation in Gebäuden

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Abstract

Dementia is a complex neurodegenerative syndrome that by 2050 could affect about 135 Million people worldwide. People with dementia experience a progressive decline in their cognitive abilities and have serious problems coping with activities of daily living, including orientation and wayfinding tasks. They even experience difficulties in finding their way in a familiar environment. Being lost or fear of getting lost may consequently develop into other psychological deficits such as anxiety, suspicions, illusions, and aggression. Frequent results are social isolation and a reduced quality of life. Moreover, the lives of relatives and caregivers of people with dementia are also negatively affected.

Regarding navigation and orientation, most existing approaches focus on outdoor environment and people with mild dementia, who have the capability to use mobile devices. However, Rasquin (2007) observe that even a device with three buttons may be too complicated for people with moderate to severe dementia. In addition, people who are living in care homes mainly perform indoor activities. Given this background, we decided to focus on designing a system for indoor environments for people with moderate to severe dementia, who are unable or reluctant to use smartphone technology.

Adopting user-centered design approach, context and requirements of people with dementia were gathered as a first step to understand needs and difficulties (especially in spatial disorientation and wayfinding problems) experienced in dementia care facilities. Then, an "Implicit Interactive Intelligent (III) Environment" for people with dementia was proposed emphasizing implicit interaction and natural interface. The backbone of this III Environment is based on supporting orientation and navigation tasks with three systems: a monitoring system, an intelligent system, and a guiding system. The monitoring system and intelligent system automatically detect and interpret the locations and activities performed by the users i.e. people with dementia. This approach (implicit input) reduces cognitive workload as well as physical workload on the user to provide input. The intelligent system is also aware of context, predicts next situations (location, activity), and decides when to provide an appropriate service to the users. The guiding system with intuitive and dynamic environmental cues

(lighting with color) has the responsibility for guiding the users to the places they need to be.

Overall, three types of a monitoring system with Ultra-Wideband and iBeacon technologies, different techniques and algorithms were implemented for different contexts of use. They showed a high user acceptance with a reasonable price as well as decent accuracy and precision. In the intelligent system, models were built to recognize the users' current activity, detect the erroneous activity, predict the next location and activity, and analyze the history data, detect issues, notify them and suggest solutions to caregivers via visualized web interfaces. About the guiding systems, five studies were conducted to test and evaluate the effect of lighting with color on people with dementia. The results were promising. Although several components of III Environment in general and three systems, in particular, are in place (implemented and tested separately), integrating them all together and employing this in the dementia context as a fully properly evaluation with formal stakeholders (people with dementia and caregivers) are needed for the future step.

Zusammenfassung

Demenz ist ein komplexes neurodegeneratives Syndrom, von dem bis zum Jahre 2050 weltweit 135 Millionen Menschen betroffen sein könnten. Menschen mit Demenz erleben einen fortschreitenden Verlust ihrer kognitiven Fähigkeiten und haben Probleme alltägliche Aufgaben durchzuführen, was auch Orientierung und Navigationsaufgaben einschließt. Sie haben sogar Schwierigkeiten, sich in einer für sie vertrauten Umgebung zurechtzufinden. Orientierungslosigkeit oder die Angst davor sich zu verlaufen können sich zu negativen psychische Zuständen wie Ängstlichkeit, Misstrauen, Illusionen oder Aggressionen entwickeln. Häufiges Ergebnis sind soziale Isolation und eine reduzierte Lebensqualität. Darüber hinaus betreffen diese Probleme auch die Leben von Verwandten und Pflegern der Menschen mit Demenz.

Die meisten bestehenden Ansätze zur Navigation und Orientierung konzentrieren sich auf indoor Aktivitäten und Menschen mit milder Demenz, die fähig sind Mobile Geräte zu nutzen. Wie Rasquin (2007) beobachtete, kann aber sogar ein Gerät mit drei Knöpfen zu kompliziert für Menschen mit mittlerer bis schwerer Demenz sein. Zusätzlich finden die meisten Aktivitäten von Pflegeheimbewohnern innerhalb des Gebäudes statt. Vor diesem Hintergrund beschlossen wir uns auf das Design eines Indoor-Navigationssystems für Menschen mit mittlerer bis schwerer Demenz zu konzentrieren, die nicht in der Lage oder nicht willens sind Smartphones zu nutzen.

In einem Nutzerzentrierten Design Ansatz erhoben wir zuerst den Kontext und die Anforderungen für Menschen mit Demenz um Bedürfnisse und Schwierigkeiten (besonders der räumlichen Orientierungslosigkeit und Navigation) zu verstehen, die in Demenz - Pflegeeinrichtungen auftreten. Dann schlugen wir ein „Implicit Interactive Intelligent (III) Environment“ für Menschen mit Demenz vor, das die implizite Interaktion mit natürlichen Bedienoberflächen betont. Die Grundlage dieses III Environments besteht darin, Orientierungs- und Navigationsaufgaben durch drei Systeme zu unterstützen: ein Überwachungssystem, ein intelligentes System, und ein Leitsystem. Das Überwachungssystem und das intelligente System erkennen und interpretieren automatisch die Standorte und Aktivitäten der Nutzer, d.h. Menschen mit Demenz. Dieser Ansatz (implicit input) reduziert mentale sowie körperliche Belastung des Nutzers hinsichtlich der Eingaben. Das intelligente System kennt den Kontext, sagt bevorstehende Situationen vorher (Standort, Aktivität) und entscheidet, wann es dem Nutzer Ausgaben zur Verfügung stellt. Das Leitsystem ist mit seinen intuitiven und dynamischen Umgebungshinweisen (farbige Beleuchtung) zuständig die Nutzer an ihre Plätze zu führen.

Insgesamt wurden drei Varianten eines Überwachungssystems mit Ultra-Breitband und iBeacon Technologie, unterschiedlichen Techniken und Algorithmen für verschiedene Nutzerkontexte entwickelt. Sie zeigen hohe Nutzerakzeptanz bei vernünftigen Preisen sowie akzeptabler Messgenauigkeit und Klassifikationspräzision. Im intelligenten System wurden Modelle integriert, die die aktuelle Aktivität und Fehlverhalten der Nutzer erkennen, ihren nächsten Standort und Aktivität voraussagten und frühere Daten analysierten, Probleme identifizieren und vermerken und Pflegern Lösungen in visuellen Benutzerschnittstellen vorschlagen. Die Leitsysteme wurden in sechs Studien getestet um den Effekt ihrer farbigen Beleuchtung auf Menschen mit Demenz zu evaluieren. Die Ergebnisse sind vielversprechend. Obwohl einige Komponenten des III Environments im Allgemeinen und drei Systeme im Speziellen bereit sind (implementiert und separat getestet), ist es für zukünftige Schritte notwendig, alles zu integrieren, im Demenz Kontext einzusetzen und mit offiziellen Interessenvertretern (Menschen mit Demenz) vollständig zu evaluieren.

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Chapter 1

Introduction

This dissertation addresses building an indoor navigation assistance system for people with moderate to severe dementia using assistive technology. The contribution includes the focus on population overlooked i.e. people with moderate to severe dementia, the development and testing of three systems (an indoor monitoring system, a guiding system, an intelligent system), and a list of guidelines when working with and designing for people with dementia. Particularly, the thesis focuses on a novel approach with Implicit Interactive Intelligent (III) Environment emphasizing implicit interaction and natural interface. It covers details of developing an indoor monitoring specifically for people with dementia, designing and testing the effects of intuitive environmental guiding cues i.e. light and color, and building models for an intelligent system to recognize activity, predict next situation and give appropriate services to users at anytime in anywhere. In this chapter, the overview of dementia, overall problems, thesis objectives, and the methodology are presented.

1.1 Dementia

Demographic change makes today's societies face enormous challenges in the next decades. Dementia is one of those challenges. The term dementia describes a set of symptoms related to cognitive abilities including memory loss, mood changes, difficulties in spatiotemporal orientation, and problems with communication and reasoning (Alzheimer's Society, 2011; Span et al., 2013). Dementia is not a natural part of growing old (Georges, 2015), but statistically, the likelihood of getting the disease increases significantly with advancing age. It is caused by a progressive decline in brain functions, the most common type being Alzheimer's disease (60-70% of cases) (World Health Organization, 2017). To date, there is neither a cure for the disease nor an effective treatment to stop dementia's progression. However, research is actively underway to develop interventions to delay disease onset and to slow the disease's progression (Roberson and Mucke, 2006).

People with Dementia. According to the American Psychiatric Association (Rabins et al., 2007), the essential characteristics of people with dementia are multiple acquired cognitive deficits including memory impairment and at least one of the following impairment: aphasia (speaking problem), apraxia (motor planning disorder), agnosia (inability to recognize people, objects, etc.), or a problem in executive functioning (think abstractly, plan, initiate, sequence, monitor, and stop complex behavior). People with dementia experience a progressive decline in their cognitive abilities and have serious problems coping with activities of daily living, including orientation and wayfinding tasks (spatial disorientation) (Passini et al., 2000).

Population. The World Health Organization (World Health Organization, 2017) estimates that 47.5 million people have dementia worldwide, and 9.9 million new cases are found every year. The graying of the world population, i.e. combining of the growing senior population, increased life expectancy, and declining birthrates, suggest that the burden of dementia and long-term healthcare will be even more formidable. By 2050, dementia could affect about 135 million people worldwide (Prince et al., 2014). Between 2013 and 2050, the rates of dementia are projected to increase by 90% in Europe, 226% in Asia, 248% in America, and 345% in Africa (Prince, 2015). The population of people with dementia in Germany is currently 1.5 million, and this number is expected to rise to 2.5 million by 2030. It is at the second place, only after the USA (is currently 5.3 million and projected 13.8 million by 2050) in top 10 leading assistive technology research countries: USA, UK, Canada, Sweden, Italy, Germany, The Netherlands, France, Australia, Spain (Asghar et al., 2017).

Societal and economic impact. The estimated global societal cost of dementia was 818 billion US dollars in 2015, a 34% increase from 2010, and is predicted to be two trillion dollars by 2030 (Prince, 2015). The cost includes informal caregivers (e.g. family, friends, and volunteers), professional caregivers, and medical care. By 2040, dementia will represent approximately 25% of all Medicare spending in the US (Alzheimer's Association, 2014). Studies show that hospitalizations and emergency department visits, and cost of treating an episode for people with dementia are significantly higher than those with other diseases (Champlain Dementia Network, 2013; Feng et al., 2014). For example, the health and social care costs of dementia (£11.9 billion) in the UK is even higher than that of cancer (£5.0 billion), stroke (£2.9 billion), and chronic heart disease (£2.5 billion) combined (Luengo-Fernandez et al., 2015). Although having second largest population with dementia in top 10 countries, the current investments in Germany is only $ 2.6 billion (lowest among top 10 countries) (Asghar et al., 2017).

1.2 Diagnosis, Signs, and Symptoms of Dementia

1.2.1 Diagnosis

Dementia diagnosis often comes late, when the disease has already caused cognitive decline and brain damage. The delay in diagnosis hampers the effectiveness of current treatment available and preventive interventions. In the United States, 75% of people with dementia are undiagnosed (Steenhuysen, 2011). That number in England is about 50% (Department of Health, 2011) and in Germany, it is 44.5% (OECD, 2015). Diagnosing dementia and determining types of dementia can be challenging. The doctor needs to review the patient's medical history, symptoms, and run some tests such as neurological evaluation (e.g.memory, language, visual perception, etc.), brain scans (CT/MRI or PET scans), blood tests, and psychiatric evaluation to check the mental health condition. In order to assess dementia and to increase the precision of a decision by reducing subjectivity and increasing objectivity, several assessment scales have been developed over decades e.g. GDS - the Global Deterioration Scale for Assessment of Primary Degenerative Dementia (Reisberg et al., 1982), FAST - Functional Assessment Staging (Sclan and Reisberg, 1992), or CDR - Clinical Dementia Rating (Morris, 1993). However, in the literature, the stage of dementia is normally referred to as "early/mild dementia", "middle/moderate dementia", or "severe dementia". All scales can be converted into those three phases (Fig. 1.1). For the long-term, researchers need to find methods to screen for the disease before symptoms occur. One approach is using specific protein detection in cerebrospinal fluid and blood, genetic risk profiling, and brain imaging to predict the disease. For example, McDonald (McDonald, 2014) showed a link between the protein TDP-43 and cognitive decline and Alzheimer's. People with the TDP-43 protein in their brains were ten times more prone to having cognitive impairment at death.

1.2.2 Signs and Symptoms

Dementia is a slow decline in memory, thinking, and reasoning skills. When people grow older, the memory often changes but it is not typically disrupting daily life. It may be a symptom of dementia. According to Alzheimer's Association (Alzheimer's Association, 2009), there are ten warning signs (WS) or symptoms of dementia/Alzheimer disease (summarized in Figure 1.2). Each sign might be linked and affected by other signs. Following is brief descriptions of each sign and the difference with respective typical age-related change.

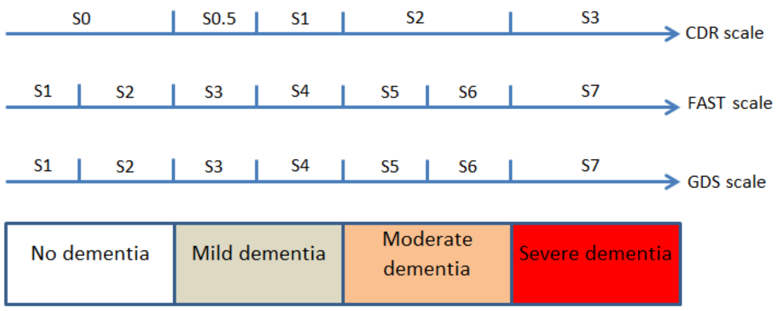

Fig. 1.1 Stage of dementia (S: Stage).

1. *Memory loss.*
   Memory loss is the most common sign of dementia/Alzheimer disease. People often forget recently learned information, as well as important dates or events. Moreover, they could ask for a same question/thing over and over, and increasingly need to rely on family members/carers or memory aids (e.g. electronic devices, reminder notes).
   Typical age-related change: Age-related change makes people sometimes forget names or events, but they normally remember those things later.

2. *Challenges in executive functioning.*
   People may get a disturbance in executive functioning including the ability to think abstractly, develop and follow a plan, or work with numbers. They may experience trouble following a cooking recipe, managing bills, and concentrating that take them a lot more time and efforts to do things they used to handle easily on their own.
   Typical age-related change: Making occasional errors when working with bills, numbers.

3. *Difficulty completing tasks.*
   People with dementia often get difficulty in completing tasks even familiar/daily tasks. For instance, they may forget the rules of a favorite game, the way to a familiar location.
   Typical age-related change: Occasionally needing support to handling technology devices, e.g. smart TVs.

4. *Confusion of time and place.*
   People with dementia can get disorder in time and place. They may lose track of dates and the current time of the day (day time, night time). A thing could confuse people with dementia if it is not happening immediately. Orientation is another severe problem. They may forget where they are, how they got there, and where they would like to go.

Typical age-related change: Getting confused about the day of the week or hard to find the way but figuring it out later.

5. *Trouble understanding visual images and spatial relationships.*
   Sometimes having a visual impairment is a sign of dementia. People may have difficulty in reading, determining color/contrast, or judging distance.
   Typical age-related change: Problems relating to cataracts.

6. *Word-using problem.*
   Struggling with vocabulary, having problems in naming objects are problems that people with dementia often experience. They may have trouble joining/following a conversation. They then tend to stop in the middle of the conversion, cannot continue, and may repeat themselves.
   Typical age-related change: Sometimes taking more time to find the right word.

7. *Misplacing things and incapability of retrace steps.*
   People with dementia may leave things in unusual places. However, unlike typical age-related changes, they cannot retrace their steps to find objects again. They sometimes accuse others of stealing.
   Typical age-related change: Misplacing things but able to trace them back.

8. *Poor judgment.*
   People with dementia could have problems in judgment or decision-making, e.g. dealing with money, less attention to their cleanness.
   Typical age-related change: Making a bad decision occasionally.

9. *Withdrawal from social activities.*
   People with dementia may start to isolate themselves from social activities or hobbies. They may not be able to complete a hobby, and avoid being social (e.g. talking with others, joining work projects or group activities).
   Typical age-related change: Only sometimes feeling weary of works and social relationships.

10. *Changes in mood and personality.*
    The mood and personality of people with dementia can change quickly. They often feel confused, suspicious, anxious, or depressed. They also easily get upset at work, at home, with family and friends.
    Typical age-related change: Being a bit irritable. However, noting that mood changes

with age may also be a sign of other conditions.

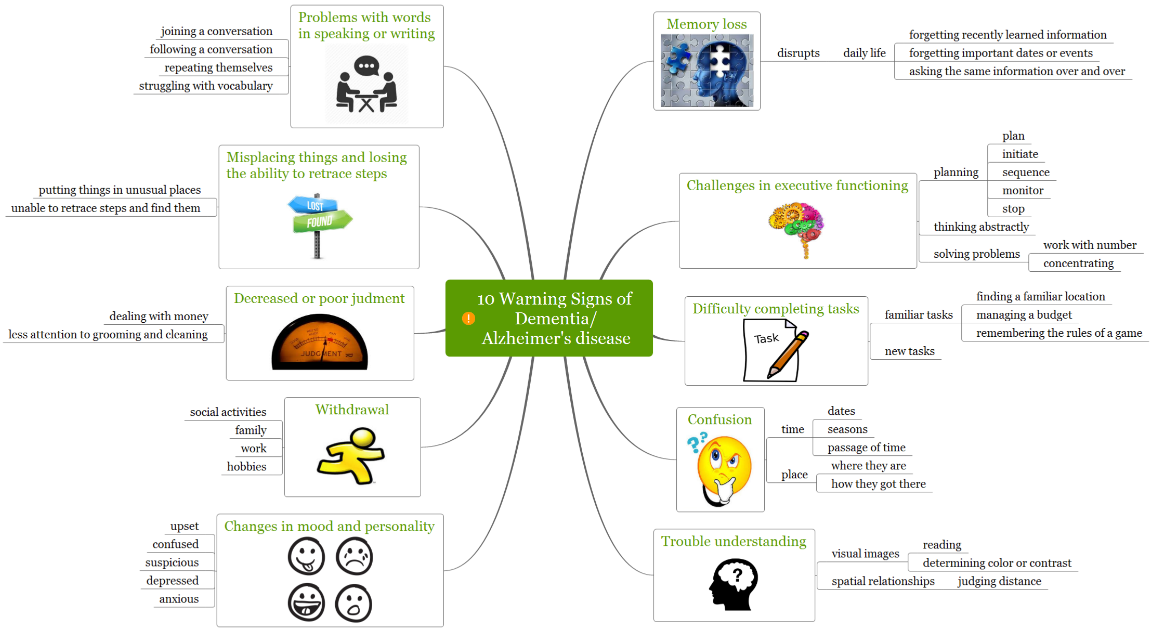

Fig. 1.2 10 warning signs of Dementia/Alzheimer's disease (After (Alzheimer's Association, 2009))

1.3 Challenges in Supporting Navigation for People with Dementia

The first problem is that literature on assistive technology has focused on people with mild to moderate dementia more than people with moderate to severe dementia (Span et al., 2013). Secondly, the research in technology for people with dementia has been biased very much toward surveillance and safety issues (Bharucha et al., 2009; Orpwood et al., 2008; Sixsmith et al., 2007; Span et al., 2013; Topo, 2009). Indeed, safety issues are important but it is not the only thing. Navigation (wayfinding) was emphasized by other works e.g. (Mahoney et al., 2003; McShane et al., 1998a; Passini et al., 2000) but there have been only limited projects focused on solving this problem with assistive technology. Among the ten warning signs listed above, at least warning signs *memory loss - WS1*, *planning abilities - WS2*, *Confusion of place - WS4*, *Trouble understanding visual images and spatial relationships - WS5* could lead to orientation and navigation problems. People with dementia normally face severe problems relating to orientation and navigation, specifically in spatial dimension (wayfinding difficulties). Problems of orientation and navigation in the dimension of time (losing track of the date or of the passage of time) and in that of memory (loss of portions of memory or disorder in the memory time-line) are not examined in the present work. Wayfinding is shortly considered as an ability to reach desired destinations. It is a basic physical, psychological, and social human need. The term "wayfinding difficulties" includes spatial disorientation, problems with prospective memory (to remember how to reach to a destination), and loss a sense of direction. The causes of wayfinding difficulties in dementia could be memory deficits (Monacelli et al., 2003), visuospatial deficits (Liu et al., 1991), and dementia-specific changes in orientation strategies and the loss of planning abilities (Passini et al., 1998).

Using GDS scale, Reisberg et al. (Reisberg et al., 1982) state that the spatial skills in a familiar environment at stage 3 might remain intact at this point whereas it does not at stage 4. It means that at stage 3 people with dementia mostly get lost in unfamiliar locations. At stage 4 and higher, they even get difficulty finding their way in a familiar environment (McShane et al., 1998a; Monacelli et al., 2003; Passini et al., 2000). Cogan (Cogan, 1985) and Henderson et al. (Henderson et al., 1989) reported more than one-third of people with dementia were diagnosed with visuospatial disorientation and getting the lost behavior. The ratio of affected people is even higher in a complex environment (hospital, health care facility), where the stage of dementia is middle or severe. In two health care facilities and one hospital for people with dementia that the author conducted observation and experiment, all of the residents living there had problems related to wayfinding difficulties (chapter 3). Being lost or fear of getting lost limits a person's ability to perform activities of daily living independently (e.g. bathing, feeding one self, dressing, leisure) and thus consequently develops other psychological deficits such as inferiority complex, anxiety, suspicions, illusions and aggression (Mahoney et al., 2003). Frequent results are social isolation and a reduced quality of life (Passini et al., 2000; Wherton and Monk, 2008). In particular, Provencher et al. for example reported on a person in the early-stage of dementia, who was in trouble finding her way, reduced her participation in social activities (Provencher et al., 2008). Therefore, wayfinding difficulties are a prime reason for institutionalization (Passini et al., 2000). Moreover, it affects the life of relatives and caregivers, who are living with and taking care of people with dementia.

To date, previous works supporting people with dementia in navigation context have been mainly limited to people with mild to moderate dementia and outdoor environment (section 2.2). Most of them use mobile phone or PDA with GPS technology. The other side of this problem has been neglected: people with moderate to severe dementia who cannot use technology devices such as mobile phone or PDA and indoor navigation assistance. This specific topic requires overcoming many different types of problems in engineering as well as in designing user interactions and interfaces. Unlike outdoor environment, the unified global solution (GPS technology) does not work well in an indoor environment. Several technologies have been introduced focusing on indoor positioning with their advantages and disadvantages. In addition, an electronic map is required to support navigation context. Outdoor maps have been developed by commercial companies and governments, whereas electronic maps for indoor environments is not disposable and quite difficult to create a high precision one. Along with problems of infrastructure (e.g. building material dependent propagation effect, dense multipath effect), indoor navigation assistance system remains a significant challenge (Gu et al., 2009). On the user interactions and interfaces side, designers need to keep in mind the high level of cognitive impairment of people with moderate to severe dementia. They could get difficulties in handling technology devices with Graphic User Interface - GUI (e.g. virtual keyboard, touchscreen gestures) or in interpreting information (e.g. uncharacteristic picture like intersection, small text). Hence, the questions of how a user input into the system and how the guidance information is delivered to a user have to be considered carefully.

Last but not least, one critical issue from the literature is that very few works developing technology aimed at people with dementia had dementia subjects involved (Bharucha et al., 2009; Span et al., 2013; Topo, 2009). In order to develop a successful assistive technology for people with dementia, involving them to understand their needs and requirements is strongly demanded. Asking caregivers is another option but not enough even though caregivers are the one who understands people with dementia the most as caregivers care for them every day. Speaking only to caregivers in designing for people with dementia might raise many issues (Orpwood et al., 2008), such as generalizations over completely different people with dementia or reporting problems only from their own perspective. However, recruiting and working with people with dementia, especially people with moderate to severe dementia is an arduous journey. Ethical issues and getting informed consents would take much time. Besides that, people with moderate to severe dementia get problems with interpretation and finding words (*word-using problem - warning sign WS6* mentioned in section 1.2.2). Moreover, they also tend to be withdrawn and sensitive (*withdrawal from social activities - WS9*, and *changes in mood and personality - WS10*), which makes strangers (e.g. assistive technology designers) unable to have a conversation with them. So how can we involve people with dementia in the design process? How can designers work with people with dementia and validate the assistive technology?

1.4 Objectives of the Thesis

We focus on the missing part of literature: people with moderate to severe dementia and indoor navigation assistance. The aim of this thesis is to solve the challenges above (section 1.3) by developing an intelligent long-term assistance system for people with moderate to severe dementia (people with mild to moderate dementia can use the system as well) in the context of navigation in indoor environments. Long-term assistance or long-term care refers to a variety of services and supports, which helps with basic personal tasks of everyday life, also called as Activities of Daily Living (ADLs) such as eating, using the toilet, moving to a place. As mentioned earlier, the problem in navigation (wayfinding) is one activity, but it also affects other ADLs, leads to social isolation and reduced self-confidence, and quality of life. By supporting indoor navigation, we expect that it could foster people with dementia' independence, self-esteem and quality of life, which is important and highlighted by some works e.g. (Orpwood et al., 2008; Robinson et al., 2009; Sixsmith et al., 2007)

In this dissertation, I present a new approach with the Implicit Interactive Intelligent (III) Environment (presented in chapter 4) focusing on implicit interaction, natural interface, and context-awareness. The III Environment detects and analyzes situations of the environment, current location, and states of users. Based on that, the system predicts the destination and potential next activities, adapts to the current situation, then provides the most appropriate guiding cues, reminders, suggestions, or other assistance to people with dementia in the right place and at the right time. The users are free from handling technology devices (virtual world), stay in and interact with the physical world where they are familiar with. This way, the cognitive workload is minimized. The first step towards the III Environment is accomplished by fulfilling the following research objectives. Empirical studies are conducted to reveal insights about the behavior of people with dementia and their relationship to technology (chapter 3). Accompanying the empirical studies, artifact works with three-part systems (i.e. guiding system - chapter 5, monitoring system - chapter 6, and intelligent system - chapter 7) (Ly et al., 2015) are contributed. The era of computing is changing (Figure 1.3). Hence, the interaction between human and computer are also shifting quickly. The traditional interaction with a computer, mouse, keyboard is being replaced by tangible interaction and implicit interaction. In fact, handling computerized devices is a hard task for people with dementia. A promising vision would be a smart environment like III Environment, where all equipment, environmental cues are connected and adapted to support people with dementia.

More specifically, the following research goals are derived:

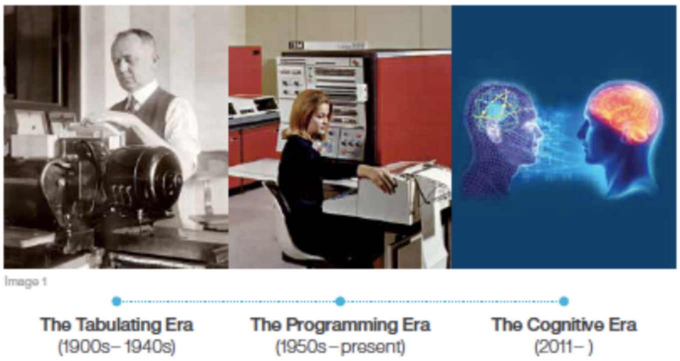

Fig. 1.3 Eras of computing (Kelly, 2015).

- To explore the specific needs, individual navigation behaviors, and possible barriers to people with dementia (chapter 3).
- To suggest and test implicit guiding cues for navigation (chapter 5).
- To develop and test an indoor monitoring system adapted to the context of care home facilities (chapter 6).
- To develop the concept of an intelligent system that recognizes current locations and activities, predicts next situations, and decides to provide appropriate guiding cues at the right time in right place (chapter 7).
- To summarize the lessons learned from adopting a user-center design approach in the context of moderate to severe dementia (chapter 8).

1.5 Methodology

Two main approaches adopted in this thesis were User-Centered Design (UCD) and an iterative software development (followed Agile Software Development). In short, UCD is a design process putting users at the center, conducting user research, and involving them in the iterative design and evaluation of the product. According to the ISO 9241-210:2010, "This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance". Four main phases of UCD (iterative) process are *specify the context of use*, *specify requirements*, *design*, and *evaluation* (ISO 9241-210). We considered both *specify the context of use* and *specify requirements* as *requirements gathering* (Fig. 1.4). In this process (Fig. 1.4), the guiding system went through the whole cycle iteratively. Prototypes of light and color were implemented, evolved, and validated. Due to the long and complicated ethical issues and getting informed consents, the monitoring system was also through full circle but only tested and validated in the laboratory environment. However, it could be equivalent to validating in dementia care facilities. The technical part (monitoring) would be the same between normal people and people with dementia. About the designing part, we carefully considered several factors e.g. size, weight, battery to ensure that our device could at least replace the device residents in dementia care facilities are using. The intelligent system was on the other hand only through two phases: requirement gathering and design & prototype. We conducted some tests in the laboratory environment and with short observed data in dementia care facilities but it was indeed not validated enough. The future work is to bring this intelligent system to the field and to validate it properly.

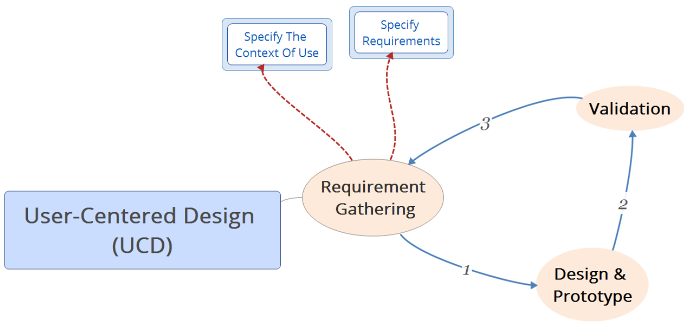

Fig. 1.4 User-Centered Design process (After ISO 9241-210)

Actually, the UCD is not a complete process model for software development as it only deals with user research, design, usability testing, and evaluation. Therefore, the Agile Software Development needed to be involved. Iterative software development methods support a broad range of the software development life cycle that is achieved through regular cadences of work, known as sprints or iterations. Principally, this iterative methodology can be described as "iterative" and "incremental". In the traditional approach, every aspect of development such as requirements, design has only one chance to get it right, while this paradigm (followed Agile method) continually revisits those aspects throughout the life cycle. The development reduces the risk of building the right product wrong with test-driven development, continuous integration, software testing, and evaluation every sprint. Integrating UCD and iterative software development would create a comprehensive systems development methodology (Rannikko, 2011) The key point was to buy enough time to do UCD work before programming.

Table 1.1 shows the list of facilities and participants we worked with throughout this thesis. Besides these five dementia care facilities, I also visited two facilities in Dresden, Germany. However, we did not either get the information of residents and caregivers or conduct a study there. Thus, those two was only considered as extra facilities for additional information (called Extra 1 and Extra 2). The facility A and B were accompanied with us through the whole circle of Fig. 1.4, whereas the facility D and E were mainly for validation phase to reinforce the findings of light and color effects on dementia context.

1.6 Thesis Overview

Following this introduction, chapter 2 reviews the research on assistive technology supporting people with dementia in general and specifically in navigation contexts. The missing parts, advantages, and disadvantages of literature (existing technologies and projects related to people with dementia) are elaborated as well. The chapter raises questions and problems which we try to solve in this dissertation. Chapter 3 introduces the *gathering requirement* process using user-centered design. The study (study 1) with an adapted Contextual Design method in dementia context (mainly in two dementia care facilities, named A and B - cf. Table 1.1) and a process of recruiting participants, collecting and analyzing data are presented. In the end, difficulties of people with dementia in wayfinding and interacting with technology devices are pointed out. The following chapter 4 describes our vision with Implicit Interactive Intelligent (III) Environment. The characteristics of III Environment, system architecture, and system infrastructure are discussed. Chapters 5, 6, 7 describe respectively three parts of the system: the guiding system, the monitoring system, and the intelligent system in order to show the feasibility of developing III Environment. Chapter 5 suggests and tests the implicit guiding system with an implicit guiding cue (lighting with color). Five conducted studies show the effects of lighting with color on people with dementia in different contexts: finding a suitable color (study 2), guiding at an intersection in facility B (study 3), drawing attention and gaze (studies 4 and 5 in facilities D and E), preventing people with dementia staying in specific areas such as an exit area with study 6 in facility E. Chapter 6 describes the process of developing an indoor (dementia care facilities) monitoring system. Different technologies and algorithms are implemented and tested. Chapter 7 is about the intelligent system and proposes models to recognize activities, predict next situations, detect issues, suggest solutions, and provide appropriate services. The last chapter - chapter 8 wraps up the findings of the empirical and artifact works presented. This chapter reviews and evaluates the new approach of intelligent and implicit assistance to people with dementia, especially people with moderate to severe dementia. As recruiting and working with people with dementia is challenging, the lessons learned are added to the list of pointers that other researchers who are new to the field can derive benefits from. Directions of further research are also discussed.

Table 1.1 Dementia care facilities overview.

Facility	No. resident	No. dementia resident	No. Participant	Age	Gender	Dementia stage	Typical residents	No. caregivers	Study
A (Würzburg)	27	27	8	65-84	1 men / 3 women	mild to severe	Quite wealthy	2-3 / floor	Observation, interview, favorite color
B (Würzburg)	25	12	7	82-94	2 men / 5 women	moderate to severe	Local people	2-3 / 2 floors	Observation, interview, guiding experiment
C (Ansbach)	85	about 40%	na	na	men = women	5% in severe stage, the rest is equally share to mild and moderate	Local people	2-3	Interview
D (Black Forest)	56	56	7	>60	1 men / 3 women	25 mild - 31 moderate to severe	Local people	2-3 / group	Light and interactive drawers experiment
E (Black Forest)	45	45	13	>60	women > men	moderate-severe	Local people	3 / group	Observation, light and interactive drawers experiment

Chapter 2

State-of-the-Art

This chapter presents a literature overview of assistive technology for people with dementia. Assistive technology is an umbrella term including assistive, adaptive, rehabilitative devices, software program, and product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities (Wikipedia, 2017a). The first section 2.1 reviews assistive technologies for people with dementia in general with different topics and purposes. The next section 2.2 specifically focuses on projects supporting people with dementia in navigation context. The last section 2.3 discusses the big picture of related works, points out the biases of specific concern areas and targeted user, and elaborates limitations of those projects such as the problem of lacking studies involving dementia subjects. Note that this chapter is restricted to works on assistive technology and people with dementia. Three systems in chapters 5, 6, 7 will also have their own state-of-the-art sections, which contains works either not assistive technology or not focusing on people with dementia. For example, chapter 5 presents an original approach with an implicit guiding cue. The related work part (section 5.1) includes physical environmental guiding cues (in architecture area), which are static and not assistive technology but still considered as they might be turned into assistive technology later. Chapter 6 reviews indoor positioning technologies, but most of them were introduced and implemented for normal people, not people with dementia. Therefore, those technologies are not listed in this chapter but necessary to be mentioned in chapter 6 on the way we select new technologies and develop them for dementia context.

2.1 Overview of Assistive Technology Supporting People with Dementia

This overview is based on our searching (with databases GoogleScholar, ACM, IEEE, ScienceDirect, and PubMed with criteria people with dementia, Alzheimer, and technology) and two literature reviews on assistive technology for people with dementia, (Bharucha et al., 2009) and (Vogt et al., 2012). Bharucha et al. reviewed systematically for clinicians and clinical researchers alike the current availability, capabilities, and developmental stage of technologies in dementia care context. They identify 58 total technologies with potential applications to dementia care in the literature database of clinical, engineering, and computer science. Among of them, 11 cognitive orthotics e.g. (Beigl, 2000; DeVaul, 2003; Tee et al., 2005), 15 environmental sensors e.g. (Biswas et al., 2006), 10 physiological sensors e.g. (Knight et al., 2005; MIT Technology Review, 2004), and 22 advanced integrated sensor systems are identified. Vogt et al. present a systematic literature review and direct designers to context-awareness on designing assistive applications for people with dementia. Their aim is to assist the preliminary phase in the design and development of assistive applications for people with dementia by analyzing services of context-aware assistive applications in dementia care. In their systematic literature review, they searched the bibliographical databases of ACM, IEEE, ScienceDirect, and PubMed for assistive applications for people with dementia. After removing results that did not involve people with dementia in evaluation phase, the number of research projects remained was very low: ACM with 1 result (Chang et al., 2008), IEEE 0, ScienceDirect 1 (Riley et al., 2009), PubMed 1 (Robinson et al., 2009). In the third iteration of searching, three additional research and development projects were added (Donnelly et al., 2010; Lee and Dey, 2008; Mulvenna et al., 2010). In the end, following projects were identified: KITE (Robinson et al., 2009), COACH (Hoey et al., 2010; Labelle and Mihailidis, 2006; Mihailidis et al., 2008), COGKNOW (Davies et al., 2010, 2009; Du et al., 2008; Mulvenna et al., 2010), Context-Aware Wayfinder (Chang et al., 2008), ExPress Play (Riley et al., 2009), CPVS (Donnelly et al., 2010), MemExerciser (Lee and Dey, 2008). They categorized these projects based on context-aware services.

Table 2.1 summarizes related works of technologies in dementia context.

2.1.1 Cognitive Orthotics - Activity Assistance

The first categorized group (cognitive orthotics) includes memory aids and applications for other progressive cognitive and functional impairments associated with dementia e.g. aphasia, agnosia, apraxia, visuospatial, or executive dysfunction. Great attention has been paid to memory aids, not mentioning commercially available simple task and time-based reminder systems, the aids reviewed are context-aware using artificial intelligence to trigger reminder or guidance appropriately. They are implemented either to support multiple different tasks throughout a routine day (Memory Glasses (DeVaul, 2003), MemoClip (Beigl, 2000)) or a sequence of steps in tasks (PEAT-Planning and execution assistant and training (Levinson, 1997), ISAAC (Gorman et al., 2003), AutoMinder (Pollack et al., 2003)). According to Bharucha et al. (Bharucha et al., 2009), although these memory aids are in the right direction, the major limitation for all of them is lacking clinical trials specifically with dementia subjects. Besides that, those projects are not yet able to handle deviations from programmed routines and contextual uncertainties. Other than prospective memory dysfunction in the area of cognitive deficits, related intelligent assistive technologies are found lacking. Within a broad domain of dysfunction (aphasia), very few of aids have been conducted. The existing ones such as VERA (Tee et al., 2005) and Cook's Collage (Tran et al., 2007) address only a specific task i.e. cooking. About visuospatial dysfunction, three navigational tools, one indoor application (Morris et al., 2003) and two outdoor applications (Liao et al., 2007; Patterson et al., 2002a), have been developed that may assist people with mild to moderate dementia. None of these systems are commercially available, and all await rigorous clinical testing in applicable populations.

Some studies in (Vogt et al., 2012) can be listed in this category as well. A notable example is the HYCARE (Du et al., 2008), which is a memory assistant to plan future events and activities. Express Play (Riley et al., 2009) is an activity assistance prototype system designed to enable people with dementia to create music. A touch screen interface was used to control a system which utilizes chords to create pleasant sounding music regardless of any prior musical knowledge. In addition, a life-logging MemExerciser (Lee and Dey, 2008) supports people with episodic memory impairment by recording information during the day as images, location, and time. KITE (The Keeping In Touch Everyday) project (Robinson et al., 2009) is an outdoor navigation and communication system for people with dementia. The person with dementia needs to carry a mobile device with a call button contacting the caregiver and a navigation function finding the way home.

ACTION (Assisting Carers using Telematics Interventions to meet Older person's Needs) project (Hanson et al., 2007) provides 'Living with Dementia' program (the Life Story Book, the Diary, the family Tree) with the aim to provide people with dementia (living at home) and their family caregivers with early information, education, and support. ACTION helps families to use technology, improve family caregiving skills and caregiver confidence. They conducted qualitative studies with identifying user needs (discussion group, video recorded), development phase (computer training sessions at the university) and verification phase. Their participants were divided into development group (user needs phase and development phase) with 7 people with dementia (4 men, 3 women aged 68-81, MMSE score 20 and above - mild dementia) and test group (verification phase) with 19 persons with dementia (MMSE > 25 - mild dementia - mapping scores scale in (Perneczky et al., 2006)). The first results indicate that people with mild dementia can learn and benefit from user-friendly technology.

CIRCA (Computer Interactive Reminiscence and Conversation Aid) project (Astell et al., 2006, 2010) aims to develop a multi-media interactive experience to facilitate communication (reminiscence sessions) between people with dementia and caregivers. The initial objectives were to increase people with dementia' well being and means of expression, to facilitate positive social interactions between people with dementia and caregivers, and to reduce the caregivers' stress. The prototype was a touching screen with three categories (entertainment, recreation, local Dundee life) and media (photos, videos, music). Participants were 11 people with dementia (6 female, 5 male) with age between 65 and 95. MMSE scores were between 9-23 (in range of moderate-severe dementia). Nine caregivers also joined in 20-minute reminiscence sessions. The methods evaluation questionnaire, observation, and video of sessions were used. After the evaluation, all participants said they enjoyed the session and would like to use the system again in the future.

The next project is ENABLE (Topo et al., 2004). The ENABLE provides a tool named Picture Grammaphone (PG) Multimedia program. They aim at supporting the well-being of people with dementia, to stimulate them and give them pleasure. An assessment study of the PG was conducted over three weeks with 23 people with dementia over five dementia care facilities in Finland, Ireland, Norway and the UK. In general, according to staff, most of the participants benefited from its use. They also state that multimedia products can be used in dementia care if support is available and the design of the product takes into account the people with dementia' requirements.

2.1.2 Physiological and Environmental Sensors

The next group of assistive technologies for dementia care is physiological sensors including vital signs and metabolic parameters, and fall detectors. The monitoring of vital signs and metabolic parameters have been improved significantly from measuring a single parameter (e.g. temperature) to multiple parameters simultaneously (e.g. blood pressure, pulse, oxygen saturation). That information can be recorded, monitored continuously in real time, and transferred to family and professional caregivers (Medical Mood Ring (MIT Technology Review, 2004), Tadiran's MDkeeper (Aerotel, 2007)). In addition, fabrics with embedded bio-sensors have been developed that remote continuously physiologic monitoring of multiple vital functions e.g. (Di et al., 2006; Knight et al., 2005). Again, the critical point is that the evaluation of prototype has been conducted with small samples of non-demented subjects. Moreover, these "smart garments" still need several re-configurations to ensure the comfort of people with dementia including light weight, perceived invisible, ease of laundering, resistance to sweating or allergic skin reactions.

About fall detectors applications, although both manual and automatic simple alarms systems exist to notify caregivers, the automated ones must be worn at all times whereas the manual ones need the users to trigger manually. Passive unobtrusive sensors are used to address these limitations. For instance, the SIMBAD (Smart Inactivity Monitor using Array-Based Detectors) project (Sixsmith and Johnson, 2004) uses wall-mounted low-cost passive infrared sensors to detect inactivity and falls. The advantage of this approach does not require users to wear or trigger a device. However, the accuracy of fall detection was only 37.5% in a controlled laboratory experiment. Another system (Alwan et al., 2006), on the other hand, implements a piezosensor-based system that records floor vibration patterns. In a laboratory experiment with anthropomorphic dummies, the accuracy of fall detection reached 100% of cases with minimum false alarms. Unfortunately, both systems have been deployed in a laboratory environment with non-demented subjects. Another direction of fall-detection systems is using video processing technologies e.g. (Lee and Mihailidis, 2005; Nait-Charif and McKenna, 2004).

In general, these systems have several major technical limitations including that it can only track one person at a time, often assumes the tracked person and his mobility device are one object, not mentioning high cost in computation, and a mock-up testing environment (not a real world residential settings with dementia subjects).

The third group of assistive technologies is environmental sensors. The works in this group usually combine several low-cost commercial sensors to tackle a clinical problem. Using acoustic, pressure, and ultrasound sensors, Biswas et al. (Biswas et al., 2006) tried to detect movements of a single experimental subject (non-dementia). Using the Bayesian inference technique, the agitation recognition rate improved to 94%.

2.1.3 Advanced Integrated Sensor System

The last but not least assistive technologies group is advanced integrated sensor system. The method is normally fusing data from a network of heterogeneous sensors and applying artificial intelligence. This kind of approach shows a great potential for the future with the vision that not only improves activity and behavioral recognition but also increases the sophistication of the supervision, guidance, and feedback provided to the users. Among several systems, three systems COACH, CareWatch, and CareMedia are noticeable as they are only ones having clinical studies with representative people with dementia conducted (Bharucha et al., 2009).

COACH (Cognitive Orthosis for Activities in the Home) system (Hoey et al., 2010; Labelle and Mihailidis, 2006; Mihailidis et al., 2004, 2008) supports people with dementia in a handwashing task. Using a video camera, hand-tracking bracelets, and machine learning algorithms, the COACH system monitors the progress of handwashing activity, detects the failure, and provide voice prompt if needed. In a clinical trial of 10 people with mild to moderate dementia (only one person in severe dementia stage), the system increased by 25% the number of handwashing steps correctly completed without caregiver assistance. The main drawback of this work is highly dependent on context and is limited to only one activity (handwashing).

CareWatch (Rowe et al., 2007) is an alarm system that detects people with dementia in bed, moving in house, or opening a door. The system alerts the caregiver of both emergency and non-urgent situations through customizable text or voice alarm. A randomized clinical trial of CareWatch was conducted in 55 homes of people with mild to moderate dementia, mostly from Alzheimer's disease. Two conditions were randomly assigned: control condition (28 homes) and to receive CareWatch (27 homes). CareWatch has operated for > 200 months of combined system time without any major failures. After a reliability period (2 consecutive weeks), caregivers became proficient at using CareWach, and no unattended exits were recorded during the night.

The next is CareMedia project (Hauptmann et al., 2006) - an automated video and sensor analysis system that monitors activity, behaviors, and social interactions of people with dementia continuously in real time. The first study was conducted with four ceiling-mounted video cameras and microphones in a non-private space of a locked dementia unit. Seven sessions of physical aggression and six elopements among eight residents were captured over 80 hours of observation. The result also showed that > 75% of all social interactions occurred during meal times. A more comprehensive study was then conducted with 23 ceiling-mounted video cameras and microphones. The system recorded 15 people with dementia 24 hours/day for 25 days (about 13,800 camera-hours of video data). Those data seems to be annotated manually to train machine learning algorithms to identify activities such as falls and aggression.

Besides three systems listed above, two other notable projects related supporting people with dementia are presented following. COGKNOW (Davies et al., 2010, 2009; Du et al., 2008; Mulvenna et al., 2010) is an EU funded project providing context-aware services such as time-based and event-based reminders (are set by a caregiver), video recorded instructions, music, radio, and communication to people with dementia through a stationary touch screen interface or a mobile device. An additional outdoor navigation function to get home and a help function (calling directly to the main caregiver) are presented on the phone.

INDEPENDENT project (Orpwood et al., 2008, 2007; Sixsmith et al., 2007) developed four items of the (69 items) wish-list: Music player (access to music), Window-on-the-world (social isolation), conversation prompting, and supporting sequences. The aim was straightforward that designing technology to support quality of life. Participants were 26 people in the early stage of dementia (16 people with dementia living at home, ten people living in care homes). For the Music player tool, people with dementia in care home settings in Sheffield and user's homes in Liverpool participated in, whereas people with dementia in care homes of day centers joined Window-on-the-world. Overall, they used qualitative studies with in-depth interviews, focus groups with formal caregivers, family caregivers and volunteers, workshops with medical engineering, architecture, social gerontology, representatives from home care and residential care providers, industry and user organizations. About the Music player, usage was fine initially, but several users forgot about the existence of the player and stopped using it. They added a small illuminated panel to the player, which lights up for a couple of minutes every half hour and then turns off again. This attention-drawing feature turned out worked well. Some of the testing for Window-on-the-world, Conversation Prompter, Sequence Support were underway and needed iterative user work, but they seem to be successful.

Table 2.1 Summarizing Potential Technologies in Dementia Care

Category	Project / Product	Description	Target Population	Dementia Subjects Involved	Indoor / Outdoor
Navigational Tool	Activity Compass (Patterson et al., 2002a)	A mobile device with GPS system that learns a subject's routine travel behavior, predicts likely destinations, and reroutes a lost individual	Normal aging, mild cognitive impairment (MCI), other dementia	No	Outdoor
Navigational Tool	Opportunity Knocks (Liao et al., 2007)	A mobile phone with GPS and Bluetooth that learns the subject's standard route, alerts of a navigational error, and reroutes the lost individual	Normal aging, MCI, other dementia	No	Outdoor
Navigational Tool	IMP (Morris et al., 2003)	A walker-based device supports in navigating lost or confused users using a laser beam range-finder, a handheld computer with a touchscreen interface, and a navigation software	Normal aging, MCI, other dementia	No	Indoor
Navigational Tool	KITE (Robinson et al., 2009)	Two prototypes for the Runner (a mobile device - belt with a call button contacting the caregiver and a navigation) and the Driver (notebook) supporting navigation using GPS	People with mild dementia	Yes	Outdoor
Navigational Tool	COGKNOW (Mulvenna et al., 2010)	A mobile phone application with GPS helps finding home	People with mild dementia	Yes	Outdoor
Cognitive - Memory Aid	Memory Glass (DeVaul, 2003)	A wearable (eyeglasses) context-aware memory aid and reminder system	People with mild dementia	No	n/a
Cognitive - Memory Aid	MemoClip (Beigl, 2000)	A memory aid (a badge) is clipped to clothing that associates task information with time, location and context	People with mild dementia	No	n/a

Table 2.1 Summarizing Potential Technologies in Dementia Care

Cognitive - Memory Aid	PEAT (Levinson, 1997)	An automatic planning software operates on a PDA or mobile phone and provides personalized cueing to guide the user through multi-step procedures and ADLs using digital pictures and voice recordings	People with mild dementia	No	n/a
Cognitive - Memory Aid	ISAAC (Gorman et al., 2003)	A wearable individualized cognitive aid that organizes and delivers individualized prompts (speech audio, text, checklists, or graphic format), procedural and personal information	Normal aging, MCI, other dementia, anoxic or traumatic brain injury	No	n/a
Cognitive - Memory Aid	AutoMinder (Pollack et al., 2003)	Model a subject's daily plans, track their execution, and determine whether and when to provide reminder(s)	Normal aging, MCI, or other dementia	No	n/a
Cognitive - Memory Aid	HYCARE (Du et al., 2008)	A memory assistant to plan future events and activities (part of COGKNOW project)	Elders with mild dementia	Yes	Indoor
Cognitive - Memory Aid	MemExerciser (Lee and Dey, 2008)	A life-logging records information during the day as images, location, and time	People with episodic memory impairment, MCI	Yes	Indoor
Cognitive - Leisure Activity	Express Play (Riley et al., 2009)	Activity assistance prototype system designed to enable people with dementia to create music with a touch screen interface	People with dementia	Yes	Indoor
Cognitive - Multimedia - Communication	ACTION (Hanson et al., 2007)	Multimedia education and support program (the Life Story Book, the Diary, the family Tree)	People with mild dementia	Yes	Indoor
Cognitive - Multimedia - Communication	CIRCA (Astell et al., 2006, 2010)	A multi-media interactive experience using touching screen to facilitate communication (reminiscence sessions) between people with dementia and caregivers	People with moderate to severe dementia	Yes	Indoor

Table 2.1 Summarizing Potential Technologies in Dementia Care

Cognitive - Multimedia	ENABLE (Topo et al., 2004)	Picture Grammaphone (PG) - multimedia program aima at supporting well-being of people with dementia, to stimulate them and give them pleasure	People with mild to moderate dementia	Yes	Indoor
Cognitive - Aphasia	VERA (Tee et al., 2005)	An interface using text and sound for visual cooking instructions customized for aphasic users	Normal aging, aphasia	No	Indoor
Cognitive - Aphasia	Cook's Collage (Tran et al., 2007)	A video-based reminder system for a cooking task by displaying the steps taken on a monitor	Normal aging, aphasia	No	Indoor
Environmental	Light sensor, temperature sensor, force sensor, pressure sensor, contact sensor, video camera, etc.	Commercial sensors product which can be effective in combination with other environmental sensors to track activity patterns and deviations from personal norms			Indoor
Physiological / Functional	Medical Mood Ring (MIT Technology Review, 2004)	A wearable device (a ring) monitors temperature, heart rate, and blood oxygen level. It can transmit vital signs to a cell phone or computer to allow a caregiver to determine remotely whether a person needs assistance.	Any person requiring monitoring of metabolic or physiological parameters	No	Indoor
Physiological / Functional	Tadiran's MDkeeper (Aerotel, 2007)	A device monitors pulse, 1-lead EKG and blood oxygen level and transmits data to a remote medical center for further analysis and care	Any person requiring monitoring of metabolic or physiological parameters	No	Indoor
Physiological / Functional	SIMBAD (Sixsmith and Johnson, 2004)	A wall-mounted inactivity and fall detector consisting of low-cost, array-based passive infrared sensors	MCI, or other dementia	No	Indoor
Physiological / Functional	University of Virginia floor vibration-based fall detector (Alwan et al., 2006)	A piezoelectric sensor coupled to the floor surface to evaluate the floor's vibration patterns	MCI, or other dementia	No	Indoor

Table 2.1 Summarizing Potential Technologies in Dementia Care

Advanced integrated sensor system	COACH (Hoey et al., 2010; Labelle and Mihailidis, 2006; Mihailidis et al., 2008)	Supports people with dementia in a handwashing task using a video camera, hand-tracking bracelets, and machine learning algorithms	People with dementia	Yes	Indoor
Advanced integrated sensor system	CareWatch (Rowe et al., 2007)	Alarm system that detects people with dementia in bed, moving in house, or opening a door	People with mild to moderate dementia	Yes	Indoor
Advanced integrated sensor system	CareMedia (Hauptmann et al., 2006)	An automated video and sensor analysis system that monitors activity, behaviors, and social interactions of people with dementia continuously in real time	People with mild to severe dementia	Yes	Indoor
Advanced integrated sensor system	COGKNOW (Davies et al., 2010, 2009; Du et al., 2008; Mulvenna et al., 2010)	Context-aware services such as time-based and event-based reminders video recorded instructions, music, radio, and communication to people with dementia through a stationary touch screen interface or a mobile device	People with mild to moderate dementia	Yes	Indoor
Advanced integrated sensor system	INDEPENDENT (Orpwood et al., 2008, 2007; Sixsmith et al., 2007)	Four items: Music player (access to music), Windowon-the-world (social isolation), conversation prompting, and supporting sequences	People with mild dementia	Yes	Indoor

2.2 Assistive Technology Supporting People with Dementia in Navigation Context

This section briefly summarizes works, projects, studies supporting people with dementia in navigation context. It focuses on the contexts of use, assistive devices, and guidance cues. Related works in navigation context are divided into two categories: outdoor navigation and indoor navigation.

2.2.1 Outdoor Navigation

The first project is the Activity Compass (Patterson et al., 2002a), a cognitive aid for early-stage Alzheimer's patients. The system is a Palm pilot-based GPS system that learns a model of subject's routine travel behavior to predict the most likely destinations and to reroute a lost individual. A user can choose destinations by clicking on pictures and follow arrows and icons on the screen to get to the destination. The feedback is mainly implied by what aspects of the route are followed or ignored. The large and bulky handheld device (Fig. 2.1) is one disadvantage of this system.

Fig. 2.1 A Prototype Activity Compass (Patterson et al., 2002a)

The next project Opportunity Knocks (Liao et al., 2007) accomplishes much the same as the Activity Compass. Actually, they had software and data from the work of (Patterson et al., 2002a). This system is a cell phone embedded device using GPS and Bluetooth that learns the subject's standard routes in the community e.g. goals or locations where the user frequently changes mode of transportation from GPS data logs. When the system detects an abnormal behaviors (e.g. taking a wrong bus), it alerts the subject of a navigational error by making a knocking sound and re-routes the lost individual. The difference between this work and the Activity Compass is the predictive models combining learning flat transportation models (Patterson et al., 2002a) and hierarchical models. The predictive methods of these two works will be discussed more and categorized in the chapter 7. In addition, these two projects (Activity Compass and Opportunity Knocks) need substantial training to be effective. Besides that, these projects are implemented for outdoor environment and not suitable for our purpose. Moreover, the critical points are that both of them did not have studies involving people with dementia and their interfaces seem too complex for severe dementia.

Other projects related navigation for people with dementia or people with cognitive impairment include DAISY (Wainstein and Tyler, 2007), "Walk navigation system" (Kaminoyama et al., 2007), COGKNOW (Mulvenna et al., 2010) for outdoor environment and Context-Aware Wayfinder (Chang et al., 2008) for indoor environment. The DAISY (Dynamic Assistive Information System) project (Wainstein and Tyler, 2007) aims at supporting people with cognitive difficulties navigate urban environment. DAISY is a mobile phone-based navigation system that provides the user with pre-trip information (preview the entire route before going out) and in-trip reassurance (provide the current location and next steps to reach the destination). Fig. 2.2 shows the interface of the DAISY system. The user needs to enable GPS by selecting "Connect GPS" from the menu. When the user selects a destination from a pre-defined list (e.g. Tesco, College, Aunt's in the figure). The journey is divided into stages, each with its own destination. This was linked to audio instructions such as "turn right", "keep walking". The destination could be anything photographable, but better be distinctive in the destination area. The target/landmarks could be a particular statue, or a distinctive doorway, or shop front. Also using photographs, Kaminoyama et al. (Kaminoyama et al., 2007) introduce a human navigation system that uses photographs for people with early-stage dementia, for instance Fig. 2.3. The walk navigation system can be displayed on a mobile phone or PDA. In this system, the user does not need to recognize their current position and direction because they follow scenes displayed by a photograph (the pictures are required taken at specific places in advance). Both DAISY project and "Walk navigation system" use GPS for the outdoor navigation and have no dementia participants in studies. The COGKNOW project (Mulvenna et al., 2010) (mentioned earlier in section 2.1) provides several functions such as support in reminding, support social contact, support daily activities, and enhance feelings of safety, which includes an outdoor navigation function (TakeMeHome). In order to use this function, the user needs to carry and handle the application on a mobile phone. Although they claim that three iterative development cycles were performed with around 15 people with mild dementia and their caregivers participated in each cycle, no report of results on TakeMeHome function specifically was found.

Fig. 2.2 DAISY interface (Wainstein and Tyler, 2007)

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Fig. 2.3 Examples of Walk Navigation (Kaminoyama et al., 2007)

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Some projects tried to overcome limitations of mobile phone / PDA by focusing on designing assistive devices. KITE (Robinson et al., 2009) is another notable research project because they tried to involve people with dementia as co-designers. The KITE project aims at developing assistive technologies while attempting to explore the views of people with dementia and caregivers. Two prototypes (armband and electronic notepad) are proposed for a man who enjoyed running (the Runner) and a woman who was still driving (the Driver). Fig.

2.4 is the final device for the Runner as an armband (measured 9.5cm x 7.4cm x 3.5cm). For the Driver, the device is made as a physical notebook with the device built into it (measured 13cm x 4.6cm x 10cm). The tracking technology is for an outdoor environment using GPS in-cooperated with the Global communication system (GMS). The assistive device for the Runner is more likely an emergency system than a navigation (wayfinding) support system. If the user gets lost, he presses the button to send a message to his carer. The carer gets a notification and the Runner's location displayed on a phone-based map. Although the design and functionality seem to work well, the device slipped down his arm no matter he wore it next to his skin or over clothing. Similarly, the Driver liked the concept and the style of the device but concerned that the notepad was too large and not fit into the small bag she usually carried or in her coat pockets. In addition, she was worried that the panic button on the device might be too easy to press.

Fig. 2.4 Runner: final device (Robinson et al., 2009)

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2.2.2 Indoor Navigation

IMP – Intelligent Mobility Platform (Morris et al., 2003) is an indoor navigation system which is based on a robotic walker 2.5. In general, it uses a laser beam range-finder, a handheld computer with a touch-screen interface, and navigation software that using an arrow to guide the user. The physical system has been built on top of a Nomad XR4000 mobile robot platform. Two types of sensors (gathering environmental information and feedback from user actions) are equipped for the robot walker. More specifically, in order to perceive obstacles or obstructions, two circular arrays of Polaroid ultrasonic transducers, two circular arrays of Nomadics infrared near-range sensors, three large touch-sensitive doors, and a SICK LMS laser range finder are used. With this information, the system can combine with a pre-computed map of the environment to know where it is positioned at all time. The feedback systems is a laptop display with buttons around. The software components of this robot walker used for navigation, localization, map building and editing, motor control, and sensory interface is built on top of Carmen (Carnegie Mellon's Navigation Toolkit). The objectives of the user interface are 1) enable the user to park and retrieve the walker, 2) allow the user to select a destination from a list, 3) inform the user their current location, 4) guide the user to the chosen destinations. A map of the residence with the current location of the walker is displayed on a graphical screen on a laptop attached to the walker. Four possible destinations are shown in a large, high-contrast font (user can scroll through additional destinations). A large arrow on the screen continuously directs the user toward the destination. A distance-traveled is also displayed on the screen. The IMP also has a shared control system with three modes: *passive* mode (user moves freely), *active* mode (if the user moves in the wrong way, the robot's motion is slowed and eventually stopped), and *forced* mode (user has no control over the direction, only be able to switch the robot on/off). Fig. 2.6 illustrates a scenario of using the robotic walker. The results of the walker robot experiments with elderly participants illustrate the control concepts and technical feasibility of a mobile robotic walker. However, there are still drawbacks. Firstly, the robot walker is quite large which is nice because of sturdy enough to supply sufficient physical supports to the clients but makes the navigation in trouble with narrow places. Secondly, it is only suitable for persons who need an ambulatory device such as a walker. Last but not least, although their target was elderly people with cognitive impairment (people with dementia), they only conducted experimental trials with four residents of a retirement facility, who have no dementia. Moreover, the interface and interaction with robot seem too complex for people with moderate to severe dementia.

Context-Aware Wayfinder system (Chang et al., 2008) is another example of supporting people with cognitive impairments in indoor navigation context. Instead of using GPS, the user with PDA provides location information by scanning the QR code tag (Fig. 2.7) to the server over WiFi. Then the device receives back images of next waypoint from the server and guides the user by overlaying directions (Fig. 2.8). Each QR code matches with a photo on the training blog. This project is notable as they involved people with cognitive impairments in the studies. Participants were six cognitive impaired people (including mental retardation, epilepsy, organic depression, Parkinson's disease, dementia, schizophrenia, brain syndrome). The criteria of cognitively impaired classification and the differences among them e.g. dementia and brain syndrome were not described. Each participant had five routes testing the system. The ratio of trips succeeding in wayfinding was 93.3%. The limitations of this include fragile PDA, small screen, and requiring a certain level of cognitive to handle the

Fig. 2.5 The IMP robotic walker (Morris et al., 2003)

Fig. 2.6 The IMP robotic walker showing a) the robotic walker escorts an elderly person, b) the haptic interface for controlling the walker and c) the walker display with an arrow toward the destination (Morris et al., 2003)

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PDA, input the destination, scan the QR code, and interpret the guidance cues with pictures.

Fig. 2.7 A participant (middle) on the experimental route using the PDA (Context-Aware Wayfinder system) and the counselor standing behind him (right) (Chang et al., 2008)

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Fig. 2.8 An image with direction is shown on the PDA (Context-Aware Wayfinder system) (Chang et al., 2008)

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2.3 Discussion and Insight into Designing for People with Moderate to Severe Dementia

The first striking seminal point we extracted from all literature reviews of dementia focused assistive technology (Bharucha et al., 2009; Gillespie et al., 2012; Span et al., 2013; Topo, 2009; Vogt et al., 2012) is lacking studies involving dementia subjects. Most assistive technologies were developed principally for younger participants, who are non-progressive traumatic or anoxic brain injuries. Therefore, the generalizability issue to the progressive deficits associated with neurodegenerative dementia remains. Recall that Bharucha et al. (Bharucha et al., 2009) were only able to identify three clinical studies involving people with dementia as participants whereas Vogt et al. (Vogt et al., 2012) could find six projects. Although these literature reviews are a bit outdated (published in 2009 and 2012) and there are recently other projects involving people with dementia e.g. (Siriaraya and Ang, 2014), the number of those projects and studies is still very small. In navigation context, lacking dementia subjects is also a critical shortage. Among projects listed in section 2.2, only COGKNOW (Mulvenna et al., 2010), KITE (Robinson et al., 2009), and Context-Aware Wayfinder (Chang et al., 2008) had targeted population involved in their studies. In contrast, others did not have participants in studies as they targeted i.e. people with dementia or cognitive impairment. They either had normal young people like the works of (Kaminoyama et al., 2007; Liao et al., 2007; Patterson et al., 2002a; Wainstein and Tyler, 2007) or normal elderly people in retirement houses such as IMP (Morris et al., 2003).

The second critical point is the stages of dementia that assistive technologies have been focused on. Topo et al. (Topo, 2009) indicate the research was biased toward moderate to severe stages of dementia. In contrast, Span et al. (Span et al., 2013) affirm opposite that people with mild dementia were most often involved (12/26 publications). People with moderate dementia participated in 10 publications mostly in combination with an involvement of people with mild dementia. Seven publications did not have any classification at all. Two publications (one IT program) did not consider classification relevant, and none of the publications focused exclusively on people with severe dementia (Span et al., 2013). The reasons of this disunion could be published date, databases, search keywords, considered publication types. In addition, the work of Span et al. (Span et al., 2013) is more recent with no restriction of the date of publications (quantitative, qualitative, and mixed-method publications in all languages) included up to July 2011. Based on these criteria and our searching and experiences, we lean towards the opinion of Span et al. that related projects have focused more on people with mild to moderate stages because Span et al. (Span et al.,

2013) review is more recent with broader searches. Moreover, when considering carefully the projects stated with moderate to severe dementia participants such as a notable COACH project (Hoey et al., 2010; Labelle and Mihailidis, 2006; Mihailidis et al., 2008), the number of severe dementia participants is always minimal (1/8 participants in case of COACH project). A lot of participants with moderate dementia were closer to the mild stage than the severe stage. The situation is similar in the navigation context. The research has been biased toward people with mild dementia in navigation support system. None project of navigation assistance was found focusing on people with moderate to severe dementia.

Furthermore, based on literature reviews (Bharucha et al., 2009; Gillespie et al., 2012; Span et al., 2013; Topo, 2009; Vogt et al., 2012), it is normal that the studies for people with dementia have a small number of dementia participants and use a qualitative method. For example, Span et al. (Span et al., 2013) define that among 26 publications (more than one publication belong to one project still counts e.g. COGKNOW project has six publications) included, 16 publications used a qualitative approach; four used a quantitative one; whereas six use a mixed-method one. The COACH project, which is highly rated by many publications e.g. (Hoey et al., 2010; Labelle and Mihailidis, 2006; Mihailidis et al., 2004, 2008), has three versions and 10, 4, 6 dementia subjects respectively. Three projects supporting navigation context also have a small number of participants (KITE project (Robinson et al., 2009) with two people: the Runner and the Driver, COGKNOW project (Hettinga et al., 2009) with four participants, Context-Aware Wayfinder system (Chang et al., 2008) with six mixed participants). All of this shows the fact that recruiting people with dementia as participants for studies is a challenge. Moreover, dealing (recruiting and working) with people with moderate to severe dementia is even more difficult than people with mild to moderate dementia. People with dementia need a big deal of support and assistance, and this need increases as the disease progress. People with moderate to severe dementia often need help 24 hours a day (Cohen-Mansfield et al., 1995). Also, a lot of ethical issues, informed consents problem from care facilities and representatives of people with dementia e.g. relatives, lawyers need to be concerned (will be discussed more with our experiences in chapter 3).

We concur with the other works i.e. (Bharucha et al., 2009; Orpwood et al., 2008; Sixsmith et al., 2007; Span et al., 2013; Topo, 2009) that the research has been biased toward safety issues. Evans et al. (Evans et al., 2015) present the results of CHI Squared analysis about the distribution of research across themes different from an expected even split (Fig. 2.9). It is clearly that safety devices and memory aids have the most over representation (significant differences $p < 0.05$). About the thesis topic (navigation), the number of projects for people with dementia in localization and navigation is very limited, especially for an indoor environment (only IMP and Context-Aware Wayfinder were found). This bias may be associated with the fact that the caregivers were the main source of information in a vast majority of the studies and they tend to emphasize care issues such as management of ADL (Activities of Daily Living) and safety issues e.g. (Kirsi et al., 2004). When informal caregivers (e.g. family members) of people with dementia were interviewed, their main concerns were safety, lack of time for themselves, lack of meaningful activities for people with dementia, and difficulties experienced in orientation (Bank et al., 2006; Nolan et al., 2002b). On the other hand, people with dementia report how difficult it is to find something to do (activities), to sleep or to live with the insecurity that you do not know where you are and what time of day it is (orientation and navigation) (Harris, 2006). Unfortunately, the voice of people with dementia is often ignored (Savitch and Zaphiris, 2006; Wilkinson, 2002). Exclusion of people with dementia in research may strengthen the stigma attached to dementia (Vernooij-Dassen et al., 2005; Werner and Heinik, 2008). Only in a few studies, people with dementia act as informants, either by being interviewed e.g. (Baruch et al., 2004; Topo et al., 2004) or by videotaping and by direct observational methods (Lucero et al., 2000; Margot-Cattin and Nygard, 2006), whereas according to Topo et al. (Topo, 2009) many others used available technology and assumed that it suited the people with dementia' purpose.

Theme	Chi^2 Adjusted Residual
Memory Aids	*2.71**
Safety Devices	*4.60**
Preventing Social Isolation	-0.57
Supporting Everyday Tasks	-1.20
Leisure Activities	*-5.279**
Clinical Devices	*-1.986**

*significant at p<0.05

Fig. 2.9 CHI Squared Adjusted Residuals for differences in distribution to expected even split (Evans et al., 2015)

Based on the evidence above, involving people with dementia is indeed the main problem of designing and developing for them. It is not only difficult in recruiting people with dementia but also requires empathy for the users as well as awareness of their abilities, needs and to their environment (Monk, 2008; Orpwood et al., 2010). However, it seems to be imperative to gain an understanding of their unique needs and requirements (Davies et al., 2010; Orpwood et al., 2010; Stalker et al., 1999). Stalker et al. (Stalker et al., 1999) even state that if the people with dementia is the user, then "Reliance on carers for this information is foolhardy".

For example, novelty is often seen as a problem for people with dementia. Orpwood et al. (Orpwood et al., 2010) argue that "People with dementia will not be able to learn to use new devices in their home". Due to the poor involvement of people with dementia in development processes of IT applications, people with dementia often get trouble in using new IT applications. The products do not match their needs and capacities: many applications are too difficult to use, contain too many functions, and are not attractive (Hanson et al., 2007).

The next question is what phases of the development and what methods used when we involve people with dementia. Brender (Brender, 2006) classifies four development phases in Health Informatics area: explorative (user requirement specification), technical developmental (technical requirements, assessment with experimental character, not in real-life conditions), adaptation (IT-based solution is put into daily operation), and evolution phases (IT-based solution in a stable condition and new development are initiated). Based on this classification, Span et al. (Span et al., 2013) indicate that most publications have involved people with dementia in the first two phases: explorative phase (13 publications) and technical developmental phase by having them use the device (11 publications). Only three publications (i.e. (Astell et al., 2007; Hanson et al., 2007; Riley et al., 2009) have involved people with dementia in the adaptation phase, and none of the publications have involved them in the evolution phase. Moreover, different methods were used for collecting data in different phases. Interviews, observations, and usability were the most used methods. Others were focus groups, workshops, questionnaires, self-assessments, video and audio records. All studies combined two or more methods and described no standardized measure or protocol regarding the involvement of people with dementia (Span et al., 2013). Among publications that people with dementia were involved, their roles are varied. In most publications, people with dementia were involved as an object of study or informant and researchers concerned more on information related to their research questions than in the effects of participation of people with dementia. Only two publications (i.e. (Hanson et al., 2007; Robinson et al., 2009)) seem to be standout that involved people with dementia as co-designers. For the future development of assistive technology for people with dementia, user centered design (UCD) is strongly recommended for new development as well as modification of existing ones (Bharucha et al., 2009; Evans et al., 2015). However, UCD has diverse methods and can barely be applied directly to people with dementia. Some researches have already provided guidelines focusing on the design process and participatory design methodology for people with dementia e.g. (Hendriks et al., 2013; Lindsay et al., 2012; Wallace et al., 2013) but only for people with mild to moderate dementia. We otherwise focus on people with moderate to severe dementia and realize a gap of adapting the UCD methods.

The next thing we would like to discuss is about the assistive device in navigation context. It is clearly that mobile phones and PDA were overused. Unfortunately, our users i.e. people with moderate to severe dementia cannot use those devices properly and frequently. Other devices such as robot walker e.g. IMP – Intelligent Mobility Platform (Morris et al., 2003) or intelligent wheelchair e.g. NOAH (Viswanathan et al., 2012) are interesting but only suitable for people who need an ambulatory device and have a mild degree of cognitive impairment as well. Participants seemed to like the prototypes of KITE project (armband and notebook), but the armband prototype is quite hard to carry and basically, is an emergency button, not a navigation support system; whereas the notebook for the Driver is like a tablet with a modified appearance. Differently, without localization technique, a wearable belt is introduced (Grierson et al., 2011) to facilitate navigation for people with dementia using four small, vibrating motors that are adjusted to the front, back, right and left. Choosing a device for people with moderate to severe dementia is challenging because not only about the technique (indoor tracking technique is more difficult than outdoor) but also about user perspectives (size, weight, appearance), energy efficiency, and cost (hardware and computation).

The last but not least key point is instruction and guidance cues for people with dementia. The systems normally use mobile phones / PDA and instruct next steps by arrows, images, texts on the screen, or voices from speakers. That kind of guidance cues have some drawbacks. Kaminoyama et al. (Kaminoyama et al., 2007) mention that the users have to constantly watch displays or scenes and thus be dangerous at crossroads and on stairs. Moreover, uncharacteristic photos or places where scenes are similar (e.g. intersection) confuse users. Hettinga et al. (Hettinga et al., 2009) point out that warning sounds have a negative effect on the quality of wayfinding for people with mild dementia. A familiar voice is a better choice with a positive impact. So what do we use if texts, arrows on the screen are not a good choice for people with moderate to severe dementia? The potential approach is environmental cues. In this thesis, we try to find a good navigation environmental cue and turn it from static into a flexible, dynamic cue.

Chapter 3

Study 1: Requirements Gathering

Adopting user-centered design approach, context and requirements of users (i.e. caregivers and mainly people with dementia) were gathered as a first step to understand needs and difficulties (especially in spatial disorientation and wayfinding problems) experienced in dementia care facilities. The qualitative studies were conducted to identify the types of difficulties - specifically wayfinding problem and potential guiding cues in two dementia care facilities in Würzburg, Germany. The section 3.1.1 describes the method chosen - Contextual Design, elaborates on why we used it, how it fits into the research context (dementia care facilities). Due to the impairments of people with dementia such as warning signs (section 1.2.2) WS6 - word-choosing problem, WS1 - memory loss, or WS2 - cognitive problem (challenges in executive functioning), the Contextual Design method cannot be applied directly and is adapted (details of adaptation in section 3.1.1).

Working directly with people with dementia is extremely important, as speaking only to caregivers raises many issues (Orpwood et al., 2008), such as generalizations over completely different people with dementia or reporting problems only from their own perspective. However, very few research prototypes in the field of care facilities include clinical studies involving people with dementia (Bharucha et al., 2009). Even fewer studies involve them as co-designers (Span et al., 2013), for notable exceptions see KITE (Lindsay et al., 2012), and ACTION (Hanson et al., 2007). Earlier research in the field of user-centered design has already produced some guidelines focusing on the design process and participatory design methodology for people with dementia (Hendriks et al., 2013; Lindsay et al., 2012; Wallace et al., 2013). They focus however on designing for people with mild to moderate dementia. In these studies (Hanson et al., 2007; Lindsay et al., 2012), for example, participants are recruited only if they have sufficient cognitive abilities to be able to actively participate in discussions. Participants, for example, are still actively engaged in hobbies, leisure activities, or are willing to learn how to use a computer. Due to severe cognitive impairments, people with moderate to severe forms of dementia cannot fulfill these criteria and co-creating assistive systems with them remains a challenge.

Previous works have tried to understand the reasons of wayfinding difficulties and focused on physical environment features to support orientation. Wayfinding difficulties have been described as an execution and attention problem (Chiu et al., 2004), which is also conceptualized as a problem in reaching destinations while appropriate solutions are not available in memory (Chiu et al., 2005). Wayfinding difficulties cover multiple problems such as a problem of prospective memory (steps to reach the destinations) (Berg, 2006), concentrating/focusing on a task (Mahoney et al., 2003), or sense of directions, etc. Physical environment features aiding orientation for people with dementia include layout of care facility, its unit size, room configurations, presence or absence of noise, provision for protected wandering (Zeisel et al., 1994), whereas Marquardt et al. (Marquardt and Schmieg, 2009) suggest small number of residents per living area, provision of only one living and/or dining room. Other potential interventions are additional supporting features such as landmarks, signs, color contrasts, good lighting (Marquardt, 2011).

It is worth conducting studies (not only based on other works) gathering requirements as the first step to understand more about our users - people with moderate to severe dementia who were barely considered in the other projects. We expect that people with moderate to severe dementia get more difficulties due to more severe impairments. Hence, working with and designing assistive system for them is also more challenging. Furthermore, as mentioned above, interventions supporting wayfinding were limited to physical environment features which are static and hardly adapted to different individuals and situations. Plus, the assistive system from other works was usable only for people with mild to moderate dementia (section 2.2). In these studies, we were trying to explore physical environment features which can be turned into a flexible, adaptive cue in an assistive system for supporting orientation and navigation for people with moderate to severe dementia. Besides that, wayfinding difficulties severely impact other daily activities of people with dementia. We then investigated other difficulties of people with dementia and their relationship with wayfinding problems as well. The interaction between people with dementia with environmental cues, potential devices were also an important aspect considered.

***Research Questions*:**

- What are the problems (especially wayfinding and disorientation difficulties) that people

with dementia get in dementia care facilities?
- How do people with dementia interact with assistive devices and environmental cues?

3.1 Methodology

3.1.1 Contextual Design

User-Centered design (UCD) is the process of designing a tool or a system that puts the users at the center. Instead of requiring users to adapt or to learn how to use the system, the UCD's objective is to understand how users need, want, and be capable to use the system, and then to optimize the system around that. According to ISO 9241-210:2010, four main phases of UCD (iterative) process are *specify the context of use* (who will use the product, purposes and conditions of using), *specify requirements*, *design*, and *evaluation*. We considered both *specify the context of use* and *specify requirements* as *requirements gathering*. Table 3.1 lists popular UCD methods/tools and their main characteristics.

As our first objective was requirements gathering (context and users), methods focusing mainly on design phase i.e. usability testing, card sorting, and participatory design were out of consideration. Questionnaires require a high sample size which was hard to achieve. Recruiting participants with dementia was not easy as described in section 3.1.3 and 3.1.4. Interviews and focus groups were also not optimal due to cognitive impairment issue of people with dementia. Problems in *word-using*, *executive functioning*, *changes in mood and personality*, and *withdrawal from social activities* (Fig. 1.2) make interviews and focus groups sessions involving people with dementia inefficient. Contextual design (CD) (Fig. 3.1) was a good option as it is a structured UCD process to gather users data in the field (requirements gathering phase). The data then is used to create and prototype product, and to test and refine iteratively it with users (designing phase). The core of CD is to go out on the field and try to understand users e.g. their intents, desires, and operations which are sometimes invisible to the users, especially people with dementia who get problems in planning, thinking, and expressing (Fig. 1.2).

CD method was originally developed by Beyer and Holzblatt (Beyer and Holtzblatt, 1998) at Digital Equipment Corporation (DEC). They recognized the need for a structured design process using their useful practices in fields to make it accessible and actionable to design teams. Their initial work was to improve the limitations of usability testing and human factors works that time, which was focused on lab-based quantitative measures and not lead

Table 3.1 Popular user-centered-design methods and tools (after (Teoh, 2006))

Method	Short description	Cost	Sample size	Using phase
Usability testing	Asking participants to follow the think-aloud protocol (i.e. verbalizing what and why they are doing it) while using a prototype or performing tasks. The generated data could be non-statistical (note of difficulties users encounter) or statistical (time of completing tasks - not recommended as think-aloud protocol would slow users down substantially)	High	Low	Design & Evaluation
Card sorting	Asking participants to sort cards with statement written on each. Multiple sorts of individual are combined and analyzed statistically	High	High	Design
Questionnaires	Asking users a pre-defined set of questions. Good way to generate statistical data	Low	High	Requirement gathering & Evaluation
Interviews	One interview speaking to one participant at a time. Can explore unique point of view from participants but the output is usually non-statistical	High	Low	Requirement gathering & Evaluation
Focus groups	Encouraging a group of users to share opinions, feeling, ideas on a topic. Data output is non-statistical	Low	Low	Requirements gathering
Contextual design	Incorporating ethnographic methods involving user behavior observations and conversations for gathering data in the field. The data from users is aggregated and findings are applied into the final product	High	Low	Requirements gathering & Design
Participatory design	Not just ask users opinions but also involve them actively in the decision making and design process	Low	Low	Design

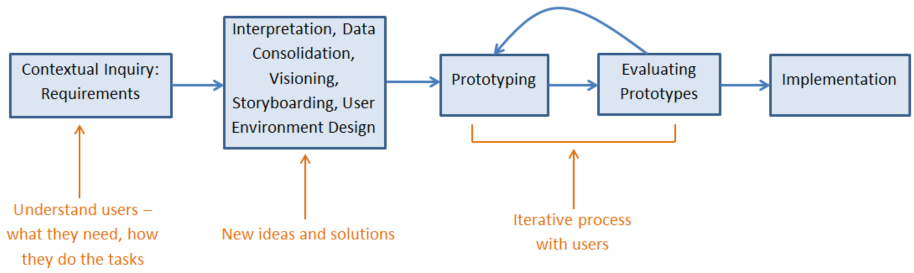

Fig. 3.1 Contextual Design process

to fully new insights and design ideas. In the recent update (Holtzblatt and Beyer, 2014), they added further models to CD adapting to a new generation of users and mobile devices. One advantage of this UCD process is its user research method, the Contextual Inquiry (CI) which was a blend of interview and observation, and was defined as a structured method for gathering and using field data. CI is a part of contextual design methodology. CI (field studies) along with user requirement analysis are considered most important in practice, but not widely used (Vredenburg et al., 2002). The CI method offers several advantages such as the open-ended nature of the interaction (potentially uncover *tacit knowledge*), highly reliable, detailed, and flexible. It allows capturing statements directly from the users in their environment. Another advantage of CI which is important for dementia context is that CI was inspired by ethnography and involved observations. So the behaviors data, which users would not talk about in interviews due to a verbalizing problem or unaware of that behavior, can be collected. Data gathered by those methods helps designers to keep in mind authentic picture of the users when developing a product. The whole design process is then guided by user needs and less by designers' preferences (Friess, 2012). Prototypes and later product are consequently optimized for actual users rather than for designers themselves. High user involvement throughout the stages of design has developed usable and higher acceptance products (Damodaran, 1996; Kujala, 2003). Moreover, CI method does not capture only users' skills or tasks but also the context in which future system should be used. Eshet and Bouwman (Eshet and Bouwman, 2017) found "specifically the unfamiliarity of practitioners with the users' mentality and tasks" to be one of the "key motivators to explore target users in their real-life context [...] especially in early requirements phase". They conclude with suggesting context to be the "final frontier in the design of specific consumer systems" (Eshet and Bouwman, 2017). Therefore, we chose and adapted CD process to our user group - people with dementia in the usability context of dementia care facilities.

3.1.2 Our Adapted CI Method

However, the CD process, specifically CI method is barely applied directly to dementia context as it requires high temporal and cognitive efforts from the user. They typically need to agree on being observed for two hours including questions on the nature of their actions and the underlying reasons as well. It would be too burdensome for users as people with dementia, cognitively as well as emotionally, due to their impairments (have to answer questions, reasons about tasks that they might not know or remember). Asking people to verbalize their actions or describe specific objects (Wood, 1997) is out of the question because people with dementia tend to have problems naming everyday items. That is also why naming tasks are used among others for diagnosis (Buller and Ptok, 2005). Our solution was to shift the focus from continuous questions to observations. We were not mute completely but still occasionally engaged in conversation or posed our questions to caregivers. Another factor that needs to be considered is the high variability of cognitive fitness over the day but also between days (Sandman et al., 1986). A single observation session would therefore not be representative. We adjusted standard CI methodology and distributed observation sessions across each day and over multiple days in a row (facilities A and B). Another advantage in distributing observation sessions was that we could see behavioral triggers that depended on the time of the day (e.g. breakfast, coffee time, being visited by family members in the evening, scheduled activation sessions). A single observer, however, would have been less distracting but could have had trouble processing all the events at the active times of the day. In addition, residents' facial expressions, gestures and unclear pronunciation would often leave room for interpretation that it turned out to be useful having two observers in each residential group. The use of the term "observer" rather than "interviewer" already points towards our being cautious to not overexert people with dementia with too many questions. If a resident is in a chatty mood, the observers, of course, join the conversation and ask questions encouraging the person to keep talking. Even though adapting CI method could provide more valid results, but the changing also made CI much more resource-intensive.

3.1.3 Recruiting Dementia Care Facilities

In order to conduct studies, we had to recruit dementia care facilities. The table 1.1 in chapter 1 shows the overview of dementia care facilities where we conducted studies. Two care home/facilities Extra 1 and Extra 2 in Dresden, Germany with a one time visit were not listed in the table. The first criterion was that they had people with dementia as residents. The more dementia residents and the more diverse of dementia range (mild, moderate, severe), the better it is for us to investigate. Location near Würzburg was another criteria as we

Table 3.2 Methodology adaptation of original Contextual Design method by Holtzblatt and Beyer (Holtzblatt and Beyer, 2014)

Methodology change	Original method	Adaptation to dementia context
Additional preparation	–	Experimenters learn consulted opinions from caregivers and ethical guidelines to deal with residents
Type of data collection	Mainly semi-structured interviews	Mainly observations
Duration of data collection	Two-three hours per user	12-15 hours / 3 days in facility A, 50-55 hours / 5 days in facility B, 30-35 hours / 5 days in facility D
Number of interviewers	One per user	One-two per dementia residential group
Role of interviewer	Active and curious	Curious but rather passive
Questions	Ask about what you observe	Might need to ask caregivers or relatives instead of users
Prototyping	Start with paper prototypes	Use robust hardware and high fidelity simulations (e.g. Wizard of Oz)

planned to conduct studies which could last for weeks. The first attempt was to contact the dementia care facility A, where a former colleague conducted a study with people with dementia relating to a smart radio (Pusch et al., 2013). Before contacting the manager, a project overview in a short version (a half of page) and a longer version (two pages) were prepared. The overviews described main objectives of the project, how it could help people with dementia and facilitate works of caregivers. As I do not speak German, a colleague was supporting in contact and communication with the manager. The manager also joined in caring for people with dementia daily, and she is therefore always busy. After a couple of time talking by phone, we finally got an appointment with the facility's manager. We visited the facility, observed how things work there, discussed the project with the manager. In the end, the manager was interested in the project. However, she did not want to setup new guiding cues or change the environment, or to interrupt people with dementia by wayfinding sessions. We did observation, talking to people with dementia, interview with the manager.

We then tried to find another dementia care facility where is more open for conducting experiments by searching on the internet, contacting people who had experiences working in a hospital or health care facility. It was a long shot after all. Eventually, we found a potential facility B. It took few phone calls until reaching the manager. The author and a colleague, who went together to the facility A, discussed and agreed that our plan giving to the manager in the beginning seemed to be very long-term with too many objectives, studies which could overwhelm her. Therefore, we changed the strategy. We just gave the manager a general idea that we want to learn about people with dementia and to find solutions to support them as well as caregivers. We asked his permission to be around watching how the facility works. Then after one meeting to another, we provided more information to him with our insights, ideas, and experiments. The plan was adapted to the situation of the facility instead of a strict plan giving to the manager from the beginning. After all, observations, interview with caregivers, and a wayfinding experiment were conducted.

Results of this requirements gathering phase (affinity diagrams and difficulties of people with dementia) were drawn mainly from studies in facility B. They were supplemented by some observations in facility A and a few insights from visits to facilities Extra 1 and Extra 2.

3.1.4 Recruiting Participants

Firstly, we took into account the ethical guidelines of the Alzheimer's Society for general issues and consulted opinions of professional caregivers in both dementia care facilities A and B for their own protocols and special issues. Our criteria for participants are: being diagnosed with dementia as well as retaining hearing and speaking ability and additionally mobility (i.e. being able to move independently) for a navigation study (chapter 5).

In facility A, there were two floors with 27 people with dementia. They were in a variety range of dementia (from mild to severe dementia). Two-three caregivers were responsible for one floor. We asked permission of the manager of facility A and people with dementia directly to join our favorite color study. We got eight participants in that study. Facility B had 25 residents, and 12 of them were people with dementia. All of them were in the later stage of dementia (moderate to severe). Each floor of the facility was in charge of one-two caregivers.

In facility B, we asked caregivers to filter the potential participants who they think are fit for our project according to age, health records. We then contacted relatives or legal representative (e.g. lawyer) of people with dementia to collect their signatures for informed consents. The informed consent consisted of a short description of project objectives, methodology, how to protect the data. Anonymization process was used to mask personal identifiers, such as name. All of the related information were encrypted, stored in security local driver, and deleted after an analysis process. Besides that, the participants can stop participating at any time. Several ethical issues were also considered. In the end, four participants participated in both observation and navigation studies in facility B. The age of the participants ranged from 82 to 94 years.

3.1.5 Data Collection Process

Table 3.3 shows an overview of data collection. In facility A, we spent the first day (from 10:00 to 16:30) to visit and get familiar with the environment, caregivers, and residents. A semi-structured interview with the facility manager was also conducted that day. In the next two weeks, we conducted a study about the favorite color of people with dementia (section 5.2). Besides the favorite color study, we also observed residents, living environment, and interaction during three days.

In facility B, I firstly prepared project descriptions and got it translated into German with the help of a colleague for showing to the facility manager. Then, I also designed protocols of observations and light studies, expected results for two bachelor students as well as implemented and tested technical stuff (remote light control). Before the observation started, we visited the facility and did a briefing with the shift leader/ boss of the caregivers who told us some useful information about the people with dementia (like how to behave, how they could behave). We also talked about the following experiment and how and when it should be conducted. I, a colleague, and two bachelor students have spent two days for getting familiar with environment, caregivers and residents. It took two weeks for reaching relatives or legal representative of participants and explaining the project and getting their signatures for informed consents. The studies were then ready to start. Two bachelor students conducted one week of full-time ethnographic observations (beginning of October 2014). Observation continued in the following six weeks as the observers were present in the facility while conducting another study, which focused on reactions of people with dementia when seeing lighting with color in wayfinding. I participated about 50% duration of observation and light studies as an extra observer.

The observation sessions usually started when people with dementia get up (about 07:30 a.m.) and lasted until the usual sleeping time (07:00 p.m.). As one caregiver gave us a list of potential participants for the light and colors experiment, we focused on six people on the list at first but also tried to observe behaviors from other people with dementia as well. I prepared the interview questions with caregivers in English (Annex B). Two bachelor students then translated into German and did interview caregivers when they had free time during the observation studies. The interviews were captured in written notes.

Caregivers were asked to involve in conducting studies (e.g. to calm participants, to motivate them). We tried to anticipate situations that create stress or anxiety (e.g. talking to a stranger, or being in an unfamiliar environment) and prepared solutions/strategies to minimize/deal with those situations (e.g. establish eye contact with an authentic smile, make friends by talking about the past and personal hobbies; create a familiar environment including their photos and other personal items; have a small chat before doing tasks; give compliments to motivate and encourage participants such as "You are doing great!" or "Well done!").

Participant Observations

The observation was collected mainly in the public areas like corridors, kitchen, and meeting room. The daily activities with timestamp were noted down as well as incidents that residents experienced both positive and negative emotional states. Besides that, the actions, verbal communications, and behaviors of people with dementia when they were on their own and when they were with caregivers were separately documented. Related information which can influence the lives of people with dementia such as environmental cues, settings of facilities, caregivers, visitors, conversations, and statements were also recorded. There were always two or three researchers at one observation session to cover a larger area and more participants. Having more than one observer also avoided bias and supported for cross-checking and discussion later. We attempted to keep a moderate distance from residents, not too close to interrupting their activities but not too far so that we could document the situation in detail. Occasionally, residents went toward us and wanted to talk. These situations were sensitive and hard to keep it in neutral. Although it is necessary being friendly and making them comfortable with our presences, a distance with residents should be maintained to prevent disrupting their daily activities. Regardless, talking with residents was still a good chance to

Table 3.3 Data collection in facilities A and B.

Facility	Date	Time	Objective
A	July 2014 - Day 1	10:00 - 16:30	Visit and get familiar with environment, caregivers, and residents
A	July 2014 - Day 1	11:00 - 12:00	A semi-structured interview with the facility manager
A	July 2014 - Day 2-4	10:00 - 12:30 or 14:00-16:30	Observation
A	July 2014 - Day 5-8 in two weeks	10:00 - 12:30 or 14:00-16:30	Favorite color study
B	October 2014 - Day 1-7	7:30 - 19:00	Full-time ethnographic observations
B	October 2014 - Day 8-27	7:30 - 12:30 or 13:00 - 17:30	Lighting with color in wayfinding study + Observation
B	October 2014 - Day 28-29	7:30 - 12:30 or 13:00 - 17:30	A semi-structured interview with a caregiver

understand more about them and interpret the data correctly. We were trying to be curious but rather passive, mainly listen to their story.

Semi-Structured Interview

During the observations and experiments, three semi-structured interviews were conducted. Interview questions are in the Annex B. The interviewees were two managers and two caregivers. The details of interviews were captured in written notes. The main goal was to capture the facility's organization, insights and opinions of the interviewees about the residents' difficulties in general and wayfinding difficulties in particular, and about our suggestions for solutions, prototypes.

3.1.6 Data Analysis

CI was defined as a structured method for gathering and using field data which forms the bases for a Grounded Theory. Grounded Theory relies on no underlying theory: "Let the data speak". It is different from the traditional model, where choosing an existing theoretical framework and only collecting data to show whether the theory applies to the phenomenon under study.

The data analysis process was followed Contextual Design method and also guided by Grounded Theory by Charmaz (Charmaz, 2006) and the approach of Miles and Huberman (Miles and Huberman, 1994) such as how to code the transcript data, how to analyze using a thematic analysis technique. This kind of methods aimed at understanding the problems of people with dementia under their own point of views and using their own words.

The procedure mainly consisted of three phases. The first phase was *data reduction* where the mass of qualitative data (e.g. interview transcript, field notes, observations) was reduced and organized including coding, summarizing, discarding irrelevant data. Two bachelor students and two researchers (I and a colleague) gathered in an interpretation session to hear the story of the interview, observation retold in order. In each turn, the others in the team added individual insights and facts as notes. The data was then coded, summarized, and discarded (if it was irrelevant and redundancy information) in a loop until all team members were satisfied with the results. The discarded data was still stored for accessing later if necessary, as those data might have needed to be re-examined for unexpected findings. The second phase was *data display* to draw the ideas/conclusions from the mass of data. A good display of data (e.g. graphical format, charts) is essential (Miles and Huberman, 1994). In this phase, we used *affinity diagram* technique to organize, cluster the notes, to classify issues, and to get new ideas, solutions. During the process, every fact about or comment from the people with dementia was written down on yellow Post-its (first level). Each note needed to be understandable on its own. A note could be a quote from a person of dementia such as "I wander around there hundred times, there to the front and back again, it's terrible!". It could also be an observation note "Mrs. X walks to the stair gate while coming back from the toilet; she seems to want to open it, then abandons it and walks back to us (maybe she remembers that she should not do it?)". After re-writing data in Post-its so that each Post-it contains a single different information, all of Post-its were hung up on ten poster walls. The notes were read through by three people (I and two bachelor students) independently to gain an overall understanding. After that, the data was clustered and grouped into higher levels (blue, pink, and green) by theme. For example, a blue note "I am restless" was moved to be near another similar blue note "We run around and interrupt our meals for it". The higher level of affinity notes contained information of all subordinate notes. The highest level groups (green) normally consisted of one or two keywords per category, e.g. "loss of personality" (Bopp et al., 2015). Guidelines from Holtzblatt (Holtzblatt and Beyer, 2014) were followed:

- Blue notes guidelines:
  - Represent the data to highlight the key point
  - Use direct language summarizing an observation, not a category
  - Written from the user's point of view, talking to the team
  - Written in a short, succinct way - simple, direct
    * No need to be a complete sentence
    * No more than 2-3 lines long on the post-its
    * Not design ideas
- Pink and green notes:
  - Reflect a theme/category of findings, but still, use "I" language as the Affinity tells a story of the user's life

Finally, for further refinement and verification, three of us critically discussed and reviewed the diagram until we reached an agreement.

3.2 Findings

The results of affinity diagram are first presented briefly in this section. Then, difficulties focusing on wayfinding and interaction difficulties are analyzed and described.

3.2.1 General Results of Affinity Diagram

Collected data from observation and interview sessions were clustered using the affinity diagram method (Holtzblatt and Beyer, 2014). Fig. 3.2 illustrates a part of our affinity diagram. The diagram with all three top levels (blue dash, pink bullet, and green square) is described in Annex 3.2.1. This part only presents a general overview of top categories - green notes level. Remind that in the affinity diagram, "I" language is still used for reflecting a theme/category of findings as the diagram tells a story of the user's life.

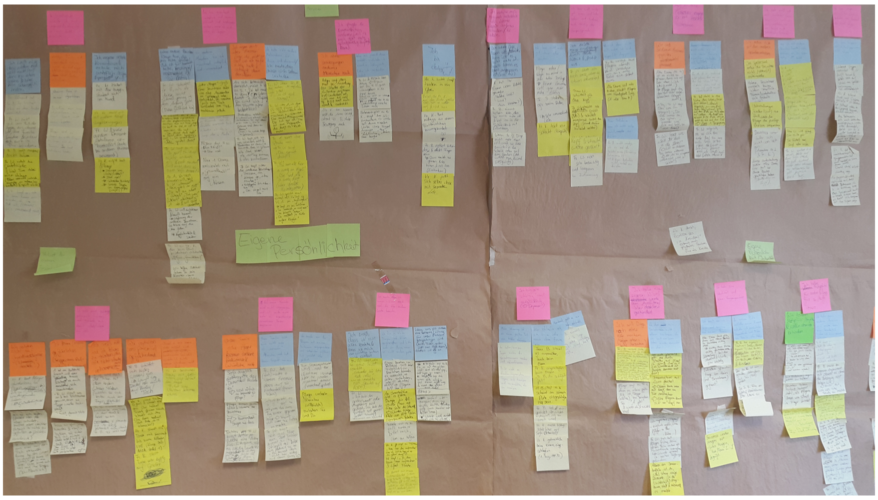

Fig. 3.2 A part of our affinity diagram with four levels (yellow, blue, pink, and green). We were running out of strong yellow and blue notes. Therefore, the white light yellow notes (look like white notes in the picture) were treated as the strong yellow notes and the orange notes were the same as blue notes.

"Orientation and Navigation" is the first topic and also the main part of this thesis. Most of the residents with dementia get a problem in orientation and navigation, physically ("Standing up/walking is very hard for me") or cognitively ("I do not know where I am, I'm scared and desperate"). We focused more on people with a cognitive problem, who get no physically constrained in locomotion. The situations of getting wayfinding difficulties are discussed more details in the next section 3.2.2. When getting lost, people with dementia were looking around, finding others to ask, walking along handrails, or following the light i.e. ceiling

light or sometimes sunlight through a window ("I walk to the light when in sight"). In general, "Caregivers take/lead us everywhere, and we do not have an understanding of our surroundings/environment". People with dementia sometimes are stopped and brought back to place by caregivers although they wanted to walk around.

The next topic is *"How I am treated by other people"*. People with dementia think others tried to be nice to them but did not treat them normally because of dementia. The caregivers convince them to eat, to take medicine "like we were children" (according to a participant). They felt good with the meals "The meals are prepared, accommodated to us, and treated carefully by the caregivers". "If the other people (caregivers, residents, visitors) noticed my need of help or comforting, they would try to provide me". For example, caregivers tried to comfort sad residents by talking and establishing physical contact. Other residents (non-dementia) also tried to help or got some help for them. However, caregivers were overworked and overwhelmed, then "Caregivers occasionally neglected us or did not pay attention to us".

"How I behave towards other people" is the next green note. People with dementia from time to time did not know or forgot how to behave properly. They could walk around naked, fart, burp in front of other people, or take any objects they like although objects did not belong to them. They did not care much or lacked awareness about their hygienic conditions. Besides that, social isolate (*withdrawal from social activities - WS9*) was also an issue. People with dementia reacted suspicious and cautious to strange people. They also did not talk to other residents often as they admitted that they failed to understand the counterpart (due to impaired hearing, speaking, or thinking). Following group activities with many people was then even harder. As they cannot express their needs verbally, they used to express feelings (approval/refusal) by strong gesture/facial expression or grumbling, sometimes by an offensive way like hitting caregivers when they did not want to the task. In addition, mimicking other people' behaviors, repeating some keywords were some reactions when they were not able to understand or answer/respond questions/tasks.

"Loneliness". As a result, most of the residents with dementia felt lonely. They sought companies, wanted to be close to others especially family and sometimes other residents. Based on our observation and talking with residents, they were pleased when getting someone's attention, felt happy about compliments and commendation, or greeted back when someone say hello to them. They seemed to be happier and (more) attentive when someone was taking

time for and addressing them personally.

However, people with dementia still have *"remaining capability"*. Some of them can verbally answer questions, present their thoughts and wishes. They also noticed new people in facility And recognized people the next encounter. Residents, who might get less *confusion of time and place - WS4*, noticed changes of surroundings, time of day, had an ability of temporal orientation depends on daylight/brightness.

"Engagement and vitalization" is certainly another important topic. There is a specific lack of activities for people with dementia. According to them, "we do not have any purpose/meaningful engagement because everything is done for us" or "we sit around apathetically and only wait for the next meal". Some group activities from caregivers or therapists were not interesting enough because topics were irrelevant or not understandable for residents. They wanted to have activities or objects surrounding in the environment: "I like being surrounded by life/joy. It activates me, and I could then search for something interesting".

Last but not least is the issues with *"personality and identity"*. People with dementia always felt not at home and suffered from homesickness. They complained not having any private sphere: "Caregivers stop us from doing things and redirect us to other activities", or "Caregivers control our surroundings (TV, radio, shutters), restrict our freedom". As they got a problem with short-term memory rather than long-term memory, stories, personal items e.g. pictures of family or hobbies in a long time ago could provide a positive affect (reminiscence activity).

3.2.2 Wayfinding and Interaction Difficulties of People with Dementia

In this part, we discuss the difficulties of people with dementia based on the affinity diagram of facility B and multiple observations in dementia facilities.

Wayfinding Difficulties

Difficulty finding their bedroom: in facility A, according to the manager, at least a half of dementia residents got trouble in finding their bedroom. In facility B, all four participants in observation and navigation studies faced this problem. Most of other nine dementia residents were also reported having this difficulty. Few residents were looking for their bedroom in the wrong block (facility A) whereas some could not recognize their room when passing by. Dementia residents would often search for their room for 5-10 minutes, many times they did not find it successfully and had to ask people around such as caregivers or even visitors. One resident did not want to leave her room as she could not find the way back to it. To assist the situation, the facility A put their youth picture on the door along with some personal objects around. The interesting thing was that people with dementia e.g. some residents in facility A did not recognize themselves in the mirror or their recent photos, but they still recognized their youth portrait pictures (Nolan et al., 2001, 2002a). Facility B, on the other hand, hung some pictures which the people with dementia seemed to like e.g. flower or car on the wall and put some objects next to it as well. Both facilities had plates of name and room number on the door. However, those approaches were not so effective due to some reasons. Due to visual impaired, people with dementia barely read the text and number or read it incorrectly. Besides that, people with dementia used to pass by their rooms without noticing. Their gaze was usually a bit down on the floor (Fig. 3.3) and even if they looked at the door, the chance they found the right item/information would be low (resonate with (Namazi and Johnson, 1991a)). This raised another problem *"how to grab people with dementia' attention and gaze?"*

Fig. 3.3 A person of dementia with lower gaze than normal people

Another big problem of people with dementia is *Entering the others' bedrooms*. In facility B, there were 2 participants often mistakenly walking into other residents' rooms. Sometimes they were reminded by other residents or caregivers and were brought back to their bedroom. There was a case the participant 3 went to the wrong bedroom, climbed and lied on the bed even though there was a person on it. Another situation was that participant 3 also got into the wrong room and undressed all clothes. It was inconvenient not only for people who entered the wrong room but also for other residents as well.

Getting trouble with room number: Participant 4 continuously had difficulty remembering room number or reading the number correctly. This resident seemed to be scared and desperate, constantly asked people around if they can show her room.

Difficulty finding a public area such as activity room, kitchen, meeting room: Dementia residents in facility B barely found the activity room/kitchen. The caregivers had to come to individual's bedroom and brought them to the place. This reduced the independence of people with dementia and made caregivers overwhelmed. We also observed that if the caregivers let people with dementia freely choose the dining table, they would likely choose the wrong table because they could not see the information e.g. name on the table.

Do not remember the destination: This issue could be the reason of other difficulties such as wandering in the corridor or finding places. In facility B, sometimes participants walked around for a while and got lost, but when caregivers asked and offered help, the participants said that they forgot where they wanted to go.

Getting trouble in orientation (where am I?): this was mentioned in the affinity diagram. Our participants got into this situation frequently. This problem severely influenced the confidence of people with dementia.

Getting trouble with the route: Even if people with dementia knew where they were, where they wanted to go, remembered the number of their bedroom, they still could not find the way due to experiencing difficulty comprehending and executing route instructions.

Going the wrong way at an intersection: At decision points like an intersection, people with dementia used to get confused. These situations were hard for them to distinguish and orientate.

Cannot interpret explicit guiding cues: The explicit guiding cues such as a plate of text, a sign, a number in the navigation context did not work well with people with dementia due to impairment of visual, memory, cognitive. For example, if a person of dementia went into the lift, according to the caregivers, this was rather random and not attempted intentionally for transportation. They were normally no longer able to understand how the elevator works. The facility also tried to attach information besides the buttons (Fig. 3.4) using texts (first floor, second floor) and pictures with arrows (kitchen room, bedrooms area). Unfortunately, that solution did not work well. They used to press the yellow button (an emergency button with bell icon), whereas the gray buttons were never pressed.

Fig. 3.4 Inside the elevator in facility B

Safety issues: Another issue is that residents with dementia in facility B and residents E used to stay in the exit areas and try to escape. Although the facilities hid the open button of exit door or forbade the residents opening the door with RFID chips attached on their hands, it still needed to be careful as the residents would escape when the exit door was opened by visitors. One time in the exit door area of the facility B, a caregiver tried to guide a resident to other areas such as common room, the resident even hit and resisted coming with the caregivers.

Interaction Difficulties

Graphic User Interface (GUI) and technology devices like smartphone/PDA were also observed that challenging people with dementia. Firstly, in the dementia care facilities where we conducted studies, no one used such technologies. An assistive device with one button still can confuse them. In a visit to the dementia care facility C, it was noticed that residents wear a necklace with an emergency button on it. But according to the caregivers, the button was misused by being pressed constantly. Caregivers had to guess if it was truly an emergency based on residents' face, talking, or behavior. More generally, people with dementia have interaction problems. They probably do not know their current state, what they expect, and how they can interpret the system, which leads them to a situation that is impossible to use and to input explicitly into the system. This aspect is important to address in order to build a successful system for them. Moreover, each person of dementia is different. One static guiding cue might not satisfy all of them. The system is needed to be flexible and adaptable to individuals and situations.

3.3 Data Validation

To ensure the trustworthiness of the data, the *verification* phase was executed. As recommended by Onwuegbuzie (Onwuegbuzie and Leech, 2007), the following techniques were used throughout the data collection and analysis.

- *Prolonged engagement*: it refers to the studies that are conducted for a sufficient period which is enough for representing the user's voice. In our studies, we spent few days getting familiar with residents and environment, building trust with participants. We also adapted and prolonged the observation time of the original CI method to understand more participants and check for misinformation.

- *Persistent observation*: whereas prolong engagement provides scope, persistent observation provides depth. We tried to identify and separate relevant from irrelevant observations.

- *Triangulation*: Triangulation combines multiple methods, sources, investigators, and theories to reduce the systematic biases and then increase trustworthiness in the analysis. Denzin (Denzin, 1973) outlined four types of triangulation: data triangulation, investigator triangulation, theory triangulation, and methodological triangulation. We used a variety of sources and methods (*data triangulation*) such as qualitative data/method e.g. observation, interview and quantitative data/method i.e. experiments. Throughout the analytic process, we always had at least 2-3 researchers (*investigator triangulation*).

- *Leaving an audit trail*: all researchers and bachelor students who involved studies had an audit trail (raw data, reduced and analyzed data, process notes) that others can judge the process, key decisions through which the research has been conducted.

- *Member checking/informant feedback*: This technique normally lets the participants play a major role assessing the credibility. However, as our participants got severe problems in word-using, communication, and interpretation, they are not a reliable source. We still afforded them the opportunity to assess but also combined the review from caregivers and cross-checking among observers (2-3 researchers).

- *Weighting the evidence*: Some data are better/stronger than others were given more weight. Stronger data is typically collected through situations following (Miles and Huberman, 1994): when data are observed or reported firsthand; when data are collected with persistent observation and prolonged engagement; when the data are collected in informal settings; when the field-worker is trusted.

- *Checking for representativeness*: Miles and Huberman (Miles and Huberman, 1994) list several reasons leading to inaccurate generalization (low representativeness). One of those is generalizations made from non-representative events or activities due to researcher's non-continuous presence at the field. We overcame this problem by conducting studies with a long and continuous period (weeks). We also addressed multiple residents in different care facilities as well as used a triangulation technique to improve representativeness.

- *Checking for researcher effects/clarifying researcher bias*: Miles and Huberman (Miles and Huberman, 1994) identified two kinds of researcher bias: effects of the researchers on the participants (Bias A), and effects of the participants on the researchers (Bias B). We tried to minimize the Bias A by following techniques: prolonged engagement, persistent observation, making research intention clear, using unobtrusive measures when possible. The Bias B was reduced mainly by triangulation technique.

- *Making contrast/comparisons*: Findings can be compared with the other works, as well as with the experience and knowledge base of researchers, caregivers, or even family members. The difficulties (wayfinding and others) of people with dementia as well as physical features (potential guiding cues for an assistive system) were compared with related works to see if there is a conflict or resonation. Also, as mentioned earlier, multiple researchers and caregivers involved in designing ideas/solutions process.

- *Replicating a finding*: we tried to extend situations, population, individuals, times, settings, or context by recruiting more than one facility, conducting studies in a long-time and continuous period, later studies involving other facilities (different places with different participants). By doing so, the confident of the findings were increased.

3.4 Discussion

Through qualitative studies such as observation and interview with adapted CI method, the requirements were gathered as the first step to implement an assistive system for people with dementia in an indoor navigation context. The recruiting (facility, participant) and data collection procedures were first described. The data analysis was then processed with affinity diagram which revealed difficulties and needs of people with dementia, as well as potential approaches and solutions. The drawback of this method was resource-intensive which also makes lesson learned (section 8.1) valuable for other researchers when conducting studies with people with dementia, especially people in moderate to severe stages.

Overall, this chapter presented findings for two research questions mentioned at the beginning of the chapter, which are problems and needs of people with dementia and their interaction with devices and environment. Based on these results, we defined requirements for the navigation assistance system, which shaped the way three-part systems were developed (will be described in next chapters).

- First, the results of studies (observations, affinity diagram) reaffirm that people with moderate to severe dementia get trouble in finding places such as bedroom, kitchen, or activity room. Therefore, a navigation assistance system in dementia care facilities is needed (**R0**). The components of this navigation assistance include at least a device monitoring the location of users i.e. people with dementia and guiding cues (one or more) instructing the users.

- Mobile devices could not be used, not only in monitoring the users' location but also in showing instructions to the users. Current approaches in dementia care facilities mostly rely on explicit guiding cues such as texts, arrows, or images. Unfortunately, those guiding cues do not work well with people in moderate to severe stages of dementia due to their severely cognitive impairment and decreased visual acuity. The situation with an elevator above (Fig. 3.4) is an example. Thus, the requirement (**R1**) is finding a guiding cue, which can instruct people with moderate to severe dementia e.g. turning left, turning right, or going straight ahead. This guiding cue is also better to be implicit, dynamic, and flexible, which can adapt to different situations and individuals, rather than static texts and arrows on the wall.

- Finding an appropriate guiding cue is only a halfway solution. Another issue is to draw the attention of people with dementia to the guiding cue. The requirement (**R2**) is that the guiding cue has to be able to grab the attention of people with dementia.

- For the problem that people with dementia often stay in exit areas, caregivers are too busy to watch out this area all the time. Besides that, as mentioned earlier, the effort of caregivers bringing residents to other areas might be counterproductive. In this case, a cue which can create an outward orientation feeling (stay shortly or move away) without a negative effect is needed (**R3**).

- Besides problems in wayfinding, having no or very few activities might affect people with dementia' physical and mental state. This issue was noted not only in one place but in all facilities we visited and conducted studies (5 facilities in total). Developing new assistive technologies providing interesting and meaningful activities for people with dementia is one thing. Our guiding system could be the central service that is able to guide the users to the places of those assistive technologies and stimulate them to use those additional services e.g. interactive drawers introduced in chapter 5 (**R4**).

- For monitoring location, mobile devices such as smartphone and PDA are normally used, but they are not suitable for people with moderate to severe dementia. Then, the requirement (**R5**) is to develop a new monitoring system with an appropriate device for people with moderate to severe dementia.

- A big challenge is that people with dementia hardly to command the system explicitly e.g. input into the navigation assistance application on a mobile device. Besides, they often forget the destination. For the long-term and intelligent assistance we aim at, the system needs to predict the destination people with dementia wanted to go based on their recent behaviors or at least to suggest the most meaningful place and activity at that time for the users (**R6**).

Chapter 4

Approach and Solution Overview

From observations we conducted in facilities A, B, D, people with dementia (especially people with moderate to severe dementia) have no or very few activities, which can lead to a physical and mental reduction. Participants with higher levels of physical activity are reported at reduced risk of cognitive decline (Blondell et al., 2014). "I'm dying of boredom" - that is what a participant said in a case study (Wood et al., 2009). We also noticed that few dementia residents were quite active and talkative in their first days in dementia care facilities B, D but then getting less activity engagement as well as emotional vitality expression. Developing assistive technologies for meaningful and interesting activities for people with dementia in care facilities is in high demand.

One important designing factor in this situation is how the services are presented as people with dementia get a serious problem handling Graphic User Interface (GUI) and new technologies. It might be the time to move from the traditional interface GUI to another approach like natural user interface (NUI) or tangible user interface (TUI). However, in my opinion, for the long-term, it is not only about one single service for one single problem, but rather the whole living environment. One activity engagement service does not make a big impact if we can not guide them there and stimulate them to use it. Our chest of interactive drawers (chapter 5 - studies 4,5) is an example. These drawers have screens on it showing the pictures with the aim of triggering people with dementia' memory (reminiscence activity). We believe that the effect of those drawers is much better with the support of our guiding system which can guide them to the drawers, grab their attention, and stimulate their usages (requirements R1, R2, R4 in chapter 3). Besides that, the drawers can change pictures to personalized ones accordingly, which increases the effect of the reminiscence activity (thanks to the monitoring system - requirement R5 in chapter 3 that can recognize the location and the identity of residents). Therefore, we aim at building an Implicit Interactive Intelligent

(III) Environment where all services are connected and share information together with the guiding system in the center. The III Environment can provide appropriate assistance at any time and stimulate people with dementia' usage of services. This environment shares some visions with ubiquitous and pervasive computing, wearable and mobile computing environments, but also highlights and focuses more on implicit interaction, tangible user interface, location-based service and personalized service. In this chapter, we present the idea of III Environment, its characteristics, as well as scenarios of how the III Environment can support people with dementia. We also elaborate on how to build the III Environment, later add the services into the environment, connect and combine services.

4.1 Implicit Interactive Intelligent (III) Environment

The terms "home automation", "smart homes", "intelligent home", "home networking" which refer networking devices in the house have been used more than a decade. Other related terms are "aware house", "changeable home", or "ambient intelligent" which focus on the environment that can respond and modify itself depending on residents and their needs. "Home automation" has been early introduced since the 1970s. X10 technology which transmits 120 kHz signal on the electrical power line was developed and patented in 1975, and was released to the market in 1978 by Pico Electronics. Each signal was coded with a House and Unit code. The early 1980s, many Japanese companies such as Matsushita, Toshiba, Mitsubishi, Sanyo, Sony, Sharp published their home automation packages. The next project "smart house" was established in 1984 by National Research Center of National Association of Home Builders (NAHB), the USA with industrial partners. By 1987 more than forty companies had joined the project to develop an application (Smith, 1988). The breakthrough in home automation was in 2001 when Van Berlos built The Smartest Home of the Netherlands (Berlo, 2002). The lessons from Smart Homes projects in Netherlands from 1998 to 2003 were that developments that time focused on alarms, monitors addressing safety and security only. The monitors and alarms also needed the human response back-up. New demands and the needs for guidance about the use of assistive technology for elderly people were problems as well as they had difficult to learn new and complex procedures.

Many works and systems use speech recognition and voice command for home automation. For example, Potamitis et al. propose an integrated system for smart home control for people with disability to perform real-life tasks using speech recognition. Haque et al. present a system controlling smart home based on timer and speech interaction. The system controls the home appliances by timer or voice command via personal computer. Visual Basic 6.0

and Microsoft voice engine tools are used for implementation. The other popular approach is controlling the system remotely with mobile phones. Ciubotaru et al. (Ciubotaru-Petrescu et al., 2006) design and implement an SMS based control for a monitoring system which involves sensing unit, a processing unit, and a communication module that uses GPRS modem or cell phone. Other examples are a remote monitoring through mobile phone involving the use of voice commands (Jawarkar et al., 2008) or a primary health-care management for rural population with mobile web-technologies (SMS and cell phone technology for information management, transactional exchange, communication) (Singh Rahar, 2011).

In general, the environment in those projects is mostly for a single person, which is no need for identifying. The events/activities detected are caused by the user. Our context (dementia care facility) where many residents and caregivers live in an environment. Therefore, the system needs to detect not only the events/activities but also who triggers them. Our monitoring system (chapter 6) would deal with this problem. Besides that, most of other works focused on monitoring the environment, controlling remotely for normal people. The interaction between the user and system are explicit via SMS, personal computer, and/or speech recognition, voice command. The user needs to understand and aware the situation, state of himself and environment, and how the system works to use it effectively. In some specific cases when the system does not know what to do, normally the system would ask the user explicitly input/command. The people with dementia are different as their abilities to use technology, learning, interpreting, explicitly commanding system are all reduced or impaired.

An Implicit Interactive Intelligent (III) Environment is proposed in this thesis, which is for multiple people with dementia in a care facility. The III Environment approaches a different way. The system does not inform the situations for people with dementia and not wait for the explicit input via speech recognition or SMS. The system instead provides people with dementia appropriate services at the right time. Moreover, the main objective of III Environment is not alarm or monitor, but how to improve the people with dementia' quality of life.

Some works about an impact of the Care Environment on people with dementia were also conducted. However, they mostly focused on architecture design. Several studies tried to identify evidence for a relationship between the design of institutional settings and functionality, independence, well-being or behavior in people with dementia (Wahl et al., 2009). They look for the answers to questions about the type of institutional care, its size, model, floor plan typology, environmental cues to improve the quality of life and reduce anxiety (Reimer et al., 2004). However, this environment (dementia-friendly design) is quite static, lack of adaptive and flexible. Our III Environment is something else, focusing on assistive technology, which can be an extension of above dementia-friendly architectural environment making the living environment personalized and adapted for people with dementia.

The III Environment comprises of physical part and digital/virtual part. Before understanding the relationship of those two parts in the III Environment, the physical world and the digital/virtual world need to be clarified. Definitions of the *physical world* and the *virtual world* were taken from Pederson (Pederson, 2003). According to him, "The physical world is the world built of and containing matter directly perceptible to humans, and whose state is defined by arrangements of such matter in places, constrained by and modified according to laws of nature, within a geometrical three-dimensional space, at any time instant partially perceptible by humans through their senses". And "The virtual world is the world built of and containing digital matter (bits) that after transformation into physical phenomena becomes perceptible to humans, and whose state is defined by arrangements of such phenomena in places, constrained by and modified according to (human-designer) law of logic, within a topological multi-dimensional space, at any time instant partially perceptible by humans through displays (possibly multi-modal and audio-visually up to three-dimensional) built into computational devices residing in the physical world".

For instance, a user (e.g. a visitor, a person with dementia) being lost in a building wants to find the room of Mr. A. Let's assume that he has an indoor navigation application on his smartphone. He would open the application and input the destination (room of Mr. A), then follow the instruction such as texts, arrows, or voices. In this situation, the user has to shift from physical world to digital world. The activity of handling a navigation task on a smartphone could be considered as a partly physical activity. However, this activity could be performed in an exquisite and subtly way if the system automatically identifies the user and knows that he is being lost and has an appointment in room of Mr. A (***Intelligent***), then guides him using environmental cues (e.g. light, projected text/arrow, or sound) (***Interactive***). The system interpreted the situation without waiting the user explicitly command the system (implicit input) and triggered environmental cues (implicit output) (this process is ***Implicit*** interaction). More details about implicit and explicit interaction would be discussed in section 4.1.1. This example is also the approach of an indoor guiding system we built for people with dementia. This provides the user especially people with dementia a better experience and requires less cognitive efforts. In this type of system, context-aware computing and user's intent recognition are important.

The III Environment is a place, where the gap between the physical world and the digital world is minimized or ideally disappeared as those two worlds are unified. The implicit interaction plays the important role in this environment. The III Environment aims at supporting people to perform their daily activities without the need to shift their attention to handle computing infrastructures. In this vision, the virtual world is embedded in the physical world and is interacted implicitly via natural interfaces (e.g. tangible user interface). The natural flow of human activities is thus maintained. This approach would be the key to supporting people with dementia especially people with moderate to severe dementia. Their cognitive workload on commanding digital/virtual world is minimized, and their focus is maintained in the physical world where they are familiar with.

4.1.1 Characteristics of III Environment

This section is structured along the three I: **Implicit** Interaction (I1), Novel **Interactive** Styles (I2), and **Intelligent** Adaptation (I3). I1 and I2 are tightly linked, and hence, some concepts e.g. invisibility can be used to justify both I1 and I2.

Implicit Interaction (I1): This part presents our new approach with implicit interaction instead of the traditional explicit interaction. The main point is that the system does not wait for the input of people with dementia but implicitly collects data, predicts the need and situation of them, then provides the output accordingly.

A key challenge in designing assistive technology for people with dementia was to find a simplicity-degree and type of the user interaction. Increasing the level of user interaction opens more potential engagement, but could also isolate people with more impairment in either physical level or cognitive level. However, reducing the level of interaction could limit the activities available and lead to a less interesting prototype for the user. Besides that, the type of interaction in existing system was normally explicit interaction, which requires a substantial level of effort to interact with the system.

For the people with moderate-severe dementia, the high level of interaction and explicit interaction are challenges. They get confused even with a three-buttons device (Rasquin et al., 2007). In a visiting to another dementia care facility C, it was noticed that residents wear a necklace with an emergency button on it. But according to the caregivers, the button was misused by being pressed constantly. Caregivers had to guess if it was an emergency based on residents' face, talking, or behavior. To solve this problem, we focused on *implicit interaction* by using a reasoning system and an adaptive guiding system.

Implicit interaction consists of implicit input and implicit output. The term *implicit input* refers the situation where the user does not provide intentionally an input to the system. The system automatically detects and interprets the activities performed by the user in the living environment. This approach reduces a cognitive workload as well as a physical workload on the user to provide input. In our case, people with dementia will not have to specify explicitly the place they want to go.

According to Schmidt (Schmidt, 2000), the *implicit output* is "the output that is not directly related to an explicit input and which is seamlessly integrated with the environment and the task of the user". Our guiding light (chapter 5)which is automatically turned on by location monitoring is an example of the implicit output. The idea behinds implicit output is to provide output to or interrupt the user at the appropriate time. The mode and suitable time for interruption would be defined by the system. For example, there is no need to remind the user to have lunch when the system has detected the context that the user is currently in the kitchen and preparing for having lunch.

Explicit input is opposite of implicit input that the user explicitly knows what he wants and how he expects the system to proceed. The explicit output is the response directly to the explicit input. Due to the context of people with dementia, an explicit input could increase the cognitive workload for them. Moreover, they also might not know and are not able to learn how to give an explicit input and how to interpret an explicit output. Therefore, this thesis focused on implicit input and implicit intuitive output. In ambiguous cases which the system has no clue how to proceed, the system does not request the user to make explicit input like normally. It does nothing and waits until having more information to proceed further. For people with dementia, doing nothing might be better than confusing them with the request. In the future, a speech recognition module can be added to the monitoring device for people with dementia to handle explicit input as well. At that point, the system would be complete. However, in the scope of this thesis, we want to investigate the effect of the implicit interaction.

Invisibility and Transparency: Invisibility and transparency are also important properties of III Environment. Invisibility refers a psychological phenomenon that the user performs tasks and in his sub-conscious mind, the computing technology almost disappears (calm computing) (Weiser and Brown, 1997). It is all about the human's perception of a system in an environment. According to Schmidt (Schmidt, 2005), four major factors influenced invisibility are the human, the system, the task, and the environment. The degree of invisibility is hard to measure as it depends on the relationship between those four factors. Going along with the Norman argument (Norman, 1998), the system has invisibility if it becomes a natural extension to the task. The following test can be helpful to determine the relationship between the tool, the user and the task. It starts first with the simple question *"what are you doing?"*. If in the answer, the tool is mentioned then it is central to the user's attention. On the other hand, if only the task is mentioned, the tool has some degree of invisibility to the user. Then, further questions could be used: *How are you doing the task?* and *What steps are you performing to accomplish the task?*. To answer those questions, the user would reveal how much visible the tool and the task are in the user's mind.

Controlling the invisibility degree is challenging. It is strongly related to how familiar of the system the user gets. With the above questions, the longer time the user uses the tool, the more focus they pay on the task (more invisibility of the tool). In addition, one could be natural and easy to use for some people but might be strange to others. Typically, the familiarity can be trained when the user spends enough time using it.

Addressing invisibility degree of the system is even harder for people with dementia. First, people with dementia who get cognitive impairment hardly answer above questions (*How are you doing the task?* and *What steps are you performing to accomplish the task?*). In the study about favorite color in facility A, a question was given to participant 4 that *"What is your favorite color?"*. A list of colors was shown. She pointed and talked the name of some colors like the task was naming the color, then lost the question: *"Color? Pink...yellow...blue...Oh! This flower is beautiful!"*. Furthermore, due to the memory problem, training is not an easy solution for people with dementia. That is the reason instead of building a new interface/tool, we rather tried to transform ordinary items which they use every day to be smart items. Transparency is a part of invisibility where technology is transparent and the user does not change their behaviors. The smart radio (Pusch et al., 2013) and interactive drawers (section 5 - studies 4,5) with different degree of invisibility are examples. Although both of prototypes showed positive effects to people with dementia, without prompting from caregivers the smart radio having a higher degree of invisibility and transparency seems to be easier to use. To evaluate, instead of asking them above questions, we rather observed them living with/using the system for a period.

Novel Interactive Styles (I2): This part is about how assistive services should be presented to people with dementia. The TUI is recommended over the traditional approach GUI. Invisibility and transparency are also aspects needed to be considered in designing for people with dementia.

User Interface - from GUI to TUI: In III Environment, the typical explicit interaction such as direct manipulation GUIs (Graphic User Interfaces) is shifted towards implicit interaction based on situational context.

There was no real inventor of the GUI (evolved with the help of a series of innovators) as well as an exact definition of the GUI. Typically, GUI is a user interface using graphical icons and visual indicators to interact with electronic devices. GUI is restricted to a two-dimensional display screen and is used in computers, handheld mobile devices such as smartphones, MP3 players, gaming devices, etc. Devices for GUI normally include a keyboard (physical for computers and virtual for smartphones), pointing devices for the cursor control such as a mouse, pointing stick, touchpad, joystick. To represent information, the most common elements are used in GUIs is the windows, icons, menus, pointer (WIMP) paradigm, especially in personal computers. From 2011, another class of GUIs named post-WIMP were used in some touchscreen-based operating systems such as Apple's iOS and Android. This kind of interaction uses more than one finger contacting a display such as pinching and rotating.

Still, explicit interaction with GUIs is toward direct manipulation and is mainly restricted to screen, keyboard, mouse (physical or virtual). Implicit interaction, on the other hand, extends interface designing dimensions. Featured examples are the Tangible user interface (TUI) (Ishii and Ullmer, 1997), Embodied user interface (Fishkin et al., 2000), or Multi-modal user interface (Coutaz, 1992).

Traditional computer interface GUI is illustrated by "Model-View-Controller" (MVC) architecture - a GUI interaction model (Smalltalk-80) (fig. 4.1). The fig. 4.2 taken from Ishii demonstrates Tangible user interface (TUI). The main difference between these two interfaces is the representative part in the physical world. The aim of TUI is to embed digital part into physical objects. TUI gives physical form to digital information, couples physical representation e.g. manipulable physical objects with digital representation e.g. graphics or audios. It is not disputed that GUI devices like keyboards, screens, mice are also in physical form. However, the physical representation of GUI is low. Siftables (Merrill et al., 2007) (fig. 4.3) is an example of TUI, a simple calculation is one application of Siftables where instead of inputting number by keyboard and seeing the output on the screen, the user can arrange the physical cues of numbers and operations to make the calculation.

As we argued that people with dementia get problem in handling virtual/digital world, the TUI approach focused on physical representations is recommended. However, the implicit output should be as intuitive and subtle as possible because everyday physical objects that suddenly talk or play music might confuse people with dementia. Each person with dementia is different so their reactions could be variety as well. Evaluation needs to be conducted carefully to ensure there is no negative feedback. Thanks to the personalized system approach of III Environment, we can choose to continue providing service/implicit output for people who like it or stop showing for people who do not need or want it.

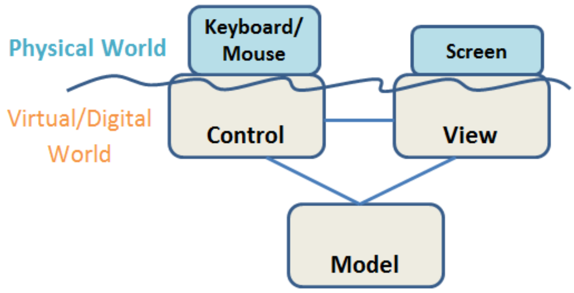

Fig. 4.1 GUI Interaction (Smalltalk-80) (Ishii and Ullmer, 1997)

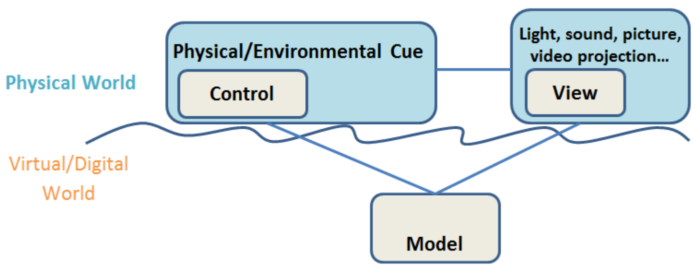

Fig. 4.2 TUI Interaction (Ishii and Ullmer, 1997)

Pervasive/Distributed computing: The main idea of pervasive computing is to move computing away from traditional PC environment (not packed on a special device) and to view them as a part of the physical environment (distributed in virtually everywhere in the physical world within many devices like in wrist watch, clothes, in the walls and doors of buildings).

Fig. 4.3 TUI example - Siftables (Merrill et al., 2007)

Several autonomous computer entities connect and operate to achieve a common goal (e.g. caregivers can access to the system with smartphones around the facility instead of going to a specific stationary computer). According to Orwat et al. (Orwat et al., 2008), pervasive computing is predicted to improve traditional health care. Capacities of remote, automated patient monitoring may enhance patient self-care and independent living. Pervasive computing can increase the effectiveness and efficiency of health care providers by automatic documentation of activities, process control or the right information in specific work situations.

Real-time services: Real-time responses are expected from services of the system. For example, the caregiver would like to know the current location of residents and bring them to the doctor. In this case, the monitoring system needs to be real-time. The term real-time does not mean that the system has to update every second as it might be costly for computation and storage. However, the delay should be at most few seconds to ensure the quality of interaction.

Intelligent Adaptation (I3): When the system does not get input from the users i.e. people with dementia, it can analyze and become aware of the situation, then provide appropriate services (implicit output) at anytime in anywhere. That is a brief description of our intelligent adaptation.

Context-aware computing: An early definition of context simply is information about location, close people and its change (Schilit and Theimer, 1994). Other typical definitions are:

- Context is knowledge about the state of user and device (e.g. surroundings, situation, location) (Schmidt et al., 1999).
- Context refers to the physical and social situation in which computational devices are embedded (Moran and Dourish, 2001).
- Dey (Dey, 2001) proposes another definition, more universal, which is *"Context is any information that can be used to characterize the situation of an entity. An entity is a*

person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"

In this thesis, context is used as *an integration of any information (e.g. identity, activity, history, environmental states) around an entity (person with dementia)*. For example, eating, wandering, or sleeping can be considered as context elements because a tuple of information (time, location, identity, activity) belong to one person.

Context-awareness is commonly considered as the system uses context to provide relevant information and/or services to the user depending on the user's task (Abowd et al., 1999). However, the categories of context-aware features are quite various. Schilit et al. (Schilit et al., 1994) identify four categories of context-aware applications, which differs between information and commands and if they are manually or automatically presented and executed (Fig. 4.4). They are proximate selection (manually retrieve information based on context), automatic contextual reconfiguration (add, remove, or alter components based on context), contextual information and commands (information and commands are shown, executed manually, and adapted to the current situation), and context-triggered actions (simple if-then condition-action rules, automatically invoked). Abowd et al. (Abowd et al., 1999) propose three categories as a presentation of information and services (combination of Schilit's proximate selection and contextual commands), automatic execution (same as Schilit's context-triggered actions) of a service, and tagging of context to information for later retrieval. They also emphasize certain types of context (location, identity, activity and time) that are more important than others in practice. In this thesis, context-awareness is used as *the ability of the system to adapt and provide proper services to an entity (people with dementia) based on context*. The concept of three application categories from Abowd et al. is used. Our monitoring and intelligent systems also focus on and can detect above contexts: location, identity, activity and time.

	Manual	Automatic
Information	proximate selection & contextual information	automatic contextual reconfiguration
Command	contextual commands	context-triggered actions

Fig. 4.4 Categories of context-aware services (Schilit et al., 1994).

Automatic context-aware computing is a supplement to implicit interaction for III Environment as they limit the need for explicit input. The input data (i.e. implicit input) is derived through context aware computing, which has an awareness of the environment, situation, user's intentions. In order to achieve this characteristic, a monitoring system to capture location, identity, state of users, physical objects was implemented (chapter 6).

User activity and intention recognition: Activity and intention recognition is another essential part of III Environment. To support people with dementia in an effective way, the system should be able to capture and derive the user's activity and intention. By this, the system can interpret context elements and trigger automatically services to users. This is also a cornerstone of implicit interaction. The chapter 7 would discuss more details about this aspect.

Adaptive: The system would adapt to the changing situations (physical environments and internal condition change dynamically).

Location-based and Personalized Services: The activities performed by the user are based on the location context e.g. having lunch in the kitchen or taking sleep in the bedroom. In the III Environment, location-based services consist of mobile nodes (MN) and stationary nodes (SN). Mobile nodes are moving agents like people with dementia, caregivers, whereas stationary nodes stand for immobile services such as readers in a monitoring system, input devices for caregivers, or interactive drawers (chapter 5) for a reminiscence activity. The MN interacts with SNs in an indirect way (e.g. location information is sent automatically to near readers-SNs for monitoring and guiding services - chapter 6) or in a direct way (e.g. interact with drawers-reminiscence service, mentioned in sections 5.2.4 and 5.2.4). The services are connected and synchronized via a server if needed. For example, when the system based on monitoring service and interactive drawers service detects that the user is active and in a good mood, the music service at the triggered time will play cheerful and vibrant songs. In case the system infers the user is sitting on a couch and seems to be sleepy, the guiding system would guide the user to the closest sofa and the music service plays lightly and tunable songs.

Besides providing services according to the location, III Environment also adapts the services based on identity of the user. The set of pictures in interactive drawers or songs in music service is different and personalized for the user A and the user B although if they are in the same context. Another example is that the user A gets a visual problem, the guiding system thus adjusts the brightness of light higher than the case of the user B. If multiple users at one place using the same service, the service will be provided based on mutual favorite or postponed to another time. Combining with the time dimension, expert rules, history activities brings the adaptive and context-aware characteristics of the III Environment.

4.2 System Architecture

Applying implicit interaction paradigm for an indoor guiding system for people with dementia, we propose a three-part system (Fig 4.5) including monitoring part (more details in chapter 6), intelligent part (chapter 7), and implicit guiding part (chapter 5). The users i.e. people with dementia do not have to explicitly input to the system. The monitoring tag (e.g. iBeacon, UWB tag) they wear will automatically and implicitly communicate to readers in the environment (implicit input). The objective is to monitor the location of people with dementia in real-time. Location data will then be handled by the intelligent system to determine the current context (e.g. the user is being lost or not? where is potential destination? when to guide and stimulate him to use which service?) based on not only current location but also identity, history of activities, patterns, and expert rules. The intelligent system then controls the guiding system to provide relevant cues at the appropriate time.

In contrast to people with dementia, other stakeholders (e.g. caregivers, designers) in some situations needed an explicit tool displaying and visualizing localization information. For example, when needed the caregivers can request a visualized map and see dementia residents' location on smartphones/tablets around the environment which also plays readers role for the monitoring system. The other information related to physical and mental aspects of people with dementia as well as predictions and suggestions are also analyzed, visualized, and provided to caregivers, doctors, or designers. The caregivers are also able to control the guiding system manually via an interface. Also, caregivers need to input expert knowledge (activities schedule, users' preferences, etc.) to the intelligent system to make the intelligent system more efficient.

4.3 System Infrastructure

Figure 4.6 shows how we developed the III Environment. This is a web-based system using Internet/Intranet of Things (IoT) and the distributed technologies. First, the server was run by Nodes.js - a server-side Javascript. Node.js uses an event-based server execution procedure, which is appropriate for real-time applications. Using Javascript in the backend and running on the Google's V8 engine make complication and execution faster than most. The synchronization process between server and client is also better and quicker. For the database, CouchDB - a document-oriented NoSQL database architecture and is implemented in the concurrency-oriented language Erlang was used. In CouchDB, each database is a collection of independent documents instead of storing data and relationships in tables like a traditional

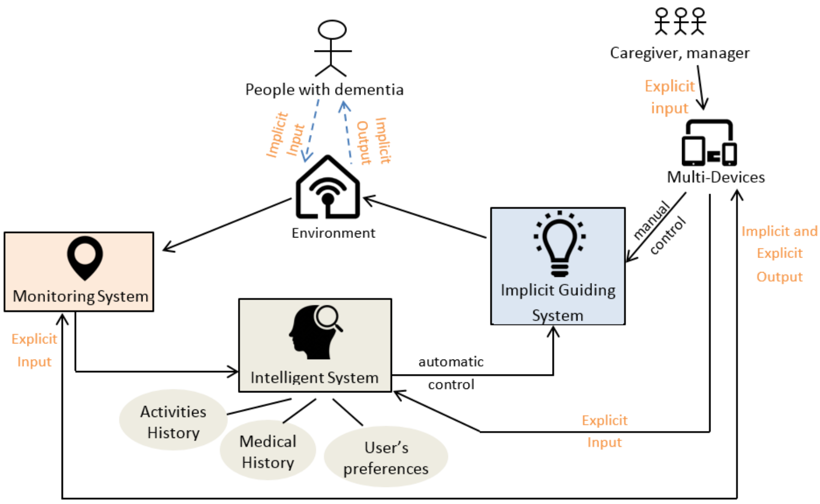

Fig. 4.5 Three-part system: monitoring, intelligent, and guiding systems.

relational database. CouchDB offers many advantages such as easy replication across multiple server instances, fast indexing and retrieval, JSON based document format which is easily translatable across different language. It maintains high performance and strong reliability as well as scalability. The server handles most of the works which give a thin-client scenario. After being analyzed and processed, the data will be visualized according to the request from users (i.e. caregivers, doctors) on HTML-pages on any client-device (could be their private smartphone or public smartphone/table distributed around the building). Privacy problem was solved using pass-code and log-in function. An Automated Manager played an important role here as a decision-making process. The Automated Manager consists of Knowledge Manager, Context Manager, and Interaction Manager which will be discussed more clearly in chapter 7. In the end, the Automated Manager gave the decision when, which, and how a service is provided to the user.

With this infrastructure, the III Environment had a strong backbone with high real-time performance and strong reliability, scalability. Different services can be added up separately and then communicated even though they are implemented by different programming languages and technologies. In the scope of this project, we demonstrate with two different services i.e. guiding service and interactive drawers service.

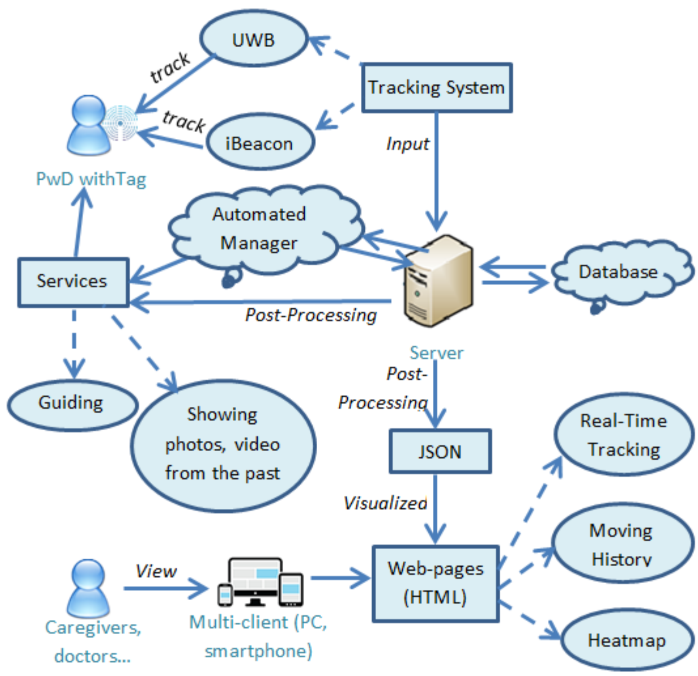

Fig. 4.6 System infrastructure of III Environment

4.4 Scenario

To illustrate more about III Environment and systems, scenarios in a real environment are presented.

Guiding scenario: As mentioned in section 3.2.2, one of the major problems of people with dementia is finding places such as bedroom or kitchen. Fig. 4.7 is an illustration of the guiding scenario. The user Leon is detected being at a crossroad by the monitoring system. Based on the Knowledge Manager, the Context Manager detects that Leon is being lost at the location $P23$ and the potential destination is $R.107$ (her bedroom) according to the intelligent system. The Interaction Manager prepares set of interactions for guiding her to the bedroom $\{$P23, L3; P24, L4; P25, L6$\}$. The intervention type is guiding, and thus, the green color is selected. The lighting brightness is 70% with static form (not moving). The system first turns on lighting $L3$. Leon starts following the green lighting - L3 (turn right - Fig. 4.7b). Once he passed $L3$ and reached $P24$, lighting $L3$ is turned off, and lighting $L4$ is turned on instead (Fig. 4.7c). He continues passing $P25$, lighting $L4$ is turned off and lighting $L5$ is turned on guiding him to the bedroom. Leon finally arrives at his bedroom $R.107$ (Fig. 4.7d).

The study in section 5.2.3 shows the first results that people with dementia have attraction and go toward the guiding light without any negative feedback. Note that, if user Leon in the scenario above at the point of fig. 4.7b does not turn right following the lighting, but turn left instead, the Interaction Manager re-calculates the plan with new current position, increases lighting brightness to 90% and changes to moving lighting with direction. After ten minutes, if Leon still does not follow the lighting and if the system detects an emergency situation, the caregivers would be notified for interference. The details of Knowledge Manager, Context Manager, Interaction Manager will be discussed in chapter 7.

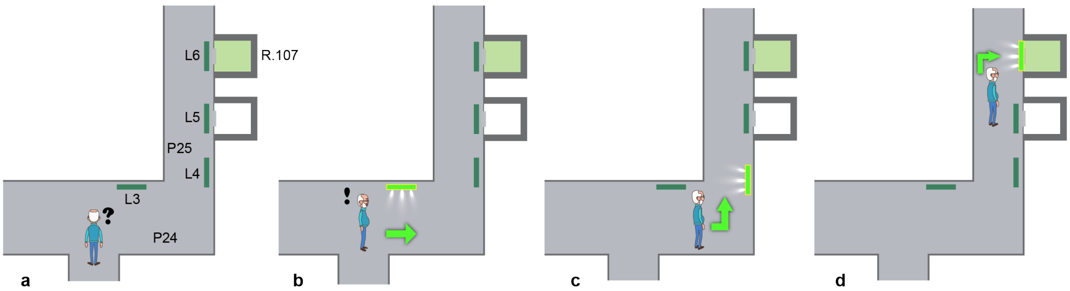

Fig. 4.7 Guiding scenario: Supporting people with dementia in finding the bedroom

Safety scenario: The safety issue with exit areas was also mentioned in section 3.2.2. Dementia residents living there saw caregivers and visitors leaving the building by an exit door and wanted to leave as well. They always had a feeling that the facility environment was not their home. However, they could not open the exit door as in facility B one hidden button needed to be pushed to open the door, whereas in facility D (area 4) the door was locked if the residents wearing a wristband location device (look like a watch) were nearby. They were normally around the exit door for a while (few minutes), were waiting the door opened to escape. According to the caregivers, it would be better if people with dementia are distracted from that area as some people e.g. caregivers, visitors could use the exit door and the residents might escape. Sometimes in facility B, the participant 3 said swear words and even hit a caregiver when the caregiver tried to guide her back to the bedroom or public room.

Fig. 4.8 demonstrates the real layout of facility D (area 4) where people often go to and stay at the area with the exit door. Leon is moving towards the exit area (Fig. 4.8a). Based on the Knowledge Manager, the Context Manager detects the situation that Leon needs an intervention in the exit area (some others do not need). The Interaction Manager then prepares lighting (at the exit door) with red color, brightness 70%, and static form. When he is 1.5 meters away from the exit door, lighting with red color is turned on (Fig. 4.8b). After staying three more seconds, Leon comes back to the kitchen area, and the lighting is turned off.

A study in section 5.2.5 tests the red lighting to distract people with dementia from that area. The red lighting is automatically turned on when the residents come towards the exit door. The study shows that dementia residents would spend significantly reduced time in the exit area with the red lighting or stop going there when the lighting turns on. No negative feedback is recorded.

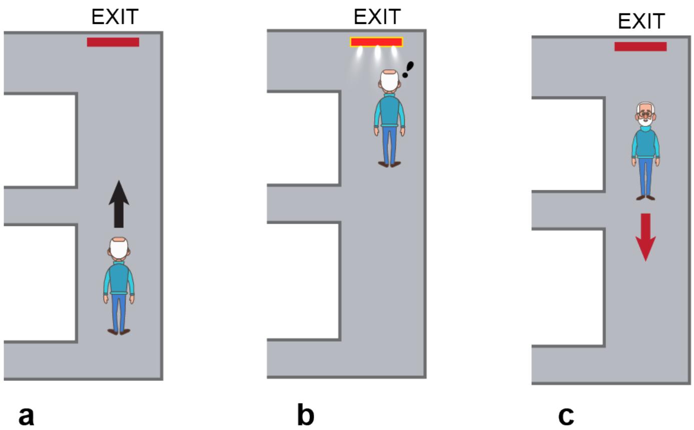

Fig. 4.8 Safety scenario: Distracting people with dementia from exit door area

Stimulation scenario: In the dementia care facilities, the activities are normally all set by the caregivers to activate people with dementia. This issue might reduce the independence of people with dementia as well as increase the workloads of caregivers. In the III Environment, the system would try to guide and stimulate people with dementia' usage of services.

Fig. 4.9 shows the scenario, which combines services i.e. using the guiding service with lighting to guide and stimulate people with dementia to use another service which is interactive drawers in this case. Leon has been moving around corridors for 15 minutes. Based on the Knowledge Manager (with rules and expert information), the Context Manager detects that he is free and active. The system then decides to guide him to the interactive drawers. The Interaction Manager prepares lighting with green color, brightness 70%, and static form. When Leon goes to the intersection (Fig. 4.9a), the lighting on the right side is turned on

(Fig. 4.9b). He follows to the lighting. After passing it, the lighting is turned off (Fig. 4.9c), and the lighting from interactive drawers is turned on instead. Leon finally interacts with interactive drawers, and the lighting behind drawers is turned off. The pictures on drawers display according to his biography.

Studies with drawers and lights conducted in facility D and E show the preliminary positive result of combining services (sections 5.2.4 and 5.2.4). The service of interactive drawers could be changed and adapted to an individual or group of residents (adaptive and personalized service of III Environment).

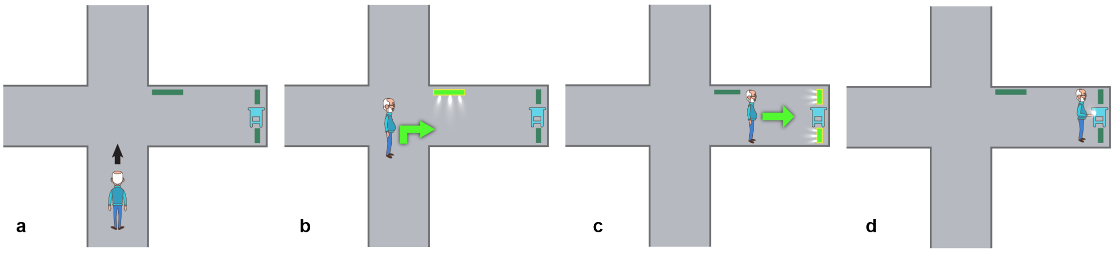

Fig. 4.9 Stimulation scenario: Guiding and stimulate people with dementia to use extra services e.g. interactive drawers

Caregiver scenario: Caregivers needed to find Leon quickly to have them check with doctors and do therapy. Caregivers can access visualized map by any devices around the environment or use private ones such as smartphones, tablets, computers. The visualized interface included not only location monitoring but also information analyzing with location history, heatmap would be implemented and presented more details in chapter 6.

4.5 Discussion

The multiple problems such as loneliness, lacking extra activities, lacking independence from chapter 3 raised not a single service for a single problem, but rather the whole living environment. Other works are either related to a smart home, an intelligent environment which are not focused on people with dementia and care facility environment, or more likely care environment focused on architectural design. This thesis proposed another approach with Intelligent Implicit Interactive (III) Environment emphasizing implicit interactions (both implicit input and implicit output) for people with dementia in care facility environment. The ideas of III Environment, as well as its characteristic, were presented. The system implementation (architecture, infrastructure) were also elaborated. Four scenarios demonstrated how the III Environment could support people with dementia and improve their quality of life. This thesis conducted studies (details in chapter 5) to test and evaluate those scenarios. The core parts of III Environment (guiding system, monitoring system, and intelligent system) with implementation and evaluation would be discussed more details in next chapters. In the future, besides guiding service and reminiscence activity with interactive drawers, more services will be implemented adding to the III Environment for different scenarios. For example, the system can remind some favorite activities e.g. auto turning TV on near the user, select the football channel with his favorite team. In addition, the system also adapts services based on time (daytime or nighttime), individual, multiple people, physical state, mental state, and current mood.

Chapter 5

The Guiding System

Chapter 3 presented wayfinding difficulties of people with dementia. People with dementia get lost or disorientated in different places and situations such as getting lost in a corridor on the way to the kitchen, or not recognizing their bedroom. Thus, the guiding cue for the guiding system needs to be not only effective but also flexible, adaptive to individual and situation. Regarding supporting people in indoor environments, previous researches can be divided into two main categories. First, supporting orientation and navigation by physical environment features (e.g., (Marquardt, 2011; Nolan et al., 2002a)), and second, providing information to users (i.e. people with dementia in our context) through interaction (input/output) with assistive devices such as smartphones (e.g. COGKNOW project).

The underlying concept of the first category is the Competence-Environmental Press Model (Lawton and Nahemow, 1973) and Functional Environmental Need Model (Teresi et al., 1994) exploring the relationship between users' competence (physical, mental, and intellectual ability) and environmental demands. The lower the competence is (age-related deficits, physical disability, and ultimately multiple physical/cognitive impairments), the more environmental needs of users. The studies by (Marquardt, 2011; Passini et al., 2000) focused on the layout, size, configuration of a facility, as well as signs, color, and lighting, were then conducted. The second category using assistive devices, on the other hand, does not emphasize physical environment's features. Their works (section 2.2) rather let users interact with devices instead. The devices get input from the users and then output information and instructions back to users. The feedback could be a text or an image displaying on the device's screen, or sound/speech from speaker device.

There is a gap between two above categories where one focuses on the environment around users, and the other one develops devices to be carried by the users. The approach with physical environment features shows a lack of flexibility and adaptation as physical features are quite static, whereas works with assistive devices seem not fit people with moderate to severe dementia. Little attention has been devoted to a solution involved both approaches. Our solution tried to combine both approaches focusing on the implicit interaction between people with dementia and their physical environment as introduced in chapter 4. The guiding cue in this interactive guiding system would be lighting with color. In this part of the thesis, we elaborate on why lighting with color is chosen over other explicit guiding cues (e.g. sign, text, arrow) and present our studies conducted to test and validate the guiding system.

Note that there are blocks of text were published in (Ly et al., 2015, 2016a,c).

5.1 Related Work of Indoor Guiding Cues

Some studies such as (Passini et al., 2000) aim at generating design criteria to support wayfinding for Alzheimer's patients. They first raised the importance of wayfinding in the care home as a basic human need for the residents. Three major factors affected the mobility of an Alzheimer's patient in the context of a care home are psychological and mental state of the person, the physical environment, and the caregiving environment. Based on interviews with the staff of a care home and wayfinding experience with residents living in it, the results show that even residents with severe cognitive decline can reach certain destinations. Wayfinding decisions of people with dementia are based on environmental information that needs to be easily accessible. The residents are then able to proceed from decision point to decision point. Suggested solutions about the physical environment were provided, such as monotony of architectural composition and the lack of reference points should be avoided, or signage has an important function. Moreover, recommendations also resonate with our Affinity Diagram in chapter 3 such as the elevators are a major anxiety-causing barrier because people with dementia do not understand the signage (buttons) in the elevators, or visual access to the main destination could facilitate wayfinding.

Physical environmental interventions supporting orientation and navigation could be divided into two levels: floor plan typology and environmental cues (Marquardt, 2011). The floor plan typology or building structure were not examined in this present work as those structures have to be planned during construction of the care facility and can not be altered retrospectively. The environmental cues were more suited for an assistive system because those cues represent for residents' immediate environment, could be changed/re-designed later, and be used and combined to address different senses. Signs and pictograms are useful for bathroom's identification (Namazi and Johnson, 1991b). Hanging personal items (Namazi and Johnson, 1991b) or names/photographic labels (Gross et al., 2004) on bedroom doors also helps people with dementia to identify their rooms. In order to increase effectiveness, multiple cues can be combined. For instance, a youth portrait picture of a resident, a sign with the resident's name, personal memorabilia outside the bedroom (Nolan et al., 2001, 2002a). In the studies, mean room finding increases by 45% with those interventions (Nolan et al., 2001, 2002a).

Victoria Dept.of Health (Victoria Dept of Health, 2010) lists effective wayfinding cues as landmarks e.g. a particular tree or garden bed, color, lighting levels, floor surfaces, interior and exterior neighborhood schemes, sculpture, paintings and other decorative features. Other useful suggestions are also provided such as placing signs at eye level for those using wheelchairs, using bright contrasting colors, keeping signs simple as people may no longer be able to understand the complex language or writing.

Lighting and color are promising cues for orientation and navigation and were used in many previous works (Hilary and Mark, 2007; Sarah A. M. and Hedley, 2013). Noell-Waggoner (Noell-Waggoner, 2002) states that sufficient lighting is a central aspect of a supportive environment and having a major influence on people with dementia' wayfinding abilities. The more light there is in a care home (both natural and artificial), the more residents are capable of finding the way around (Netten, 1989). The light has also been shown to provide positive effects such as increased sleep duration and less upset/aggressive behavior (Calkins et al., 2007; Riemersma-van der Lek et al., 2008; Sloane et al., 2007), highlighting risks of falling (Harlein et al., 2011), emphasizing day-night rhythm (Rea et al., 2010), and remembering as well as information signal (e.g. light spots and light signals) (Moffat, 2009). A notable related work is an assistive system "Guiding Light" (Chung et al., 2011) using light for supporting indoor navigation. The system uses projection based augmented reality via handheld projectors attaching on mobile phones to provide wayfinding information (Fig. 5.1).

About the color, Gibson et al. (Gibson et al., 2004) conducted a study having 19 residents (all male; mean age of 84.3; SD = 4.1) who were relocated to the unit with an orientation task including finding their room. Eighty-four percent (84%) of participants were able to find their room, color (n = 13) was reported as the most popular cues participants used for locating their rooms. Structure (e.g. room number, name plate) with 12 participants was the second most often used cue. However, 38% of those who can find their rooms also entered another resident's room. Color choice is not only aesthetics problem but is also relevant to care and healing of patients in a care facility. "The application of color in healthcare settings" (Bosch

Fig. 5.1 Guiding Light project with handheld projectors on mobile phones (Chung et al., 2011)

et al., 2012) examined issues and suggested design considerations while noting a "lack of consensus in the literature of color in healthcare settings". They considered various aspects influencing the use of color in the facility settings: "age preferences & considerations", "function & color", and "cultural & geographic". Color could play an important role in wayfinding as "Signage is sometimes overused in healthcare. Small accents of color may play a role in "attention grabbing" assisting as a wayfinding cue" (architect Shepley Bulfinch designing for Smilow Cancer Hospital at Yale-New Haven - (Bosch et al., 2012)). Another example is the University Medical Center of Princeton at Plainsboro using color to define department entrances and aid in wayfinding. In addition, Blackman et al. (Blackman et al., 2003) reviewed the literature on indoor design for people with dementia, and reports on research investigating the accessibility of outdoor environments, describing a new approach to use virtual reality technology to enable people with dementia to identify and test outdoor design and planning improvements themselves.

Last but not least, safety aspects especially how to prevent residents from using exit doors have also been studied. Useful interventions are the use of mirrors on doors (Mayer and Darby, 1991), or a horizontal grid of black tape on the floor in front of the exit door (Hewawasam, 1996). Other approaches could be considered as reducing existing cues e.g. hiding the door knob behind a piece of cloth or blocking the view with a blind or glass window (Dickinson et al., 1995).

The studies presented in the last section showed that lighting could be used to highlight an object or to increase the visual perception (might support orientation and navigation in general), whereas colors have some positive effects on orientation tasks including finding one's own room. However, overall they are used in a static way. In contrast, our original approach was to combine lighting and color, and use them dynamically as a guiding cue. The "Guiding Light" system (Chung et al., 2011), for instance, shares the same goal guiding the users in indoor navigation. However, the requirement of using handheld projectors attached to mobile phones is impossible for people with moderate to severe dementia. As mentioned earlier, our solution tries to close the gap between physical environment features and assistive devices by combining both approaches. Lighting with color is turned into a dynamic cue with assistive technology but blended into the physical environment surrounding the users instead of being attached to a device.

5.2 User Studies

For the first prototype, a LED strip was chosen as the lighting source as it is cheap, bright enough, can be set-up easily and controlled remotely. Then, appropriate colors for people with dementia had to be selected. Green color for guiding and stimulating, and red color for alertness and outward orientation were eventually picked based on study 2 (presented later in this chapter) and following related works about colors. Firstly, ANSI and the ISO have introduced similar universal color-coding standards (ISO 3864-1) and included green for safety. In a large scale study with over 800 participants, Dittmar (Dittmar, 2001) found significant differences in color preference with advancing age, based on the color names alone (blue, green, red, yellow). Increased age was correlated with decreased preference for blue and increased choice of red/green. In both younger and older adults, there were no significant gender differences for preferred colors. In some cases of visual diagnosis of jaundice, cyanosis or other diseases, yellow or blue surfaces could make the process difficult (Bosch et al., 2012). Warm colors such as red or orange encourage "increased alertness and outward orientation". Cool colors such as blues or greens, along with low illumination, also "neutralize the negative effects of noise distraction", making it easier to concentrate on difficult tasks (Sharpe, 1974). Moreover, agitated or hypersensitive patients also do better in areas predominated by cool colors, whereas red is suggested for depression-diagnosed environments.

In addition, as we planned to conduct studies in facilities in Germany, we also consulted the color connotation by country (Germany) (Bosch et al., 2012). Red (-) is a color of the menacing character in German folk culture (Morton, 2004) and considered unlucky (Paul and Okan, 2010). Red is also associated with fear, anger, and jealousy (Aslam, 2006). Brown is associated with the earth (Bortoli and Maroto, 2008). Yellow (+/-) is associated with the sunshine, but also cowardice and persecution (Bortoli and Maroto, 2008), envy, and jealousy (Aslam, 2006). Gold is associated with wealth (Bortoli and Maroto, 2008). Gray and silver (+) connote sophistication (Bortoli and Maroto, 2008; Morton, 2004), Green (+) also represents the earth (Bortoli and Maroto, 2008). Note that (-) means negative and (+) means positive.

All of the dementia care facilities we observed or visited applied some suggestions from related works (section 5.1) to support people with dementia in finding and recognizing places. A lot of structure cues (e.g. name plate, room number with different size, font, color) and signage were provided. Facility A had additional personal items, name/photographic labels on the bedroom door. They also implemented the idea with youth portrait picture instead of lately portrait picture in some areas, and it showed a bit better performance from residents. However, the interventions were not so effective. The first reason was the types of cues themselves. The cues used in the facilities were signage, name plate, or room number. Rousek and Hallbeck (2011) reported in a wayfinding study with participants with a normal vision that 38% of participants had trouble recognizing signage because of small lettering (18%), insufficient illumination (18%), mounting signage too high (8%), etc. For people with dementia, the number not recognizing signage is expected to be much higher as they do not usually have normal vision/healthy eyes. Additionally, the study showed that 70% of participants wearing googles simulating visual impairment had trouble recognizing signage. Another reason of unsuccessful interventions was a failure to grab the attention and gaze of people with dementia on the intervention. The facilities were also concerned about the safety aspects mentioned in section 5.1, mainly about preventing people with dementia from using exit door. The facility B tried to hide the "open button" of the door in a box near there. Similarly, the facility D hid the "open button" behind a painting (Fig. 5.2). Besides, the residents living there wore a wristband device which makes sure that the door would not open even if the residents pressed the "open button". In both facilities, people with dementia were not able to open the door and exit. However, they often stayed there for a while trying to open it. If a caregiver or a visitor opens the door from outside, there might be a risk that they can get out and leave the building. Moreover, when a caregiver tried to bring a participant back to the common room from the exit door area, the participant sometimes screamed and hit the caregiver.

These situations match the problems and requirements pointed out at the end of chapter 3, specifically requirements R1 (a guiding cue instructs people with moderate to severe dementia), R2 (grab attention and gaze of people with dementia), R3 (create an outward orientation feeling in safety issues e.g. in exit areas), and R4 (stimulate people with dementia'

Fig. 5.2 Exit door in the facility D with the open button hidden behind a painting

usage of services). The lighting with color cue is expected to fulfill those four requirements.

5.2.1 Research Methodology

Hypotheses

1. At the intersection/decision point, people with dementia go toward the direction which is highlighted by lighting with suitable color.
2. Lighting with suitable color can draw attention measured by gaze direction from people with dementia.
3. Lighting with suitable color can highlight objects and stimulate people with dementia using objects/services.
4. In the case of preventing the use of the exit doors by inhabitants of the care homes, lighting with red color would reduce the staying time of people with dementia in that area.

Studies

Before testing the lighting with color cue in dementia context, a pilot study with healthy people (students) was conducted to explore a test setting for indoor guiding of spatial attention using ambient light conditions (Tscharn et al., 2016). The method was to set up a symmetrical room with three tables (left, right, and center) and to collect data (gaze direction) by an eye-tracking device. Both side-tables were illuminated from the back using white LED-strips. Three conditions were tested: a) balanced light, b) left side more illuminated, and c) right side more illuminated. First results showed that visual attention was potentially drawn to one of the two sides in a standardized scenario. Even though the difference of illuminated lighting conditions was minimal and participants did not subjectively notice the difference, gaze direction seemed to be drawn to the more illuminating direction. If ambient lighting conditions can at least slightly direct gaze even without people realizing it, it would be interesting to see in the future studies whether the lighting could be used in dementia context. Instead of creating a situation where two sides are illuminated with a minimal difference, we decided to illuminate one side clearly by lighting and expect that the effect would be stronger (not only draw visual attention but also able to guide users to one direction).

Besides that, the color was added to lighting to be dynamically applied in different contexts. Following studies were conducted to test the lighting with color cue and to evaluate four hypotheses above. Study 2 is to find out the suitable color for people with dementia. The suitable color could be either a favorite color or a popular choice of the majority. After that, study 3 investigates the first hypothesis by testing the lighting with color at one intersection of the facility B. Studies 4 and 5 with interactive drawers in the facilities D and E test the hypotheses 2 and 3 measured by gaze direction, staying time, and interaction. The last study - study 6 tests the hypothesis 4 in the facility E about the effect of lighting with red color on reducing staying time of people with dementia in an exit area.

5.2.2 Study 2: Favorite Color (Suitable Color)

This study was conducted in facility A for one week in October 2014 to find out the suitable color for people with dementia and to check if the results match with the results of the studies presented in section 5.1. Lighting will be combined with the color coming out from this study for the next studies (studies 3-5) testing hypotheses.

Methodology

We first visited the facility in advance to get familiar with the environment as well as residents living there and presented the study to the caregiver supervisor who knows all residents and other caregivers. The caregiver supervisor then selected participants for us. The criteria for participants were being diagnosed with dementia and able to respond to our questions and tasks. As all of the residents were quite old (older than 65), age was not one of our criteria.

Eventually, eight female participants (Table 5.1) were chosen (ranging from moderate to severe dementia, only one person with mild dementia). When we arrived for the testing sessions, the caregiver supervisor selected residents based on current mood and activity, which were eligible for participation. After that, we approached participants, introduced ourselves, and asked them to join our test. If needed, the caregiver supervisor would be there to introduce us and encourage people with dementia. The place for the experiment was in the common room or the garden. Two prototypes were implemented: a tablet application and printed papers. Twelve colors of RGB color space with distributed values were used (Fig. 5.3).

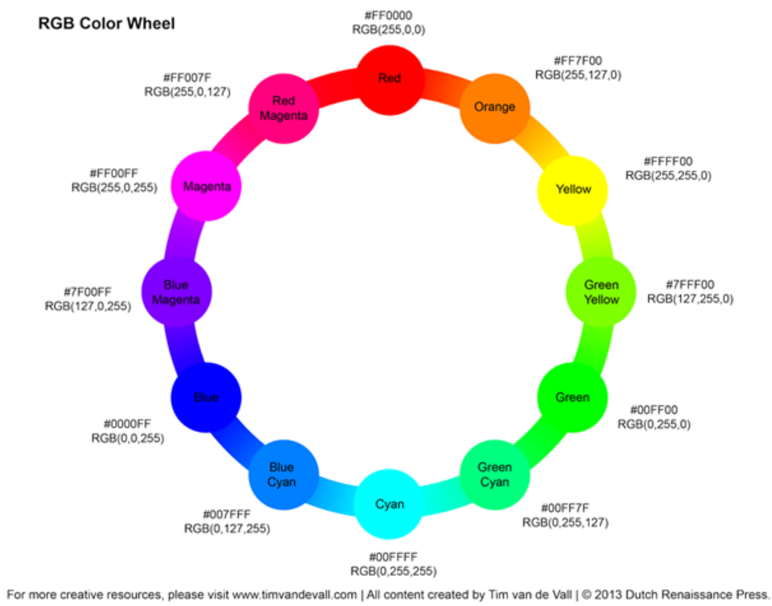

Fig. 5.3 Color set with 12 RGB distributed-value colors

Fig. 5.4 shows the user interface of the first prototype (tablet application) for picking the favorite color. The device was Google Nexus 7. The method was two alternative forced choices showing two colors at the same time and letting the participant choose one (by clicking). A color was paired to each of the other colors. The order of paired colors selection was random. The number of selections participants expected to make was $\frac{n!}{k!(n-k)!} = \frac{12!}{2!(12-10)!} = 66$ selections. Duration of the whole session with 66 selections tested with normal people was about 2-3 minutes. The information of the participants (i.e. name, age, additional info) and performance time (from seeing to choosing color) were recorded in the database.

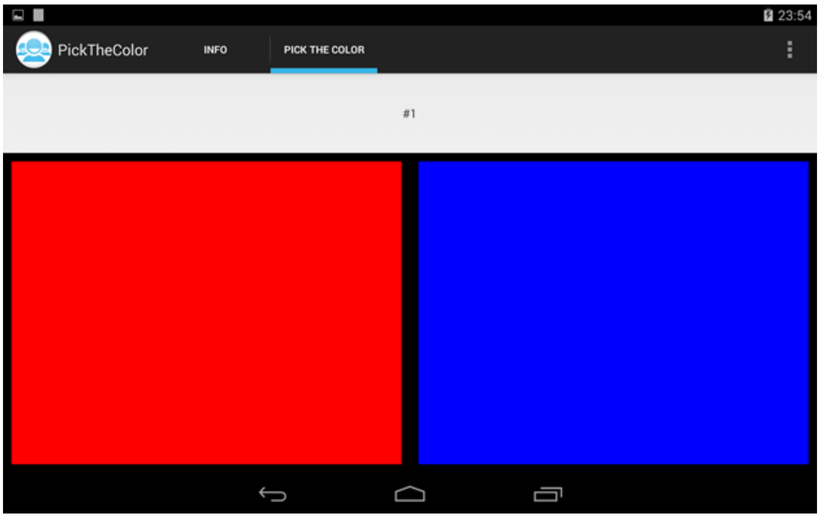

Fig. 5.4 Tablet application "Pick the color"

Using the same 12 RGB colors set above for the second prototype with printed papers (Fig. 5.5), we coded and mixed 12 colors with three basic geometric shapes (rectangle, triangle, and round) by 12x12 latin square to counterbalance suggested by Bradley, 1958 (Bradley, 1958). A full counterbalanced session would be $12 \times 3 = 36$ selections. However, only 12 sheets (four rectangles, four triangles, and four ovals) were chosen because 36 selections might be too many for people with dementia. The task for participants was simply choosing one favorite color among 12 colors. The participants' comments/feedback (if applicable) were recorded. Two testing sessions (different time, different day) were conducted to see if there was a change in choosing a favorite color.

Fig. 5.5 Color sheets for picking the favorite color with 12 RGB colors and 3 shapes (rectangle, triangle, round)

1	2	12	3	11	4	10	5	9	6	8	7
2	3	1	4	12	5	11	6	10	7	9	8
3	4	2	5	1	6	12	7	11	8	10	9
4	5	3	6	2	7	1	8	12	9	11	10
5	6	4	7	3	8	2	9	1	10	12	11
6	7	5	8	4	9	3	10	2	11	1	12
7	8	6	9	5	10	4	11	3	12	2	1
8	9	7	10	6	11	5	12	4	1	3	2
9	10	8	11	7	12	6	1	5	2	4	3
10	11	9	12	8	1	7	2	6	3	5	4
11	12	10	1	9	2	8	3	7	4	6	5
12	1	11	2	10	3	9	4	8	5	7	6

Fig. 5.6 12x12 latin square for color mixing. Each row is corresponding to the order of 12 colors on the printed papers prototype.

Findings

The first prototype (tablet application) was tested with eight participants. However, the testing was not successful and had to be canceled after the first three participants. The problem was how to convey the instructions of the task to the participants. Some participants had hearing problems or did not understand/be able to answer questions. We gave them a tablet opening the application and asked them to click on one color which they like more than the other (Fig. 5.4). It took 5-10 minutes for them to get familiar with the device and to understand how to perform the task. More importantly, they lost the concentration very quickly (after 10-15 choices, about 1-2 minute). Giving them a short break allowed them to continue the task, but only in few choices (3-5) and then they did not want to continue. Sixty-six selections were too many for them. As all three participants did not have experience in using a tablet, they were confused or got distracted from the task. Two participants also commented that the tablet was a bit heavy for them if using for a while.

Then, the second prototype (printed papers) was tested. Table 5.1 shows the results of testing with eight participants. The simple question "What is your favorite color?" did not work most of the time. The question needed to be rephrased, such as "If you can choose the color for your room, which of the presented colors would you choose?". In addition, the colors picked were different and not so consistent, except participant 5 with mild dementia. Due to the dementia problem and the fact that color picking depends on the context/mood as well, the results were reasonable. In the end, green was the most popular pick.

Discussion

This study was conducted in the early phases of this project along with observations to find out a good/favorite color combining with lighting to test in the further phases. In general, the results supported the findings of previous studies e.g. green being a preferred color (Dittmar, 2001). However, this study also revealed a lot of difficulties when working with/conducting

Table 5.1 Color picking with sheets. Note that most picked color is presented with the number of time they selected that color.

P	Gender	Dementia stage	No. successful sessions	Most picked color	Remark
1	Female	Moderate	12	Green (6 times picked)	Keep asking when it's finished
2	Female	Moderate	7	Magenta (3) = blue magenta (3)	Not really pay attention
3	Female	Moderate-Severe	6	Yellow (2) = green (2)	Distant, no attention and emotion
4	Female	Moderate-Severe	6	Green (3) = blue (3)	
5	Female	Mild	4	Green (4)	Consistent
6	Female	Moderate	6	Magenta (4)	
7	Female	Moderate	2	Green (2)	Was too tired
8	Female	Moderate	8	Orange (4)	Was bored

studies to people with dementia (cognitive and mental problems e.g. mood swings, memory, poor concentration, and difficulty in answering tasks/questions; physical problems e.g. feeling heavy after holding a tablet for few minutes; or problems of using/interacting with technology). Several lessons learned from this study as well as next studies will be summarized in chapter 8. For examples, for the next studies, a larger buffer time between sessions is prepared. Backup sessions are also needed in cases some sessions failed due to mood swing and physical problems. The number of questions has to be reduced to a minimum, as people with dementia are limited in their concentration and suffer from other cognitive impairments. Observation with an extra observer is recommended. In addition, the problem of how to present and instruct the task to people with dementia should be prepared carefully in advance. Besides that, how they perceive the weight, size (Google Nexus 7 with 300g was a bit heavy for them after using for few minutes) and use the device (did not know how to handle gestures of the tablet) is a concern when designing devices for people with dementia e.g. monitoring system in chapter 6.

5.2.3 Study 3: Guiding with Lighting with Suitable Color

In this section, study 3 conducted in the facility B to test the hypothesis 1 "At the intersection/decision point, people with dementia go toward the direction which is highlighted by lighting with suitable color" is presented.

Methodology

The study was conducted in the facility B over four weeks in October-November, 2014 (chapter 3). Fig. 5.7 shows the layout of facility B. The building was divided into two floors connected by a staircase and an elevator. The bedrooms were distributed on both floors and were located along a corridor. On the upper floor, at the end of the corridor was the dining room, as well as a small seating area with a sofa. The testing sessions were held on the lower floor and run daily in the afternoon (between afternoon coffee and dinner). At that time of the day, the residents seemed quite active.

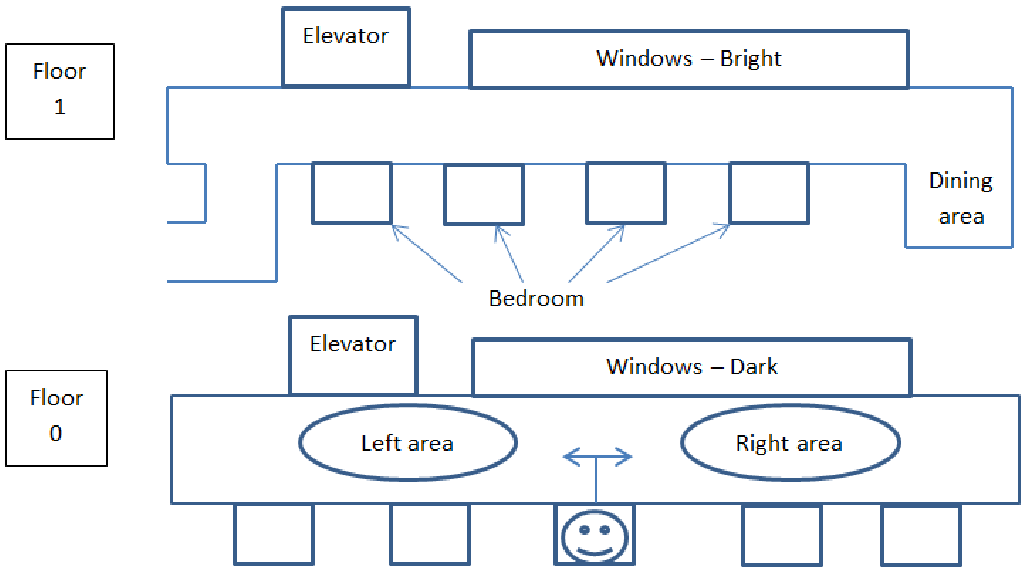

Fig. 5.7 The layout of facility B

Participant

The criteria for choosing participants in the study were:

- Being diagnosed with dementia or Alzheimer
- Remaining mobility (can move by themselves)
- Remaining ability of hearing and speaking (verbal reaction)

Based on these criteria, six potential candidates were selected by the caregivers. We then informed the family members or legal representatives about plan and purpose of the study as well as technology using and data collecting. After all, we got four participants with signed informed consents. Among the four participants, there were two women and two men with the ages between 82 and 94 ($M = 87.75, SD = 4.5$). Sensory deficits such as problems with hearing or vision were compensated by a hearing aids or glasses. One participant needed a disability walker but could move without help. According to caregivers, they were in the moderate to severe stage of dementia.

Material and Experimental Procedure

During each experimental session, two researchers were present. One was responsible for interacting with and instructing the task to participants (experimenter). The other researcher played the role of an observer who noted and recorded relevant data during the experiment (a lesson learned from study 2 where direct questions to people with dementia did not work well). For the additional and subsequent evaluation, a video camera was placed on each side of the corridor (in the hidden positions where they were not visible by the participants). An LED strip of one meter in length was used to illuminate one of the sides of the corridor and the destination. The colors could be manipulated using an RC-5 receiver and a remote control.

Task

To determine the efficacy of lighting cues on the turning behavior of people with dementia in the crossing point decision, each participant was asked to find a specific object (their favorite things according to caregivers such as chocolates or toys) in the surrounding area. The participant had to decide in which direction he/she wanted to start the search. There were only two choices either left or right direction. He/she was brought to the starting point ("smiley face" position on the floor 0 - Fig. 5.7) where its right and left sides were symmetric and then was instructed accordingly. This procedure proved to be the most comprehensible for people with dementia after a pre-test and discussion with caregivers. The items were placed on the table on the left or the right so they could not be seen from the starting point. The LED strip for generating the lighting was placed on the ground (Fig. 5.8). Both furniture which we put the LED strip under them had the same distance of about 3.5 meters from the starting point.

When the participant was at the starting point, the experimenter stood at a distance of about 0.5 meters in front of him. The observer was sitting on the stairs behind the experimenter so that no intervention or deflection could occur. After the participant had found the object or gave up, took too much time (40 minutes), the session was terminated, and the participant was taken to the dining room or, by his request, to another place in the building. The time for one session varied from 15 to 30 minutes (including time to bring participants to the starting point, instruction time, decision time, and failed trials) but in some cases, it could also be higher (max. 40 min). Before every session, a caregiver determined whether the participant was able to join or not. If the participant showed any physical or mental problems, such as appearing fatigued, apathy, or negative mood (e.g. anxiety), the session would be canceled.

Fig. 5.8 LED strip seen from the starting point

Variables
In this study, independent variables comprise the "baseline condition" (no additional lighting in the environment) and the "lighting condition" which is varied by color (green and white) and position (left and right). The dependent variables were listed in table 5.2 including "turning direction", "instruction time", "decision-making time", and "subjective ratings". The main variable to test hypothesis 1 was "turning direction", which could show whether or not people with dementia go toward the direction of the lighting with suitable color. The additional variable "instruction time" was expected to increase because the lighting with color distracts participants from the experimenter, whereas participants should have taken less time to decide (reduced "decision-making time") and performed the task easier (increased "subjective ratings"). Besides that, notes about the use of handrails and other observations (mood and behavior of participants, feedback from caregivers) were used to justify and validate the data.

Findings
The number of successful sessions (the experimenter instructed the task and the participant made the turning decision) was 22 (about 30% of total sessions) across all conditions. The number of failed sessions was large because participants would often change mood, get sad and depressed. Participant 4 could only complete three sessions. She showed signs of

Table 5.2 Dependent variables of the study

Variable	Description	Measurement unit
Turning direction	Direction the participate decides to turn	Left or right
Instruction time	Time for instructing the task to the participant	Time in seconds (s)
Decision-making time	Time that the participant takes from finishing instruction to making the turn	Time in seconds (s)
Subjective ratings	Rating from researchers how easy the participant performs the task (with the help of videos)	From 0 (very difficult) to 15 (very easy)
Walking paths	Path which the participant walks during the sessions	Heatmap

sadness and despair.

Turning Direction
Table 5.3 summarizes the results of this study. As mentioned earlier, the turning direction frequency is the most important one to evaluate hypothesis 1, whereas other variables are used as supplementary data which need to be investigated more in the future to fully understand.

A Binomial test was used to check if participants in the lighting conditions selected the direction with the lighting more frequently than predicted by chance. They chose the direction with lighting significantly more often in 75% of tests compared to 50% predicted by chance, p = .038 (1-sided).

About the turning direction frequency, in the baseline condition without any illumination, the number of times that participants turned to the right equaled the number of times they turned to the left (50%). In the "green left" condition, which means the left side was illuminated by a green light, 75% of the sessions participants went to the left. The same pattern occurred in the "green right" condition, where 75% chose the right direction. In the "white left" condition, participants went 50% of the cases to the right and respectively the same to the left. The "white right" case had 100% chosen the right side. Altogether in the lighting conditions, participants chose the illuminated side 12 out of 16 times (75%) and 4/12 times (25%) to the wrong direction (opposite side of lighting with color). When the lighting was on the right, participants chose the lighting direction 87.5%, whereas the number was 62.5% for the lighting illuminated on the left side. Based on these observations, it appears that people with dementia are more likely to move towards the illuminated side than away from it.

Fig. 5.9 shows the details of turning behaviors of the four participants in the experiment. In case of participant 3, the lighting with color was not effective. He went toward the illuminated lighting 50% of sessions (3/6) which was similar to random effect or base line condition. In fact, as mentioned earlier in the section "Other observations", this participant was the person with the least dementia among participants. He remembered the session task and sometimes walked toward one direction before the end of the instruction. "The object was on this side (i.e. on the right), so maybe this time it is on the other side...or still the same side...?", he said. If the data of participant 3 is excluded, the result of participants going toward the side of lighting with color would be 9/10 (90%).

Instruction Time

Regarding the instruction time (Table 5.3), the baseline condition with $N = 2$ had $M = 5s$ and a standard deviation $SD = 1.41s$. Noted that there were six sessions of the baseline condition, but four of them could not be determined. The reason was high volume caused by other people during the experiment, which is why the voice of the participant and the experimenter in the recorded videos cannot be heard clearly. As a result, the instruction time and decision-making time were undetermined. Each lighting condition (both left and right side) had $N = 8$ with average instruction time respectively green light: $M = 8.50s$, $SD = 6.16s$ and white light: $M = 13.63s$, $SD = 12.22s$. The instruction time appeared to be higher in the lighting conditions than in the baseline. It seemed that the lighting caught participants' attention, which distracted them from the experimenters.

Decision-making Time

The decision-making time (Table 5.3) was similar with the instruction time. The average length of the decision-making time in lighting condition was higher than the baseline condition. It was unexpected and remained as a question for future work.

Subjective rating

With the light, the participants finished the task easier according to subjective ratings of an experimenter and an observer (Table 5.3). The instruction time and decision time took longer but after turning participants seemed to be more decisive and confident. There were three times in base line condition that the participants could not finish the task but in the lighting condition they all managed it without giving up. However, as the subjective rating was not

Table 5.3 Results including turning direction behavior, instruction time and decision making time in seconds (s), subjective rating of easy-finding level (very difficult 0 - very easy 15). M1 and SD1 belong to the Experimenter whereas M2 and SD2 belong to the Observer.

Condition	Direction			Instruction Time (s)			Decision Time (s)			Subjective Rating				
	N	Left	Right	N	M	SD	N	M	SD	N	M1	SD1	M2	SD2
Baseline	6	3	3	2	5.00	1.41	3	40.33	10.02	5	4.2	5.22	6.4	4.93
Green left	4	3	1	4	7.00	2.45	4	72.50	64.68	4	7.5	4.80	8.25	4.11
Green right	4	1	3	4	10.00	8.76	4	47.75	52.54	4	9.25	2.22	8.75	2.75
White left	4	2	2	4	18.50	16.68	4	51.00	61.56	4	10.75	1.71	9.25	2.36
White right	4	0	4	4	8.75	2.63	4	57.50	41.11	4	7.5	4.36	9.25	3.86

Date	Participant	Trial	Condition	Light side	Turning Decision
23/10/2014	1	1	White	-1	-1
27/10/2014	1	2	Green	-1	-1
28/10/2014	1	3	White	1	1
30/10/2014	1	4	Green	1	1
31/10/2014	1	5	Baseline	0	1
04/11/2014	1	6	Baseline	0	-1
28/10/2014	2	1	White	1	1
29/10/2014	2	2	Green	-1	-1
30/10/2014	2	3	Baseline	0	1
03/11/2014	2	4	Green	1	1
06/11/2014	2	5	White	-1	1
20/10/2014	3	1	Baseline	0	-1
21/10/2014	3	2	Baseline	0	1
22/10/2014	3	3	Green	1	-1
23/10/2014	3	4	White	-1	1
24/10/2014	3	5	White	-1	-1
28/10/2014	3	6	White	1	1
05/11/2014	3	7	Green	-1	1
06/11/2014	3	8	Green	1	1
21/10/2014	4	1	Baseline	0	-1
23/10/2014	4	2	White	1	1
24/10/2014	4	3	Green	-1	-1

Code	0	-1	1
Side	Baseline	Left	Right

Fig. 5.9 Raw turning behavior data of the lighting study 3.

double blind, the confidence and validity of these results have to be interpreted with caution.

Other observations
Color-highlighted objects grabbed people with dementia' attentions. The elevator example in section 3.2.2 hinted this idea. Residents used to press the yellow button instead of gray buttons with information next to them e.g. numbers, texts, images. Hypothesis 2 about grabbing their attention by lighting with color is tested and presented later in this chapter (studies 4, 5).

According to a caregiver, a dementia resident was observed again and again attracted by light at night. She was able to find the toilet independently when the lighting around the toilet area was switched on. In addition, a similar effect of the moonlight on that participant was reported, which may indicate the function of light as a point of orientation. The participant repeatedly moved toward windows with the shining moonlight. This point supports hypotheses 1 and 2 that lighting is a helpful cue for people with dementia in orientation and navigation.

In addition, participants seemed to move mainly along the wall and not in the middle of the corridor. The reason was people with dementia usually hold the handrails both in sessions and in normal daily moving. Also, when people with dementia chose a direction to go, normally they continued until the end of that path. Therefore, a guiding support at a crossing point or the starting point is important.

The mood of the subjects varied considerably from day to day. Participant 1 showed energetic behaviors on some days such as walking much and quite fast, sometimes laughed loudly, and her facial expression seemed more conspicuous. She spoke very clearly whereby her individual words could be understood. On other days this person was noticeably quieter, moved more slowly, spoke almost nothing, and returned eye contact less frequently and shorter. Sometimes she reacted to the lighting source, pointed the lighting, looked at it for several seconds. Participant 2 also showed differences in mood and behavior. Most of the time, he was relatively calm and spoke few short but understandable sentences. Besides, in the sessions, he needed comparatively long time to understand the instructions. On the other hand, participant 3 showed the most persistent behavior (less severe dementia than other participants). He spoke not much but used complete and comprehensible sentences, and responded with meaningful answers. He also remembered the task of the experiment even after several days. He said twice that he knew where the object was on the previous day.

Therefore, he sometimes walked toward one direction before the end of the instruction.

It was noticed that all residents seemed to be more tired on the days after switching to the winter time. The weather might also affect the mood and active behaviors. When it was raining, the chance of a failure session would be higher than in a sunshine day. Moreover, we noticed that in the afternoon residents with dementia were more restless than in the morning. They went to the exit area and wanted to go outside more frequently. Besides that, the sessions conducted in the afternoon were also more likely to fail than the session conducted in the morning.

Discussion

Although some literature e.g. (Taylor and Socov, 1974) indicates that people tend to choose the right for an equivalence of two possible directions and the study with participants as students (Tscharn et al., 2016) indicated the same, our data suggested that there was no bias of choosing right or left sides in the baseline condition where none of the sides were illuminated (50% for both sides). The reason could be that the setting was not symmetrical as expected. However, as the turning behaviors were compared between our baseline and lighting conditions, the bias was not a big issue. In the baseline condition, the participants moved to the left and the right equally (50%). In the lighting conditions, a Binomial test showed that participants chose the direction with lighting significantly more often in 75% of tests compared to 50% predicted by chance (or baseline condition). In the case of excluding data of participant 3 who remembered the session task and started walking before the end of instruction, the results showed that participants moved toward the side of lighting with suitable color 9/10 times (90%). Only in one session participant 2 went to the right while the white lighting was on the left. Participant 3 said that he knew where the object was. He commented that the lighting was nice but did not interpret the lighting as a guidance cue to the hidden object. That is to say the lighting with color in this situation could be a visual-support cue but not strong or explicit enough to be a guiding cue. This led to an interesting assumption that for the people with lower dementia stage, who retain more of their cognitive abilities, explicit guidance cues are stronger than implicit intuitive guidance cues. That also explained the study with normal students (no dementia symptoms, high cognitive level) (Tscharn et al., 2016) showed that the illuminated lights caught gaze direction but did not affect the behavior of choosing a side. Still, the reason could be that the difference of illuminated lights on two sides was indeed too hard to distinguish. To stick the assumption that an explicit cue is better for people with lower dementia stage, the lighting can still be an additional visual cue to catch people's gaze and attention to the explicit cue.

Overall, this study's results supported hypothesis 1 "At the intersection/decision point, people with dementia go toward the direction which is highlighted by lighting and suitable color". The lighting with color can be used as a guiding cue for people with dementia. Again, the turning behavior was the most important factor to evaluate hypothesis 1, whereas instruction time, decision time, and subjective ratings of experimenters were additional data. The instruction time was longer in the lighting conditions than in the baseline condition, we suggest, that the lighting drew the attention of participants away from the task, making following instructions more difficult. However, the increment of decision time was unexpected and need to be investigated more in the future. According to the experimenters (subjective ratings), after making a decision, the participants were moving faster and more directly to the destinations. They appeared to be more determined and often looked at the lighting source as a respective destination. In the end, the performance of lighting with color cue was not perfect, but we argue that there would be no intervention which can change the behaviors of people with dementia 100% due to a vast of dementia's problems and types. The idea was using lighting with color to suggest/recommend people with dementia to a place which supposed to provide them appropriate service, not forcing them to go. The lighting with color gave them a comfortable feeling about the direction the system wanted to guide and more importantly, there was no negative feedback recorded. The color green and white did not show a significant difference of the effect as both of that colors were quite welcome and attractive to people with dementia.

In addition, on the walkways of the participants, they usually did not go directly/straightly to the potential places of the objects e.g. desk, sofa, but moved along the walls. The reason was probably the handrails, which the subjects hold on in most cases, even if they were guided by the caregivers. Presumably, handrails provide additional security for people with dementia. Hence, another prototype attaching lighting to handrails was implemented 5.10 but not evaluated yet.

5.2.4 Studies 4 and 5: Drawing Attention, Highlight Objects, and Stimulate Interaction using Lighting

This section presents studies to test hypothesis 2 "Lighting with suitable color can draw attention, eye's direction from people with dementia" and hypothesis 3 "Lighting with

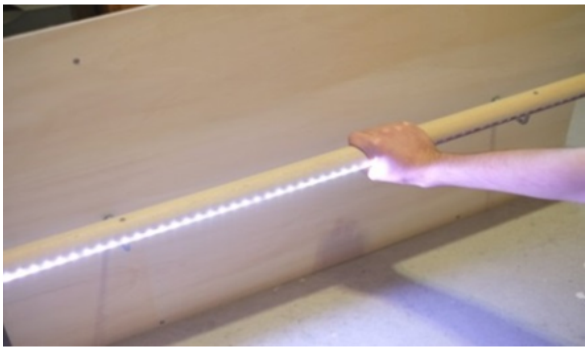

Fig. 5.10 Handrail with lighting prototype

suitable color can highlight objects, stimulate people with dementia using objects/services". The two following studies describe how the prototype of interactive drawers (reminiscence activity) for people with dementia were developed and tested in two facilities D and E. The first results suggested that lighting can catch the gaze from people with dementia. Moreover, the lighting could even help stimulate people with dementia to interact and use the service.

Study 4: Interactive Drawers in Facility D

As discussed earlier in section 3.2.1 about "Engagement and vitalization", people with dementia living in a care home environment normally suffer from a lack of activities (Wood et al., 2009). The topic of reminiscence activity was one of our extra services in III Environment. Recently, available studies suggest that reminiscence activity can improve cognitive functions and/or mood of people with dementia (Woods et al., 2005). By presenting memory-triggers such as showing pictures where they lived or playing a song they liked, reminiscence activity aims at counteracting the loss of self-identity (Cohen-Mansfield et al., 2006). An assistive technology of reminiscence activity should adapt to an individual based on the person's biography. This is a reason why an identity recognition is needed in our monitoring system (chapter 6). Cooperating with INTERMEM project (INTERMEM Project, 2015), a prototype of a chest of drawers was implemented using a tangible user interface and Ubicomp technologies that can be interactive and adaptive (Ly et al., 2016a). This approach also allows people with dementia to do reminiscence activity by themselves, consequently enhance their autonomy, independence, and quality of life.

Figure 5.11 shows the scenario how a resident's attention is drawn by a guiding lighting cue (Fig. 5.11a). He then follows the lighting cue which guides him towards a chest of drawers (Fig. 5.11bc). The drawers display personal pictures related to him e.g. pictures of his family or hometown (Fig. 5.11d). After that, he can decide to open a drawer, by that seeing more about the topic (Fig. 5.11e). Tangible items are put inside the drawer, which are associated with the same topic as the picture on the front of the drawer (Fig. 5.11f). Initially, we imagined that the objects inside the drawer are interactive and music is played when an item is picked up. For example, Christmas music, for the small iconic Christmas tree or garden sounds when an apple or gardening tool is picked up.

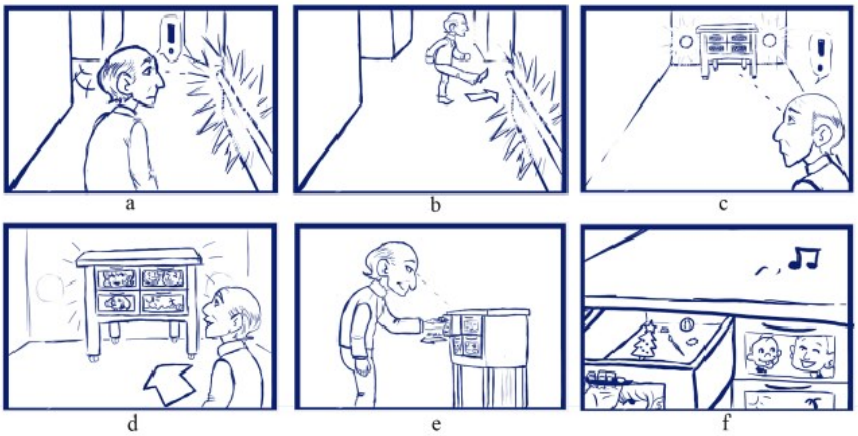

Fig. 5.11 Scenario of how III Environment combines guiding lighting and stimulating lighting for an extra reminiscence service - interactive drawers

Methodology

We conducted studies in the facility D and tried to setup the scenario described above. Two among four residential living groups in this facility were chosen as participants because they were people with moderate to severe dementia and still mobile enough to possibly operate the interactive chest of drawers. The hardware of the prototype was four iPad minis and a chest of drawers with smoothly sliding drawer. The drawers' front sides were cut out the iPads' shape using a milling machine (Fig. 5.12). The iPads were fixed with aluminum mountings so they would not fall out when people directly pushed them or forcefully closed the drawers. Following is descriptions of three iterations of testing. The first two iterations were baseline trials where no lighting was used. The third iteration was the "lighting condition" using LED strip attached on the drawers. However, as three iterations were in three different blocks in the facility D, the third iteration also included a "baseline condition" to control the result of the "lighting condition". Based on the hypotheses 2 and 3, it is expected that residents with dementia would have more gaze direction to and interactions (more stop, longer dwell times, more physical interaction) with the drawers in the lighting condition than in the baseline condition.

The first baseline iteration lasted for three hours (in the afternoon - between coffee and dinner time) in one of the residential groups (G1). The prototype was placed on a hostess trolley and covered with a white cloth. After moving the trolley into the community area and placing it against a wall, we took places on a sofa standing close to it to observe and take notes. There were 12 participants (residents with moderate to severe dementia) sitting there. Age was not recorded as it was not relevant and all residents were older than 65 according to caregivers. Each time a participant passed by the interactive drawers, this was counted as one data point. For participants who were sitting for 15 minutes without passing the drawers, caregivers went to ask each of them (one data point/person) if they noticed the drawers or not.

Following a recommendation from the manager, the second baseline iteration was planned to happen in a corridor between another group's community area (G2) and an accommodation wing of the building, where residents would pass by more often. Unfortunately, the area of G2 with the busy corridor was under construction and would be so for several months so the manager would not let us go there. We came back to residential group G1 for 1.5 hours (from 10:00-11:30) with the same 12 participants above. In this iteration, instead of using a static set of pictures on drawers as the first iteration, Wizard of Oz prototyping was used. The pictures displayed on the drawers were changed remotely by the Wizard. The Wizard can use a smartphone, tablet, or laptop to control the lighting installation via an administrative website (Fig. 5.13).

Apart from few technical improvements nothing needed to be changed in the third iteration as we waited to gain access to the users of interest. Compared to the prototype being shoved around on a hostess trolley, the setup this time was more appealing. As displayed in Fig. 5.14, the prototype was placed on top of another set of drawers next to a sofa in the corridor of G2. It looked more as if it belonged there and less like someone parked it there but would soon pick it up again. As this area was in the corridor connected a community area and an accommodation wing, we just collected data of everyone who walked by and then asked caregivers about those people' information. In the end, data of seven people with moderate to severe dementia were collected. Note that one person could have more than one data point by passing the drawers several times. Due to the light coming from a window nearby we chose our LED strip over the ambient lighting solution with Philips Hue. The LED strip started at a power plug behind the sofa and led along a handrail over the sofa to the bottom center of the set of drawers. When a resident was moving to the drawers (distance is about 2-3 meters), the Wizard started the LED animation, a green lighting snake slowly moved towards the drawers (see Fig. 5.14b). After three loops the animation stopped. The duration of this iteration was about 3.5 hours in the afternoon (2 hours for the baseline condition and 1.5 hours for the lighting condition).

The variables of this study were "gaze direction" (for hypothesis 2), "dwell time" - the period participant walked by and stopped in front looking at or interacting with the drawers, and "number of interactions" (for hypothesis 3). Note that in this study and this specific facility, we did not get permission to record video, and hence, "dwell time" was measured manually. Besides that, people with dementia could not wear the eye-tracking device as well as following instructions of experimenters like students in our previous study (Tscharn et al., 2016). The gaze direction of participants was thus based on subjective observations of experimenters. The results of gaze direction were simply two options: gaze direction on the drawers or not.

Fig. 5.12 A chest of drawers with four iPads mini representing four topic at one time.

Fig. 5.13 Controlling images on drawers via a smartphone. A picture on the admin page was divided into four parts (top left, top right, bottom left, bottom right) assigning respectively to four drawers. When the Wizard clicked the top left part of the bicycle, the screen on top left drawer displayed the bicycle picture accordingly.

Findings

Table 5.4 summarizes the results of three iterations. Comparing the combined baseline

a) b)

Fig. 5.14 Prototype on top of another set of drawers in a corridor (third iteration testing session). a) normal setting; b) green lighting moving toward drawers setting

condition (iterations 1,2 and the baseline condition of iteration 3) against the lighting condition in facility D we found a significantly higher ration of gaze towards the drawers in the lighting condition, $X^2(1) = 14.49$, $p < .001$ (Fisher's exact test). Similarly with the number of interactions, a significantly higher ration in the lighting condition compared to the baseline condition was found, $X^2(1) = 28.41$, $p < .001$ (Fisher's exact test). The dwell time was correlated with gaze and number of interactions, higher in the lighting condition compared to the baseline condition.

In the first and second iterations with no lighting attached beside the drawers, the attention of participants on drawers was very limited. The first iteration in the community area with 12 people with dementia had 15 data points (10 people sitting = 10 data points, one person passed by drawers two times = two data points, another one passed by three times = three data points). Among those 12 participants, only three noticed and paid attention to the drawers. One of the residents sitting at a table nearby recognized one of the pictures: "There is the cathedral" (one gaze, no interaction). Soon another resident who was passing by, busily looking for her tights interrupted her search to stay at the drawers (one gaze, one staying with dwell time, no physical interaction). She closely examined the pictures especially one showing a creek with birches and kept mumbling about her tights. One resident who appeared to be the fittest of the group walked past the drawers several times before being asked by a caregiver whether she took notice already of the set of drawers. She answered: "I already admired it, looks really nice. So we have something new again, no? The pictures will be exchanged from time to time, right?" Furthermore, she interpreted the four seasons as the central theme. That association may be due to the four different drawers. Actually, the pictures at that time showed pictures representing the topics technology, the local city, food, and nature. We see her interpretation of the topic not as a failure of the prototype but rather as a surprising act of creativity of the resident. After all the main aim of the prototype is not to provide an image quiz but to evoke positive emotions and memories. As she paid gaze direction to drawers (two times) but did not stop and make any interaction until she was stopped by a caregiver, the dwell time and interaction were 0. Overall, in this iteration without lighting (Table 5.4), three participants (4/15 - 27% data points) had gaze direction to drawers whereas the others barely acknowledged the existence of the drawers. Only one time a participant, who was searching for her tights, stopped at the drawers (6s). No one stopped and made interactions like touching or opening drawers.

In the iteration 2, after the drawers were passed 20 times, only two people paid attention (four gaze direction to drawers detected), but no one stopped at and interacted with the drawers. After that, caregivers brought some residents one by one to the drawers and introduced them to use the drawers. The Wizard changed pictures on drawers from time to time. After letting the residents watch the slideshow for a while a caregiver actively joined in and asked specific questions about the pictures or just how they liked it. Most gave short answers. In the end, the iteration 2 showed a lack of gaze attention (4/20 - 20% data points) to the drawers, no dwell time, and no interaction (Table 5.4).

As expected, the iteration 3 with moving lighting (Fig. 5.14) drew the gaze of participants more often and increased interaction (Table 5.4). In the baseline condition of this iteration, the number of gaze direction to drawers detected was 9/40 (22.5 %) when they were in sight. Only three times participants passed by and stopped for a short time (3-4s). No physical interaction was made although 40 times people passing by the drawers were recorded. In the lighting condition, the gaze, dwell time, and the number of physical interaction were increased (Table 5.4). When residents passed by, they often stopped for a few seconds (3-6 seconds for looking at the drawers and then leaving) or few minutes (1-4 minutes for making interactions). During two previous iteration tests, the dwell time was too low (only one time for 6s in the iteration 1, dwell time when caregivers brought them there did not count) which meant no real interaction between residents and the drawers was recorded. Conversely, in the lighting condition of this iteration, a resident whose attention was drawn by the lighting approached the prototype and stroke her hand over the top of the set of drawers. She firstly moved her hand in circles covering the entire surface as if she was wiping dust. Then she used her hand to explore the front side and the edges. Later the same woman returned with a caregiver and asked him if she was allowed to open a drawer. He affirmed and after cautiously opening the drawer a few centimeters she shyly said "oh, but now let's close it again", and did so. Later a very talkative resident came by who was busy checking doors, handrails and

Table 5.4 Results of three iterations testing lighting effect with interactive drawers in facility D.

	Iteration 1 (Baseline condition)	Iteration 2 (Baseline condition)	Iteration 3	
			Baseline condition	Lighting condition
N	15	20	40	23
Gaze	4 (26.7%)	4 (20%)	9 (22.5%)	15 (65.2%)
Number of interactions	0	0	0	8 (34.8%)
Dwell time	1 time (6s)	0	3 times (3-4s/time)	10 times (3-6s/time) 8 times (1-4m/time)

about everything on how good it was crafted. He also examined our setup and found it to be "marvelous". Later he came back to open a drawer looking inside and then closing it again – this time without a statement. The two residents described above were two example being proactive in approaching the drawers during hours we stayed there with the moving light. The number of interactions increased from 0% (baseline condition) to 35% (lighting condition), which is an improvement obviously but not so high in the end. Note that there was no right or wrong interaction.

Discussion

This study aimed at testing the hypotheses 2 and 3 (draw gaze and stimulate interaction) by showing the effect of the lighting with green color cue on a chest of interactive drawers prototype for a reminiscence activity for people with dementia. Three iterations were made and the first two iterations (baseline condition) showed that people with dementia interpreted screens on interactive drawers as hanging pictures on the wall for the purpose of watching, not opening as a chest of drawers. The prototype also did not successfully get their attention and motivate them to interact with it. The moving green lighting was added to draw their attention and stimulate their interaction with the drawers. The first results seemed promising as the lighting with green color increased the people with dementia' gaze attention (from 26.7%, 20%, and 22.5% in the baseline condition of Iteration 1, 2, 3 respectively to 65.2% in lighting condition), dwell time at the drawers (number of times they stopped by and the dwell time as well - Table 5.4), and the number of interactions with the drawers (from 0% in the baseline condition to 34.8% in lighting condition). Although it increased the chances, the effect of lighting was far from a high percentage. As every person with dementia is different and they have a variety of cognitive and physical impairments, this lighting cue or any other cue is expected not to work perfectly. In fact, the lighting cue showed a fair positive influence without any negative feedback, which can be considered a success. The baseline condition and the lighting condition were tested in different groups but as mentioned earlier, in iteration 3 which included the lighting condition also included the baseline condition to validate the effect of lighting with color. Residents with dementia also seemed to move more frequently and more energetically in the afternoon than in the morning. But the influence of different times of the day on activity such as staying at the exit area (see study 3) was not as pronounced as we were in different groups at different times and the areas used for the study were community areas (far away from the exit area). In the future, different forms of lighting (not only moving) and different colors will be investigated.

Study 5: Interactive Drawers in Facility E

The study with interactive drawers was replicated in facility E to increase the validity of our results about the effect of the lighting with color cue on people with dementia. In this study, we used the technology which was implemented in the third iteration of study 4.

Methodology

The study was conducted by two researchers in one block of the facility E (called block E1 - Fig. 5.15 in early February of 2017. The prototype was set up in the block E1 with 11 participants with dementia (Table 5.5) for four days (Monday - Thursday). The variables of this study were similar to those used in study 4: gaze direction, dwell time, and interaction measured manually and collated with video data by one camera. The baseline condition (lighting was turned off) and lighting condition (moving green lighting was turned on) were tested. The baseline condition lasted from the early afternoon of Monday till the early afternoon of Tuesday. The lighting condition took the rest of time until Thursday's evening. A four meters LEDs strip was used for illuminating (lighting condition). When participants came closer to the drawers (about 3 meters away), the lighting was turned on.

Finding

Table 5.6 shows the results of testing lighting effect with interactive drawers in facility E. Comparing the baseline condition against the lighting condition in facility E we found a significantly higher ration of gaze towards the drawers in the lighting condition, $X^2(1)$ = 6.74, p = .013 (Fisher's exact test). However, there was no significant effect of the number of interactions in the lighting condition against the baseline condition, $X^2(1)$ = .69, p = .501 (Fisher's exact test).

Fig. 5.15 Prototype setting in block E1

Table 5.5 Participants living in block E1 - facility E.

Participant	Gender	Dementia stage
1	Female	Mild
2	Female	Mild
3	Female	Mild
4	Female	Mild
5	Male	Moderate
6	Female	Severe
7	Female	Severe
8	Female	Moderate
9	Female	Severe
10	Female	Severe
11	Female	Moderate

Table 5.6 Results of testing interactive drawers in facility E.

	Baseline condition	Lighting condition
N	18	56
Gaze	6 (33.3%)	38 (67.9%)
Number of interactions	2 (11.1%)	11 (19.6%)
Dwell time	4 times (4-8s)	12 times (4-8s/time) 11 times (2-10m/time

The results showed that in the baseline condition, among 18 times participants passed by the drawers, six times (33.3%) they had a glance on the drawers and did not stop to interact. In the lighting condition, 38 out of 56 times (67.9%) participants gazed at the drawers and lighting (sometimes they were looking at the lighting strip only, not the drawers). Participants stopped at drawers more and had longer dwell time in the lighting condition compared to the baseline condition. The problem was that participants did not really spend time interacting with the chest of drawers but rather walking around it or sitting on the sofa beside it. The real interactions (opening drawers, looking at and talking about pictures) only happened when somebody e.g. a caregiver, a researcher explained the drawers, talked with participants, and incited them to do so. The data with intervention from caregivers were not counted.

During the study, participants were observed that always went directly between two ending points (exit door and kitchen) of the block E1 (Fig. 5.16a). Nevertheless, when the lighting was illuminated (green lighting - Fig. 5.16b,c), they tended to go discovering the area with drawers, sofa, and tables e.g. relaxing on the sofa, having a bottle of water on the table (Fig. 5.16b) or deviated a bit from the main route to the lighting direction (Fig. 5.16c). This observation reinforced hypothesis 1 that the lighting with color can guide people with dementia to a direction or a place.

Discussion

The results of this study bear close resemblance with the results of study 4 and reinforced hypothesis 2 "Lighting with suitable color can draw attention and eye's direction from people with dementia". In both studies, the gaze of people with dementia at the drawers was significantly increased from less than 34% to 60%-70%. With more attention on the drawers, the interactions between people with dementia and drawers were consequently higher in the lighting condition compared to the baseline condition (the dwell time were longer, number of interactions was higher). The effect of lighting with hypotheses 2 and

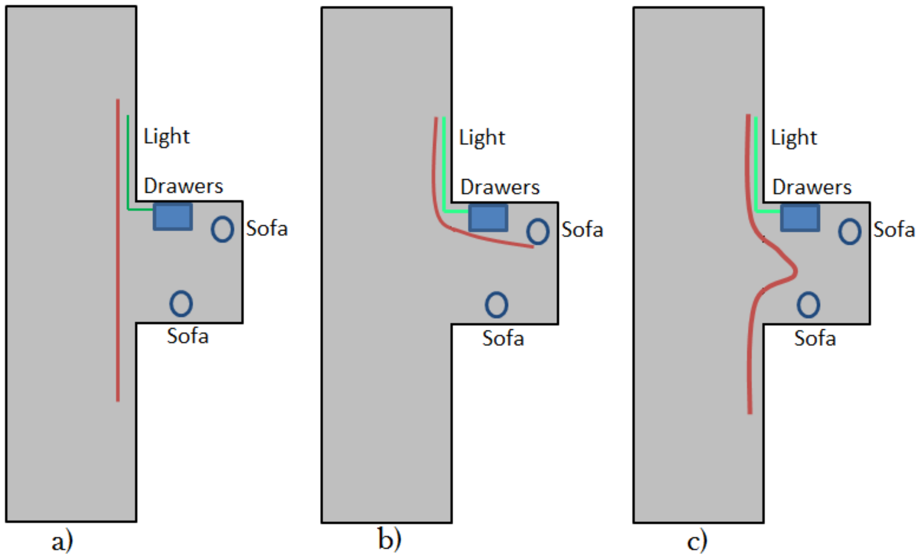

Fig. 5.16 Typical movement of participants - red line in situations: a) without light; b) and c) with the lighting on

3 were then supported. However, according to feedback from participants, they did not interpret the prototype as drawers to open. This might be a reason that in study 5 the effect on the number of interactions in the lighting condition was not significant compared to the baseline condition. They considered them as pictures which can change over time and stood from a distance watching pictures (not physical interactions). They did like to see more pictures, enjoyed the prototype, but the reminiscence activity was much better with a person (e.g. a caregiver) keeping company and talking with them. This raised the issue of building prototypes/extra services for people with dementia in a way they can interpret and use properly. Some lesson learned about this issue will be discussed more in section 8.1.

5.2.5 Study 6: Prevent People with Dementia using Exit Door with Red lighting

In previous studies, green lighting and white lighting appeared to be suitable to grab the gaze and attention of people with dementia and to deviate their movement to the light. However, in some situations, we do not want to guide people with dementia to a place but to prevent them away from it or at least make them stay there only for a short time. For instance, people with dementia should not stay long in the exit door area (block E1 of the facility E) (mentioned in section 5.1). Our approach was using a red lighting to create an ambient/intuitive feeling of alertness and outward orientation. Study 6 was then conducted to test hypothesis 4 "In the case of preventing user using the exit door and staying long in that area, lighting with red color would reduce the staying time of people with dementia in that area".

Methodology

The study was conducted in block E1 of the facility E for four days at the beginning of February 2017. The 11 participants were the same as in study 5 (Table 5.5), however, not all of them showed this behavior (will be shown in the data). People with dementia used to go toward the exit area and stayed there for a while (Fig. 5.17a). A one meter LED strip with red color was set-up next to the exit door. Note that the lighting in the actual setting was more red and ambient than in the picture. Two conditions baseline (no lighting) and red lighting were tested and compared to see the influence of the lighting. In the red lighting condition, the lighting was turned on by a Wizard when the participants went toward the exit area, passed by the sofa area, and reached the point (x-mark - Fig. 5.17b). We did not want to influence people with dementia' nature of behaviors by bringing them to the exit area and set-up testing sessions. We stayed at the star position of the Fig. 5.17b) to control the lighting and noted the behavior of the residents. As the flashing/moving red lighting could lead to an unpleasant experience for people with dementia, we chose the static setting for the lighting. The dependent variable was staying time - period participants stayed in the exit area (the area between x-mark area and exit door), which was measured manually as the camera could not cover this area. If he/she reached the x-mark, saw the lighting turned on, and then turned around, the staying time would be 0. A within-subjects design was used because of two advantages: power and reduction in error variance associated with individual differences. The 'carryover effects' was minimized in case of people with dementia, especially people with moderate to severe dementia, who got a problem with short-term memory.

Finding

Due to the nature of data collection procedure, the participants could go to the exit area more than one time over the course of study. The mean value of their staying time was used for the further analysis. A Wilcoxon Signed-Ranks Test indicated that staying time in exit area in the baseline (no lighting) condition scores were statistically significantly higher than staying time in exit area in the red lighting condition scores, $Z = 21$, $p = .031$ (Fig. 5.18).

Then, a 2x2 ANOVA (Fig. 5.19) was conducted on the influence of two independent variables (lighting condition, time of day) on the staying time of people with dementia in the exit area. Lighting condition included two levels (red lighting, no lighting) and time of day consisted of two levels (morning - from 8:00 to 12:00, afternoon - from 12:00 to 19:00) (Table 5.7). The main effect for lighting condition yielded an F ratio of $F(1,16) = 94.96$, $p < .001$, indicating a

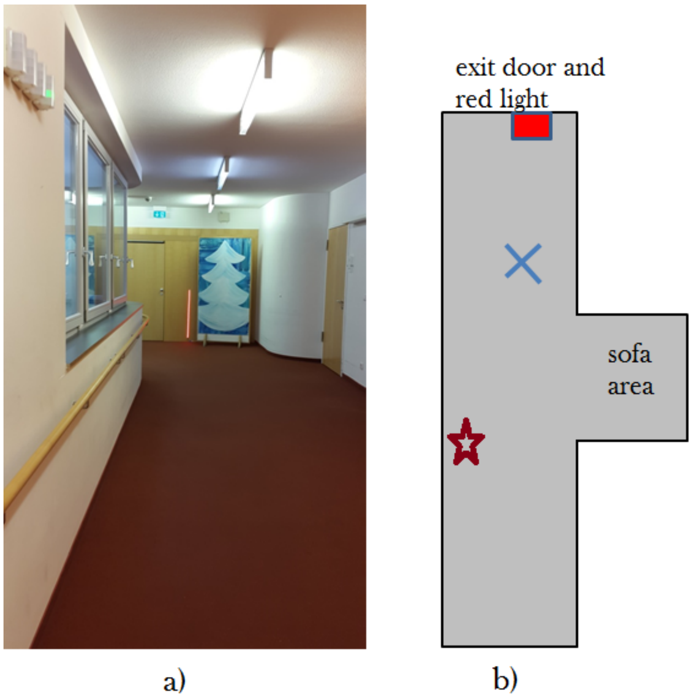

Fig. 5.17 Exit door with the red lighting LED strip beside. The lighting was perceived more red and more intense in real than in the picture.

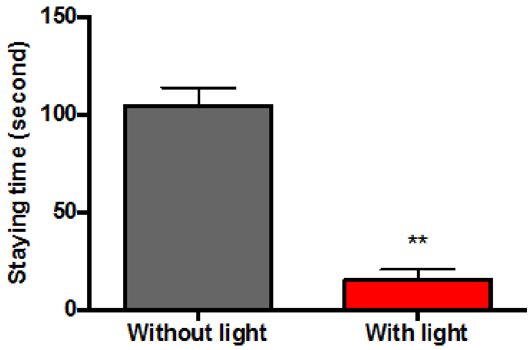

Fig. 5.18 Paired t-test of the red lighting study

Table 5.7 Variables in 2x2 ANOVA.

	No lighting			Red lighting		
	Mean	SD	N	Mean	SD	N
Morning	91.50	23.64	6	18.67	22.05	3
Afternoon	124.00	25.32	5	8.34	10.99	6

significant difference between red lighting (M = 10.43, SD = 13.11) and baseline - no lighting (M = 109.90, SD = 24.11). The main effect for time of day yielded an F ratio of $F(1,16)$ = 1.308, $p > .05$, indicating that the effect for time of day was not significant, morning (M = 91.48, SD = 23.50) and afternoon (M = 124.09, SD = 25.09). The interaction effect was significant, $F(1,16) = 4.89$, $p = .042$.

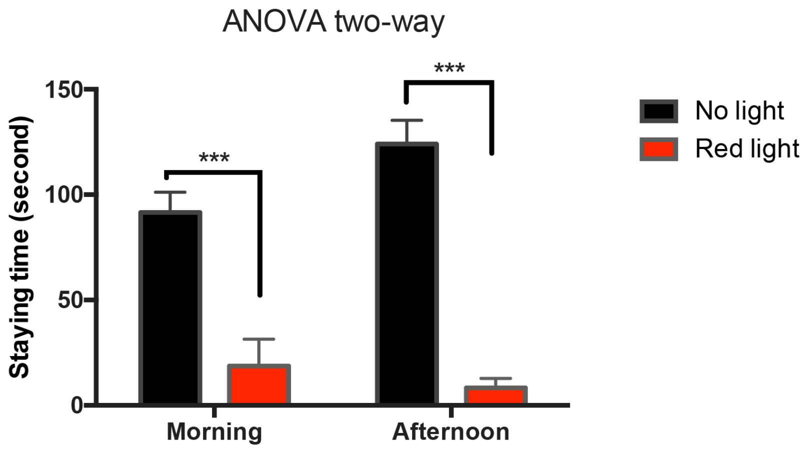

Fig. 5.19 ANOVA two way test of red lighting study (Facility E)

Discussion

Study 6 was conducted to test the effect of red lighting on preventing people with dementia going to an area, or at least increasing alertness and outward orientation. The outcome suggested that the red lighting manipulation did not prevent people with dementia going to the illuminated place. Participant 4 was the only one who stopped and turned back when seeing the red light. However, participant 4 did not usually go to the exit area, which meant the number of data points for this participant was small (only two data points for base line condition and one data point for red lighting condition). Therefore, it was hard to confirm if the red lighting meaningfully changed participant 4 behavior. Overall, at least the red lighting succeeded in increasing alertness and outward orientation as the staying time of people with dementia was significantly reduced in the red lighting condition compared to the baseline condition. The main effect for time of day was not significant. However, the staying time in the exit area without lighting in the afternoon was descriptively higher than in the morning (124.00 vs. 91.50), which matched with our note earlier in study 3 that during the afternoon time residents were more restless. According to the residents, it was late, sunset, and they had to go back home (they still did not consider the facility as their homes). In the end, carry-over effect or re-encounter problem (if people with dementia see the red light every day and get familiar with it) need to be investigated in the future. Besides that, every person with dementia is different, more participants in different care facilities are needed for an external validity (generalized inferences).

5.3 General Discussion

This chapter presents five conducted studies (studies 2 - 6) to test four hypotheses made at the beginning of this chapter and to suggest that the lighting with color cue can fulfill the requirements (R1-R4) of the indoor navigation system described in chapter 3. Before conducting the studies testing the four hypotheses, study 2 was conducted to identify which color is suitable or appropriate to combine with the lighting cues. The results of study 2 showed, in agreement with previous research that green color was a popular pick and created a comfortable feeling. Then, the green color was selected as a suitable color for the next studies. Study 3 was conducted in facility B to test hypothesis 1 "At the intersection/decision point, people with dementia go toward the direction which is highlighted by lighting and suitable color" using the lighting with green color. The setting was in a decision point where the people with dementia had to decide turning left or right to find an object. Left and right sides were symmetrical. Based on the results, participants chose the direction with lighting significantly more often in 75% (90% if excluding the participant 3 who started moving before the end of instruction) of tests compared to 50% predicted by chance (same as the baseline condition). Studies 4 and 5 were then conducted to test hypothesis 2 "Lighting with suitable color can draw attention measured by gaze direction from people with dementia" and hypothesis 3 "Lighting with suitable color can highlight objects and stimulate people with dementia using objects/services" with residents in two dementia care facilities D and E. A prototype of interactive drawers for reminiscence activity was evaluated with and without additional lighting. The outcome indicated a significantly higher ration of gaze towards the drawers in the lighting condition compared to the baseline condition. The increase in gaze was from 20%-33% in the baseline condition (three iterations in the facility D and one in the facility E) to 65.3%-67.9% in the lighting condition (one iteration in the facility D and one in the facility E). Furthermore, the number of times participants stopped at the drawer, the period of time they spent there, and the number of interactions with drawers also increased in the lighting condition compared to the baseline condition. Based on these results, hypotheses 2 and 3 are supported. After that, study 6 used red lighting suggesting the other application of lighting and color, which is preventing people with dementia from going to a restricted area e.g. exit area or at least increasing alertness and outward orientation. Statistical tests showed a significant decrease in staying time in the area with red lighting turned on compared to the baseline (no lighting) condition. Thus, hypothesis 4 "In the case of preventing the use of the exit doors by inhabitants of the care homes, lighting with red color would reduce the staying time of people with dementia in that area" is supported.

However, several limitations of the presented studies have to be noted. First, the power was small because of a small amount of participants, which was expected due to difficulties in the recruitment process (finding cooperated dementia care facilities and getting informed consents from people with dementia' relatives). The mood swings and frequent negative feelings also affected the testing sessions (for instance, about 60-70% of sessions in study 3 had to be canceled because participants did not feel well). Surprisingly, we found that time and weather also influenced people with dementia. During winter time, rainy days, and in the evening, people with dementia were noticeably more anxious, furious, which led to a high chance of a failed testing session. According to participants, they wanted to leave the place, to go back home. Another reason for the small number of data points was that during study 3 two of the residents which took part in the study passed away and one moved out of the facility. The second drawback was that even though the results showed higher engagement with green and white lighting from people with dementia, the chances of success were in the medium range (about 75% in guiding left/right, 60-70% in drawing gaze, 35% in getting interaction). However, as pointed out in chapter 3 and throughout the presented studies, each person with dementia is different, and they often have several varying impairments, which means a perfect solution is nearly impossible. Plus, the effect of the intervention on people with dementia could also depend on other factors such as their state (mood, physical health), context, and people around (caregivers, other residents, visitors).

In the end, lighting and color appear to be helpful for people with dementia in navigation and orientation context in several ways. It could implicitly grab the attention/gaze of people with dementia to an object/service or simply add on another explicit cue. The red lighting, on the other hand, created alertness and outward orientation which was useful in safety issues. One time in the testing in the facility E, the lighting was even used as a beacon/visual landmark for caregivers showing/instructing people with dementia. When a caregiver escorted a participant to the drawers, he said to the participant "we are going to the lighting strip". The participant immediately realized the destination and said: "Oh yes, the green lighting strip". Instead of talking about the name of objects, rooms, areas, it's easier to mention the lighting to people with dementia. In the future, the form of lighting with color could be used to enrich the surroundings of the residents with ambient light, bulb light, strip light, moving light, static light, under handrail, or behind the objects. During the testing, we did not have permission to change much in the settings of the facility. If the whole system of lights can be controlled, the effects would be much better. Imagining when people with dementia is going straight ahead, the system dims the lights in front of them and turn on the lighting on the left, it would be more efficient than only turning on the left lighting as we did in the studies. Using the lighting and color as an implicit interaction and controlling them automatically and intelligently are the vision in our III Environment (chapter 4). As the use of green, white, and red color was researched, how different colors can be applied differently for each person with dementia in several situations remains an open question. Although a lot of factors such as culture, age, gender, context of time and place influenced the choice and effect of color make this question hard to answer, it is worthwhile to continue developing other components of the system: a monitoring system (R5) as a precondition for individual guiding and an intelligent system (R6) as a mean to automate decisions and to ease the work of the caregivers. For this, the following chapters will discuss in more detail of how to design and develop the monitoring system and the intelligent system.

Chapter 6

The Monitoring System

Recall the Implicit Interactive Intelligent (III) Environment presented in chapter 4 and three-part system (Fig. 4.5) supporting indoor navigation for people with dementia using implicit interaction paradigm: implicit guiding system, monitoring system, and intelligent system. The implicit interaction between people with dementia and III Environment was shown in both implicit input and implicit output. Chapter 5 elaborated studies about light with color (guiding system) which was implicit output for people with dementia. Implicit input data (not be inputted intentionally by the users i.e. people with dementia) - location information of people with dementia was collected and processed by the monitoring system of the three-part system, which is presented in this chapter. Other implicit input data such as expert data or medical record will be used for the intelligent system in chapter 7.

To build a successful system, both the user and system perspectives should be considered. Field studies, observations, and interviews were conducted to try understanding people with dementia's needs and preferences (chapter 3). To repeat, people with moderate to severe dementia living in care facilities cannot use the tracking system to find a way/place. Based on observations, our target users are unable to use technology (smartphone/PDA) or unwilling to wear inertial sensors. They have difficulties in using devices with only three buttons (Rasquin et al., 2007) or orienting themselves by looking at a map. Recall requirement R5 (chapter 3), which is to develop a new monitoring system with an appropriate device for people with moderate to severe dementia. Thus, we decided that the monitoring system would be invisible from people with dementia, which led to implicit input. People with dementia only need to wear a small and light-weight device as an accessory. The interface of monitoring system was built for doctors and caregivers when they need to find where people with dementia are in case they are not in their bedroom due to medical and safety aspects. This system also plays a role connecting with and providing data to the guiding system and the intelligent system for an automatic mode, where the system acts by itself without waiting for commands from users i.e. analyzes and processes data then provides the most appropriate assistance/support for people with dementia or caregivers/doctors.

In this chapter, the system aspects are discussed in details. We review the background and state of the art (section 6.1) of indoor positioning/monitoring technologies, analyze the system properties 6.1.3, and propose solutions for dementia care facilities. Two approaches chosen for real-time monitoring systems i.e. iBeacon and Ultra-WideBand technologies are deployed, tested, and then presented.

6.1 State of the Art

One characteristic of our III Environment (chapter 4) was context-aware computing. Context-aware computing is toward the realization of a ubiquitous and pervasive computing (smart / intelligent) environment, where computers and devices are embedded and connected within an indoor environment. Location positioning is always one of the key aspects of context-aware computing. According to Abowd and Dey (Abowd et al., 1999), context types could be distinguished between location, identity, activity, and time. Similar to that, location information was also one of the main categories: users and role, process and task, location, time and device identified by Kaltz et al. (Kaltz et al., 2005) to cover a broad variety of mobile and web scenarios. Our monitoring system was built more toward the definition of Abowd and Dey as our system can determine information about location, identity, time and then use them trying to find out the activity information.

Location positioning refers a process obtaining location information of a mobile node - typically the person or object being tracked (from now called MN) with a set of reference points in a predefined area. This process is also known as radiolocation e.g. (Krishnamurthy, 2002), position location e.g. (Rappaport et al., 1996), geolocation e.g. (Pahlavan et al., 2002), location sensing e.g. (Hightower and Borriello, 2001), or localization e.g. (Ladd et al., 2005). In an outdoor environment, the GPS is usually used with latitude, longitude, and altitude as the coordinates of an entity on the Earth's surface. An indoor positioning system, on the other hand, may use a room number, and other reference objects (e.g. kitchen, toilet) to represent an entity's position.

The applications of indoor positioning are not limited to tracking the location of users and objects. Concierge services enable users to become aware of nearest supporting facilities.

For instance, multimedia contents such as a picture, video can be displayed to the nearest video screen of a mobile user.

Unfortunately, unlike outdoor environment, the GPS system cannot be used effectively inside building due to its weak signal reception when there are no lines-of-sight from a MN to at least three GPS satellites. Infrared, radio frequency (RF), and ultra sound signals are three major technologies used for indoor positioning systems. The indoor positioning faces numerous challenges such as the dense multipath effect and building material dependent propagation effect. Multipath is a radio frequency's problem where the result of radio signals travels through multiple reflective paths from a transmitter to a receiver (Sklar, 1997). Because of multipath effect, the amplitude, phase, and angle of arrival can fluctuate (also known as multipath fading in wireless mobile communications). Therefore, positioning multiple MN (people, objects) in an indoor environment is a significant challenge. Previous indoor localization research has focused on visual/camera tracking, wireless signal localization, dead-reckoning (DR).

Visual tracking i.e. (Kaddoura et al., 2005) is the most traditional approach. It is however expensive, and needs great computational effort to identify individuals automatically. Besides that, this solution also deals with ethical issues as people with dementia and caregivers do not like visual tracking devices like cameras around. The second approach was Dead-Reckoning (DR) or Micro-Electro-Mechanical Systems (MEMS) using foot and body mounted inertial sensors to track people. Most dead-reckoning systems rely on attaching motion sensors to a body's part, such as the hip (Klingbeil and Wark, 2008), foot (Widyawan et al., 2008), or the wrist. In general, the performance of this solution is affected by large errors (bias and noise) typical of sensors (rapid drift over time). The performance disadvantage, however, can be overcome by combining DR/MEMS with GPS and RFID like (Kourogi et al., 2006). In the end, such systems are always complex to build and uncomfortable to use. Last but not least, there is the approach focused in this thesis: the wireless signal solution. Wireless solutions for indoor positioning could be categorized based on three aspects: sensing technologies, measurement techniques, and location system properties (Kaemarungsi, 2005). Sensing technologies and measurement techniques can be demonstrated in a basic functional block diagram of the wireless positioning system (corresponding to location sensing and positioning/location estimation algorithm blocks in Fig. 6.1) suggested by Pahlavan et al. (Pahlavan et al., 2002). First, the signals are transmitted by or received at pre-defined reference points by location sensing devices matching up with sensing technologies such as RF, infrared, or ultrasound. The signals are converted into location metrics that could be TOA (time of arrival), AOA (angle of arrival), POA (carrier signal phase of arrival), or RSSI (received signal strength indicator) (Pahlavan et al., 2002). After that, the positioning algorithm processes location metrics and determines the location information using approaches e.g. distance based approach (Bahl and Padmanabhan, 2000), signal processing (Rappaport et al., 1996), neural networks (Brunato and Battiti, 2005), or probabilistic approach (Roos et al., 2002). Finally, the location information is displayed suitably for the end user.

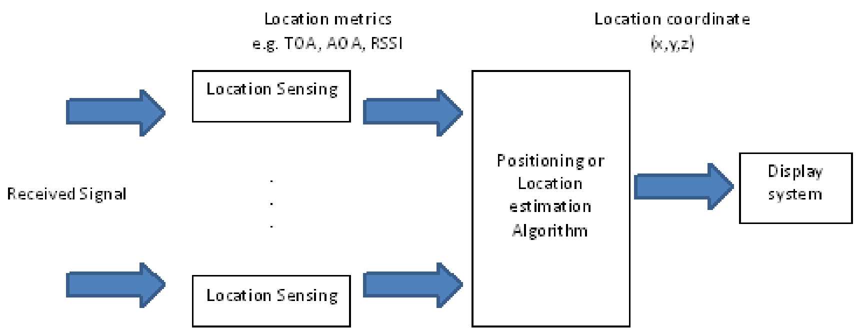

Fig. 6.1 Functional block diagram of wireless positioning system (Pahlavan et al., 2002)

According to (Kaemarungsi, 2005), a location system can also be viewed from a software engineering perspective using a location stack (analogous to the OSI protocol stack) - Table 6.1 (Hightower et al., 2002). Hightower et al. proposed this layered software engineering model dividing the positioning problem into smaller research problems to use the location information facilitating the development of future ubiquitous computing systems, which are independent of sensing techniques and measurement technologies. Table 6.1 summarizes the brief description of each layer. Based on this protocol stack, our monitoring system covers the layers 1,2,3,4 (work with raw data from sensors, transform those data into meaningful locations by a data processing and algorithms) whereas the intelligent system in chapter 7 aims at layers 5,6,7 (combine with other information to recognize users' activities and intentions).

Coming back to three main categorizations of indoor positioning systems mentioned earlier: sensing technologies, measurement techniques, and location system properties (Figure 6.2). The sensing technologies are about hardware devices, whereas the measurement techniques are more likely software technique to determine the location of the mobile node (MN). The location system properties is a taxonomy to characterize or evaluate positioning systems. The details of those three categorizations are described following.

Table 6.1 Location stack framework (After (Hightower et al., 2002)).

Layer	Description
1. Sensor	Detect a variety of physical and logical phenomena by sensor hardware and software drivers.
2. Measurements	Transform raw sensor data into the canonical measurement types along with an uncertainty representation based on a model of the sensor that created it.
3. Fusion	A general method of continually merging streams of measurements into a time-stamped probabilistic representation of the positions and orientations of objects. Through measurement fusion, differing capabilities, redundancies, and contradictions are exploited to reduce uncertainty.
4. Arrangements	An engine for probabilistically reasoning about the relationships (e.g. proximity, containment, geometric formations) between two or more objects.
5. Contextual fusion	Merge location data with other non-location contextual information e.g. personal data, color, temperature, and light level.
6. Activities	A system e.g. a machine learning system recognizes activities from all available context information including location.
7. Intention	The cognitive desires of users as they relate to what a ubiquitous computing system should do or what task is in progress.

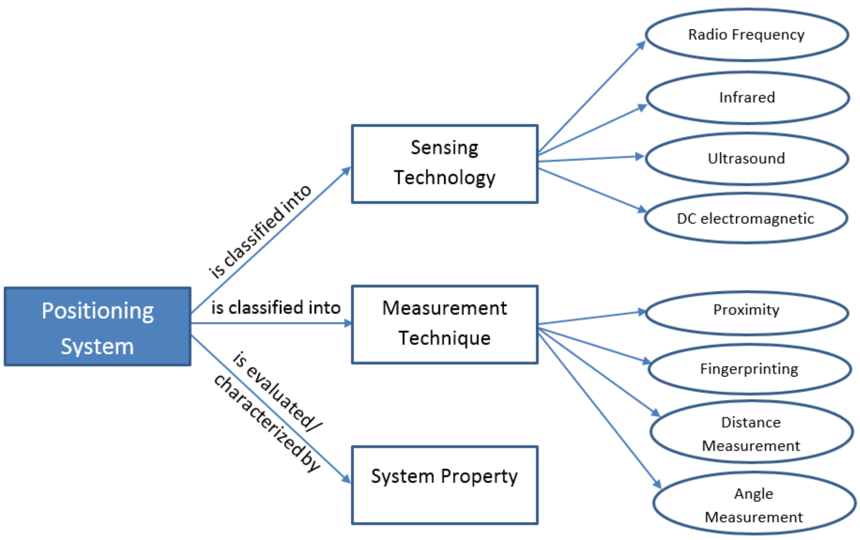

Fig. 6.2 A taxonomy of positioning systems

6.1.1 Sensing Technologies

Depending on sensing technologies and sensor's signal, the positioning systems would have general limitations for all signal types such as propagation delay, reflection, and scattering or some specific technology limitations like effective range, power constraints, safety, and cost. Four major sensing technologies are radio frequency, infrared, ultrasound, and DC electromagnetic (Tauber et al., 2002). The first technology is the radio frequency (RF). RF refers to any of electromagnetic wave frequencies between $3kHz$ and $300GHz$ including those frequencies used for communications e.g. Bluetooth, Ultra-wideband (UWB), or radar signals. RF is widely used because of its strengths that can penetrate most indoor building material. It, therefore, has the longest range in indoor environments compared to infrared and ultrasound technologies. Besides that, the propagation speed is also high as infrared (about $3 \times 10^8 m/s$). The next technology is the infrared signal which is similar to visible light. It means that it cannot pass through walls or obstructions. Infrared technology thus has a limited detection range in indoor environments. The infrared devices usually have small size whereas the propagation speed is significantly high (about $3 \times 10^8 m/s$). The disadvantages of infrared are accurate sensing due to an interference of indoor lighting and quite short range (about $5m$). The third one is ultrasound which works at low-frequency bands (about $40kHz$) and has a slow propagation speed of sound ($343m/s$). Ultrasound devices are simple and inexpensive while providing a good precision for location sensing. However, the disadvantages of ultrasound devices are short range ($3-10m$) and not be able to penetrate walls or obstructions. Besides that, the operating temperature also influences the performance of ultrasound. The last technology is DC electromagnetic, which has a high signal propagation speed but a short range (1m-3m). This kind of signal is sensitive to environmental interference from a variety sources such as the earth's magnetic field or metal in the area. Therefore, systems based on this signal need precise calibration and are expensive in practice.

6.1.2 Measurement Techniques

Alternatively, wireless positioning systems can also be categorized by measurement techniques used to determine the position of MN. The main techniques (Hightower and Borriello, 2001) are the *triangulation* that uses triangle geometry in determining a location including *lateration* (distance measurement) and *angulation* (angle measurement), *proximity* that measures nearness to a known set of points, and *scene analysis* that examines a view from a particular vantage point including *location pattern*(*fingerprint*). The positioning system can also be implemented by any combination of the previous techniques. Three major techniques (distance measurement, angle measurement, and fingerprinting) are discussed in this section.

The first technique is *lateration* (distance measurement). Distance could be measured by the received signal strength indicator (RSSI), multicarrier signal phase, time of arrival (TOA) of the received signal, and time difference of arrival (TDOA). RSSI can be converted easily to distance by the formula: $RSSI[dbm] = -(10nlog10(d) - A)$, where n is a constant value that factors in terrain, d is the distance, and A is the offset which is the measured RSSI one meter point away from the device. (Dong and Dargie, 2012). RSSI is affected by several factors such as obstacles, multipath fading, and cross-body shielding. Instead of calculating distance and using techniques e.g. trilateration (Fig. 6.3) to determine the location, fingerprinting can be applied which leads to reasonable results. This is the approach we use (fingerprinting with RSSI values from iBeacon). The fingerprinting technique and iBeacon will be discussed later in this chapter. Multicarrier signal phase measurement is the difference between a received continuous waveform (CW) carrier, or a modulated tone, and a reference signal (Bensky, 2007). The distance can be calculated as: $d = \frac{\lambda}{2} \cdot \left(\frac{\theta}{2\pi} + n\right)$, where λ is the tone wavelength, θ is the phase, and n is an integer. Distance can also be measured based on time delay. Time of arrival (TOA) and time difference of arrival (TDOA) techniques are two examples, which rely on the precision of timing between the signal transmitter and the receiver, and hence, a high accuracy clock and a precise synchronization in the communication system is important. The distance between transmitter and receiver is then calculated by the propagation delay or time of flight (ToF). Again, with distance measurement, triangulation technique e.g. trilateration can be used to estimate the MN's location.

The next approach is *angle measurement*. The angle of arrival (AOA) or direction of arrival (DOA) techniques determine the MN from the intersection of two lines of bearing (LoBs) formed by a radial line to each receiving sensor (Rappaport et al., 1996). Fig. 6.4 is a demonstration about determining the location of point P using angle measurements. The advantage is in a two-dimensional plane (2D), this approach only needs two reference points for location estimation and does not need synchronization between the measuring units. However, this technique requires large and complex hardware (directional antennas and antenna arrays to measure the angle of incidence). Thus, it is difficult to measure the AOA at the MN. Besides that, it works well in situations with lines of sight (outdoor) but in indoor environments where there are signal reflections (multipath), the accuracy and precision decrease.

Proximity technique is a simple solution, which considers the MN as the same label as the position of a "closest" known location. Common metrics include statistical functions of distance

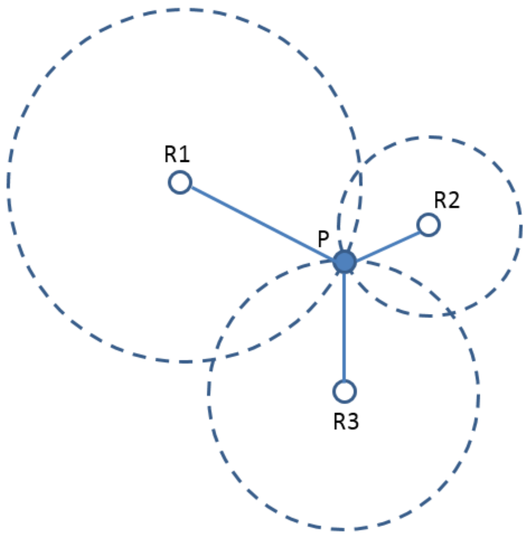

Fig. 6.3 Trilateration determining 2D position of point P using distance measurements between P and three reference points R1, R2, R3.

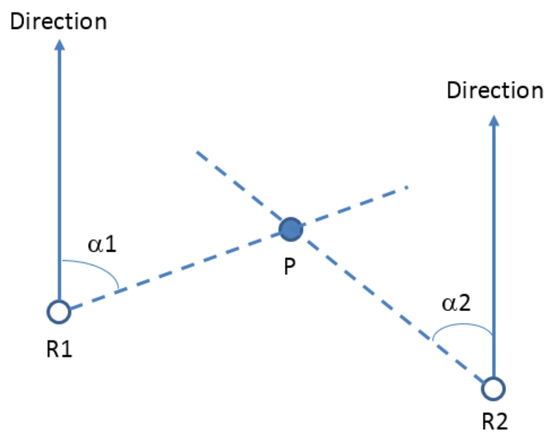

Fig. 6.4 Angulation determining 2D position of point P using angle measurements between P and two reference points R1, R2.

(find the closest distance) and physical contact detected by pressure sensors, touch sensors, or capacitive field detectors. In case proximity approaches do not include a method for identification in the proximity detection, it might need to be combined with identification systems.

Another simple and practical approach is *fingerprinting* or *location pattern matching*. This technique forms a database of location fingerprints by measurement of received signal strength indicator (RSSI) or other non-geometric features at several locations. To determine the location of MN, the system firstly measures the received signal strength indicator (RSSI) at particular locations and then searches for the closest match of pattern or fingerprint in the database. The advantage of this technique is that it does not require the MN is surrounded by at least three readers or access points for determining the location. However, this technique is very time-consuming to perform an exhaustive data collection for a wide area such as in the outdoor environment.

6.1.3 Location System Properties

In a discussion of classifying location system implementations, several issues arise, and they are generally independent of the sensing technologies and measurement techniques. A taxonomy with a set of properties was developed (Hightower and Borriello, 2001) to help developers of location-aware applications better evaluate their options when choosing a positioning system. Table 6.2 lists those system properties (Hightower and Borriello, 2001).

Table 6.3 lists some examples of positioning system evaluated by the system properties suggested by (Hightower and Borriello, 2001).

6.2 System Design and Deployment

6.2.1 Technology and System Property Selection

Our first criteria of the monitoring system were able to track the location of multiple people and identify individuals in real time within a certain indoor area about 250-300 square meters (multiple rooms with walls and obstructions). The wearing device if there is, needed to be accepted by people with dementia. The system was expected to have low-cost, good accuracy and precision as much as possible.

Some main characteristics of popular tracking technologies are summarized in table 6.4. We tried to address both the user's point of view and from the system perspective. On the user

Table 6.2 Location systems properties (After (Hightower and Borriello, 2001)).

Property	Description
Physical position and Symbolic location	- Physical position is coordination such as latitude, longitude, and altitude. - Symbolic location is based on abstract ideas of location such as in the kitchen.
Absolute and Relative referencing	- Absolute referencing systems share single or unified reference grid. - In relative referencing systems, each object can have its own frame of reference.
Remote computation and Local computation	Remote computing systems (network-based systems) use network of location systems to determine location of mobile nodes. - Local computing systems (mobile-based systems) determine their own location.
Accuracy and Precision	- Accuracy is error distance between estimated location and correct location. - Precision is percentage of correct estimation.
Scale	It depends on space, time, frequency and complexity of positioning system.
Recognition	For example, the system can classify or identify located objects such as ID or naming.
Cost	Cost includes cost of installation, devices, infrastructure.

Table 6.3 Examples of evaluating positioning system using system properties (After (Hightower and Borriello, 2001)).

Technology	Technique	Physical	Symbolic	Absolute	Relative	Remote	Recognition	Accuracy and precision	Scale	Cost
GPS	Radio ToF Lateration	x		x				1-5m (95-99%)	24 satellites world-wide	Various
Active Badge (Want et al., 1992)	Infrared Proximity		x	x		x	x	Room size	1 base per room	Cheap
Active Bats (Harter et al., 1999)	Ultrasound ToF Lateration	x		x		x	x	9cm (95%)	1 base/10 square meters	Cheap

side, the system should have a high *user (i.e. people with dementia) acceptance* for wearing or being surrounded, a reasonable price - *cost* (important for care facilities' managers), and a reliable system - *robustness*. On the system side, the *precision* of the systems and the *data complexity* have to be taken into account. If the data is too complex to interpret and process, rapid prototyping would be hard to achieve and partly unusable. Moreover, the whole III Environment in general and the monitoring system in particular need to act fast (online - delay less than a second). If the data is too complicated, it might lead to algorithms are not able to process fast enough and react when the user needs its assistance.

Noted that this table is subjective rating and might be only applied to this specific context. Besides that, these characteristics also depend on vast brands and companies of products. We rated them based on products we could reach out (contacting and discussing by email, Skype). There are still other types of sensors on the market that can perform tracking/positioning problem but not listed in table 6.4 such as infrared or pressure sensors. Even though infrared or pressure sensors might have a high rate of user acceptance (invisible to them), they were not considered because they cannot identify individuals (for context-aware and personalized characteristics). They could be combined to improve the precision of other approaches but not as a good stand-alone solution.

User acceptance was the first aspect to compare technologies. This aspect estimated how easily people with dementia and others (e.g. caregivers, doctors) living in a dementia care facility accept the device. The camera approach bothered caregivers and people with dementia as well when they noticed it. They felt being observed and uncomfortable, which can lead to a lower quality of life (Weiser, 1999). Moreover, if people with dementia suffer from a cognitive affliction, their state might be worse consequently. Therefore, one of the most important aspects we considered carefully was choosing the right technology and device/sensor to minimize the negative impact of invasiveness. Devices/sensors should also be installed with special care to hide them from the view of the people with dementia. The Dead Reckoning (DR) solution with sensors attached tightly on a specific part of user's body such as leg, hip also makes users feel uneasy. The user acceptance was thus rated 3-4 and 4-5 for the camera and DR solutions accordingly. The other technologies RFID, WiFi, Ultra wideband (UWB), iBeacon can provide small devices and do not require to attach them tightly to users' body. Therefore, the user acceptance rates were higher (1-2).

Cost was also an importance aspect when we interviewed managers of care facilities. At the moment, some facilities like the facility E had people with dementia wearing watches with sensors to prevent them going outside or opening the door. These watches normally use GPS technology or short detected range sensors. They did not want to invest much money for a monitoring system although they thought it would be nice to have one. We sought the positioning/tracking technologies from the market to apply for our case study (a monitoring system for people with dementia in dementia care facilities). We contacted several companies which provide tracking/monitoring solutions: Impinj, Ekahau, Katherin, Solcon Systemtechnik, Nofilis, Sunsero, GaoRFID, Trolley Scan. They mainly used WiFi and RFID technology, only Impinj back then also offered a new type of RFID - Ultra-high frequency (UHF) RFID. In general, the price for a system covering 100-150 square meters indoor area was about 5,000 - 10,000 euro. Implementing the system for a real dementia care facility would cost much more as the facilities are larger than 100-150 square meter. In addition, there might be expenses incurred such as supporting fee or buying a new user account. Hence, the cost of RFID and WiFi solutions were rated expensive (4-5). One reader was about 500-1000 $ according to the companies. There are also cheap RFID readers and WiFi Access Points on the market (100-150$/each). However, they could not work efficiently because with that price the RFID readers only are able to detect in a short range whereas the signals of WiFi are not strong and stable enough. In addition, using WiFi to locate a device (MN) by triangulation means that it must remain in contact with at least three access points at all times. Then, to cover the whole facility needs few access points multiplying by 3 of 4 times (for the triangulation). Adding a large number of wired access points does not only raises the cost significantly but also lead to severe network problems. Issues of channel management for WiFi coverage overlapping led to heavy homelessness and channel management. Moreover, the network can be overload quickly by the high density of access points in a small environment, which might lead to cascades of failures. About the camera solution, this is a type of sensor that offers the greatest expressivity. In some scientific literature such as (Hoey et al., 2010), video was used for a real-time vision-based system to assist a person with dementia to wash their hands. They have a variety of prices, and most models are not so expensive and are sufficiently robust to implement continuously in a smart environment. Nevertheless, much more than one is required to cover a care facility (quantity required). They are also costly in computing/handling the data. For example, recognizing simple shapes under a wide range of lighting conditions and colors requires fairly elaborate AI algorithms (Patterson et al., 2006). The camera technology was then also rated costly (4-5). On the other hand, DR and iBeacon approaches were considered cheap (sensors about 10-100 $ can work quite well) whereas UWB was in the middle range.

An aspect underestimated by many researchers when considering a monitoring/positioning system is *energy efficiency*. It is not about economical problem e.g. electricity bill but no user likes to buy and changes batteries all the time, especially people with dementia who have no interest in using the devices and changing the batteries, or they just easily forget about those things. In our III Environment, it is expected to maximize independent and autonomous. Thus, energy management or energy consumption when choosing the technology is important. Camera solution needs a fair amount of energy and requires numerous devices. That is why it was rated 3-4. WiFi tag and UWB tag have high energy requirements that limit their autonomy (only last for few hours). Hence, they were also evaluated 3-4. In this aspect, RFID and iBeacon are the winners as their batter life can last for a long time (few months or even up to a year). Noted that there are two types of RFID: active tags and passive tags. Active tags are more precise but also more expensive and energy-consuming. DR technology was rated in the middle range. Depending on the sensors, DR devices can last up to a couple of days.

Precision was an aspect hardly evaluated due to a variety of brands and products. In general, cameras would be the most precision (rated 2), but as mentioned earlier, they are very costly especially in processing and handling data to be autonomous enough. Among the other technologies, RFID and UWB slightly have a better precision than DR, WiFi, and iBeacon.

It is evident now the camera solution has the highest *data complexity* (rated 5) while the iBeacon and RFID show the advantage in this aspect (rated 1-2). The main data of iBeacon were ID (UUID + Major + Minor) and RSSI (signal strength). It is similar to RFID which contains ID and the signal strength. The DR approach normally combines more than one sensors whereas WiFi and UWB need triangulation technique that makes them rated with quite high data complexity (3-4).

We also considered the *robustness* of technologies, which meant how reliable the system would be when using them. This criterion depends on many things such as the brand of products, their quality and quantity, algorithm, context of the environment, as well as how the users use them. In general, those technologies are quite equivalent. RFID, UWB, and iBeacon were rated a bit better (2-3) comparing to the camera, DR, and WiFi approaches (3-4).

Based on those characteristics of sensing technologies (section 6.1.1 and table 6.4), the approaches iBeacon and UWB were selected. iBeacon and UWB using Decawave DW1000

Table 6.4 Comparison of common technologies. 1:Best to 5:Worst

Aspect	Camera	RFID	DR	WiFi	UWB	iBeacon
User acceptance	3-4	1-2	3-4	1-2	1-2	1-2
Cost	4-5	4	2-3	4-5	3-4	2
Energy efficiency	3-4	1-2	2-3	3-4	3-4	1
Precision	2	2-4	3-4	3-4	2-3	3-4
Data complexity	5	1-2	3-4	3-4	3-4	1-2
Robustness	3-4	2-3	3-4	3-4	2-3	2-3

sensor were quite new technology (introduced in 2013). Firstly, the camera solution is out of option due to many drawbacks mentioned above. RFID and WiFi approaches are considered costly according to offers from companies while DR solution is not so comfortable for people with dementia wearing and using. Besides that, the error of DR approach is expected to increase rapidly over time. It can, however, be compensated if combining other techniques to re-calibrate at some points. iBeacon solution has low price and remarkably energy efficiency. The precision of iBeacon is not so high but can be compromised due to a low level of data complexity. The UWB, on the other hand, is more expensive and consumes more energy but has higher precision, which is also worth testing.

Recall that we categorized positioning systems based on three aspects: sensing technologies, measurement techniques, and location system properties. The reasons iBeacon and UWB technologies chosen were not only about sensing technologies aspect above but also that those two approaches can represent for two main streams of measurement techniques (triangulation for Decawave UWB and fingerprinting for iBeacon - Onyx Beacon) and location system properties as well (physical position for Decawave UWB and symbolic position for iBeacon). As mentioned earlier, people with dementia do not use the monitoring system directly, and our aims is toward a smart and aware environment using ubiquitous computing, internet of things, and distributed technology (chapter 4). The system property is thus remote computation instead of local computation. For other properties such as accuracy, precision, cost, and time, each section following for UWB and iBeacon addresses those properties separately.

We used software part from Decawave company (TREK1000) for UWB solution but decided to implement the software part for iBeacon by ourselves as the APIs companies (Onyx Beacon) provided did not meet our requirements perfectly. Sometimes they did not have functions we needed whereas provided redundant services to our objectives. For example, in order to use Onyx Beacon APIs, it was required to connect to the Onyx Beacon company's server using an account and password. It thus consumed internet data traffic and slowed down our system. Besides that, controlling the code and data without relying on a third-party would make the integration later with other systems (lighting system, intelligent system) easier. We could also bring them as open source code in the future for others using with no need caring about copyright, term, and conditions from commercial companies.

6.3 Study 7: Physical Position with Decawave-UWB

In this section, ultra-wideband (UWB) technology using *Decawave* products is presented. An evaluation kit $TREK1000$ from *Decawave* company was used to implement and test the monitoring system.

Methodology

The Decawave company uses an $IEEE802.15.4a$ compliant sensor and triangulation approach (TOA or TDOA) for positioning. According to the producer, the accuracy of this sensor working with $1.3Ghz$ bandwidth is $+/-10cm$. The key benefits of this sensor - $DW1000$, are precise ranging, long LOS and $NLOS$ communication range (up to $290m$), high data rate (up to $6.8Mbit/s$) and low power consumption (Yavari and Nickerson, 2014). The evaluation kit $TREK1000$ contained four pieces of $EVB1000$ Evaluation Board, which includes the $DW1000$ IC, ARM programmable processor, LCD, USB connection and antenna (Fig. 6.5) (Decawave, 2015). The dimension of the $EVB1000$ is 7×7 cm excluding the off-board antenna. The price of this evaluation kit is about US$ 1000 including tax. The $EVB1000$ can be configured as an anchor (reader) or a tag (Fig. 6.6).

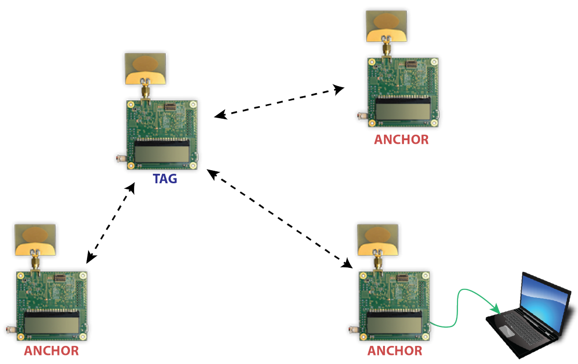

Fig. 6.5 A TREK1000 setting for monitoring system (from the Decawave website: www.decawave.com/)

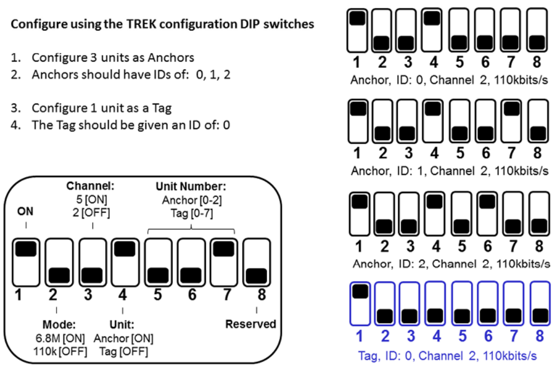

Fig. 6.6 Configure using the TREK configuration DIP switches (from the Decawave website: www.decawave.com/)

The *Decawave* $TREK1000$ with Real-Time Location Systems (RTLS) was used. Decawave provided solutions using UWB (Ultra-Wideband) technology in a single IC. For our context, the block of 2D location using Two-Way Ranging (TWR) was tested. TWR is a classical time of arrival based method, which was originally proposed in (IEEE Standard, 2007). Fig. 6.7 describes the process that the Sender and the Receiver transmit and respond messages. The Sender can easily calculate the round trip $T_{roundtrip}$ and know the reply time T_{reply} from the Msg2, the distance between the Sender and the Receiver is determined by:

$$Distance = c \times TOF = c \times \frac{T_{SR} - T_{SS} - T_{reply}}{2} \tag{6.1}$$

Here T_{SR}, T_{SS}, T_{reply} are the Sender's receive-time, the Sender's send-time, and the delay of the Receiver (from receiving Msg1 to sending Msg2), whereas c is the speed of light.

Due to several errors with clock drift and frequency drift in the case of tag-to-anchor two-way ranging, Decawave implements asymmetric double sided TWR and Poll-Response-Final methods to reduces those errors. The $TREK1000$ uses a broadcast solution that sends a single *Poll* message to all anchors instead of two-way ranging exchanges between the tag and each anchor. Then, each anchor sends a *Response* message, and after that, a *Final* message is sent to all anchors completing the exchange process. We do not go into details of implementations, but according to Decawave, this ranging scheme has very good performance because it is double-sided (round trip times measured from both sides). Also, as this broad solution reduces the number of messages to complete ranging to multiple anchors, it is power and time efficient as well (compared to individual two-way ranging exchanges).

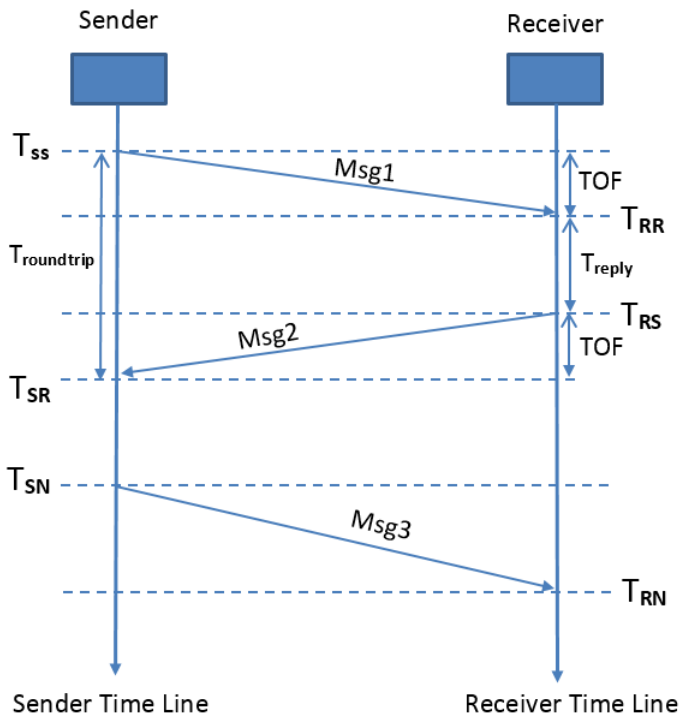

Fig. 6.7 Two-way ranging concept

Three anchors and one tag were set-up as the Fig. 6.8 in my working office. Readers were represented by three blue dots 0,1,2 while the tag was the blue dot with a label Tag 0. Three readers were put on the tables, and the user wore the monitored tag. Again, this approach used triangulation method and absolute referencing. It means that we do not need to define a list of locations such as *working desk*, *kitchen*, *corridor*, or *toilet*. It is also not necessary to collect the training data. The whole process is online. All we need was calibrating the positions of three readers. The top left corner of fig. 6.8 was a part for calibrating. It considered the anchor 0 as the point with coordinate (0,0) in the two dimension. Based on that, the coordinate of other two anchors needed to be input. This calibration is important as the accuracy of the system relies on it.

Findings

The first thing I realized that the size of a tag was larger than our expectation, which was not good for the user acceptance aspect. Thus, we designed our own board using Decawave's DW1000 IC sensor in order to minimize the size. We followed the circuit diagram of the DWM1000 as the Fig. 6.9 (Thotro, 2015). In short, to design and implement the Ultra Wideband (UWB) transceiver IC, the DWM1000 was combined with an Arduino (Sparkfun Arduino Pro Mini 328 - 3.3V/8MHz) and powered by a Li-Po battery. The module used the

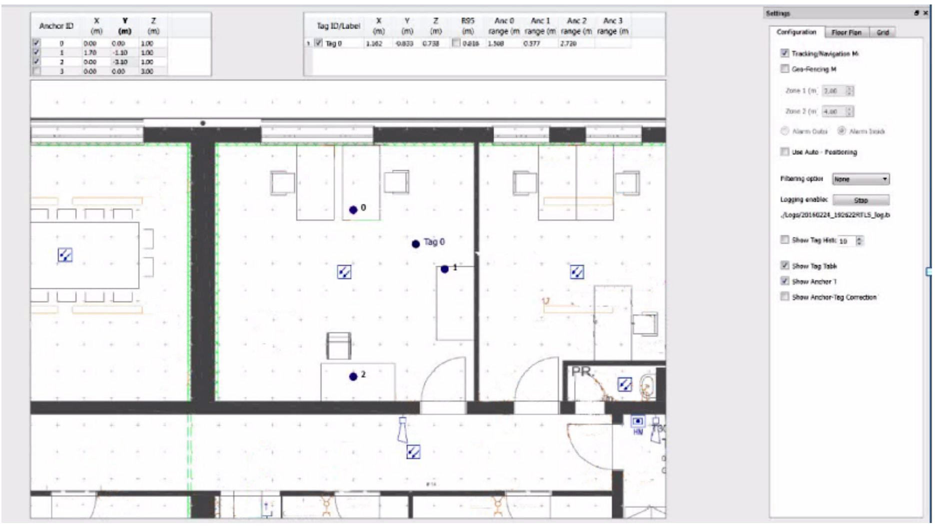

Fig. 6.8 Setup of the monitoring system using TREK1000 evaluation kit. Software is provided by Decawave (Decawave, 2015)

SPI bus for communication with the arduino. Fig. 6.10 shows the successful minimized prototype (4.2 x 1.7 cm) comparing to the other commercial product LPS mini (Loligo, 2015) (3 x 3 cm). These sizes are believed to be the minimum sizes could be reduced without affecting the antenna. Note that these sizes of tags did not include a power source e.g. battery.

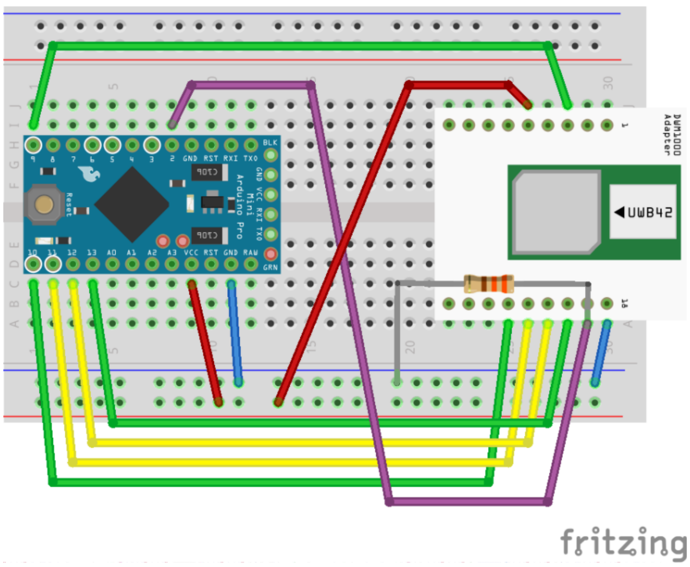

Fig. 6.9 Circuit diagram of the DWM1000 (Thotro, 2015)

The next was about energy consumption. Although Decawave company claimed that their devices have low power consumption, it was still much higher than we expected. We used a

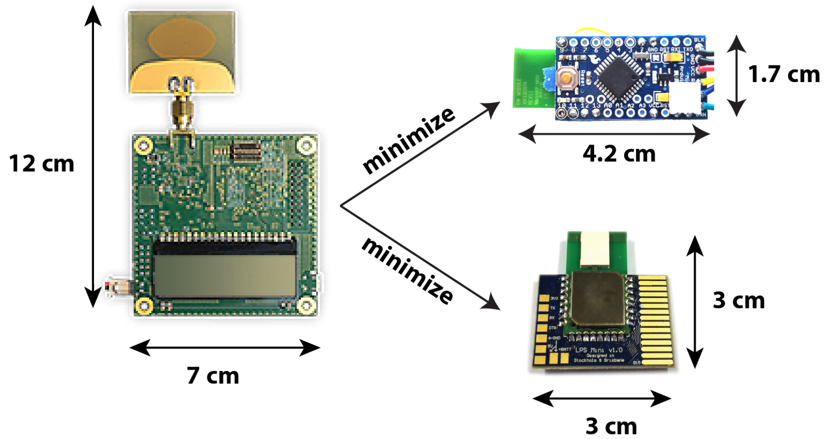

Fig. 6.10 Minimize UWB tag. Left image is a Decawave product, whereas the lower right is a commercial product (LPS mini) and the upper right is our prototype.

package of six coin cell batteries for the tag. Surprisingly, the tag only lasted for 3-5 hours of monitoring.

About the performance, it was indeed very accurate when the user was moving inside the room with three readers. The accuracy was less than 0.1 meter. The detection ranges of those three readers were also large as they can cover a big part of the whole floor of our lab (about 200-230 square meters). However, when moving to further rooms like the kitchen area, the error of accuracy was quickly increased. The accuracy could reach to 4-5 meters due to several thick walls were between readers and the delay when updating locations also occurred. Besides, The "walk through walls" and "continuous jumping" happened. In this case, more readers and different configurations are needed.

Discussion

The UWB approach using Decawave products was presented in this section. Overall, it could provide a good accuracy (+/- 0.1 m) for a large open area. The price is in the middle range (about US$ 250 for each anchor). No training phase needed is an advantage of this solution. In addition, the absolute location positioning also helps for a better movement tracking. For example, in a case of people wandering around a small area, this kind of approach can detect (needed to be careful with the error of accuracy) the problem whereas the relative positioning (reference points) with iBeacon might consider the user is staying at one location the whole time. Besides that, no training phase and defining a list of reference points means that in case we want to label and classify the location, more efforts would be needed. The energy consumption is also another issue of this approach, which stopped us investigating more. However, the energy technology might be improved in the future, and this technology could be a good option to consider.

6.4 Symbolic Location with Onyx Beacon

On the contrary of UWB approach, we would investigate Onyx Beacon using symbolic locations which can be useful later for activity recognizing part. The accuracy of iBeacon was expected lower and less consistency but the deployment cost should be cheaper and the battery-life can last longer. In this section, we present the physical indoor environment factors which can affect the iBeacon signal, describe more details about iBeacon technology, potential positioning algorithms, as well as elaborate the results of studies evaluating the monitoring system with Onyx Beacon One.

6.4.1 Indoor Environment

There are many factors affecting Bluetooth range, typically:

- The output power of the transmitter
- The sensitivity of the receiver
- Physical obstacles in the transmission path
- The antennas

For a given Bluetooth device, the radio performance and antennas are pretty static. However, the surroundings can vary a lot. The range could reach a hundred meters in outdoor environments (open area). In indoor environments, obstacles like concrete walls will affect the radio signal and the effective range will be significantly reduced. In practical, ten meters is a good guide to what can be achieved between two Bluetooth devices indoors.

The human being's movement inside the building creates random effects of radio propagation inside the building (Youssef et al., 2003). The other uncontrollable factors, which are the temperature, air movement, and interference from other devices operating at the same frequency, also cause the received signal at any particular location to fluctuate over time (Saha et al., 2003).

6.4.2 Bluetooth Low Energy (BLE) - iBeacon

Bluetooth Low Energy (BLE) is a wireless personal area network technology designed by the Bluetooth Special Interest Group (SIG) that enables short range wireless communication between devices. BLE was originally introduced under the name Wibree by Nokia in 2006 then was merged into the main Bluetooth standard in 2010 with the adoption of the Bluetooth Core Specification Version 4.0 (Wikipedia, 2017b). BLE can provide a similar communication range compared to classic Bluetooth but consume considerably less power and cost.

iBeacon is a protocol developed by Apple. It was introduced at the Apple Worldwide Developers Conference in 2013 (Wikipedia, 2017c). Various vendors have since made iBeacon-compatible hardware transmitters (i.e. beacons), a class of BLE devices that broadcast their identifier to nearby portable electronic devices. One application of iBeacon is implementing an indoor positioning system.

BLE devices can operate in an advertisement mode which notify nearby devices of their presence. An advertisement packet of BLE consists on (Fig 6.11): preamble (1 byte), access address (4 bytes), Protocol Data Unit - PDU (2-39 bytes), Cyclic Redundancy Check - CRC (3 bytes). The PDU part includes header (size of the payload and its type - 2 bytes), MAC Address (follows by Header - 6 bytes), and data (advertising data - up to 31 bytes). An example of iBeacon advertisement packet would be:

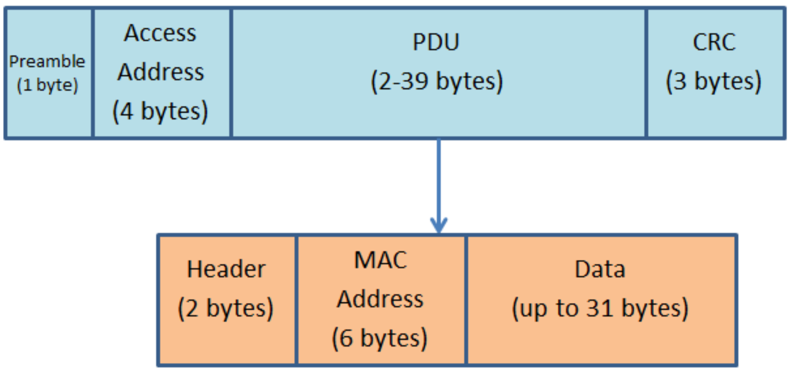

Fig. 6.11 Advertisement packet of BLE

$$6520122FFC2A000152F2553B04F3F73466FFEA25596D35EF7D22430123C5$$

The example splits into:

- *iBeacon prefix:* is fixed by the protocol (9 bytes) ($6520122FFC2A000152$)

- *UUID identifier:* is an identifier to distinguish the beacons between companies (16 bytes). In this example, it is $F2553B04F3F73466FFEA25596D35EF7DF2553B04F3F73466FFEA25596D35EF7D$.
- *Major and Minor:* these 4 bytes are also identifier to distinguish the beacons from each other. The major is 2243, and the minor is 0123 in the above example. In the end, a string combined UUID, Major, and Minor presents a unique identifier for one specific iBeacon.
- *Measure Power:* is the last byte of data advertised. It is 2's complement power signal level measured one meter away from a beacon. This value is prefixed. It is 256 - 0xC5 = 256 - 197 = -59 dBm in this case.
- *RSSI:* is the radio signal strength indicator. It is implicit in BLE advertising packet but not inside PDU data.

6.4.3 Study 8: Detecting iBeacon Signal

After reviewing the background of BLE - iBeacon, the next step was implementing and testing it. This study describes which iBeacon selected and how the first application detecting iBeacon was implemented and tested. The goal was to be able to read the data from iBeacon's signal and to evaluate whether the iBeacon technology is suitable for our monitoring system. The evaluation was using the application to check the signal consistency of iBeacon in different situations (e.g. different orientations between a reader and an ibeacon). Then, a simple test classifying symbolic locations with only two options (sofa and working desk) was conducted in a small room (an office room - about $45m^2$).

Methodology

About the hardware, Onyx Beacon with a reasonable price was used. They provided two types of iBeacon: the Enterprise Beacon with bigger size (diameter 134 mm and thickness 25 mm) containing AA Battery size that can last up to 4 years and the Beacon One with small size (diameter 53 mm and thickness 12 mm) having coin cell battery that can last up to a year. As we wanted to minimize the devices for increasing user acceptance, the Beacon One was selected. Besides that, the actual size of the sensors was smaller (diameter only 23 mm - Fig. 6.12). With this small size, the iBeacon can be easily attached to accessories of people with dementia like necklaces, Fig. 6.13 is our current prototype, and the next prototype similar to it (Fig. 6.14) is oncoming.

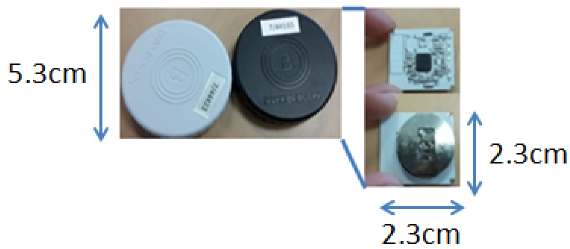

Fig. 6.12 Onyx Beacon One

Fig. 6.13 Current prototype of necklace containing Onyx Beacon One inside

Fig. 6.14 Oncoming prototype of necklace containing Onyx Beacon One inside

Besides the iBeacon (Onyx Beacon) wore by people with dementia, which is considered as a mobile node (MN - mentioned earlier in section 6.1), readers are needed to detect and localize the MN. In fact, readers for iBeacon are various and quite cheap that makes iBeacon solutions cost effective when comparing to RFID or WiFi approaches. The readers could be an Arduino board (about US$ 30), a Raspberry Pi (about US$ 50), or a smartphone. We chose Android Smartphones as the readers. In the beginning, a Samsung Galaxy S5 and two Sony Xperia Z1 compact were used for developing and testing. Later, smartphones Cubot Rainbow with the price 70 euro for each piece were used for evaluating the monitoring system in an area of our lab environment (one floor with about 250 square meters containing four rooms and corridors). In the next stages, these smartphones could be extended with more functions such as a speaker outputting sound instructions, warnings for people with dementia. However, warning sounds or instructions should be recorded by the voice of familiar people (e.g. caregivers or relatives) and be evaluated carefully as strange sounds without anyone to be seen might confuse people with dementia. The smartphone could also be a user interface of the systems for caregivers when they are finding residents or willing to see analyses and recommendations from the systems everywhere around the facility.

In contrast to Classic Bluetooth, Bluetooth Low Energy (BLE) is designed to provide significantly lower power consumption. BLE, however, is still Bluetooth and thus the Bluetooth permission $BLUETOOTH$ and $BLUETOOTH\_ADMIN$ must be declared. Noted that for the Android 5.0 (API level 21) or higher (our case for CUBOT Rainbow smartphones later), the android.hardware.location.network or android.hardware.location.gps also needed to be declared and the permission $ACCESS\_FINE\_LOCATION$ is requested.

Before the application communicates over iBeacon, it was needed to know whether BLE was supported on the device, and if so, ensure that it was enabled. If BLE was supported, but disabled, then the application requested that the user enabled Bluetooth without leaving the application (Fig. 6.16a). The next was finding BLE devices i.e. Onyx beacon in this case. The method *startLeScan()* with a parameter *BluetoothAdapter.LeScanCallback* was used. As continuing to scan drains the battery, the application set some rules. The first was to stop scanning as soon as the application found the desired device. The second rule was never scanning on a loop, and set a time limit on a scan.

An Android application (Fig. 6.15) using Android 4.3 (API level 18) was implemented to detect, read, and check the consistency of the signal of Onyx Beacon. It was recording the Onyx Beacon's RSSI at a constant distance of one meter over the course of three minutes in different readers' brand and position. The signal strength (RSSI value) was checked in four cases. The first was the reader Samsung Galaxy S5 had phone's screen lying on a table (lying face). In the second situation, the reader Samsung Galaxy S5 had phone's back lying on a table (lying back). Another reader (Sony Xperia Z1 Compact) was used in the third situation. The Sony Xperia reader was lying back. In three above situations, the Onyx Beacon was also lying on the table. There was no obstacle between the reader and iBeacon. The fourth situation was having iBeacon in the user's pocket.

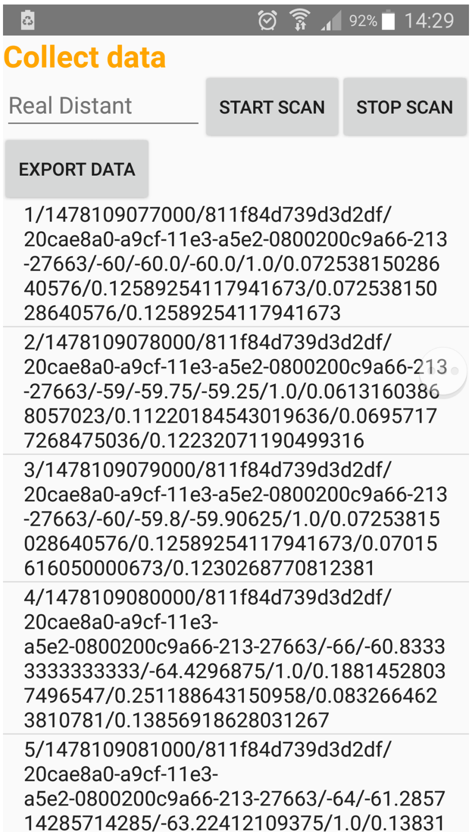

Fig. 6.15 First application testing iBeacon signal and its consistency. The message contains information when the reader detected successfully an iBeacon including timestamp, iBeacon ID (UUID, Major, Minor), reader ID (MAC address), RSSI value.

After checking the iBeacon's consistency, a simple test was conducted localizing the user wearing iBeacon in the office room. Fig. 6.17 was the set-up. The symbolic location approach was chosen with two reference points (i.e. working desk and sofa represented by red circles) and three readers (smartphones). Fingerprinting technique was used with KNN (K-Nearest Neighbors) algorithm. The details of fingerprinting and KNN are discussed in the next section (section 6.4.4). Forty-seven (47) training points on the desk and 57 training points on the sofa were collected in the offline phase (training phase). In the online phase

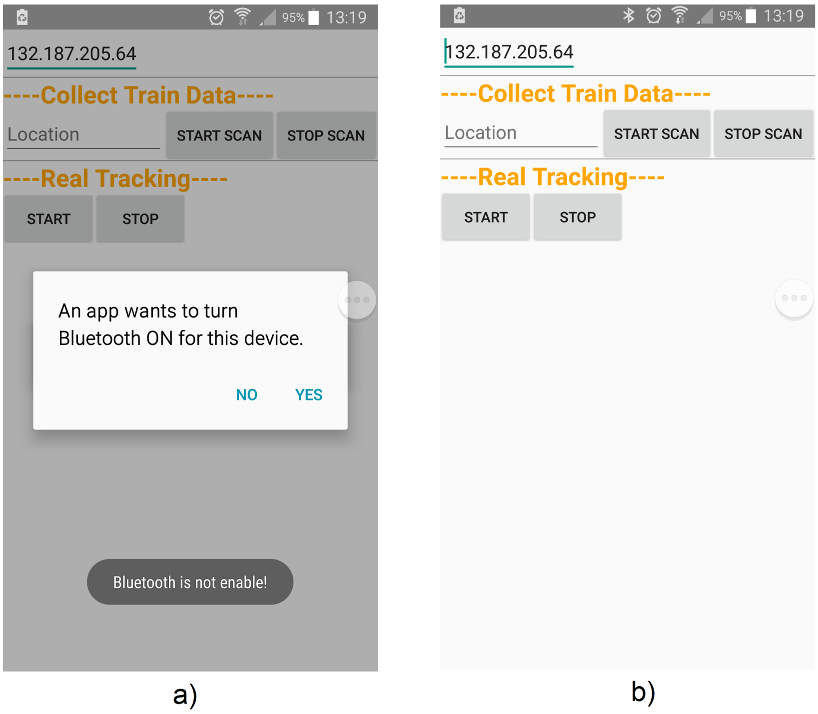

Fig. 6.16 Second application testing monitoring system

(testing phase), 55 test points on the desk and 76 test points on the sofa were classified. It was expected that in this simple and small setting with only two reference points and three readers, the precision would be at least more than 70%.

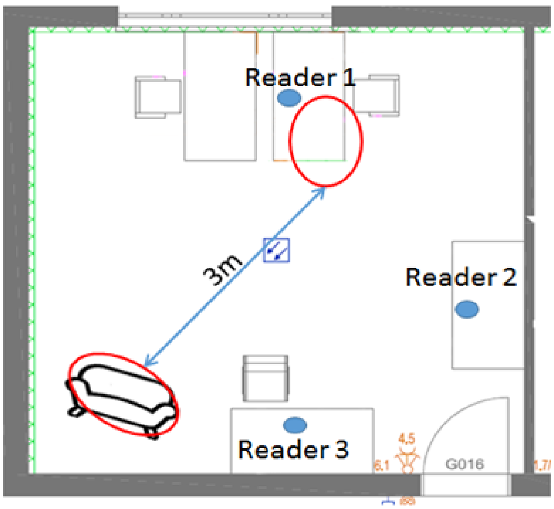

Fig. 6.17 A test classifying location (working desk or sofa) of an user with iBeacon in the office.

Findings

iBeacon theoretically broadcast radially (Fig. 6.18). Onyx Beacon is advertised that detection range (coverage area) reaches up to 70 meters. However, in the real world, with an indoor building like our lab (Fig 6.25), the detection range was up to only about 15 meters. In addition, due to path loss, the coverage area of ibeacon was not a circle anymore, for instance fig 6.19.

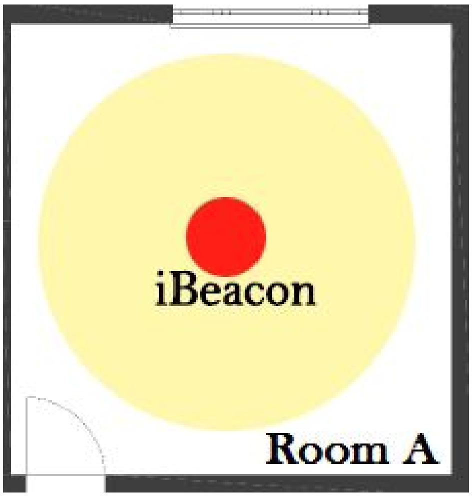

Fig. 6.18 iBeacon coverage in theory

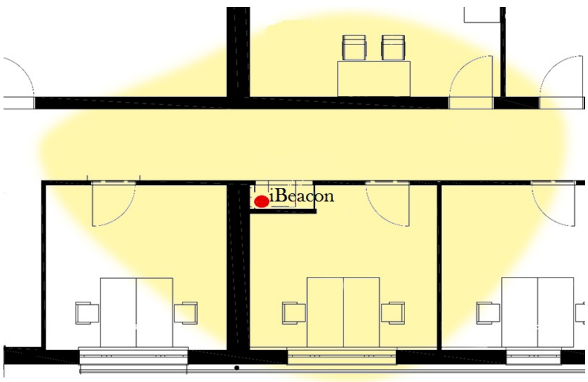

Fig. 6.19 An example of iBeacon coverage in practice (not as a circle)

About the accuracy of Onyx Beacon, the Fig 6.20 shows plotted the value of RSSI in four situations: Samsung lying face, Samsung lying back, Xperia lying back, and iBeacon in the pocket. Ideally, if the distance between reader and iBeacon does not change, the RSSI value would keep stable. However, values fluctuated in the Fig 6.20. For instance, the RSSI values in case "Samsung Lying Face" were changing consecutively between -58 and -68. The brand of readers, brand of iBeacon, and orientation from iBeacon to readers also affect the RSSI value. The same reader as Samsung in two cases that the phone's screen or phone's back lying on the table showed different signals and patterns. With the same orientation that both phones' back lying on the table but different phones' brands (Samsung Galaxy S5 and Sony Xperia Z1), the values of RSSI also changed. In the case of having iBeacon in the user's pocket, the RSSI's strength was lower although the distance was still one meter. The same situation happened when there were many obstacles between the reader and iBeacon or iBeacon was covered by hand/other objects. The reason was that the iBeacon's signal got interfered easily (section 6.4.1).

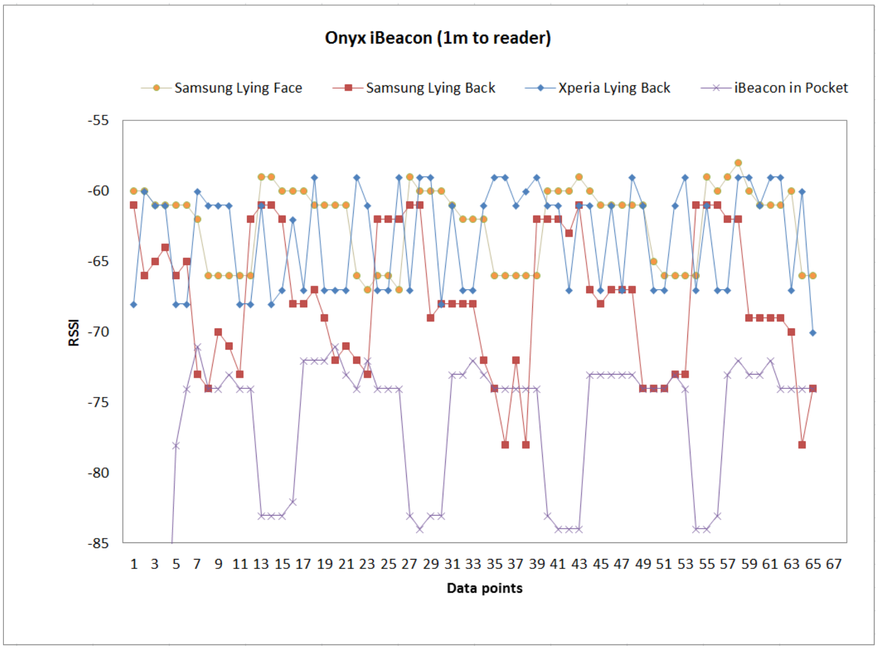

Fig. 6.20 iBeacon RSSI at distance 1m to a reader

Onyx Beacon was tested to have a detection range about 20 meters (m) without obstruction and about 15 m with walls, objects in between. Its accuracy was about 0.1-0.2 m with a short distance and no obstruction and about 3 m with long distance and obstructions. Fig. 6.21 shows the results of detecting Onyx Beacon at a distance 4 m to the reader. The accuracy could reach to 3 m.

The result of the testing in the office room with fingerprinting and KNN techniques (Fig. 6.17) was 45/55 (82%) correct points on the desk and 73/76 (96%) correct points on the sofa.

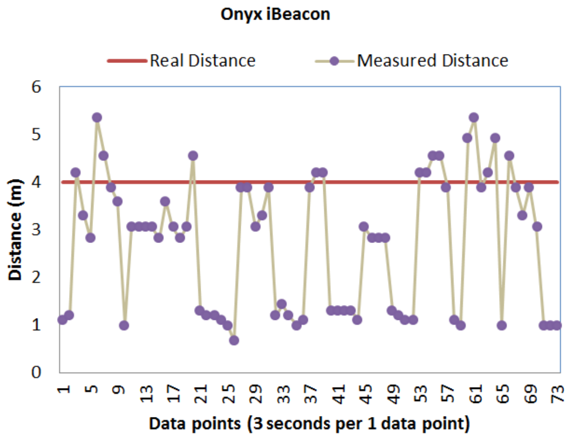

Fig. 6.21 RSSI signal converted into meters (m) of detecting Onyx Beacon at distance 4 m to a reader

Discussion

This chapters presented the overview and characteristics of iBeacon technology as well as how we implemented the first application in order to detect and read the signal of iBeacon from readers. We conducted a study comparing the signals in different positions and readers to test the consistency of iBeacon. Overall, this approach showed advantages, which have low-cost, long-life battery, and small size that can be embedded in user's accessories or blended into the environment. Through the study testing with different reader brands and orientation between a reader and an iBeacon, the iBeacon in general and Onyx Beacon One in specifically seemed a bit inconsistency and did not have a very good accuracy (about 3 m). However, for our monitoring system which highlighted the user acceptance and robustness, the iBeacon was still evaluated as a good choice, especially in situations where we only need to know if people with dementia are passing by or enter a small zone/area (e.g. entrance door, exit door). The accuracy could be enhanced by filtering technique (study 9) or different algorithms. On the other hand, we could turn the localization problem into classification problem using symbolic locations. This way, the precision of predicting the right area is more important than the accuracy (how meters the error is). That is also a reason the UWB solution was chosen for physical position approach (more focus on accuracy), and the iBeacon solution was selected for symbolic location approach (more focus on precision). The above test (Fig. 6.17) showed the potential of iBeacon in the symbolic location approach. Nevertheless, it would be more difficult in the situation with a larger area, more reference points, and the density of readers vs. reference points is reduced. This example had three readers for two reference points in a small room, which is quite expensive in practice for implementing in a large area. Besides that, this solution cannot detect every point on the map but only care about labeled reference points (working desk and sofa in the above example). It means that the positions of different sides of the table show the same location (working desk). Obviously, smaller reference points can be created to distinguish different sides of the table such as left-side table location or right-side table location, but it would increase the failure of recognizing/classifying location (reduce the precision).

6.4.4 Positioning Algorithm

The goal of positioning algorithms is to determine a position or location from samples of RSSI signals. The two simplest positioning algorithms are strongest base station selection method and random selection method. The strongest base station selection chooses the current user's location under the assumption that the closest reader or station node (from now called SN) provides the strongest signal strength. The random selection provides the user's location at random from a set of known positions (Bahl and Padmanabhan, 2000). These two algorithms may not provide satisfactory results. Thus, more complex algorithms are investigated to provide better accuracy and precision of the location information (Kaemarungsi, 2005). This section presents three algorithms: K-Nearest Neighbor, neural network, and probabilistic methods.

K-Nearest Neighbor (K-NN)

The K-NN is a type of location fingerprints. Before explaining the K-NN, the location fingerprints is described first.

The outdoor counterpart systems can use the angle of arrival (AOA) and time difference of arrival (TDOA) techniques effectively. The indoor positioning systems, however, often face the problem of non-line-of-sight and the dense multipath effect that make AOA and TDOA ineffective or highly complex for practical implementation. Moreover, the triangulation by AOA and TDOA requires the MN in the covered area of at least three readers or access points (we call station node – SN from here), which is also a difficulty.

In general, the deployment process of fingerprinting is divided into two phases: offline (calibration phase) and online phase. In the calibration phase, the location fingerprints are collected by the received signal strength indicator (RSSI) from multiple readers/access points. In the online phase, a MN will report a sample measured vector of RSSIs from different SNs to a central server or a group of SNs will collect the RSSI measurements from a MN and send it to the server. The server then uses a positioning algorithm to estimate the location of the MN. The most common algorithm is using the Euclidean distance between the sample measured RSSI vector and each fingerprint in the database. The coordinate with the fingerprint that has the smallest Euclidean distance is considered as the estimate of the position.

A location fingerprint represents a unique location with the assumption that each location inside a building has a unique radio frequency (RF) signature (Pahlavan et al., 2002). A fingerprint F is normally labeled with a location information L and are presented as a tuple of (F, L). Those dataset collected during the offline phase is called a "training set" and will be used in the online phase to estimate the location.

In general, the indoor location L has two forms. The first form (to solve decision or classification problem) is a single value from a two-valued set, usually $\{1, -1\}$, which means inside or outside a given area. The second form is a d-uple of coordinates (to solve regression problem), where d is the dimension of physical space (from 1 e.g. position along a corridor to 5 e.g. position in three-dimensional space and orientation expressed in spherical coordinates) (Brunato and Battiti, 2005).

The location fingerprint is usually denoted as an array or vector of signal strength received at any position in the covered area. The size of the vector depends on the number of readers or station node (SNs) that can detect the signal of the estimate location. For an area that can receive signals from n SNs, the location fingerprint can be presented as a vector: $F = (r_1, r_2, ..., r_n)^T$ where r_i is an average RSSI element of the SN_i over a window of time T. Another approach to location fingerprints is to calculate the probability distribution for RSSI signature at a given location (Bayesian algorithm) (Roos et al., 2002). The "likelihood function" $P(F \mid L)$ is used providing the probability of the occurrence of the RSSI vector given the known location information, where F is the observation vector of RSSI and L is the location information (Roos et al., 2002). In addition, the location fingerprint could be considered as a part of pre-processing. Pre-processing is a step that cleans raw data e.g. training data before any further operation. This process includes encoding, reducing unnecessary elements, or filtering. In the section 6.4.5, we would present how we implemented the pre-processing for faster location estimation and reduced noise.

The K-Nearest Neighbor (K-NN) is a non-parametric method used for classification and regression. A form of the discriminant function is normally used to classify a sample of RSSI fingerprint into a position. Basically, the K-NN selects the class which is most common among its k nearest neighbor (calculated by the distance between *mean* or *average* RSSI vector). The parameter k is a positive integer and typically small. If $k = 1$, it is called Nearest Neighbor and the location is simply assigned to the closest neighbor. A set of n location fingerprints is denoted by $\{F_1, F_2, ..., F_n\}$ and each fingerprint has a mapping to a set of positions $\{L_1, L_2, ..., L_n\}$. With m SNs, each location fingerprint i in a time window T can be denoted as $F_i = (r_1^i, r_2^i, ..., r_m^i)^T$. Similarity, a sample of RSSI fingerprint in online phase is expressed as $S = (s_1, s_2, ..., s_m)^T$. The distance between a measured RSSI vector $S = (s_1, s_2, ..., s_m)$ and a database location fingerprint entry $F_i = (r_1^i, r_2^i, ..., r_m^i)$ is calculated as:

$$D(S, F_i) = \sqrt{(s_1 - r1)^2 + (s_2 - r2)^2 + ... + (s_m - rm)^2}, \tag{6.2}$$

Note that this formula is for Euclidean distance. The Manhattan distance uses different parameters and weighting factors.

Neural Network

Instead of using discriminant functions such as minimum distance metric to handle RSSI fingerprint mathematically (K-NN), neural network uses a generalized structure i.e. *neuron*. The neuron (Fig 6.23) has n total number of inputs represented as $x_1, x_2, ..., x_n$ with corresponding weights for the inputs as $w_1, w_2, ..., w_n$. The activation value a is calculated as the summary of the weights multiply by the inputs: $a = \sum_{i=0}^{n} x_i w_i$. The output is 1 if the activation value is greater than a threshold t and otherwise it is 0. To obtain outputs more than binary $0, 1$, a non-linear function is used, e.g. symmetrical curve such as *sigmoid* (or *sigmoidal*) function (Fig 6.22): $output = \frac{1}{1+e^{-a/p}}$ where e is mathematical constant (2.7183), a is the activation value, and p is a number controlling the shape of the curve (p is usually set to 1.0).

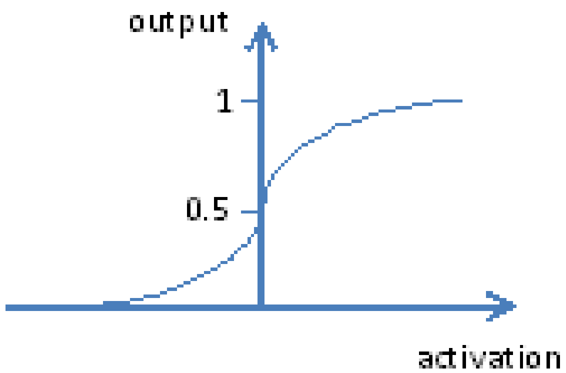

Fig. 6.22 Sigmoid function

The curve is always centered around 0.5. Negative activation value provides a result less than 0.5, whereas the positive activation value outputs a value greater than 0.5. One way of linking several neurons up is the feed-forward network. It consists of an input layer, output layer, and one or more hidden layers. Inputs are sent to neurons in the hidden layer, and then outputs of hidden layer's neurons become the input of the next layer.

After the neural network has been created, it needs to be trained. A simple approach is to initialize the neural network with random weights then feed it a series of inputs which represent (supervised learning). Different ways can be considered to adjust the weights. One of the popular algorithms is back-propagation.

The advantage of a neural network is that it requires no prior knowledge of any environment parameters such as the location of SNs and building characteristic (path loss exponent). However, the accuracy and the precision are a bit less than K-NN in some cases e.g. (Duda et al., 1973). However, the neural networks have a slow training time with a need of a large training set to get accurate location estimation. Other drawbacks are over-training and over-fitting when the training iterations are big and lead to a poor location estimation performance. Also, the error performance of neural networks cannot be calculated analytically due to their complexity.

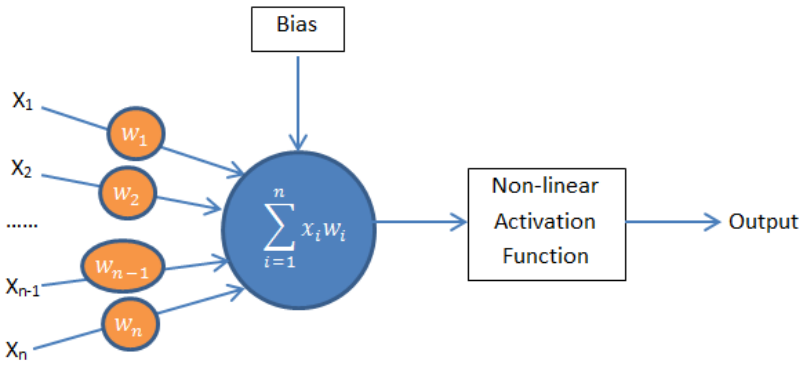

Fig. 6.23 Neural network diagram

Probabilistic methods

The machine learning approach (e.g. neural network or support vector machines) are quite complex and need a careful selection of parameters. Although they are non-parametric classifiers like k-nearest neighbor (k-NN), they are considered as black boxes and cannot provide insight on how to improve the systems. They also do not assume any knowledge of the location fingerprints distribution. The probabilistic methods are different. They use additional information (explicit knowledge) of location distribution to provide better performance on location estimation. However, the drawback of probabilistic methods is the requirement of a large training set to estimate the conditional probability distribution precisely. This project thus limits to the k-NN approach.

6.4.5 Study 9: Implementing and Evaluating Monitoring System with K-Nearest Neighbor (k-NN) algorithm

After learning about iBeacon and positioning algorithm, we combined both of them to implement the monitoring system. In this section, we elaborate how we set up the test case in our lab, implement the iBeacon with k-NN positioning algorithm (section 6.4.4), and evaluate the monitoring system. The first results of the system's performance (precision and accuracy) is also presented. The term precision and accuracy are distinguished as follows. Accuracy refers to the closeness of a measured value to a known value. In a positioning system, accuracy is normally calculated by the distance in meters between estimated location to the correct location. The smaller accuracy value is, the better accuracy system has. Precision, on the other hand, is usually calculated by the percentage of correct estimation at certain accuracy. Accuracy and precision are independent to each other. A system can be very precise but inaccurate or vice versa, be accurate but imprecise. Our system used symbolic location approach, and hence, the precision was more focused on.

Methodology

Another application on readers (smartphones CUBOT Rainbow) was developed for the monitoring system (Fig. 6.16b). The application first needed the IP address of the server to connect. It could automatically find and connect to the server, and the user does not need to enter the address manually. Two main parts were collecting train data for the offline phase and tracking real-time. There were two buttons to start and stop scanning/tracking. Depending on the mode, the data will be sent to the database as the training data or real-time data respectively by using *HTTP protocol*.

We implemented the "k-Nearest Neighbor" (k-NN) as the positioning algorithm (section 6.4.4). It is one of the algorithms that are simple but work well in practice. K-NN a non-parametric lazy learning algorithm. It does not take any assumptions on the underlying data distribution. This is an advantage as in the real world, practical data rarely follow typical theoretical assumptions made e.g. gaussian mixtures. It is called lazy algorithm because there is no "generalization" using training data. K-NN keeps all the training data, which minimizes the training phase but cause a costly testing phase. The cost consists of execution time and memory to store all training data. However, the cost for memory is quite cheap, and a "cache solution" (presented later) could improve the execution time significantly.

Fig 6.25 shows the set-up of the monitoring system. In this experiment, there was six readers ($R_1, ..., R_6$) with six reference points ($P_1, ..., P_6$). P7 and P8 were added later. According to section 6.4.4 about K-NN, the set of positions is $\{P_1, P_2, ..., P_6\}$. We also had six SNs (i.e. readers).

Let's say one position had plenty location fingerprints in training phase. The number of fingerprints could be different for each position, e.g. position P_1 had 30 fingerprints whereas P_2 had 40 fingerprints. The more fingerprints in training phase, the more chance the right position is determined but also higher execution cost. Each location fingerprint i in a time window T is denoted as $F_i = (r_1^i, r_2^i, ..., r_6^i)^T$ (r_j^i is the RSSI value from R_j to that position).

The server did not get directly the fingerprint F_i from the beginning. A pre-processing is needed for handling the raw data from readers. The fig. 6.24 briefly shows the data flow from reader till the location is determined. When a reader detected the iBeacon, a data package with information *(iBeacon_ID, reader_ID, rssi, timestamp, location)* would be sent to the server through HTTP protocol. The location information was inputted for training purpose. Those RSSI values in data packages were filtered and grouped by *iBeacon_ID* over a time window T which was mentioned above, then were transformed to a fingerprint. The tricky part here was the timestamp and choosing time window T. First, the application in reader's side was developed that it would detect the iBeacon for every 3 seconds (s) and send the results to the server via the internet. Second, the communication between iBeacon and a reader was two-way communication. When a reader is communicating with one iBeacon, another reader has to wait. Therefore, even though the detecting time from a reader to iBeacon was very short (few *ms*), the detecting timestamp and sending timestamp among readers to the server were not identical. The speed of data sending to the server via internet also affected timestamp. If the time window T is too short, there is a possibility that one or many readers couldn't send the data to the server on time. It means that fingerprint misses some values, which can lead to false training data and false location determining. On the other hand, if the time window T is too long, the monitoring will not be real-time enough. In addition, another problem with long time window T is that the user could have moved to another location during that time T. The fingerprint then includes values of more than one location, which should not happen. The figures 6.27, 6.28, and 6.29 show the different results with different time window T. During the time window T, one reader can send 3 data points of RSSI value to the server, while another reader only sends one data point. Thus, the fingerprint i should be re-denoted as $F_i = (\overline{r_1^i}, \overline{r_2^i}, ..., \overline{r_6^i})^T$ where $\overline{r_j^i}$ is the average of RSSI values that the reader R_j has sent to the server in the window time T. In this training phase, each fingerprint was labeled to a position (F_i, Pj).

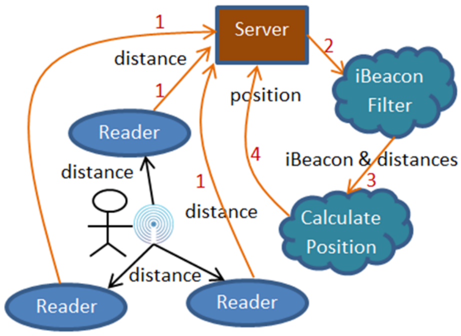

Fig. 6.24 Data flow from readers to the server

In the online phase, the server received same data from readers except for the location information, which we were going to determine. The data package format was *(iBeacon_ID, reader_ID, rssi, timestamp)*. The same process with average values in time window$T$ like in offline/training phase was applied turning raw data from readers to a sample of the RSSI fingerprint. That fingerprint was expressed as $S = (\overline{s_1}, \overline{s_2}, ..., \overline{s_6})^T$. After getting the online sample of the RSSI fingerprint, the next step was calculating the distance from the sample S to each training RSSI fingerprint F_i in the database with m training fingerprints. The Euclidean distance was used: $D = \frac{1}{m}(\sum_{i=1}^{m} |s_i - r_i|^2)^{\frac{1}{2}}$. The procedure of k-NN algorithm was simply selecting the k training fingerprints, which have shortest distances to the sample S. Then, the label of the position that has a majority vote would be determined position. Choosing a number of k is another problem. Small k could improve the system over the single nearest (i.e. $k = 1$) neighbor approach. However, a large k might increase the location estimation error. The figures 6.27, 6.28, and 6.29 shows that in this set-up of this system $k = 3$ actually was better than $k = 5$.

Another thing in this online phase was about getting all of the training data points (RSSI fingerprints) and then calculating distances between the online sample and those points. The execution cost for this process could be high i.e. taking a long time. We developed a "cache solution" for this problem. As mentioned earlier, before computing the distance between the training data and real-time data, both training data and real-time data were needed to run through a pre-processing every time. As the training set was the same, the data after pre-processing could actually be calculated for the first time and then stored (cached) for the next time. This solution was simple but be able to reduce the computing cost significantly.

Fig. 6.25 Map plan with readers (R), symbolic locations / reference points (P)

Findings

Firstly, about the computing time, the Fig. 6.26 showed the significant change with the cache solution (645.370*ms* reduced to 20.802*ms*). After ten times repeated testing, the average of getting data was 638.550*ms* without cache solution and 18.728*ms* with cache solution.

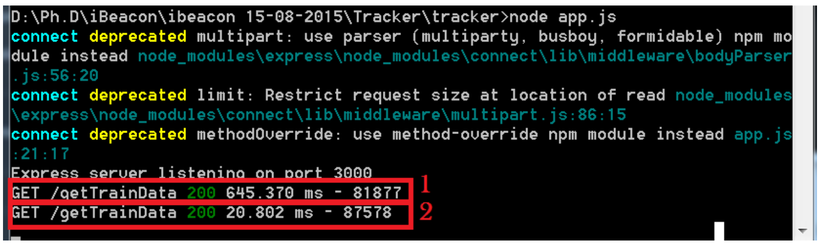

Fig. 6.26 Getting all of the training data without cache solution (1) and with cache solution (2)

The next is about the performance of the monitoring system. As this approach used reference points system, the system only considered if it detected the right location, not about the distance error in meters. Therefore, the performance was measured by the precision, not the accuracy. The figures 6.27, 6.28, and 6.29 are results from testing the monitoring system using k-NN algorithm. In this testing, the readers and reference points were set-up like fig. 6.25. In the training phase, each location (reference points) were trained for 2.5 minutes. In the online phase, each location was tested for 2.5 minutes. Then, the precision percentage of the system was calculated (guessing right location times/total times). The testing phase was repeated ten times. Fig. 6.27 was the average of those 10-times repeated testings. The location determining performance seemed pretty low. The configuration with highest performance was 83.82% with $k = 3$ and *time window T* or *group time (gt) = 9s*.

When filtering out RSSI value < -90 (fig. 6.28), the furthest, weakness, and unstable signals were left out. It reduced the covering area of readers a bit but increase significantly the performance of the system. With $gt = 2s, gt = 3s$, the performance was still a bit low (about 80%). However, with $gt = 6s$ and $k = 3$, the precision got up to 93.24%. It achieved event higher results with $gt = 9s, k = 3$ (94.91%) and $gt = 9s, k = 5$ (93.87%). The performance changes from $gt = 2s$ or $gt = 3s$ to $gt = 6s$ were significantly improved, whereas it was slightly improvement from $gt = 6s$ to $gt = 9s$.

If continue filtering out RSSI values from -85 to -90, the performances kept improving marginally (fig 6.29). The higher the percentage precision was, the smaller improvement it gained. Comparing two figures of filtering RSSI value < -90 and < -85, for instance the configuration $k = 3, gt = 2$ improved from 76.54% to 80.83% (4.29%). The improvement of configuration $k = 3, gt = 6$ on the other hand was only 0.79% (from 93.24% to 94.03%) and stay the same with configuration $k = 3, gt = 9s$.

Parameters k and group time gt also influenced the performance. Theoretically, increasing k means having more data to compare which could enhance the performance of the system. However, Bahl and Padmanabhan [13] reported that for small k there is a small improvement over the single nearest neighbor approach, while for large k the location estimation error performance is increased. Phongsak et al [16] reported that for $k > 8$ the performance became worse. We found the same result here as increasing k made the system worse. In our case, $k = 3$ had a better result than $k = 5$. It led to the problem that choosing these parameters depended on the physical environment and was more likely about an empirical choice than a theoretical part. About the group time gt, with the higher value, the performance also increased respectively. It was understandable as the system had more time and data points to determine the location. The group time equals to $6s$ and $9s$ showed the distinctly better than group time $2s$ and $3s$. On the other hand, the difference between $gt = 6s$ and $gt = 9s$ was small. However, the trade-off of high value gt was that the monitoring would be delay a bit comparing to the real-time and at that moment the location was moved to another one. In the end, the $k = 3$ and $gt = 6s$ seemed the best combination because they still guaranteed the good precision whereas maintained the real-time characteristic. During 6s, people with dementia having slow speed could not move far from the determined location (1-2m according to our observations).

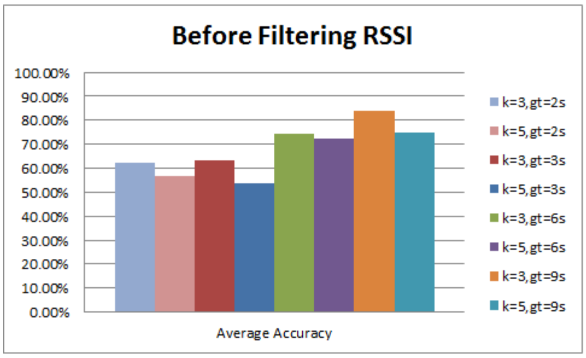

Fig. 6.27 Average precision of the monitoring system before filtering

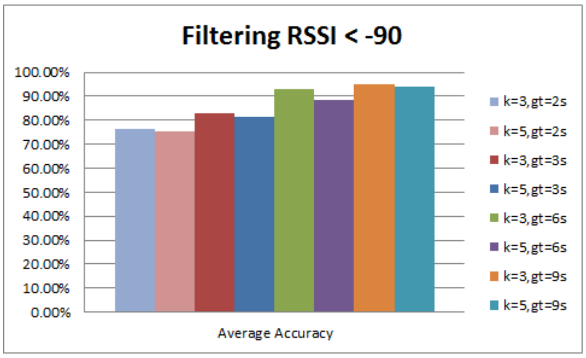

Fig. 6.28 Average precision of the monitoring system after filtering out RSSI values < -90

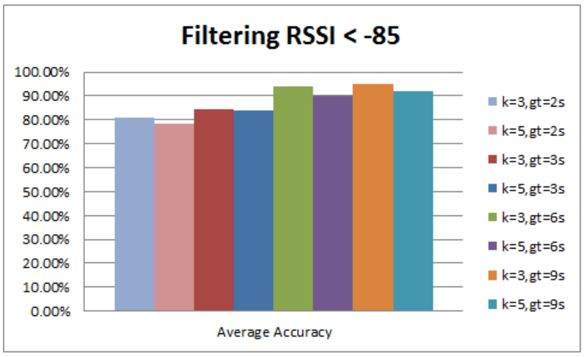

Fig. 6.29 Average precision of the monitoring system after filtering out RSSI values < -85

As mentioned in section 6.4.1, many factors could affect the signal of iBeacon such as interference to the environment or human being's movement. We changed some settings to test more about the system's performance. For example, adding more reference points e.g. sofa in between my working desk and a printer reduced the precision of the system a bit (Fig. 6.30b). The system also performed worse when 5-6 people (normally 1-2 people at one time) were walking quickly around the corridor a lot and opening/closing the doors more often (Fig. 6.30a). Besides that, wearing iBeacon on different body parts influences the system's performance as well. In previous tests, the user worn iBeacon as a necklace (on chest). Fig. 6.30e indicates that the precision was reduced when the user worn iBeacon on the wrist, used to swing the hand while moving and sometimes put the hand in the pocket. However, there were also few ways to enhance the system. Obviously, adding more training data was an option. Fig. 6.30d shows the results when training data of 1.5 minutes was added. The performance of the system indeed increased slightly. Besides, to counter the problem of human's body affected the signal, readers were mounted higher (from 1m to 2m height). The precision was improved (Fig. 6.30c).

Above results presented the investigation of stationary mobile (or quasi-static) devices. Now, mobility tracking/monitoring is considered. Fig. 6.31 shows the real route the user walked with the average speed $0.7m/s$ (brown line) and the route the system detected, projected to respectively symbolic locations (P1-P5), and displayed (yellow line) to the web interface. The accuracy was not excellent (the different between brown line and yellow line) but the high precision was remained (right location classification - locations were mapped correctly to the closest symbolic location). This approach had the advantages that were a simple implementation, no "walk through walls" or "continuous jumping" situations. However, the disadvantage was that it could not detect if the user was walking around a point (still close to that point and thus the system detect the user stays there without moving).

Discussion

In this section, the cost-efficient monitoring system implemented using iBeacon and k-NN algorithm was presented. We also described how to set-up readers in a real test case at our lab and elaborated the performance of the system. In general, the performance was acceptable for an indoor monitoring. In contrast to study 7 with physical position, this study (study 9) used symbolic location approach, which only mapped or projected the estimate location to the closest reference point. This way limits the weakness of iBeacon which is signal inconsistency by focusing on the precision of a classification problem instead of the accuracy of a regression problem. No "walk through walls" or "continuous jumping" is also another advantage of this solution. Still, similar to all other indoor monitoring systems, a lot of aspects could interfere the performance of the system such as changing in the environment

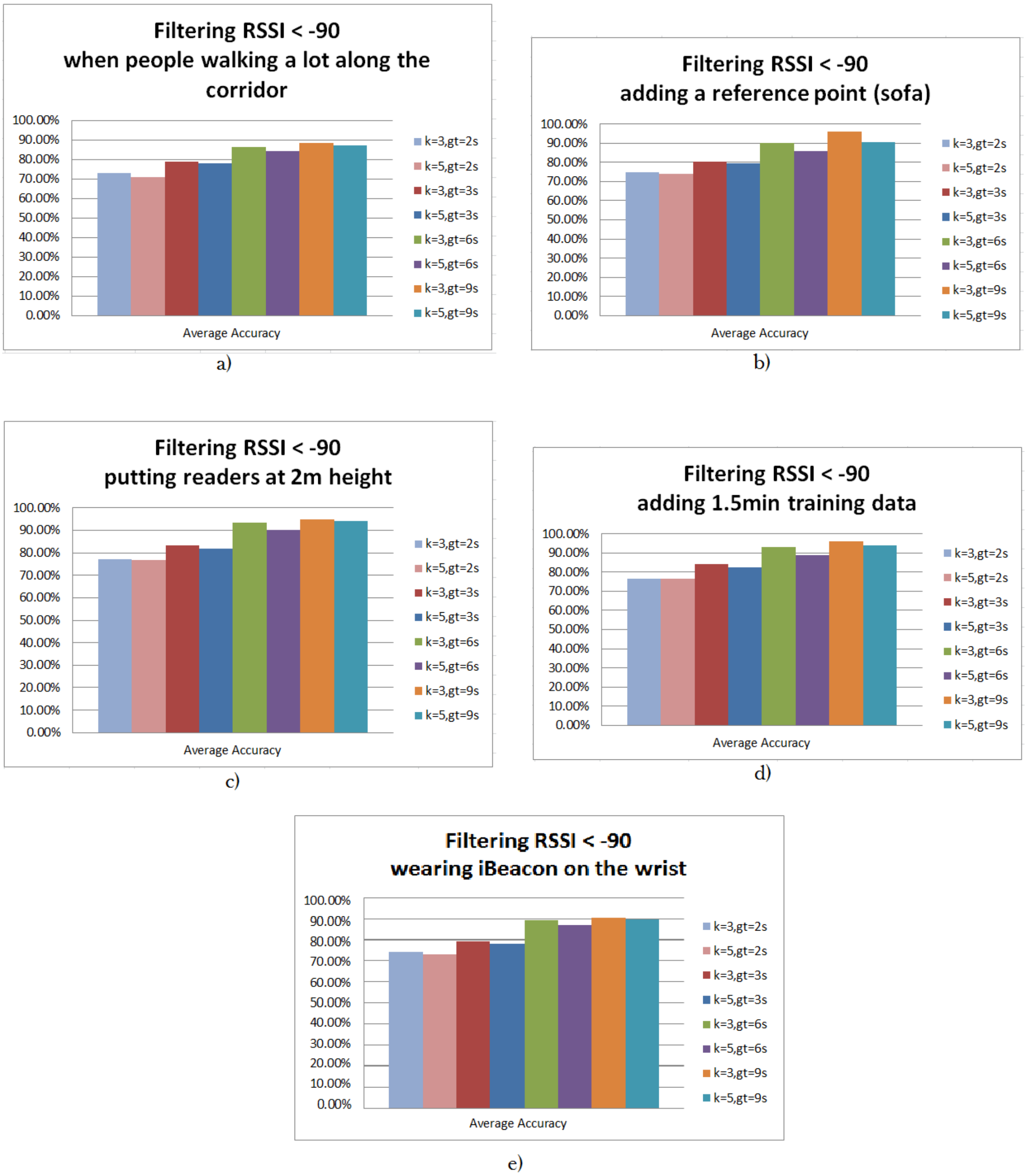

Fig. 6.30 Average precision when: a) people walk a lot, b) adding a reference point, c) putting readers high, d) adding training data

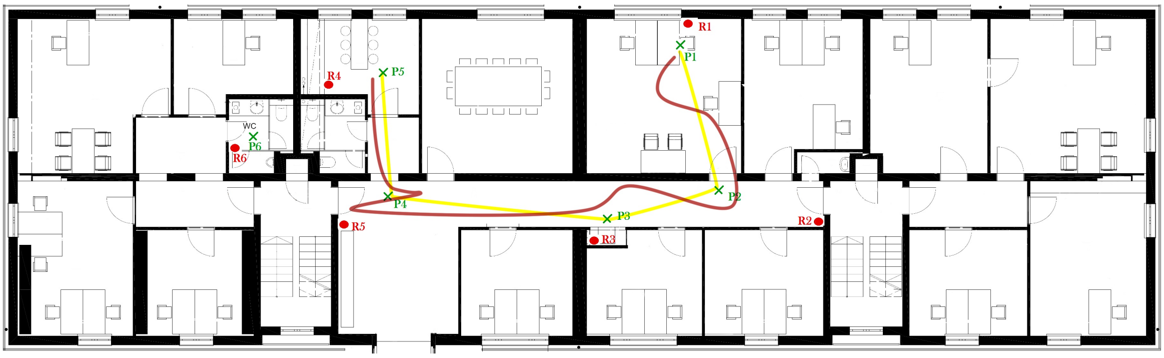

Fig. 6.31 Monitoring system with mobility tracking. Brown line was the route the user moved whereas the yellow line showed the route the system detected and displayed. Readers (R), symbolic locations / reference points (P).

and even traffic of human's movement. Besides that, the parameters such as k and group time gt were set empirically, which meant if going to another environment, they would be expected to change and adjust.

6.4.6 Study 10: Implementing and Evaluating Monitoring System with Proximity Based Localization Algorithm

Systems with UWB using two-way ranging and iBeacon using K-NN algorithm were developed to address a continuous monitoring problem (for finding and navigating people). Another use case is delivering location-based services to people with dementia as with the drawers. Above systems could trigger location-based services as well, but they are costly in computing, configuring, and calibrating the setup in the environment for this scenario. Thus, another simple algorithm i.e. proximity based localization algorithm was implemented.

Methodology

The same indoor environment, iBeacon, and readers as previous studies (lab environment) were used in this study to compare the monitoring system's effectiveness. With the proximity based localization algorithm, the object is simply considered in a zone if it is detected by a reader. Instead of building reference points like $P_1, \ldots, P_6$ in the Fig. 6.25, the circle areas with readers as the center are locations. If there were more than one reader detected the signal from the iBeacon, the reader having the strongest signal to the iBeacon in a time window T would be selected as the location.

In order to obtain a good precision and accuracy, reader's range must be adjusted carefully. The lesser the range is, the better the performance is but it is needed more readers to cover the whole area. Consequently, to enable localization throughout the environment, a dense deployment of readers is required. We used 6 readers R1-R6 in the Fig. 6.25 to represent for working office, corridor1, printer, corridor2, kitchen, and toilet.
We firstly tested with similar detecting range of readers as with k-NN algorithm (filtering out RSSI values < - 90). Then, the detecting range of reader was changed to 3 meters to compare the performance.

Findings

As this approach simply detects if the iBeacon is inside or outside the readers' area (select the reader having the strongest signal if the iBeacon are inside more than one reader's coverage), there was no training phase, pre-processing, distance calculation needed and the computation cost was thus significantly low.

About the performance, the precision reached to 95%. No accuracy was needed in this situation. One way to enhance the performance of the system with this algorithm is limiting the detection range of readers to 3-4 meters (Fig. 6.32). There are two ways to reduce the detection range: to calculate the distance by the formula $d = 10^{((TxPower - RSSI)/20)}$ (Dong and Dargie, 2012) and then filter the distance, or filter the RSSI directly. Limiting the detection range would make the location more distinctive. Besides that, the lesser the range is; the better of performance is due to strong signals. The precision was then up to 99%. One percent of the error happened when the user stayed at the edge of coverage ($< 0.3m$). It also minimizes the risk that affected when people/objects interfere signal of other readers by walking through, obstructing. This approach is perfect option when focusing on critical zones and triggering services when users are nearby. However, there would be some blind zones such as P2. Adding more readers can solve this problem but also raise the cost of the system.

Discussion

This study tested a simple approach proximity based localization algorithm instead of k-NN algorithm for the monitoring system using iBeacon. It was shown that reduced the cost in computation, configuration, and parameters selection. When decreasing the detecting range of readers, it can improve the performance with good accuracy whereas minimize

Fig. 6.32 Limiting the detection range of readers to 3-4 meters. Readers (R), symbolic location / reference point (P)

the interference from other aspects like human moving in between or door closing/opening. However, it led to the situation either not be able to cover the whole environment (leaving out some zones) or adding more readers, which increases the infrastructure cost. Moreover, the positions of readers, which are normally near the socket due to charging issue, are not always the locations we want to cover and detect. Also, the number of reference points is equal to the number of readers. For example, in the setting above, there were only six location points accordingly six readers. With the k-NN, more points like P7, P8 could be easily added without adding more readers. Overall, it depends on how the context is. In the case of location-based services, where the main objective is triggering services when the user is close enough, this algorithm is the good approach.

6.5 The Front-End of Monitoring System

Note that a part of the description below was published in (Ly et al., 2016b).

In a literature review of previous studies on technology and dementia (Topo, 2009), a total number of 66 studies were analyzed. Among these, 63% focused on improving the independence and well-being of people with dementia and 37% focused on supporting their caregivers. Caregivers represent an important user group. They interact with and caring for people with dementia every day. Due to dementia symptoms such as quick emotional changes, word-using problem, it is not easy caring for people with dementia, especially people with moderate-severe dementia. Many caregivers admitted that they are always busy and often feel overwhelmed. Caregivers cannot give people with dementia the best care as they might not know what people with dementia want and need. This seemingly simple situation is also hard to solve because people with moderate-severe dementia have difficulties in answering questions and/or describing their problems/situations. Many projects aim at supporting caregivers. For instance, they can use technology to activate residents with dementia e.g. (Lucero et al., 2000), for their own education e.g. (Calleson et al., 2006; Engstrom et al., 2005), or to improve access to diagnoses e.g. (Cullum et al., 2006; Mundt et al., 2005). Some projects e.g. (Bank et al., 2006) provide a virtual place where caregivers can gain access to information and connect to other members of the caregiving community. However, there is a specific lack of studies regarding navigation and orientation in indoor environments supporting people with moderate to severe dementia and supporting the stakeholders (i.e. caregivers, doctors, designers) who work with them. In existing projects, people with mild to moderate dementia often use smartphones or PDAs to access the system. People with moderate to severe dementia, however, seem reluctant or unable to manipulate complex mobile devices. (Ly et al., 2015) thus propose an intelligent and implicit assistance for navigation with a three-part framework: a monitoring system with a small size and lightweight tag, an implicit guiding system and an intelligent part that refers to context-aware computing (also mentioned in chapter 4). In the guiding system, implicit cues with light and color for people with dementia were suggested. Apart from the people with dementia themselves, other stakeholders were not involved. In this section, we present an extension of the system in (Ly et al., 2015) designed to support stakeholders in dementia care (i.e. caregivers, doctors, designers of assistive technology and dementia-friendly architecture) besides the people with dementia themselves. This platform provides a visualization tool including real-time monitoring of the whereabouts of patients, a history of movements, and a location heat map that could facilitate the stakeholders' work.

6.5.1 Methodology

Several studies including ethnographic observation and interviews were conducted in health care facilities for people with dementia, which were presented earlier in chapter 3 and 5. Besides conducting studies with people with dementia, we also observed and interviewed one caregiver in facility A and two caregivers in facility B about their difficulties in interacting with people with dementia and possible solutions. The observations of both, the people with dementia and the caregivers, were naturalistic observations (i.e. unstructured), which involved studying the spontaneous behavior of participants in navigation settings. Naturalistic observations allowed for greater ecological validity by observing the flow of behavior in situations and greatly helped in generating design ideas. We conducted two focus group sessions with two caregivers and one manager to discuss these design ideas and prototypes. Prototypes of the stakeholder support system evolved iteratively based on caregivers' feedback and interaction. In addition, we worked with an architect who is an expert in dementia-friendly architecture. The main questions for caregivers and the architect were about their methods and tools of work and their difficulties when working with/designing for people with dementia, particularly relating to localization and navigation problems.

6.5.2 Findings

Taking a big-picture approach, we considered the whole eco-system with people with dementia at the center and including other stakeholders e.g. caregivers, architects. We observed that people with dementia do not use technology devices or are otherwise challenged in using them, cf. (Rasquin et al., 2007). Thus, an implicit interaction was proposed for people with dementia (Ly et al., 2015). In contrast, other stakeholders (e.g. caregivers, designers) in some situations needed an explicit tool displaying and visualizing localization information. Thus, we developed a platform that handles location sensors' data, turn these into meaningful information for stakeholders, and visualizes these. This platform can facilitate the work of caregivers (and designers), save time, and help in reducing their workload. Many caregivers admitted that they are always busy and often feel overwhelmed. The interview revealed that sometimes they needed to find residents quickly, for example, when they needed to see a doctor, had an appointment for treatment, or when collecting people for lunch. In many cases, caregivers spent 20-30 minutes to find the residents. Thus, in emergency situations, too much time would be needed to find people with moderate to severe dementia. Therefore, real-time localization and monitoring emerged as necessary features of the system. Caregivers and doctors also want to see the movement history of residents (how long and how far they have walked for a certain amount of time) and some sort of 'heat map' showing how often people were in a specific location. That information along with data from biosensors and their medical history can help caregivers and doctors diagnose the physical condition of the patients. The caregivers suggested that such data should be visual and easy to use rather than being represented in tables with texts and numbers. Moreover, people with moderate to severe dementia tend to be withdrawn and sensitive, which makes it difficult for designers to work with them (another factor being their severe cognitive impairment). Thus, also technology designers and architects may benefit from a location history and heat map. These data support designers in finding potential guidance cues and understanding the behavior and patterns of movement of people with dementia. The architects otherwise can figure out which interior setting, floor plan topology, furniture, etc. make people with dementia feel comfortable: Do they visit certain areas more frequently? Do they stay longer after an architectural intervention? Can they easily find the location?

We used the JSON (JavaScript Object Notation) format to store the location data and to visualize and display the data to the users (i.e. caregivers, doctors, designers). Fig. 6.33 shows the real-time monitoring interface. One person or multiple people can be selected displaying the data. Not selecting anyone (default) or selecting all people in the list would display the data of everybody.

The movement history is replayed by JSON data (Fig. 6.34). It works similar to a video player. On the right side of "Slow Down" button, there is a bar represented for a time line of the day. The gray sections represent times that people were moving. The white sections indicate times without movements. To click on a specific place of the timeline, the system would jump to and display data of that specific time. Users can choose people, a period of history time (*from date*, *to date*), *play/stop*, adjust the moving speed of the replay with *speed up* and *slow down* (the slowest speed is 0/ stop).

Fig. 6.35 demonstrates the heat map displaying information of person Lea Hofer for one week (from 1st December 2015 to 8th December 2015). Names of the place, numbers of visits, and hours of staying are displayed. For example, this person visited the sofa 45 times but only stayed for 20h in total, whereas the person was in the bedroom 24 times with 85 hours. The darker a circle is, the more frequent the person visited that place. This heatmap only displays the data of one person at a time (not multiple people like real-time tracking or location history replay). Clicking on the "View Analysis" button, the suggestion about residents from the intelligent system would display (Fig. 7.14 in chapter 7).

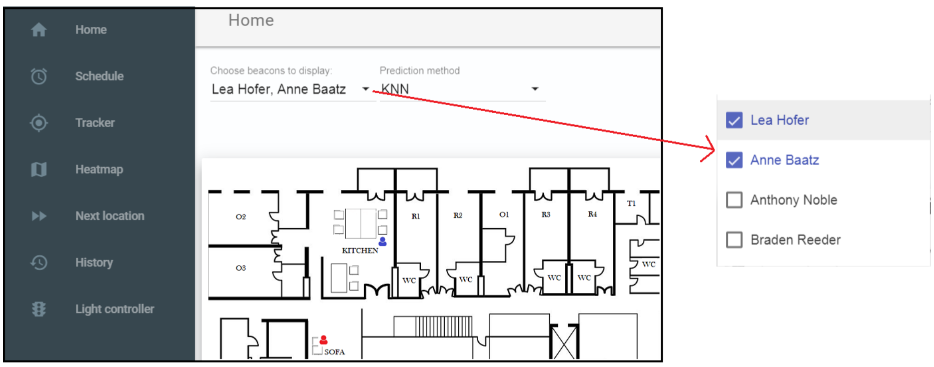

Fig. 6.33 Real-time tracking.

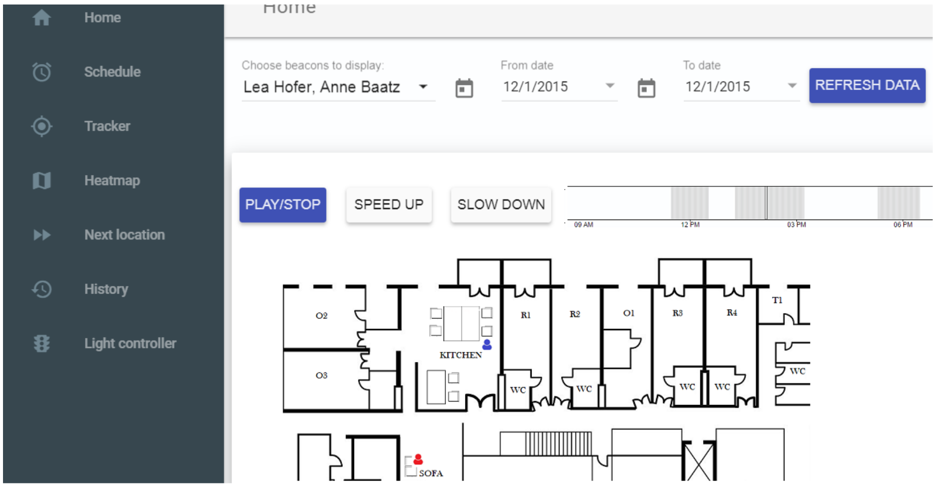

Fig. 6.34 Location history replay.

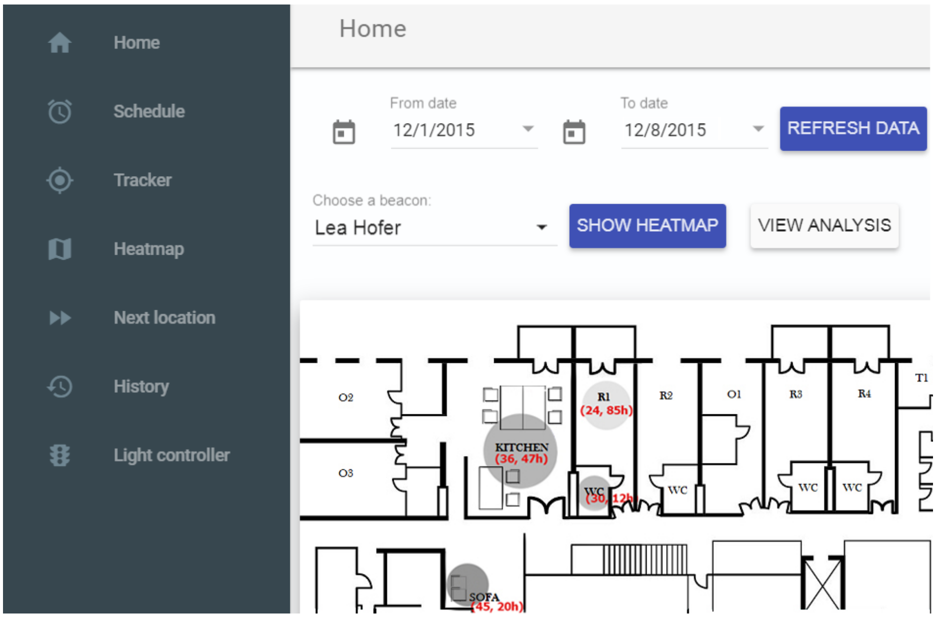

Fig. 6.35 Heatmap.

6.5.3 Discussion

Focusing on dementia care facilities, we extended a system (III Environment - chapter 4) for supporting the indoor navigation of people with dementia (Ly et al., 2015) to support other stakeholders (i.e. caregivers, but also doctors, architects, and designers). The main functions of this platform are real-time monitoring, a history of movements, and a heat map of frequent places. IoT and distributed technologies, as well as JSON, were chosen as the basis of our development, since it provides online services for users with any device anytime and anyplace within the network. Also, it supports the integration of different technologies, frameworks, and programming languages. The first implementation of our platform was presented. Overall, the first feedback from the stakeholders (caregivers and researchers who wanted to see the heatmap of how often and how long people were at their interactive drawers for an evaluation - studies 4,5 in chapter 5) indicated that we seem to be on a good way. However, the platform needs further work, and a formal usability test involving the relevant stakeholders. On the technical side, we expect to optimize the combination of iBeacon and UWB technologies for the monitoring system. On the stakeholder side, we believe that adding an intelligent component that analyses the residents' movement behaviors and highlights potentially critical situations to the caregivers could be helpful (presented in the next chapter - chapter 7). Designers and architects may profit from integrated cognitive architectures that can simulate the effects of environmental interventions on the behavior of the inhabitants. Finally, on the side of people with dementia, we would like to explore the impact of making the display available to the residents. Will they be interested to see the whereabouts of their peers? What social dynamics ensues from this? How can we be ethical about the data collection and displaying the location of people to others? Can we expect people with moderate and severe dementia to decide to opt out? These will be important challenges to consider.

6.6 General Discussion

Monitoring in an indoor environment is indeed a significant challenge. There were so many technologies but lacking a global/unified solution. Many aspects could affect the technologies such as physical environment (wall, obstacles, human's movement, or temperature, light level), price, and accuracy. It is even more challenging for developing a system for people with dementia with the highlight of sensors' appearance (for user acceptance) and energy efficiency (robustness). Different indoor monitoring/positioning technologies were reviewed and categorized. Based on the objectives and challenges, two technologies were selected:

iBeacon and ultra wideband (UWB).

Three versions of a monitoring system were developed and evaluated (Table 6.5), which could be used in different contexts and situations. All these three systems were absolute referencing, remote, and able to recognize identity (recognition). The first one was using Decawave TREK1000 products (UWB technology). This system implemented lateration techniques (ToF and two-way ranging), provided physical position (regression problem). The accuracy was good (about 0.1m), however, needed the scale at least one station node (SN) per room to maintain that accuracy. Otherwise, the accuracy would be worse depending on how dense the SNs is. This solution is a decent choice for a situation where the caregivers and managers want to observe the movement of people with dementia very closely. However, the problem of energy efficiency needs to be solved.

The second monitoring system used Onyx Beacon One products (iBeacon technology). The techniques and algorithms for this one were BLE, fingerprinting, and K-NN. It addressed the symbolic location (for classification problem), instead of physical position like UWB. It provided about 93% of precision. Although the precision is not so high, this approach is still a good option for continuous monitoring (for finding and navigating people) as it is cheap, high user-acceptance, good energy efficiency, low-cost in process and computation. In a case of error, the location would be displayed near the real location, which provides us a rough idea of the user's whereabouts though. This approach (study 9) was selected for our context and interfaces displaying to caregivers (presented in 6.5).

The third kind of monitoring system was similar to the second one using iBeacon technology but implemented proximity technique instead of fingerprinting. This solution does not require any training or complex configuration. It simply detects if the user is inside the coverage area of SNs. This approach is good for delivering location-based services such as triggering interactive drawers when users (people with dementia) are nearby the drawers.

In order to increase accuracy and precision of location monitoring, iBeacon technologies could combine with other sensors such as pressure sensors. For example, in a symbolic location e.g. a working office, the system can detect exactly the user is sitting on the *chair 1*, *chair 2*, or *sofa* by the value of pressure sensors attached under chairs. It also clarifies the activity of the user (sitting or standing). Fig. 6.36 is our current prototype of a chair with a pressure sensor (Pololu Force-Sensing Resistor: 0.6 inches-Diameter Circle 1696). The Arduino board (WeMos D1-R2) with WLAN WiFi was used. It can communicate with our

Table 6.5 Characterizing and evaluating our positioning systems using system properties from (Hightower and Borriello, 2001).

Technology	Technique	Physical	Symbolic	Absolute	Relative	Remote	Recognition	Accuracy and precision	Scale	Cost
UWB	Radio ToF Lateration	x		x		x	x	0.1m	1 SN (Station Node) / 1-2 rooms	Medium
iBeacon	BLE Fingerprinting K-NN		x	x		x	x	93%	1 SN / 1-2 rooms	Cheap
iBeacon	BLE Proximity		x	x		x	x	95% - 99%	1 SN / service area	Cheap

monitoring and intelligent systems via HTTP protocol. We succeeded combine and exchange information between sensors and our systems with this first prototype, but more formal tests are needed in the future to evaluate the effective.

a) b)

Fig. 6.36 A chair prototype with a pressure sensor (Pololu Force-Sensing Resistor) and an Arduino (WeMos D1-R2). a) The view from above; b) Arduino board under the seat.

Besides that, a front-end system with web interface was implemented for facilitating the works of caregivers, managers, or people like designers, architects. Real-time monitoring, movement history, and heatmap functions were described. In the next chapter (chapter 7), more functions of this front-end system, which are toward analysis of data and suggestions/recommendations from the intelligent system would be shown.

Chapter 7

The Intelligent System

Previously, the Implicit Interactive Intelligent (III) Environment with three part-systems: a monitoring system, a guiding system, and an intelligent system was introduced for providing a long-term assistance to people with dementia. The details of two systems (the guiding system and the monitoring system) were discussed as well in chapters 5 and 6. In order to connect those two systems, the intelligent system is proposed. In a navigation context, this intelligent system first processes the input data from monitoring system (people with dementia' symbolic location and identity), analyzes the context if any person with dementia needs assistance (e.g. being lost). If yes, the system then predicts his destination (requirement R6 - chapter 3), calculates the route from his current location to the destination, and controlled lights (on/off) in places corresponding to the calculated route as the output to guide him. In this chapter, we describe the state of the art of recognition techniques and cognitive assistance works. Overall, other projects relating people with dementia and smart homes / intelligent environment have focused on people in the early stage of dementia and the living-alone environment. Given the lack of critical attention paid to people with moderate to severe dementia and a multiple-users living environment like dementia care facilities, a preliminary framework using hybrid models and techniques solving the navigation context problem is proposed and presented with three main modules: Knowledge Manager, Context Manager, and Interaction Manager.

7.1 State of the Art

Assisting people with dementia is widely considered to be a challenging problem. Several European projects have targeted the area of Ambient Assistive Living (Boer, 2010). The existing approaches either focus on monitoring the subject (Demiris et al., 2004) or assisting on a single ADL (Activities of Daily Living) (Mihailidis et al., 2004). EasyADL (Backman et al., 2006) addresses these concerns, but their solution is using Virtual Reality (VR), which we believe is not the proper long-term approach. The reason was that the issues depend on many aspects such as end-user situation, real-life testing, and acceptability, which VR cannot go very far. The majority of products and services assisting people with dementia were mainly sending reminders based on static schedules of users. They lack input from a dynamic understanding of user's activities.

One of the major problems of assisting people with cognitive impairment is to identify the on-going activity of the users, from observed basic actions. This difficulty was considered as plan recognition problem in the field of Artificial Intelligence (AI) (Carberry, 2001). Plan recognition process is normally divided into two phases: taking a sequence of user's actions as input and predicting the user's goal (Schmidt et al., 1978).

The majority of plan recognition approaches (logical (Kautz, 1991), probabilistic (Charniak and Goldman, 1993), or hybrid (Avrahami-Zilberbrand and Kaminka, 2006)) assumes that the observed entity acts coherently. This assumption is a limitation in a cognitive assistance context as the observed entity, especially people with dementia can act erroneously. Some works take into account this problem such as the COACH system (Boger et al., 2005), which is a system assisting people with dementia to perform their hand washing activity. The COACH system showed good results but is limited to only one activity (hand washing).

Plan recognition could be classified into two main categories: *intended plan recognition* and *keyhole plan recognition* (Bouchard et al., 2007). The difference between these two categories is the awareness of users about being observed. The *intended plan recognition* means that the user (person of dementia) knows that he is being observed and is adapting his behavior to show his intention to the observer. The *keyhole plan recognition* is on the other hand similar to observing a person through a keyhole, which the user does not know or not take it into account. Working with people with dementia normally means dealing with *keyhole plan recognition*. The difficulty is increased significantly as people with dementia usually act incoherently and make erroneous plans while healthy people make behaviors and activities coherently with their intentions and plans. Moreover, the system might know all possible ways to perform an activity correctly but it is nearly impossible to get all erroneous plans that can happen.

Following to (Bouchard et al., 2007), the *keyhole plan recognition* can be divided into three major streams: logical approaches, probabilistic methods, and learning techniques.

7.1.1 Logical Approaches

Kautz's theory (Kautz, 1991) was one milestone of the logical approaches to plan recognition. His model starts with a number of plans (action types), which each of them includes subtypes (specialize the action) and decomposition (steps to perform the action). All of them creates an interconnected hierarchy. This hierarchy is assumed to be correct and complete, which means containing no error and all actions can be observed. The first-order logic was used to express the hierarchy. A set of hypotheses were then defined based on McCarthy's circumscription theory (McCarthy, 1987). These hypotheses compose inference rules to extract interpretation from the hierarchy for observed actions. Kautz raises the issue of recognizing multiple interleaved plans. Fig. 7.1 is an example. If the actions observed are $(Get\ Gun, Go\ To\ Bank)$, by default we deduce that the person intends to rob the bank $(Rob\ Bank)$. However, there might be a case that he gets the gun for hunting $(Hunt)$ and then drops by the bank to withdraw money $(Cash\ Check)$. So even if two observations can be connected, their intentions are not necessary related as well. According to Kautz (Kautz, 1991), this issue should be taken into account in the process of recognition. Kautz only addresses this issue partially as he considers all the observed actions that can be explained by a common plan need to be induced by the same intention although they could be carried out for different purposes. Besides that, all plans inferred are considered equally (same probability), which is also another limitation.

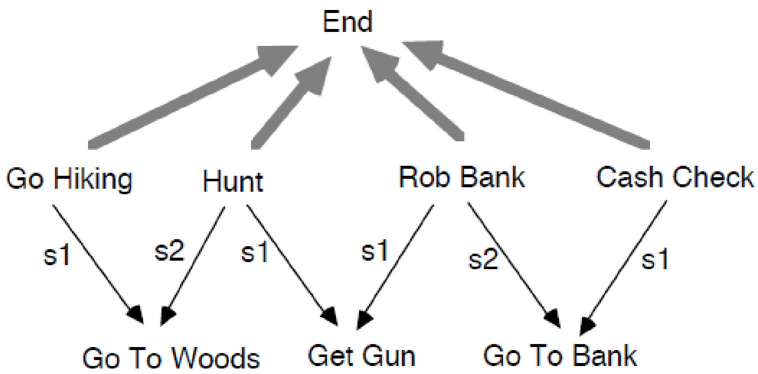

Fig. 7.1 Recognizing multiple interleaved plans (Kautz, 1991)

Based on Kautz's work, Wobke proposed a logical approach using situation theory (a particular case of possible worlds theory). The difference is that in possible worlds theory all statements must be true or false, whereas with situation theory the statement can be unknown in a given situation. He aimed at providing a more intuitive semantics for the interpretation of the possible plans and solving the problem of equiprobability in Kautz's work. By defining a partial order relation between plans, elements of the hierarchy regarding situations are defined by the level of plausibility. Then, more refined conclusions can be drawn by choosing the most plausible ones. However, three limitations still remain. First, it is assumed that the observed agent cannot maintain two distinct convergent intentions, which sets this work on the different path from the problems raised by Kautz (multiple interleaved plan). Secondly, Wobke's approach is based on situations semantic that formal apparatus is difficult to make operational in a real context. Last but not least, the system or observe agent is assumed having a complete knowledge. It cannot recognize a plan which is not included in the plans library.

In order to recognize erroneous plans using Kautz's logical theory, Py (Py, 1990) proposes a method adding an event type *Error* to the plan hierarchy trying to explain all observations that cannot be explained by a normal event. A computer assisted teaching system for geometry was implemented using this approach. When the students plan the use of theorems to prove some geometrical properties and make the mistakes, the system would recognize and correct them. The main limit of this work is requiring a pre-defined modified version of each plan for each type of error, which could be very costly when dealing with many plans.

7.1.2 Probabilistic Methods

In general, probabilistic methods without a learning process mainly based on Markovian models (Boger et al., 2005), Bayesian networks (Albrecht et al., 1998), or Dempster-Shafer theory (Carberry, 2001). These approaches manually assign a probability to each possible plan and then simply conclude with the plan having highest probability. The main advantage of this approach is showing the fact that some certain plans have a higher probability to happen than others. On the other hand, the disadvantage is that the handcrafted stochastic model computing the probability of hypotheses are static and highly dependent on the specific context (Carberry, 2001).

COACH project (Boger et al., 2005) is an example of applying a probabilistic method to dementia context. This is a cognitive aid for people with dementia, which actively monitors a person's handwashing task and then offers assistance e.g. reminders or prompts if necessary. This system is based on Partially Observable Markov Decision Process (POMDP). By using cameras, observations of activity performed by a person with dementia are considered as a set of state variables. Based on a pre-defined handcrafted model (Fig. 7.2), the completion status of the task is determined. After a certain time, if the status does not evolve, the system will try to guide the person until the next activity. Even though the COACH project has shown good results in real case assistance scenarios for a handwashing activity, it remains a limitation that is only able to monitor one specific activity. Moreover, the state variables are closely related to this specific handwashing context which would be difficult to extend for multiple activities recognition.

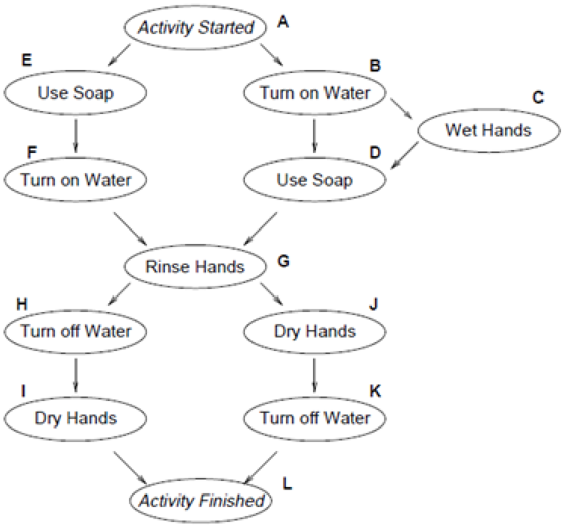

Fig. 7.2 The five essential steps of handwashing activity (Boger et al., 2005)

7.1.3 Learning Techniques

Learning technique is another main stream of plan recognition. These techniques try to find patterns from behaviors of the observed person and to extract from them a predictive model characterizing his common routines. Many of learning recognition approaches are based on probabilistic approaches. The main difference is that, instead of using a pre-established stochastic model to update the plan likelihood, they keep a trace of their previous observing experiences and use them to learn the parameters of the stochastic model dynamically (Bouchard et al., 2007). Then, a predictive model is created based on the observed agent's habits. For example, a hierarchical Bayesian learning model was proposed for recognizing and predicting the future person's location and his transportation mode (Liao et al., 2007). This probabilistic learning technique is based on Rao-Blackwellised particle filters (Doucet et al., 2000), a type of Bayes filters for estimating the state of a dynamic system. The main objective of this work is developing a personal guidance system that will help a cognitive impaired person to move safely and independently. This model detects user errors and deviations from common routines, compares the probability of the learned hierarchical model with a prior model. By doing, it can give a concrete means to know when an assistance is needed. However, although it can recognize a new behavior, it is unable to distinguish if the behavior is a coherent new routine or an erroneous known plan. Another example is using Hidden Markovian Models (HMM) and an updated Viterbi algorithm to evaluate how well a person performs daily activities and provide some suggestions (Wilson and Philipose, 2005). When a person has failed to complete an activity, this method evaluates the performance based on a set of correct (performed and rated) examples done by experts. It then finds the closest successful solution by computing the edit distance between the user's actions and the learned examples. The advantage of this solution is the capacity to evaluate how bad the erroneous plan of the user is and provide an appropriate adapted solution. The drawback of this method is that it cannot anticipate the possible abnormal behavior of the patient.

There are also learning techniques not based on probabilistic. A general framework for learning-by-observation systems based on inductive learning algorithms e.g. C4.5 decision tree was proposed (van Lent and Laird, 2001). This work tries to mimic human behavior and models knowledge from observation as a machine learning problem. The problem with this approach is that only being effective in a deterministic environment. If the tasks were changed, the decision trees would have to be relearned from a new set of observations.

Regarding the ADLs recognition for cognitive-impaired people such as people with dementia, many works used learning approaches have tried to address this problem. *Activity Compass* (Patterson et al., 2002b) is an example. It is a cognitive aid for Alzheimer's patients in mild degree. The system is based on the learning recognition model, which directly addresses the issue of incoherent behavior recognition and identifies incomplete or erroneous plans performed by Alzheimer's patient (incoherent behavior recognition problem) by matching these plans to the closest learned pattern. However, this work requires a long training period to be efficient and cannot distinguish the different types of patient's deviations. Also, the habits of the patients might change from time to time depending on several factors such as new experiences, time, physical and mental state. The routines thus need to be relearned constantly by the system.

7.1.4 Other Approaches

Besides three main streams of keyhole plan recognition mentioned above (logical approaches, probabilistic recognition methods, and learning techniques), there are still other types of plan recognition approaches developed. For instance, a method without a plans library (avoid assuming that observer agent/system has a complete knowledge of the domain) was proposed (Hong, 2001). This technique exploits the construction and the analysis of graphs of goals without the need of a plan hierarchy. It, however, transforms the issue of a hierarchy of plans into another equivalent problem of describing a hierarchy of actions and goals. Moreover, all possible goals are assumed known by the observer. Therefore, although the observer agent might not need to know all possible plans, it might require a complete knowledge of goals instead. This work also requires many observations to be effective and barely predict the final goal of the observed agent before all the actions of the plan are performed.

Another approach is taking advantage of human-agent collaboration in the process of the plan recognition (Lesh et al., 1999). The human-agent interaction could be a human focus of attention and the possibility for the agent to ask the user for clarification. This method brings a limitation to the dementia environment where a communication link between the user and the agent is difficult. More specifically, it is unpractical to ask for clarifications from people with dementia, who suffer cognitive impairment.

To address the issue of recognizing the incoherent behavior of Alzheimer's patients, a hybrid approach exploiting the probabilistic description logic was proposed (Roy et al., 2007). This work follows the line of Kautz and Wobke' approaches. Using *Lattice theory* and *Description logic*, the recognition problem is transformed to classification issue. It defines algebraic tools that use the existing relations between possible plans to dynamically generate new plausible extra-plans (were not pre-established in the knowledge base). The advantages of this approach are taking into account behavioral incoherent characteristic and multiple plans and organizing results into a structured interpretation model (lattice), which can minimize the uncertainty. Taking example that the observed action is *GoToKitchen* among actions knowledge base (*GoToKitchen, GoToLivingRoom, GetWater, TurnOnTv, SmartWashing*), two possible plans explaining observations are *WashDish(GoToKitchen, StartWashing)* and *PrepareTea(GoToKitchen, GetWater)* among four plans knowledge base *WashDish(GoToKitchen, StartWashing)*, *PrepareTea(GoToKitchen, GetWater)*, *WatchTV(GoToLivingRoom, TurnOnTv)*, *PrepareTea(GoToKitchen, GetWater)*.
Fig. 7.3 shows the result as a recognition space lattice which explains situations and highlights the advantages. However, the problem of this work is that the first observed action is assumed to be correct and coherent with the goal. Moreover, some "judgment" and "organization" errors are difficult to predict because of the low-level sensors, and the system cannot resolve when the patient repeated one of few actions indefinitely.

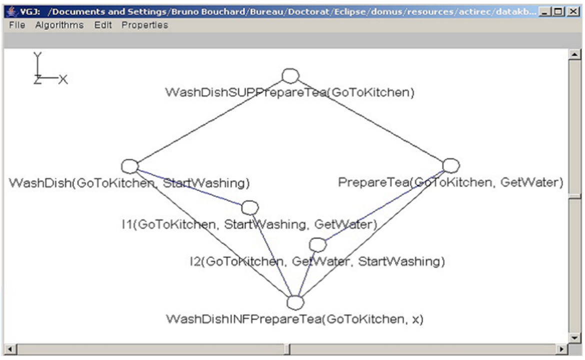

Fig. 7.3 Recognition space lattice (Roy et al., 2007)

7.2 Our Approach and Methodology

7.2.1 Context

The first difference between this thesis and other smart homes/intelligent environments is about the context. While other works normally take into account the user living alone, we focus on dementia care facilities where many people with dementia are living in the same places. Having multiple users in an intelligent environment creates a great challenge. Dealing with only one user lets the researchers be much more free in choosing sensors and technologies. Recognizing activities is thus also easier in this case. For example, in the situation of one user, if the door switch sensor is triggered, it means the user is opening/closing the door (activity). That is also the location he is being. However, in multiple users situation, we need different sensors/techniques to identify who that user is performing the activity of opening/closing door is. It is even more difficult to detect and identify when there is more than one user standing closely (same place). Another example is identifying the food has been taken out using RFID or UWB tags on the food. If there is only one user, it is suggested that he is taking out the food. This deductive way cannot be applied to multiple users. In fact, it depends on how close multiple users are to each other and the accuracy of the monitoring system. In general, if the distance between users is less than 3 meters, it could lead to the false detection.

Many works also tried to recognize each low-level action in high-level behavior, to detect if the actions go wrong and then correct them. Taking the eating meal scenario as an example (Roy et al., 2007). In this example, *taking meals* can be considered as a high-level behavior which includes several low-level actions such as bringing food to the mouth. They use the Passive Infrared (PIR) to detect if the user (person with mild dementia) enters the kitchen. They determine this use case scenario as the lunch time and monitor the *lunch-taking* plan.

By using fixed camera and pressure sensor, the system recognizes that the user sits at the table and does nothing but make some hand movements. It then detects the initiation error (fail to start) and sends the voice reminder that it is lunch time and suggest the user goes to the fridge taking out the lunch. Similarly, using the voice prompt, the system reminds/suggests users at next steps when they make errors e.g. opening and closing the fridge indefinitely (recognized by reed switch sensor), taking the wrong food (recognized by using RFID or UWB tags on the food), or judgment error such as forgetting to wear kitchen gloves to take out the hot food. Besides that, they also aim at solving other errors like sequence error (e.g. taking medicines before having lunch instead of after lunch). This kind of work is indeed very interesting but still far from our context and objective. First of all, it is costly because of requiring several sensors for one person and one big room (Fig. 7.4). The cost and complexity of setting up would be multiplied with several users and rooms. Also, camera solution is expensive in the computation to be autonomy enough (mentioned in monitoring chapter - chapter 6) and might get noise and error easily with other people around. Coming back to the meal-taking plan, the number of possible plans actually could be very large, but in this work, they have selected a particular targeted plan for eating which is hard to apply directly to the real environment. Moreover, low-level actions like *hand to mouth*, *cup to mouth* are considered as micro-context (are assumed to be accurate at the acceptable level of uncertainty). Also, using voice prompt is suitable for one user (person with mild dementia) but might not work in case of people with moderate-severe dementia, especially with multiple users around at one place. We observed in dementia care facilities that even though a caregiver spoke loudly directly to a person with moderate-severe dementia, it was likely that the person with dementia did not pay attention or understand and the caregiver had to repeat a couple of times.

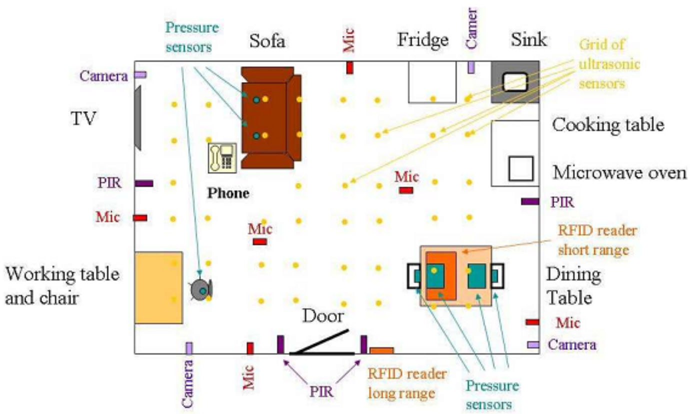

Fig. 7.4 Ambient multi-modal sensors (Roy et al., 2007)

Overall, prior researches in the field of cognitive assistance and smart environments e.g. remarkable work from Bouchard et al. (Roy et al., 2007) have focused on people with mild to moderate dementia who live alone. Those works have tried to keep people in the early stage of dementia being independent as long as possible. In fact, very little attention has been devoted to the dementia care facilities where many people with moderate-severe dementia living at the same place. Based on our observations (chapter 3), it is true that we need to motivate the confidence and enhance the independence of residents who suffer dementia. However, in many cases due to severe cognitive impairment, they certainly still need supports and cares from others e.g. caregivers. Therefore, we do not aim at removing other people like caregivers out of people with dementia' ecosystem. Instead, our intelligent system plays a role in the middle of people with dementia and caregivers, connects them, and support both of those population (to encourage the confidence and independence of people with dementia as well as to reduce work-load, stress of caregivers). Our objective is not recognizing and correcting each low-level action such as each step of taking a meal. We believe that the whole process (setting-up environment, detecting and correcting actions) is too complex and costly. It is impractical in a real dementia care environment where there are many users with an enormous number of low-level actions.

7.2.2 Our Preliminary Framework using Hybrid Models and Techniques

Our intelligent system combines different methods including statistic approaches, learning techniques, and Hidden Markov Model (HMM). The system consists of three main modules: *Knowledge Manager*, *Context Manager*, and *Interaction Manager* (Fig. 7.5). Each module includes some smaller blocks of functions like the figure. The first module - *Knowledge Manager* contains expert information input by caregivers or through a learning process such as rules (e.g., *rule1* - if the user is not in the bedroom at the night time (22:00-6:00), the user's state is set as *wandering at night*, and the system guides the user back to bedroom), the correct path/schedule of activities that people with dementia should do, or probability distribution of location/activity (e.g. based on location history last two months, at 14:00-15:00 on Tuesday, 90% the user U1 is having a coffee in the kitchen and 10% sleeping in the bedroom). The *Context Manager* then uses data from *Knowledge Manager* and the input from the monitoring system to analyze the context (as a controller, checks rules/events from *Knowledge Manager* and triggers appropriate functions from *Interaction Manager*). For example, according to the monitoring system, the user U1 is in the *corridor1*, and it is at 1:00. The *Context Manager* detects the situation fitting the *rule1*, which means the user U1 is *wandering at night*, the system needs to take action guiding him with the destination is his bedroom. After that, the *Interaction Manager* takes in charge calculating the route from the current location (*corridor1*) to the destination (his bedroom *BR-U1*). The routes between symbolic locations are pre-defined in *Knowledge Manager*. In this example, the route from *corridor1* to *BR-U1* is $\{$corridor1,L12; P1,L1; P3,L31; P4,L42$\}$, which means at the *corridor1* the light L12 is turned on to guide the user U1 to P1, and then P3, P4 using lights L1, L31, and L42. After that, the user U1 should reach the bedroom *BR-U1*. When the user takes a wrong direction, the route is re-calculated and still be able to guide him to the destination. The *Interaction Manager* is also based on the identity of the user (thanks to the monitoring system) and configures the setting of lighting (color, brightness level, form i.e. moving or static). Above is a simple scenario. The next level is to decide what the users try to achieve (predict next location and activity), whether this is an appropriate behavior and how to react. Sometimes the system also needs to detect idleness and highlight interesting things to do in the environment (e.g. the interactive drawers). Note that the users' history locations, current location, identity, weather, date time, and partly expert knowledge are achieved. The routes between each two points of symbolic locations are pre-calculated, as well as the settings of lighting for each person of dementia and situation are prepared. Each lighting was mapped correspondingly to decision points on the calculated routes. To solve above scenarios, finding what users are doing, if they need support, and the potential destination and activity are needed. Activity recognition is presented first, and then three mechanisms (rule-based, detect erroneous from caregivers' correct path of activities, and predict next location/activity based on HMM) are described. These three mechanisms can be implemented independently or combined with others.

Location Detection and Activity Recognition

Transforming low-level sensors data to intermediate-level information (location labeled) and then to high-level information (activity) is beneficial. Fig. 7.6 displays a part of our system transformation. The first part of our macro-context method is data processing, which is an important step for training accurately in machine learning techniques. Data collected from ubiquitous sensors are stored with a timestamp, sensor ID, sensor values and location labels. In order to recognize the performed activities, a recorded dataset (thanks to the monitoring system - chapter 6) is processed into the form $\left\{(x_1,y_1,z_1),...,(x_n,y_n,z_n)\right\}$. The term x_i represents the vectors containing values of sensors such as *iBeacon_Paul* or *pressure_sofa_corridor*. The values of y_i are timestamp whereas values of z_i show location labeled such as *kitchen* or *bedroom*. The next part is mapping the location to appropriate activities with the support of *temporal reasoning* which is input by caregivers and improved by a learning process. A simple example of activity recognition is that with iBeacon data, the system detects that the user U1 is in the *corridor*, at the *sofa* location. Plus the pressure

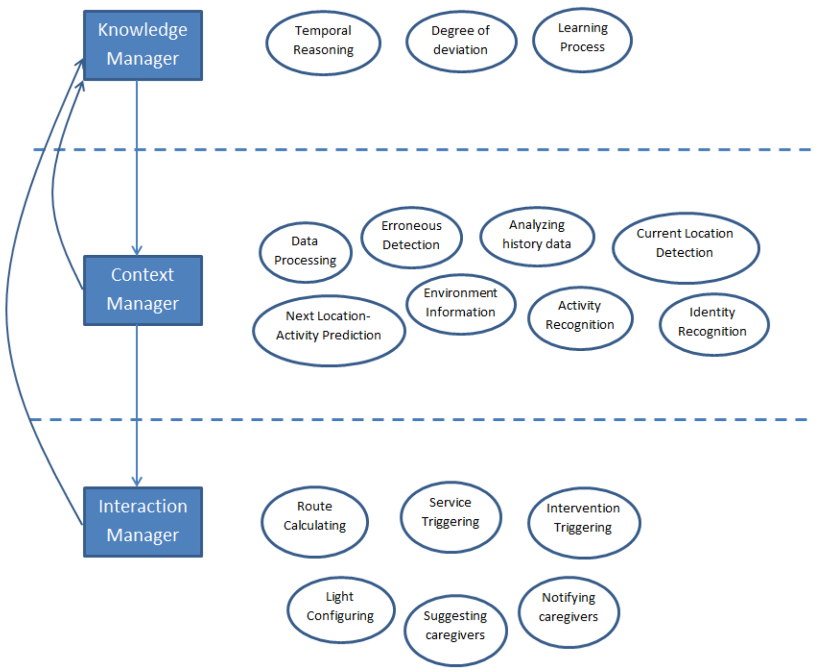

Fig. 7.5 Three main modules of the intelligent system: Knowledge Manager, Context Manager, and Interaction Manager

sensor on sofa had the value over the threshold (pressure detected), it inferred that the user U1 was sitting on the sofa and making the activity *resting*. Obviously, there might be more than one activity can be done at one location. The location *kitchen* can be matched to with activities *eating*, *resting*, or *singing*. Based on a statistical model (*temporal reasoning*), each activity has a probability within a certain *time frame*. A *time frame* includes two values: day (7 possible values from Monday to Sunday) and hour (24 possible values from 0 to 23). If the user's location was the *kitchen* and the time frame was at 12:30 on Monday, the probability of activities $\{eating, resting, singing\}$ is respectively $\{0.8, 0.1, 0.1\}$. At another time frame (at 15:10 on Thursday), as this was supposed to be the group session of the facility, the probability of *singing* activity was increased to 0.75 whereas the *resting* activity had 0.2 probability and the *eating* activity got only 0.05 chance to happen. The probability was calculated based on a learning process from previous activities with a *log-service*. There was also a *window time* for the probability-calculating process from the *log-service*, e.g. last 30 days or last 90 days, which could be changed later. A cache was implemented here storing the results of that probability-calculating process to not re-calculate it every day. However, after a certain time (30 days by default), the system would compute again and update the results to the cache. By doing this, the habits or patterns of residents' daily activities were ensured to be up-to-date, and the system could detect activities correctly. Moreover, we can also compare the activities of people with dementia between this month and last months, analyze the difference and make the intervention if necessary.

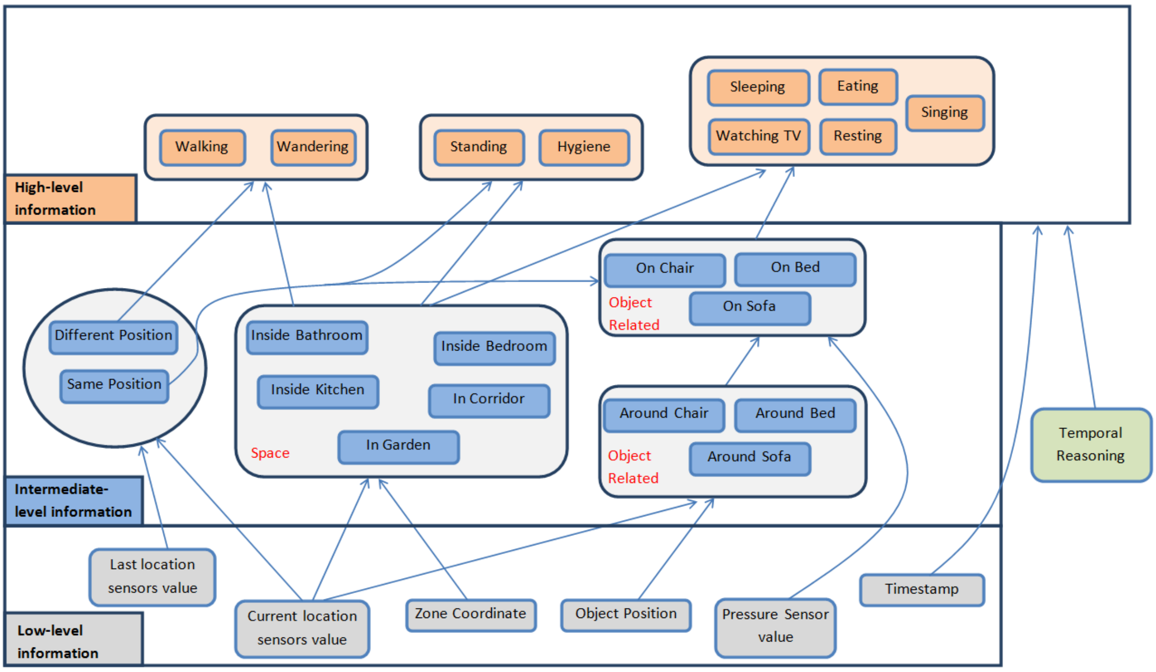

Fig. 7.6 Transforming low-level sensors data into high-level information

Rule-Based

Rules (in *Knowledge Manager*) can be used for the system (Context Manager) detecting if the users are in difficult situations (e.g. being lost, wandering at night) and trigger appropriate assistance. Nools library (C2FO, 2011) with RETE algorithm (a pattern matching algorithm for implementing production rule systems) was implemented. Following are some pseudo code examples. It typically has rules expressed in an 'if-then' syntax or 'left hand side' (LHS) and 'right hand side' (RHS).

- If the user (person with dementia) is going to or being at exit area, keeping him/her away that area by red light.
  ```
  if distance (current_location (PwD), exit_area) <= 1.5m, then
  prepare_lights(exit_area, on)
  ```

```
prepare_lights(exit_area, on):light_E1_state = on, light_E1_color =
red, light_1_type = static, light_1_brightness = 60

Override rule:  if (PwD == P7), then light_E1_brightness = 80
```

- If the user is not in the bedroom at the night time, guiding him/her back. If it does not work, caregivers are notified.

```
if current_location (PwD) != bed_room (PwD) and
(time < 6:00 or time > 22:00), then guide_back_bedroom (PwD)

guide_back_bedroom(PwD) = calculate_route (current_location,
bedroom) + prepare_lights(current_location, bedroom)

if guide_back_bedroom().duration > 10 min, then notify (caregivers)
```

- If the user is on the corridor for more than 15 min between 12:00-13:00 or 16:00-17:00, guide him/her to the kitchen

```
if current_location (PwD) == corridor and
current_location(PwD, corridor).duration > 15 min and
(12:00 < time < 13:00 or 16:00 < time < 17:00),
then guide_to_kitchen(PwD)
```

- If the users (P3 or P5) is resting on the *sofa3* for more than 15 min between 14:00-15:00 on Wednesday, guide him/her to the interactive drawers.

```
if current_location (PwD) == kitchen and
current_location(PwD, kitchen).duration > 15 min and
(PwD == P3 or PwD == P5) and (10:00 < time < 11:00 or
14:00 < time <15:00) and today == Wednesday,
then guide_to_drawers(PwD) and prepare_drawers(PwD)

guide_to_drawers (PwD) = calculate_route
(current_location, drawers) and
prepare_lights(current_location, drawers)

prepare_drawers(PwD): select_pictures(PwD)
```

In our system, LHS can be improved with Activity Recognition e.g. in the rule above `current_location (PwD) != bed_room (PwD) and (time < 6:00 or time > 22:00)` can be recognized as activity *wandering at night*. Another example is `current_location (PwD) == corridor and current_location(PwD, corridor).duration > 15 min` is considered as *being lost*. A long condition set in the example of guiding people with dementia to the interactive drawers could be recognized as *idleness* activity. The advantages of this solution are better comprehension, easier in building complicated rule and plan, and reduced complexity (e.g. multiple sets of conditions might have the same activity and same treatment - only need to map the activity to the system's reaction once). The system might use the activity recognition method presented above or building another rule set for labeling activities directly from sensors' data.

Detecting Erroneous Issue

Another mechanism is detecting erroneous issue (if people with dementia need an intervention from the guiding system) based on a correct path of activities from caregivers. Other works such as (Roy et al., 2007) try to detect the erroneous activities or plans and then correct them by explicit instructions like video or voice. The meal-taking scenario above is an example. Recall that our users are people with moderate-severe dementia who have severe cognitive impairment. Unlike people with mild dementia, they are barely able to comprehend and follow the instruction like voice prompt. Therefore, it is not necessary having a complex and costly process to detect each low-level action of having meals activity, which could get an error in detection and confuse people with dementia. In many activities such as having meals, taking medicine, or doing treatment (this group of activities is considered as *fundamental activities*), the support from caregivers is the most flexible and effective. With the meal-taking scenario in dementia care facilities, one-two caregivers were always in the kitchen preparing meals (also eliminate the risks of cooking, taking the hot food for residents with moderate-severe dementia) and being ready to support them if needed. For other activities like singing, playing a game, and trying our interactive drawers, we considered them as *supportive activities* which caused no harm when they did it wrong. We might give them some implicit instructions but we do not want to correct them at every step. Let them discover and enjoy their world! One effective solution to increase the confidence, as well as life quality of people with dementia, is encouraging them. No matter what they do, it is always right. Of course, designing those services, assistance devices are sometimes tricky and need to be evaluated carefully. Our chest of interactive drawers (chapter 5) is an example of attempting that kind of services, trying to engage reminiscence activity for residents with dementia. It was not about them following steps of using as we expected. In the end, helping them discover, try using, and have a positive feeling are all matters. Our approach focuses on implicit intervention, creating more freedom in thinking and behaviors of people with dementia. In some cases needed strong intervention and support, caregivers' assistance is the choice. About the erroneous issue, we considered detecting the erroneous current location of people with dementia instead of activities or plans because, in our model, we already linked plans and activities to locations. The correct path of locations throughout the day (started with waking up and finished with going to bed in *bedroom* location) was mostly built by experts e.g. caregivers. However, people with dementia did not have to follow exactly the correct path made by caregivers. Besides detecting the erroneous location, the system also calculated the degree of deviation between the erroneous location and correct location based on a five point scale. For instance, at 15:00 - 16:00 on Wednesday, the residents were suggested to be at the *Corridor1* location for trying the interactive drawers. The vector of deviation degree for *Corridor1* location to {*Kitchen, Sofa, Bedroom, Therapy Room, Garden*} is respectively $\{1,1,1,3,3\}$. As this location (activity) was recommended by caregivers, however, was not mandatory. If the user was in the *kitchen*, *sofa*, or *bedroom*, it is still acceptable, no need for intervention (degree value 1-2). If the value of deviation degree was 3 (for *Therapy Room* and *Garden*), the system would try to guide them to the *Corridor1* by using light. Another scenario was at 12:00-13:00 (lunch time). In this case, the residents should be in the *kitchen*. The vector to other locations was all set to 3, which meant the system would try to guide residents to the *kitchen*. After half of time (over 12:30), if the residents were still not in the *kitchen*, the degree was then changed to 5 and the system notified to caregivers. A hierarchy representation (Fig. 7.7) showing correct path of locations (deviation degree 0, green line in the figure), acceptable path (degree 1-2, blue line), mild intervention (degree 3-4, orange line), and erroneous path (degree 5, red line).

Predict Next Location and Activity

To predict next location, Hidden Markov Model (HMM) was used. HMM is a well-known approach for analyzing sequential data. The sequences are assumed to be generated by a Markov process with unobserved (hidden) states. In our case, the moving decisions of people with dementia are not directly visible, but the previous locations are visible. Each state has a probability distribution over the potential locations. Fig. 7.8 shows the general architecture of an HMM. The variable $x(t) \in \{x1, x2, x3\}$ is the hidden state at time t. The variable $y(t) \in \{y1, y2, y3, y4, y5\}$ is the location visited at time t. The arrows in the diagram mean conditional dependencies. The probability distribution of the hidden variable x at time t depends only on the value of hidden variable $x(t-1)$. The value of observed location $y(t)$

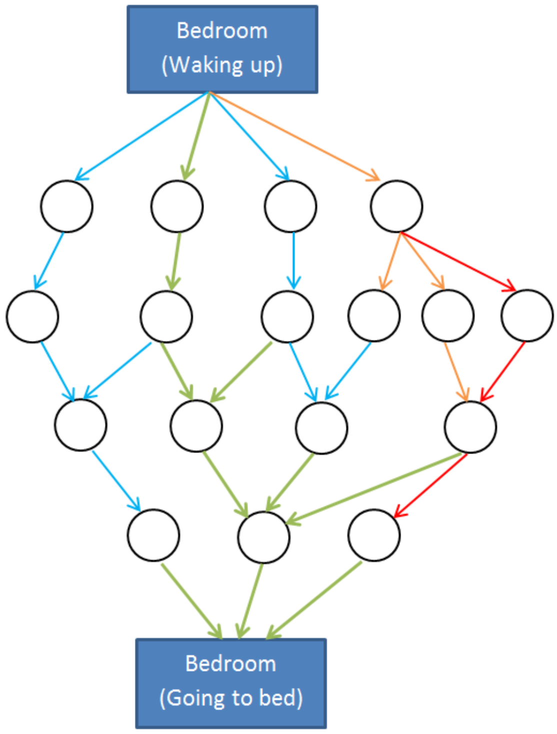

Fig. 7.7 Hierarchy representation of erroneous locations path (Green line: correct path; blue line: acceptable path; orange line: mild intervention; red line: erroneous path).

only depends on the value of the hidden variable $x(t)$ at time t.

The first problem of HMM is computing the probability of a particular output sequence being observed, given the parameters of the instantiated model. We used Forward algorithm. A summation over all possible state sequences is computed. The probability of observing a particular sequence in the form $Y = \{y(1), y(2), ..., y(n)\}$ of length n, is given by: $P(Y|X) = \prod_1^n P(y(i)|x(i))$. The next step is HMM parameter learning, which is solved by local maximum likelihood estimate of the parameters of the HMM, given the set of output sequences, using the Baum-Welch algorithm (an example of forward-backward algorithm and a special case of expectation-maximization-EM algorithm). After that, the task of user location prediction is reduced to the particular HMM inference problem of computing, given a set of sequences of the form $Y = \{y(1), y(2), ..., y(n), Y(n+1)\}$, in which location $n+1$ is the potential next location. To sum up, from a given sequence of previous locations, we compute the set of sequences corresponding to all possible next locations, use the forward algorithm to compute the probability of all such sequences, and then return the next place corresponding to the sequence with the highest probability.

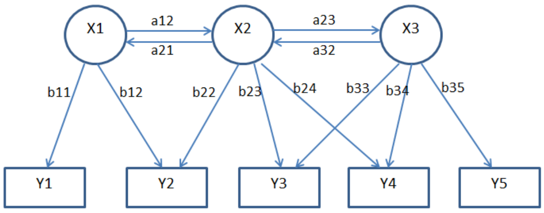

Fig. 7.8 Example of Hidden Markov Model (HMM)

Predicting problem can also be viewed as a classification problem. An observational study was conducted in facility B for two weeks in a row (only Monday, Wednesday, Friday). The duration of each day was from 8:00 to 18:00. The location of one participant was recorded manually by an observer. The Weka software (The University of Waikato, 2007) was used to test different data mining algorithms. Five attributes of the data were time (from 8 to 18), day (Mon, Wed, Fri), current_location (sofa, bedroom, kitchen, marked area), next_location (sofa, bedroom, kitchen, marked area), and next_location_time_frame(from 8 to 18). Fig. 7.9 shows the results using cross-validation folds 10 with different classification models ZeroR (no rule-base line), OneR, K-NN (k=1, k=3), NaiveBayes, Decision Tree J48 (pruned c = 2, c = 4). Overall, the NaiveBayes and Decision Tree J48 provide better performance than the others. The Decision Tree J48 also has an advantage that is able to visualize the results e.g. 7.10. In fact, the number of data points were small (35-67 depending on models) and needed to be bigger to make these algorithms works efficiently.

	Using Cross-Validation Folds 10
Model	**Correctly Classified instances**
ZeroR (no rule-base line)	41.8%
NaiveBayes	68.2%
K-NN (K=1)	61.2%
K-NN (K=3)	63.7%
OneR	58.2%
J48 (Decision Tree) pruned c = 2	64.9%
J48 (Decision Tree) pruned c = 4	73.6%

Fig. 7.9 Classification results with different models using Weka.

7.3 Discussion

After examining the related works in the field of plan recognition and cognitive assistance for people with dementia, only a little attention has been devoted to our case study, which is

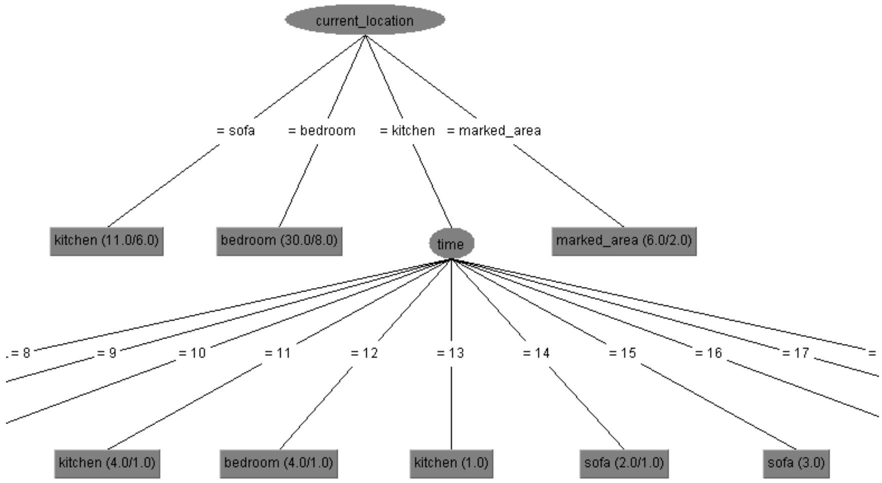

Fig. 7.10 A part of Decision Tree J48 pruned c = 4.

for people with moderate to severe dementia and multiple-living environment i.e. dementia care facilities. The difference in context and scenario brought new challenges and problems. We could not use the same setting with multiple sensors (Roy et al., 2007) to recognize activities of a single person. The limitation of choosing sensors and technologies (mentioned in the chapter with monitoring system - chapter 6) turned out a strong point with low-price setting and low-complexity of the data. Instead of going into low-level actions to recognize activities, we took another direction which linked the location to the activities with the help of a *temporal reasoning*. After that, an erroneous detection was developed for determining if the user was performing the wrong activity. Our solution had an advantage that is able to calculate the degree of deviation from performed activity to corrected one. Depending on the degree, the system can decide whether it is necessary to trigger the intervention. Moreover, using classification methods e.g. HMM, the system can predict next location of users and react to that. Those methods and algorithms are summarized in Table 7.1. Besides, an abnormal situation related physical health of users can be analyzed and visualized to caregivers based on the history data (location and movement). However, our solution had the main drawback that needed a handcrafted model from experts like caregivers for the learning process and reasoning part, which can be costly and high context-dependent. Besides that, a full implementation in a real scenario i.e. dementia care facility environment was not deployed due to complicated informed consents and cooperation with managers. Therefore, the problem was only considered solved partly although the framework was tested with simulation data and our lab environment. With the set up in the lab environment like the chapter 6 and three weeks of collecting data, the precision of predicting was reached to 94% for the one-week testing combining HMM (only location) and another approach with

Table 7.1 Summarize of models and techniques in the intelligent system.

Problem	Solution	Note
Activity Recognition	Spatial and Temporal Reasoning	Take effort to build the temporal reasoning including input from caregivers
Prepare Interaction	Pre-define routes and prepare lighting for every two symbolic locations e.g. kitchen to bedroom	
Detect Issues and Trigger Assistance	Calculate deviation from users' current location/activity to the correct path from caregivers	Assistance is based on the schedule input by caregivers
	Rule-based	The identification and utilization of a set of relational rules that collectively represent the knowledge captured by the system
	Classification algorithms (to predict next location/activity) e.g. HMM, Bayes Nets, Decision Tree J48, etc.	Based on the history locations/activity of users, not depends on caregivers' input e.g. a correct path/schedule

location and time. The approach with location and time was simple, only searched the current location and time slot to the training data and extracted the next locations with a percentage. Both these approaches provided a list of potential next locations with percentage, and the system chose the one with the highest probability. However, the user in this scenario was a healthy person and worked with the same schedule every day (not a person with dementia in a care facility). Therefore, this result was not validated. The necessary future step is fully evaluating with a real dementia care facility environment.

When the system is deployed in a dementia care facility, interfaces for caregivers inputting data for *Knowledge Manager* and getting a visualization of data analysis from *Context Manager* are needed. As no caregiver data for this part was collected, following interfaces purely are outlook from the researcher. To detect erroneous locations, a schedule (correct path of locations) needs to be identified by caregivers. Fig. 7.11 shows the web interface of the system for caregivers inputting that schedule including days (one or more among Monday-Sunday), from-to (time frame), location, activity, for (all in a group or some specific people), intervention (suggesting or urging), and description (additional information).

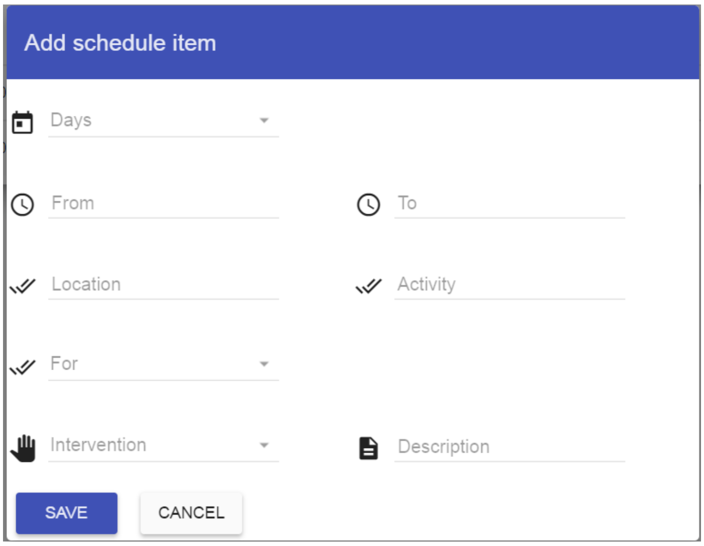

Fig. 7.11 Adding schedule

Based on the simulation data, Fig. 7.12) displays the schedule. This schedule is not only used for the intelligent system detecting erroneous locations and activities but also provide caregivers a visualization tool facilitating their works. With the processes of *location detection* and *activity recognition*, the system can display information of residents with dementia such as current location-activity, as well as next predicted location-activity (Fig. 7.13).

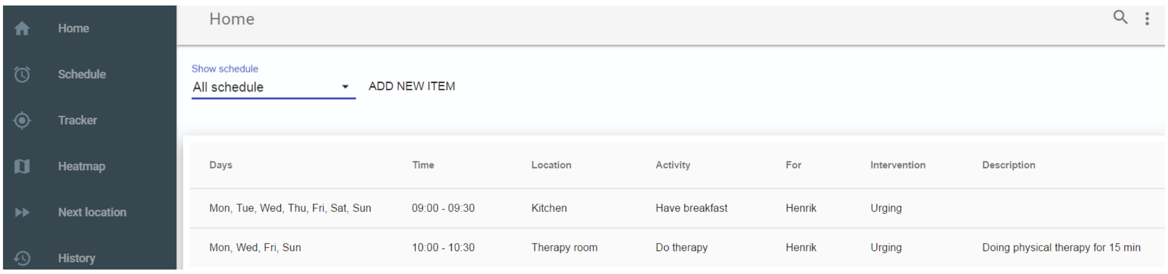

Fig. 7.12 Showing schedule

In addition, the intelligent system analyzes history data of people with dementia. In case there is an abnormal situation which can affect their health, the system notifies the caregivers and provide a potential solution (Fig. 7.14). The simulation data shows that Henrik might get hygiene issue because according to the history data, he only used toilet 30 times this month while the minimum threshold is 60 times. As this problem is not too severe, the current

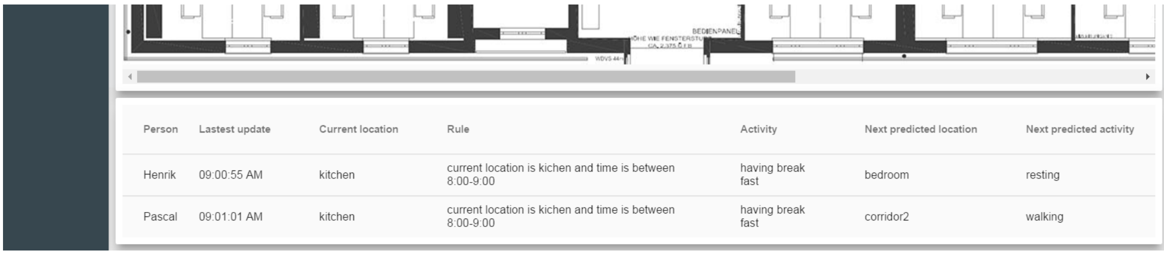

Fig. 7.13 Current location-activity and predicted location-activity

action or intervention for this problem is *suggesting* and can be done manually (caregivers go and help him). Another example with Pascal is different. He moved very little in this month (only 150 minutes), which might cause the physical issue. The current action is the higher priority (*urging*). The intervention on the figure is set *Manually* which means the caregivers will support him walk around more. The caregiver can also change to the *Automatic* mode that the intelligent system will try to use implicit intervention stimulating him moving. The light level in his room will be increased to reduce the sleeping time. The guiding system will also be triggered more for him to guide him walk between places and discover some extra services such as interactive drawers.

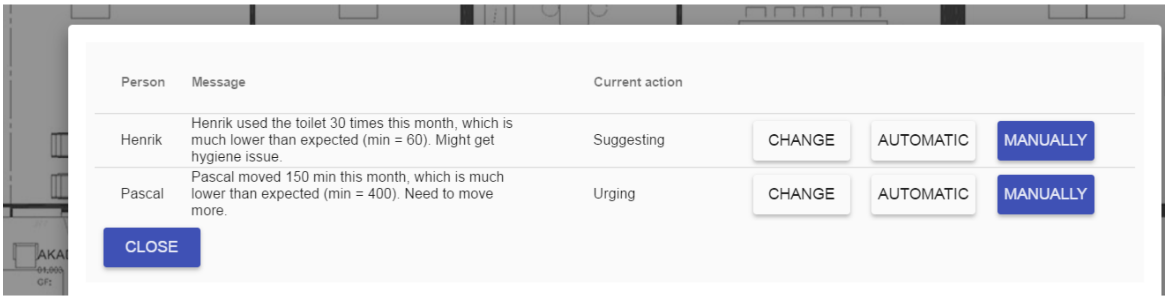

Fig. 7.14 Analyze history behaviors, detect issues, and suggests solution with automatic mode and manual mode

Chapter 8

Discussion and Outlook

In this dissertation, we explored the challenges and possibilities of supporting people with dementia, especially people with moderate to severe dementia in indoor navigation context. In particular, we focused on finding navigation difficulties of people with dementia in dementia care facilities, designing and developing a guiding system and indoor positioning system for navigation assistance systems, and initially building an intelligent system providing appropriate services to people with dementia as well as caregivers in the right place at the right time.

Based on the literature of people with dementia and assistive technology (Bharucha et al., 2009; Gillespie et al., 2012; Span et al., 2013; Topo, 2009; Vogt et al., 2012), the research has been very much biased toward safety issues. Among few studies about navigation assistance for people with dementia, the vast majority has focused on people in early stages of dementia and outdoor environments. People with moderate to severe dementia and indoor navigation assistance were overlooked even though the wayfinding issue was emphasized as either a stand-alone problem or one that affects independence, other activities of daily living, and social involvement of people with dementia. Against this backdrop, we accepted the challenge: to support people with moderate to severe dementia with indoor navigation assistance.

The mobile phones and PDA overuse is the next critical fact. Based on the conducted qualitative studies such as observations and caregiver interviews, people with moderate to severe dementia can use those technology devices. Due to the severe cognitive impairment and decreased visual acuity, they can not handle the mobile device with an application or just easily drop the device and forget about it. Besides that, the interaction between a normal user and a navigation assistance system is typically an explicit interaction with three steps: 1) the user opens the application and inputs the destination (explicit input); 2) the system shows instructions such as texts, images, and arrows in order to guide the user to the destination (explicit output); 3) the user interprets and follows the instructions (shifting between digital world and physical world) as by looking at a map or a picture and then interpreting the information on the map (for instance, the current location is the red dot on the map, move forward 5 meters then turn left) and mapping them to the reality. Skipping the step 2 belonging to the system's side, the people with moderate to severe dementia actually get difficulties in both step 1 and step 3. In step 1, they usually forget where they want to go (destination), and hence cannot input into the mobile device (not mentioning the problem of handling the device e.g. how to open the right application, how to use the keyboard). Moreover, interpreting explicit information seems not to be an easy task for our users. Understanding a map is not feasible for them due to the topographical disorientation, whereas reading small texts/images on a small screen is a problem because of visual and word-using impairments. Besides, keeping people with dementia watching screens of mobile devices might be dangerous at crossroads and on stairs.

We proposed another (you could say opposite with others) approach "Intelligent Implicit Interaction (III) Environment" emphasizing implicit interaction. Our objectives are to free people with dementia from handling technologies device, to help them stay in the physical world where they are familiar with without the need to shift their attention to a virtual world (devices). In this vision, the virtual world is embedded in the physical world and is interacted implicitly with via natural interfaces (e.g. tangible user interface). Their cognitive workload on commanding digital/virtual world is minimized, and the natural flow of human activities is thus maintained. The backbone of this III Environment is based on three systems: a monitoring system, an intelligent system, and a guiding system. The monitoring system and intelligent system automatically detect and interpret the locations and activities performed by the users i.e. people with dementia. This approach (implicit input) reduces a cognitive workload as well as a physical workload on the user to provide input. The intelligent system is also context-aware, predicts next situations (location, activity), and decides when to provide an appropriate service to the users. The guiding system with intuitive and dynamic environmental cues (light and color) has the responsibility for guiding the users to the places they need to be. Moreover, the III Environment with these three systems can easily support and integrate other services, by incorporating the concepts of Internet of Things and distributed technologies. For example, in another dementia project - INTERMEM (INTERMEM Project, 2015), a prototype of interactive drawers with screens was built showing pictures or videos. The objective was triggering certain memories of people with dementia. However, it came to a personalizing issue that individuals need different pictures/videos. With the monitoring system, we can know the location and identity of the user, then trigger the service of drawers when he or she is nearby and change the pictures/videos accordingly. The guiding system might even draw attention, guide, and stimulate people with dementia using the drawers. We succeeded building and combining services like that. The III Environment shows an enormous potential not only in supporting people with dementia in one activity (e.g. navigation) but also intelligently connecting, sharing, and enhancing all other services in their living environment.

Developing an indoor monitoring system is challenging, especially for people with moderate to severe dementia. Related projects have mostly focused on outdoor navigation and target people with mild dementia or mild cognitive impairment such as DAISY (Wainstein and Tyler, 2007), "Walk navigation system" (Kaminoyama et al., 2007), COGKNOW (Mulvenna et al., 2010). However, none of them is suitable for our context (indoor navigation assistance for people with moderate to severe dementia who cannot use mobile devices). Numerous technologies were classified and considered such as infrared, radio frequency, ultrasound, WiFi, RFID, Ultra Wideband, iBeacon, and Dead Reckoning (DR). Instead of focusing only on the system perspective (technology and precision), other aspects such as user perspectives (size, weight, appearance), energy efficiency, robustness, and cost (hardware and computation) were highlighted. Ultra wideband (UWB) and iBeacon technologies were chosen and developed eventually. Three versions of the monitoring system using different techniques and algorithms (lateration, fingerprinting, proximity) were implemented, which can solve different problems (regression problem - physical position or classification problem - symbolic location) in different contexts (continuous monitoring or location-based services). In the dementia context with continuous monitoring, we leaned toward iBeacon with symbolic location. The iBeacon can be worn by people with dementia as a watch or a necklace easily due to its small size and light weight. The signals of iBeacon are often inconsistent and could be affected by many aspects such as distance and orientation to readers, building infrastructure, obstacles between iBeacon and readers even human body. Simple solutions were proposed that could improve the performance of iBeacon in general such as filtering out weak RSSI, putting readers at 2m height, and choosing an appropriate group time. For the K-NN algorithm, selecting *k* parameter need to be done empirically. Furthermore, to significantly reduce the data processing time in K-NN, a cache solution should be implemented.

However, having a monitoring system might raise some ethical concerns. Many arguments have been made that checking people with dementia' whereabouts at any given moment would violate their freedom and privacy (McShane et al., 1998b; Robinson et al., 2006). In contrast, one might say tracking technology could enhance freedom by reducing carer concerns for their safety (McShane et al., 1994). Personally, I think that safety is predominantly prioritized over privacy in case of people with moderate to severe dementia. Besides that, technology is not naturally stigmatizing, but that stigma arises from the way in which it is used, presented, and explained to people with dementia. We tried to overcome the stigma issue in designing and developing processes. Size, weight, energy efficiency, and appearance (e.g. watch, necklace) of the device were carefully concerned. Due to many reasons and ethical aspect was one of them, technologies like camera or sensors that are tracking face expression or micro activities e.g. hand movement were also eliminated. Besides that, unlike some dementia care facilities such as facility E in study 5 preventing residents from opening exit doors or going outside with a RFID wristband, our monitoring system does not restrict them from doing anything. People with dementia could be convinced (succeeded in some dementia facilities) considering the monitoring system as a tool of enablement and independence, securing safety and allowing them to continue with activities enjoyed throughout the life course.

The next part is the intelligent system, which decides if residents with dementia need help, where and when to guide them. Related works in the field of plan recognition and cognitive assistance for people with dementia e.g. (Roy et al., 2007) have mostly focused on a setting with multiple sensors to recognize activities of a single person. Little attention has been devoted to our case study, which is for people with moderate to severe dementia and multiple living environment i.e. dementia care facilities. The system was developed with four main objectives: 1) recognize the current activity; 2) detect the erroneous activity; 3) predict the next location and activity; 4) trigger appropriate services. The system had three main modules: Knowledge Manager (handle reasoning, condition, and expert information), Context Manager (detect the state of people with dementia and environment, decide if users need to be guided, and the destination), and Interaction Manager (calculate routes, prepare lighting, or notify caregivers). Models and techniques were built that can be used independently or combined depending on the context and problem. The first one is a model mapping location, identification, time to the activity. A specific location has one or more corresponding activities. A *temporal reasoning* which learned from caregivers' input was used to decide in case more than one activity happen at the same spot. Besides that, other sensors such as pressure sensors, switch sensors, or light sensors could be added to clarify more about the location information. Objectives 2 and 3 could be considered as to detect issues and trigger assistance. A rule-based system was introduced. Another approach was based on a correct path of location/activity (learned from caregivers' input) to calculate deviation of users' current location/activity. If the degree of deviation was 3-5, the system would intervene. In contrast, classification algorithms including HMM, Bayes Nets, Decision Tree J48 could be used to predict next location/activity based on the history of users, not depending on caregivers' input e.g. a correct path. However, this approach requires a certain amount of data to effectively predict, whereas the correct path of location/activity only needs input from caregivers in the first place. Besides implicit input described above, the system can handle explicit input from caregivers, when they overhear or get a request from people with dementia. In the future, we plan to include a voice sensor into the device and to implement a natural language processing to extract the key information from people with dementia' voice (still implicit input as the user does not intentionally interact with the system). With this, our system will be completed, and be able to predict and recognize the behavior/intention more correctly. Nevertheless, size, energy efficiency, and device wearing position need to be re-considered and evaluated carefully.

About the guiding system, five studies were conducted to test and evaluate effect of our original guiding solution - lighting with color on people with dementia with four hypotheses: 1) At the intersection/decision point, people with dementia go toward the direction which is highlighted by lighting with suitable color; 2) Lighting with suitable color can draw attention measured by gaze direction from people with dementia; 3) Lighting with suitable color can highlight objects and stimulate people with dementia using objects/services; 4) In the case of preventing the use of the exit doors by inhabitants of the care homes, lighting with red color would reduce the staying time of people with dementia in that area. Study 2 was conducted to identify green as a suitable color to combine with the lighting cue for the next studies. Study 3 put participants in a decision point where they could only turn left or right with a task of finding a hidden object. The results supported hypothesis 1 by showing that participants chose the direction with lighting significantly more often in 75% (90% if excluding the participant 3 who started moving before the end of instruction) of tests compared to 50% predicted by chance (same as the baseline condition). Two studies with interactive drawers in the facility D (study 4) and facility E (study 5) supported the hypothesis 2 and partly hypothesis 3. The light and color significantly increased the gaze (eye's direction) from people with dementia (hypothesis 2). It also significantly increased the number of interactions made in study 4, however, not much showing in study 5 where they did not make direct interactions (touch or open drawers). The reason could be that participants considered drawers as picture frames, so they did not touch and open drawers. In this situation, they just stood and watched the pictures from a distance. Dwell time and gaze attention were noted increasing, which might support the assumption. For the hypothesis 4, study 6 was conducted using the red light to create an outward orientation for people with dementia in the exit area. The staying time was significantly reduced in the red light condition than the baseline condition (no light) (hypothesis 4 is supported). An interesting additional finding was a slight increase in staying time of people with dementia in the afternoon compared to in the morning. It matched to our observations that during the afternoon time residents wanted to leave the building more than in the morning time. According to them, it was late, sunset, and they had to go back home (they still did not consider the facility as their homes). Morning and afternoon factor did not change the light's effect. The red light worked for both morning and afternoon. In general, we showed that light and color could be promising cues which are dynamic, flexible, and adaptive. Different forms e.g. ambient, strip, moving lights with different colors were implemented and controlled by internet/intranet for multiple purposes i.e. using green light to draw attention, guide, stimulate people with dementia, and using red light as a warning cue creating an outward orientation feeling in order to keep people with dementia stay away from some restricted areas. More importantly, the results convinced that implicit interaction with intuitive environmental cues could work well for people with dementia even though the effect was not perfect (increasing the chance of success about 25-40%). However, there is no "magical" tool or approach that can work perfectly for people with moderate to severe dementia, who have a great variance of cognitive as well as physical impairments.

Like all other works, this project also has limitations. Firstly, the number of participants in studies with light and color was small. Recruiting people with moderate to severe dementia and preparing experiments for them were extremely challenging. Secondly, the monitoring system and intelligent system were not tested in the dementia care facility. The future work is to fix these problems by recruiting more participants, test the whole system package in dementia care facility, and validate with people with dementia and caregivers. Besides that, more colors need to be investigated on different effects on different individuals. This way can enrich and enhance the quality of the system. Guiding several people at the same time also needs to be tested. The tricky situation arises when there is more than one person in a place with the need to be guided to different bedrooms. In fact, this problem does not frequently happen in the reality as the dementia care facilities normally have a small group (5-11) of residents in one area, so the chance that many people are all lost in one spot is not regular. Anyway, one potential solution is that they have different favorite colors and more likely follow the light with that favorite color. The second solution is to add some other guidance cues such as voices (better be recorded by a familiar person to them) or projected images. Another approach is guiding them through places one by one, and then the individual might remember and stay at where he wanted to be. In the worst case, the system would notify the caregivers and require their assistance.

Along with people with dementia and caregivers, other researchers and designers can have some benefits from our work. We drew the attention on people with moderate to severe dementia and indoor navigation topic, opened a direction with implicit interaction, natural user interface, and context-awareness. Asides from contributions above, we want to share pointers (lessons learned) when working with people with moderate to severe dementia, which might be useful.

8.1 Lessons Learned in Gathering Requirements and Evaluating Prototypes in Dementia Context

From our experiences in conducting the fieldwork and evaluations, we have learned important lessons that may be useful for other researchers and designers interested in conducting user-centered design with people with moderate to severe stages of dementia. We gathered a number of lessons learned on affinity notes and clustered them regarding important issues and different user-centered design phases. The result is a set of pointers for gathering requirements (P1-P7) and evaluating prototypes (P8-P11) with people with moderate to severe dementia.

Working with people with more severe forms of dementia is much harder than with those with earlier forms of the disease. Recruitment of participants is the first challenge. Other stakeholders (relatives, caregivers, ethics commission) need to be involved in the recruiting process, as well as in conducting the actual user studies and evaluations. Participants, who suffer from severe cognitive deficits, have very short attention spans and strong mood swings. Standard approaches (e.g. asking them to actively participate in a discussion, in an interview, to give subjective ratings and feedback) thus would not work in most cases. Because of these difficulties, each session and each data point gathered is very expensive and valuable.

Gathering Requirements

Ethical Issues

Besides standard ethical procedures (World Medical Association, 2013) (e.g. participants can stop participating at any time or ensuring participants' privacy and data protection), the following points should be considered as well. First, informed consent needs not only be obtained from the participants, but also from caregivers, relatives, or sometimes a responsible person (i.e. lawyer). Second, it is recommended to get caregivers involved, not only in conducting studies (e.g. to calm participants, to motivate them) but also in recruiting participants and in almost all design and evaluation activities. Watching how people with dementia and caregivers interact with each other can help interviewers/researchers understand how to achieve positive interactions, what things to say and what things to do. Third, trying to anticipate situations that create stress or anxiety (e.g. talking to a stranger, or being in an unfamiliar environment) and prepare solutions/strategies to deal with those situations (e.g. establish eye contact with an authentic smile, make friends by talking about the past and personal hobbies; create a familiar environment including their photos and other personal items; have a small chat before doing tasks; give compliments to motivate and encourage participants such as "You are doing great!" or "Well done!"). All of these points resonate well with "sensitive HCI" (Waycott et al., 2015) and field work for healthcare (Furniss et al., 2014).

P1: Plan and consider early ethical issues and informed consent. (derived from study 1 - chapter 3)

Adjusting standard UCD methods
We adjusted standard Contextual Inquiry methodology and distributed observation sessions across each day and over four days in a row. An advantage in distributing observation sessions was that we could see behavioral triggers that depended on the time of the day (e.g. breakfast, coffee time, being visited by family members in the evening, scheduled activation sessions). We observed repeatedly the "rather active daytime" that were pointed out to us by caregivers. In the care facilities people with dementia living in groups of ten or twelve residents. In a pilot observation, we noted that rarely all residents were in the shared space at the same time and the few residents present were too much distracted by visitors (including the observers). A single observer, however, would have been less distracting but could have had trouble processing all the events at the active times of the day. In addition, residents' facial expressions, gestures and unclear pronunciation often leave room for interpretation that it turned out to be useful having two observers in each residential group.

P2: Adapt UCD methods, design process to residents' proceeding depletion of memory as well as cognitive, emotional and social abilities. (derived from study 1 - chapter 3)

In several cases, due to cognitive deficits, people with more severe stages of dementia had difficulties in answering questions or taking part in activities. Sometimes, they could not interpret questions properly or find words. Therefore, *P3: Do not use questionnaires or fully structured interviews. Interviews should be at most semi-structured with simple sentences.* (derived from studies 1-2)

Following a fixed protocol is hard because of short attention spans and strong mood swings in people with moderate to severe dementia. Simple tasks like choosing one of two colors on a touch display sometimes challenged people with moderate to severe dementia. Instead of asking directly, inviting them to play a game about choosing a color to decorate their bedroom worked better. Also, they easily lost their focus of attention and their motivation during the tasks: after a few trials of picking colors they quickly gave up and changed the topic.

P4: Tasks should be as simple, quick, playful and flexible as possible. Don't expect them to be able to follow standardized procedures. Prepare several activities and tasks to switch topics if necessary. (derived from studies 2-3)

In a navigation experiment with light and color, more than two-thirds of the planned trials had to be skipped because of the deteriorating condition of the participants. On some days they were too exhausted or too tired to take part, or suddenly started crying in the middle of a session. Here, the sessions had to be aborted. It was, therefore, crucial to collect and store data continuously.

P5: Failure of sessions is normal. Have backup trials and plan large time buffers. (derived from studies 2-3)

Physical, and Perception Factors
All of our participants were very old and frail, which limited the use of any device we introduced. When using a Nexus 7 tablet, for example, several participants complained that the tablet was heavy and its use made them uncomfortable after a few minutes. Besides that, they had little to no experience with modern technology and hesitated to use it. In fact, Rasquin et al. (Rasquin et al., 2007) reported that even a device with three buttons could confuse people with moderate to severe dementia.

P6: Be aware of the physical demands any data gathering device imposes on the participants (e.g. weight, size), their mobility issues (using when sitting or walking), the physical condition (e.g. agility, dexterity) and cognitive condition of users. (Resonate with (Lindsay *et al., 2012)).* (derived from studies 1-2)

From conversations with people with dementia in studies, we believe that the subjective perception and not the objective reality of what is going on with and around them has to be the focus of the development of assistive technologies. We argue that even slowing down a task significantly is to be tolerated as long as people with dementia experience themselves as being more independent, self-responsible and in control of situations. For example, participants felt that a tablet application was easy to use (perception level) even though it took a long time i.e. four weeks (practical level) for them to get familiar with it. With a different application, they managed to use features after 1-2 weeks (practical level) but used to complain about how hard it was to learn the use of the application (perception level). The first application is still recommended. In the end, people with dementia often feel a lack of confidence and are very sensitive about their independence and capabilities.

P7: Look at how things are subjectively perceived by people with dementia, rather than on how they are objectively in reality. (derived from studies 2-5)

Evaluating Prototypes

During our studies, we encountered several challenges not only regarding the selection and implementation of evaluation methods but again concerning recruitment and gaining participants' confidence. This section describes challenges and possible solutions regarding evaluation studies' planning and performance metrics selection.

Prototypes

The aspects of prototypes (seven principles in (North Carolina State University, 1997)) have to be addressed to fit the cognitive and physical states of participants. Rapid prototyping with real equipment is recommended because paper prototypes are hard for people with moderate to severe dementia to acknowledge as substitutes for real technology.

P8: Consider employing implemented interactive prototypes instead of paper prototypes. (derived from studies 1)

Study Design and Metrics

Due to the difficulties in finding participants and high dropout rates during studies, the final number of participants is usually quite small. Therefore, within subjects designs should be considered. Because of the nature of dementia being forgetful about the recent past, "carryover effects" between conditions should be less strong. If the number of participants is larger, mixed factorial designs are recommended.

P9: Due to the usually small number of participants, plan for within-subject experimental designs and also focus on qualitative data. (derived from studies 3-6)

Usually, evaluation studies measure efficiency (e.g. task completion times) and effectiveness (e.g. error rates). However, with people with dementia, these interpretations of summaries of these data should be treated very carefully (Vines et al., 2015). In our studies, the variance in completion times was very high. Participants either quickly understood the task or repeatedly asked questions about the task. Some just did anything without having understood the task at all. Even within the same task and same participant, for example, one trial could take between 3 and 200 seconds. Regarding error rates, what counts as an error should be defined carefully. People with moderate to severe dementia may conduct seemingly meaningless actions making the classification of actions as errors very difficult. Sometimes the number of help requests by the participants or the number of interventions given by researchers is better indicators of effectiveness than error rates. Again, it will be necessary to define beforehand the possible interventions that the instructor can give. Help requests, also initiated by implicit actions of the participants (e.g. making noises), seemingly meaningless actions, and moments when participants get lost are informative and should be recorded.

P10: Prefer measures of effectiveness (error rates) over measures of efficiency (completion times). A useful metric of effectiveness is the number of help requests and interventions needed to support the participants in performing a task. (derived from studies 3-6)

Regarding subjective measures, questionnaires with Likert scales do not work well with people with more severe forms of dementia (tested in a few first trials in study 2). They, for example, may give inconsistent answers when the same question is repeatedly asked. Moreover, expressing the degree of agreement in numbers (1...5 points) confused them in most cases. Again, one should watch out for qualitative data such as voluntary comments expressing satisfaction (e.g. "I got it!", "This is great!") or dissatisfaction (e.g. "Oh, no!", "I broke it!", "I cannot do that!"). Therefore,

P11: Because subjective data is difficult to get in a standardized way, also consider recording qualitative data such as comments. Alternatively asking caregivers or a second *researcher to provide quantitative feedback on their observations about the participant in the session is recommended.* (derived from studies 2-6)

8.2 Conclusion

This dissertation showed how the Intelligent Implicit Interaction (III) Environment and three systems (the guiding system, the monitoring system, and the intelligent system) could support people with dementia in long-term. Increasing the autonomy and independence of them also means reducing the stress and workload of caregivers. Moreover, web interfaces for caregivers were provided with multiple functions such as real-time monitoring (to find people with dementia quickly in emergency cases), location history replay and heatmap (help caregivers and doctors detect the issues of people with dementia early), and current activity and predicted next location/activity display. The system also automatically detects the issue, notify, and suggest solutions to caregivers. Besides, the interfaces for them inputting expert opinions were suggested as well to train the system more intelligent by a learning process. Caregivers gave feedback that they saw the potential and usefulness of having a monitoring system, location history replay, and heatmap functions. Overall, several components were developed which can be used separately or combined together for different purposes in different contexts. In the future, a full deployment of this project will be tested and evaluated in a dementia care facility.

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Appendix A

Affinity Diagram

Following is the affinity diagram with three top levels: blue dash, pink bullet, and green square (individual yellow notes - lowest level - are skipped for brevity).

- ***Orientation and navigation***
  - I am physically constrained in my locomotion
    - Standing up is very hard
    - Walking is very difficult
  - I found ways/possibilities to move, although the movement is difficult for me -> bypassing
    - Wheelchair users often move with their feet (pulling)
    - Support oneself on things like handrails while getting up or walking is really helpful
  - I have certain remarkable spots in my surroundings where I often go (maybe use for orientation?)
    - Couch on upper floor important location (sit, nap, maybe orientate?)
    - Stairs associated with "going to own bed room"
    - Going to windows or door next to inner yard when he/she wants to go outside
  - I am often restless and run around
    - Being restless
    - Running around and sometimes interrupting activities like meals for it
  - There are structural/human factors that restrict/exacerbate my freedom of movement

  - Not understanding the elevator
  - Being stopped and brought back to place although wanting to walk around
  - Difficult to open a way for users with wheeled walkers/wheelchairs due to narrowness/obstacles
- When I do not know where I am and if others do not help me, I am scared and desperate
  - If no knowledge about current location, reaction: scared and irritated
  - Not being familiar with the facility and being helpless and confused if no knowledge about current location
  - Visitors also do not know where residents belong, therefore generating even more turmoil/anxiety in them
- What we use for orientation: looking around, light, help of others
  - Asking others while orientating/searching
  - Orientating by looking around
  - Walking to the light when in sight
  - Walking along handrails
- I know where certain rooms/things are located and am able to communicate that
  - Moving to a certain location independently
  - Ability to give others information about way finding
- Caregivers take/lead us everywhere and we do not have an understanding of our surroundings/environment
  - Brought by caregivers everywhere/ no need to find locations by ourselves
  - Looking into other bedrooms (not know if we are allowed to go inside)

■ ***How I am treated by other people***

- The caregivers need to convince us to eat, to take medicine or do other important things
  - Need to be motivated to eat, drink, take medicine
  - Need to be convinced to do something we do not want to do by ourselves at the moment
  - Caregivers try to convince us to eat or take medicine like we were children
- If other people (residents, caregivers, visitors) notice my need of help or comforting, they would try to provide me

  - Caregivers try to comfort sad residents (i.e. people with dementia) by talking and establishing physical contact
  - Other residents (non-dementia) try to help us or get some help for us
- Caregivers are overworked and overwhelmed, so that they neglect us, which can be dangerous sometimes
  - Caregivers sometimes neglected us or did not pay attention which can result in us being damaged/hurt
  - Caregivers are overworked and overwhelmed and sometimes treat us carelessly
- Our meals are prepared and accommodated to us by the caregivers
  - Meals are adapted to fit our frailties
  - Food for us is treated carefully
- Others overcharge me with their behavior
  - Mental overload. Others don't treat us normally because of the dementia
  - Caregivers sometimes behave inappropriate

- ***How I behave towards other people***

  - I behave on my own way
    - I can go naked (sometimes forget wearing clothes)
    - I take objects I like
    - Farting, burping
  - I am not polite to others, when I am vexed
    - I am offensive if do not like behaviors of other residents
    - Grumbling and complaining when be annoyed by other people or things
    - Notice strange behavior (in our way of thinking) of others and comment (might be abusive) about that
  - I mimic others' expression as I cannot express myself
    - Mimicking other people's movements
    - Repeating single keywords we understood when someone else is telling something
  - I do not care about hygienically
    - Lack of bathing, cleaning

  - Putting half-eaten food back in its place or throwing it around/on the ground
- I cannot hear and/or see very well and often use body language
  - Impaired hearing or speaking
  - Expressing feelings (approval/refusal) by strong gesture/facial expression
  - Fighting back physically when we do not want something
  - Unable to express needs verbally
- I react suspicious and cautious to people I do not know
  - Acting suspicious towards others
  - Not know how to behave towards new people, being afraid
- I do not talk to other residents very often and if I do, we do not understand each other a lot
  - Not talk to other residents very often
  - When talking to others (visitors, residents) we often fail to understand our counterpart
- I cannot follow group activities (hard to hear, understand)
  - Unable to follow group activities / communication/ talks

▪ ***Loneliness***

- I am pleased when I get someone's attention
  - Happy about compliments and commendation
  - Greet back when greeted
  - Happier and (more) attentive when someone is taking time for and addressing us personally
- I want to be close to others (family, sometimes residents)
  - Enjoy visits from family or friends
  - Search for somebody who is close
  - Feel better when other residents are near
- I am lonely
  - Keep starring and commenting on observed events
  - Craving for company
  - Sad and disappointed because rarely visited

- I have no use for the other residents, because they disturb and anger me with their behaviors
  - Some residents annoy people with dementia
  - People with dementia get disturbed by others
- I am being isolated from the other residents, because I could disturb them
  - I am isolated during meals or activities because I could disturb others and would need individual support

■ ***Remaining capability***

- I can communicate my current thoughts/condition and answer questions
  - Verbal venting of astonishment when figuring something out
  - Verbal/active venting their wishes
  - Answering questions appropriately
- I appreciate when a person is new to me and I recognize her/him at the next encounter
  - Noticing new people in the facility
  - Recognizing people/remembering earlier encounters
- I still know how to behave properly (e.g. make way for someone, not being alone with the opposite sex)
  - Knowing that being alone with unfamiliar men/women is bad a manner
  - Sidestepping when seeing (spatial) conflicts
- Everything still works when I am eating and I eat very careful/thorough
  - Bending forward strongly/a lot while eating
  - Slow, but controlled and positive movements while eating
  - Able to open, close, drink from and use bottles on their own
- I keep myself and my surroundings tidy and clean
  - Brushing off dirt (of hands)
  - Tidy up/clean surroundings
- I notice changes in my surroundings, level of daylight/daytime and react accordingly/to it
  - Noticing changes of surroundings

  - Ability to orientate temporally/knowing the time of day
  - Temporal orientation depends on daylight/brightness
- We maintain movement patterns and detect them as well
  - Maintaining earlier movement patterns/recognizing intentions and things by movement patterns

- ***Engagement and vitalization***
  - We do not have any purpose/meaningful engagement, because everything is done for us
    - No interest in existing activities (TV, magazines)
    - No need to do work, because caregivers handle everything
  - We lengthen the only activities we have left (sleeping, eating) as much/long as possible
    - Going to sleep very early/sleeping very long
    - Eating for a long time
  - We sit around apathetically and only wait for the next meal
    - Sitting around alone and apathetic often
    - Sitting around in the dining area often, only waiting for the next meal
  - I like being surrounded by life/joy. It activates me and I then actively search for something interesting
    - Observing mostly moving, young, lively beings in the surroundings and reacting with joy
    - Objects can elicit joy, too
    - Happy because of getting attention and care, being more active because of it
  - We are not interested in group activities and therefore look around searching for something interesting
    - Not enough activities offered
    - Group activities not interesting because topics are irrelevant or not understandable to us
    - Looking around (searching for something interesting) due to boredom

- ***Loss of personality***

- I do not feel at home and suffer from homesickness
  - Not accepting the facility as home
  - Trying to go home because of homesickness, although understanding the need of staying in the facility
  - Not recognizing one's room as home or personal room
- I do not like that I am being patronized all the time
  - Ranting and raving to people e.g. caregivers if they do not treat as we want such as taking stuffs away from us, disagreeing
  - Drinking/eating too much or not enough -> Others regulate us
  - Caregivers stop us from doing things and redirect us to other activities
  - Caregivers control our surroundings (TV, Radio, shutters), restrict our freedom
  - Getting irritated if someone does something to us without explaining the reasons
- I do not have any private sphere
  - Wanting to have peaces, do not like conflicts
  - No possibility to be alone
- I do not take care of myself and could get dangers
  - Not taking care of basic needs
  - Could do things that are dangerous to ourselves (stairs, getting out of the wheelchair)
  - Unable to distinguish drinkable from harmful liquids
  - Potentially dangerous behavior
  - Not understanding why we cannot have things we want (on health grounds) although being told all the time
- My wishes are not met and I am no longer thought of as an independent, grown-up person
  - Family/caregivers do not understand our needs/wishes
  - Family does not treat us with respect anymore
- I realize that I am becoming more and more helpless and that I need the help of others
  - Realizing the inability to understand everything and to remember important things

- Depending on help of others and asking for help

- I am often sleepy and sad
  - Mood depends largely on weather and daylight
  - Often fall asleep, especially during or after meals
  - Feeling very down sometimes (emotionally)

- ***Preservation of own character/identity***
  - I have will but not showing it out
    - Wanting to do things without help (taking the stairs, dress)
    - Trying to leave facility
  - I have an identity and a past
    - Knowing who I am and can react when someone calls my name
    - Having personal items and pictures of family or hobbies in bed room or our place in the dining room
  - I empathize with other people and help them/look after them
    - Empathizing and not wanting to spoil anybody
    - Helping other people and giving pleasure by gifting something

Appendix B

Interview with Caregivers

B.1 Interview in Facility B

The interview with a caregiver was held on 09.01.2015 during the night shift as the caregivers do not have enough time at day (as there are only two or three caregivers per shift responsible for around 25 people). While we gathered some interesting information about the people and heard stories that helped us understand the situation of people with dementia and the caregivers better, not much information about navigation and orientation could be gathered. The main reason for that is most likely the fact that the people with dementia there are led everywhere and that (according to the caregiver) they are unable to navigate by themselves. They just walk around aimlessly very often like we also observed.
Note that caregiver seems to contradict herself sometimes, i.e. she says that they don't have a destination but later she talks about some people finding their own room by searching.

- Population in the facility
  - People in the facility? 25.
  - People with dementia? 12.
  - Caregivers? 2 at a time.
- General behavior
  - Hints for detecting the current mood of the person? smile, choice of words (less aggressive or the opposite).
  - Hints for the current "state" of dementia the person is experiencing at the moment:

    * Good day? more likely to remember things?: n/a.
    * Bad day? more apathetic?: n/a.
  - At what time of day are they active the most? Depends on the person.

- How many of them have navigation/orientation problems? Most of them, especially those in the advanced stages (according to the caregiver all people with dementia at the facility are in an advanced stages). At the beginning some people with dementia are allowed to go for a walk outside. You know that this is not possible anymore after they get lost for the first time.

- Which kind of problems? They "live in their own world": they think they are still in their normal daily life, for example some women think they still need to prepare lunch and get very active in order to get it ready before the children are coming home from school; they tend to run around aimlessly, because they can't fulfill their task or because their old daily routine cannot be applied to the new environment.

  - Forgetting the destination they want to go? According to the caregiver they don't have a destination.
  - Don't know the way to go? According to the caregiver they don't have a destination.
  - Others? They don't know where they are. They have their own world in their heads ("parallel world").

- Moving around? They have an urge to move, they sometimes do not know where they want to go; they just feel the need to look after someone/feed someone (from their past, like the husband or the children); they also run around at night, because they seem to lose their sense of time (i.e. they think they need to get up because a new day begins when in reality darkness is falling.

  - In which situation/context do they need to move around? For therapy, basic nursing and for meal time.
    * When do they move around (in the morning, after lunch or dinner) (To specific area?)? Depends on the person. Example: one person is very active in the afternoon (caregiver says that this can be caused by the ceasing of the sedative medicine this person gets).
    * Where do they want to go (toilet, kitchen, meeting room, garden)? Depends on the person (where they want to retract, they have their own haven or "holy

place" where they rest). Example: one person likes to go to the sofa; the caregiver suggests, that she used to sit on a sofa at home after work and did her handicraft, and perhaps she used to sit there with her husband (she gets uncomfortable when more than one person sits beside her). Often want to go home. Example: one person wants to go eating but tries to go outside rather than going to the dining room.

- Which places (bedroom, kitchen) do they...
  - Remember the way to? None, it is coincidence. BUT: They can find the place where a little basket with snacks is stored (on the table near the couch), but only if it is exactly in the same place it always is located.
  - Be able to find by their own? If they see for example food, they tend to eat it; if they can't see it, they don't, it is coincidence; they don't orientate but search. Example: some seem to have a destination before their eyes; they tend to find their own home if they can escape the facility: a person wanted to go home and left the facility; she went to her former flat where new people lived, opened the door with her key, sat at the sofa and watched TV. Example: Some go outside and search for their car if they used to have one.
- Which places/situations do they succeed and fail? Some can find their own room by reading their nameplates (Note: It can happen that a person reads the nameplates but forgets the own name. Seems to happen to women who remember their maiden names instead.) Some recognize their beds because of personal items the family brought.
- Degree of ability to complete task (at specific time). For example: at 8-10 a.m. they are tired, sleepy and cannot perform the task. At 10-12 a.m., they are more active and can perform task better than usual? n/a.

- How do/can the caregivers recognize, that the people with dementia needs help / get lost? Some speak out and some become restless, seemingly searching for something. If they get restless you have to investigate and inquire to find out what they want.

- How are they assisted in this situation?
  - By instructions? (Voice, image, text, show by hand?)? Our observation: caregivers try to comfort them and lead them somewhere.
  - Caregivers will accompany with them to the destination? Caregivers lead them anywhere, but as said before the people with dementia often don't have a destination so they are led to somewhere they can sit (sofa) or the dining room.

  - Do the caregivers need to repeat instructions? Our observation: they never instruct them.

- How do we know what room etc. the person is looking for?
  - Does the person tell us (if we ask)? Our observation: yes, if they are still able to ("I want to go home.").
  - Do they behave differently depending on their destination? No, they get "restless".
  - Do they intrude into other persons' rooms? One person with dementia combs all rooms and reads the name signs next to the doors (she seems to try to find her name/room).
    * Do we know why? (lost, seeking social interaction, other reasons)? n/a.
  - Do they wander around aimlessly sometimes (=> not sometimes but often)? If yes:
    * How frequently? At any specific time (day time, night time)? n/a (time of day). Our assumption: every day.
    * Anything they look for while wandering around? According to caregiver: no, they simply have the urge to move.
    * Any place they tend to calm down? Depends on the person. Some lay down no matter where (sofa, anyone's bed etc.). Others become aggressive as if they want to chase other people away. Sometimes they are able to find their own room; one person with dementia can find it on her own from time to time, another seems to be more successful in finding it when some navigation aids like photos are presented (on the door of her room).

- Actions, activities, behaviors when being engaged in orientation/navigation task?
  - Common (all or most people with dementia perform that common behaviors in specific condition, e.g. going faster if want to go toilet, touch the belly if want to go to the kitchen)? n/a.
  - Different (specific actions for specific person)? n/a.

- Would it be nice if we can track/monitor the location of people with dementia? (The caregivers can see where they are in the building, get lost or not, heatmap, data analysis). The caregiver we asked thought it could be helpful but has very big concerns about privacy; also tells us that she is strongly against video surveillance.

- Which kinds of technology could help people with dementia in way-finding? "-pictures, photos, arrows, not much, repeating information, name plates, helping them, they don't understand things".
  - Could people with dementia agree to wear some small devices like watches, necklace, etc.? In other facilities they wear wristbands or have "movement mats" ("Bewegungsmatten").
- Would it be helpful if the caregivers would not need to lead the people everywhere?
  - The caregiver already can't imagine how it would be("routine") but thinks yes, it would be helpful (less time exposure and effort in general).
  - She mentions that colors, arrows and pictures may be helpful for the people with dementia.
  - Other interesting facts:
    - people with dementia at the beginning of their illness try to hide it.
    - people with dementia might stop paying with small change (they will use large notes (inappropriate for buying e.g. groceries, because they do not want to count the money), but they will definitely expect change/they know the cashier has to give them back some money).
    - W knows how to use the elevator and can purposefully push a button (according to caregiver).
    - Most people with dementia don't know how to use the elevator and they don't understand the pictograms next to some buttons (i.e. knife and fork). BUT if they operate a button they tend to push the emergency button which is (bright) yellow. Caregiver notes that colors (like yellow or red) seem to attract some people (other buttons are grey/not distinguishable from the background of the elevator)
    - Theory of the caregiver (about choosing their favorite color): many people have a hard time deciding because most of them could not afford much in the past and therefore almost never had a choice.
    - Normally people must be addressed with "Sie"; "du" is only permitted if the person has stated it.
    - Many men urinate into flower pots or at wallpapers showing forests.
    - There is a special "night meal" for people with dementia that wake up at night and want their lunch.

        * Some forget to eat, others do not stop eating.
        * Some do not feel hunger and do not try to get food but if they see something to eat they take it.
        * The red, glowing buttons at the exits often seem to attract the people with dementias' attention so they walk to them.
        * One person with dementia lady once offended people politely like "Sie blöde Kuh" (not one of "our" people with dementia, but interesting fact).
        * The caregiver told us they are not allowed to say "Du" to a person with dementia if she /he does not offer it, but by calling them by their first name, one is more likely to reach them (BUT: ONLY for people they know as it is somewhat intimate).

- Daily activities?
    - When/where do they want to go (navigation)? W: almost always talking about going home. W: going to bed in the evening when it gets dark (sometimes even before)
    - Other activities (have breakfast at 8 a.m., have lunch at 12 a.m., sing, talk together in meeting room)? Activities are controlled by their environment (caregivers, daytime etc.) and not themselves.
    - Set of actions, activities, behaviors. n/a.
    - Need to note problems / unpredicted / unexplained, for instance below: (n/a)
        * Initiation error: unable to begin the task (want to go to the garden but don't know how to start, keep staying without any movement).
        * Realization error: get distraction or memory lapse, forget his original goal/destination -> skip some steps of his activity or leave it (abandon).(Going to the meeting-room, on the midway he forgot it and come back to the bed-room).
        * Sequence error: they are doing the right steps but wrong order.
        * Completion error: unable to finish his task (want to go to the kitchen -> found it but come back to bedroom instead of going into the kitchen).
        * Interleave plan (multiple plan): doing more than 1 plan at the same time and interleave together (want to go kitchen and toilet at the same time and cannot decide).

B.2 Interview in Facility A

- Population in the facility?
  - 2 floors in the building.
  - 27 people in total.
  - 15 people can walk by themselves. But only 8 people want to move, others only sit down.
  - 8 people use the chairs (4 wheel-chairs and 4 immobile chairs).
  - There are only 2-3 caregivers for each floor.
- How many of them have navigation/orientation problems? All of them.
- Which kinds of problems?
  - They don't realize that they are living in a health care facility. They always say like: "it is late now. Then, they want to go home, their son is waiting..." There are only 2 people know they are living here and directly asking where their rooms are.
  - They only go to dining room, bed-room, and garden (rarely with the assistant from caregiver). It could change if in the future we provide them good supports, let them live independently. The interesting point is that they can go to dining room automatically (with the voices, noises are from the dining room). So, the route they need help mostly is from the table (dining room) to the bed-room.
- When do they move around normally? After lunch or dinner (want to come back to bed-room).
- How do the caregivers can recognize, that the people with dementia needs help? Normally the people with dementia screams or tell to the caregivers something like: "I want to go home now".
- How are they assisted in this situation? The caregivers tell them the way (go straight ahead, turn left, and turn right...). people with dementia might not find their room or have to go 2-3 rounds to find out. Sometime the caregivers go along with people with dementia.
- Are there other daily problems? Hearing, wandering.

- The perspective of the caregiver supervisor? She believes the portrait picture of people with dementia (when they were young), is the most useful thing to help people with dementia to recognize their room. She wants to help the results, evidences to prove that idea by science. One idea is to do a study with portrait picture, test with color and lighting independently. If personalized color/lighting doesn't have strong impact, we could use color/lighting to highlight the picture (it should work) because sometime people with dementia don't notice about the picture.

B.3 Interview in Facility C

- Population? 85 old people are cared; 40% of them suffer dementia.
- Dementia stages? Only 5% of the people with dementia are in the severe state; the rest is divided in equal share to the mild and moderate state.
- In which situations do dementia patients have to find a specific place in their institution or orient themselves generally in the building? They are supported in all orientation tasks by the staff of the facility.
  - E.g. at lunch they are fixed seats for the old people, labeled with their names. They can't find them independently.
  - The doors of the toilets are provided with big pictures, but they still can't be found. The nurse said that sometimes the people have the right intention to go there, but they can't realize it independently. They already have trouble getting out of bed. If they make it out of bed, it usually fails at the next step (e.g. they often forget their wheeled walker when they get up and therefore fall).
- If dementia patients have to find a specific place in their institution, how do they orient themselves? Do they have to be supported by nursing staff or rely on stationary advice or technology? Or do they know it? They use staff and cues (signs on the walls or doors). But the cues don't work well.
- Is the orientation among tasks different?
- Can you tell us how the dementia patients behave with the individual tasks and what they do step by step to do the task? They are very restless when they want to go somewhere and talk to themselves. They run from one corner to the other and stare bowed at the floor. They wait until you show them how to do their task. It is very

difficult to recognize their intention for their task. You have to know them very good and you must read a lot on their face.

- How do dementia patients behave when they forget their intention, so forget what they wanted to do? The people don't know how to continue and stand still. They wait for someone who shows them how to continue their task.
- How do they behave when they get lost? Are they calling loudly or is there a kind of emergency button? They wear a necklace with an emergency button on it. But this button is pressed constantly and you don't know if it was an emergency or not. You have to read it on their face what intention they have.
- Are dementia patients affected or supported by their color, lighting, pictures or text? Color, Images, Texts are important.
- What colors do they prefer? Red, Green, ...? They like yellow and blue. Yellow is used on the floor and blue in labels. They labels should be as colorful as possible (texts in combination with colorful images works very well). The most images contain animals, because they like animals (birds, cats...). They like everything that reminds them of their past/childhood. Lighting should not be so strong, because it bothers them.
- Do the information need to be dark or light? Bright.
- Where should the information be? On the ground, on the wall, on a blackboard ...? They should be on the wall/doors. When they are in the wheeled chair, they don't look on the floor so often.
- Do their preferences for colors / lighting, etc. often change, and if so, how often? Their preferences are stable.
- If this information is different for each patient, How to use the same color for all patients? Everything should be personalized. Memories from their childhood are most present for them. Cues should only use content, they already know from their childhood. They can't understand things they have never seen before.
- Or does the color play no role at all, but is rather the contrast decisive? Color is more important than contrast.
- In what parts of the navigation process you think one could particularly support dementia because they have the most problems there? They forget their intention all the time. They stop when they forgot their intention and wait until you show them how

to continue. For example you have to remind them at fixed intervals to go to the toilet, because many of them have no urge.

- Think that dementia technology, in the form of a smart watch on the body? They already wear a necklace with an emergency button and accept it.