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Building a Care Management and Guidance Security System for Assisting Patients with Cognitive Impairment

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Abstract: The care of dementia patients presents a large challenge for caregivers and family members. Whether it is at home or in institutional care, patients have problems with spatial and environmental cognition. It often leads to abnormal behaviors such as a route recognition problem, wandering, or even getting lost. These behaviors require caregivers to keep an eye on the movement of the cognitively impaired elderly and the safety of these movement processes, to avoid them approaching dangerous areas or leaving the care environment. This paper used qualitative research methods (i.e., participatory interviews, case studies, and contextual observation methods) in the demand exploration phase and quantitative research methods in the product's technological verification phase. In this study, we implemented a three-stage service design process—demand exploration, demand definition, and design execution—to analyze the care status and route recognition obstacles of elders with dementia, to identify hidden needs as a turning point for new product innovations in care management and guidance security. This study summarizes six service needs for care management and guides the surveillance and safety of elders with dementia: (1) offering indoor user-centered guidance, (2) providing the instant location information of elders with dementia to caregivers, (3) landmarks setting, (4) assistance notification, (5) environmental route planning, (6) use of a wearable device as a guide for indoor route guidance. Based on the potential deficiencies and demands of observation, the care management and guidance security system (CMGSS) was designed. The experimental results show that the use of ultra-wide band positioning technology used in the indoor guiding system can accurately guide the behavior of patients to the right position, provide accurate information for caregivers, and record their daily behavior. The error range of this technology was not only within 42.42 cm in indoor static positioning but also within 55 cm in dynamic positioning, even where wall thickness was 18 cm. Although the device was designed for institutional care, it can also be applied to the management and care of general home-based patients.

Keywords: spatial cognitive impairment; care management; guidance security; wayfinding for dementia; service experience engineer

1. Introduction

According to Alzheimer's Disease International (ADI), globally, the number of patients with dementia increases once every three seconds, and approximately 9.9 million people suffer from dementia each year. That number is estimated to increase to 75 million in 2030 and 131.5 million in 2050. Recently, Taiwan's population has begun to rapidly age, and by September 2017 the number of elderly people over 65 reached 13.7%. Taiwan already entered an "aging society" in 2018 and is estimated to reach a "super elderly society" by 2026, when the elderly will account for 20% of the population (as defined by the World Health Organization (WHO)) [1]. According to the Ministry of Health and Welfare, by the end of 2017, the number of people with dementia in Taiwan exceeded 270,000. By 2031, there will be more than two people with dementia for every 100 Taiwanese. In 2061, the number of people with dementia will exceed 850,000, which means that there will be more than 5 people with dementia per 100 Taiwanese. In the next 46 years, the number of cognitively declined individuals in Taiwan will increase at an average rate of 36 per day [2]. However, according to statistics provided by the Ministry of Health and Welfare Commission's Plan in 2011, only 6.2% of these individuals live in institutions, and 93.8% of them live at home. Most of them do not use services or employ foreign nurses and are completely taken care of by their families (54.9%). Therefore, many families retire early, leave the workplace, or have their work performance affected in order to take care of their relatives with dementia; this has a negative impact on national economic development and productivity. In 2013, the Elderly Care Research Association of Japan proposed that the biggest topic of long-term care in the future was the care of the elderly with dementia. In order to alleviate the impact of dementia on society and families, Taiwan also provides for the medical and care needs of the cognitively declined and their families [2]. Dementia is a group of symptoms (syndromes), and the most common cognitive symptom is inattention. Concentration and memory disorders lead to depression, attempted suicide, and other psychological diseases [3]. Therefore, providing friendly treatment and a long-term care environment for the elderly with dementia is one of the important factors for the sustainable development of society.

1.1. Spatial Cognitive Impairment and Dementia

In the early and middle stages of dementia, patients often exhibit route recognition dysfunction that often leads to a loss of spatial sense, which can pose serious challenges to the individual finding their way, resulting instead in them getting lost. In the Alzheimer's Disease (AD) community, approximately 40–54% of patients have become lost [4,5]. These AD dementia patients with early cognitive impairment are prone to spatial disorientation, and this increases the difficulty of care if they exceed the normal range of activity [5].

Spatial disorientation can cause difficulties in moving throughout an environment. The difficulties in traversing for patients with dementia often occurs in the hesitation in choosing a turn [6], the ability to identify the spatial position [7], the ability to distinguish relevant or unrelated information [8], remembering why it was necessary to reach the destination [9], the ability to remain focused on the task [10], and the difficulty in finding things or places (such as the known target located in an unknown location) [11]. Capsi [12] used two nursing institutions to observe the spatial disorientation and the difficulty patients had in finding their way, studying six patients with dementia (including AD and other types of dementia, two severe and four mild). The results showed that the difficulty in finding a way through the environment in the patients with dementia included the inability to recognize how to get out of a specific place (not knowing where they were); difficulties in finding their own residence; mistaking other people's rooms for their own; forgetting their room number; not being able to read out the room number correctly; not finding the toilet, dining room, their own dining table position, and activity room; not knowing where the exit of the care unit was; the inability to understand/retain the path instructions; and the inability to find the way from one activity room to another. These are usually places in the institution where the staff will not be present, or where they do not notice that the residents are trying to go.

These kind of getting-lost behaviors put great pressure on the care of family caregivers. In addition to worrying about the safety of their relatives' lives, they also need to spend time with the police or other units to inform and assist in searching, thus disrupting the original pace of the caregiver's family life.

1.2. Spatial Cognitive Impairment Device for Dementia Patients

Studies have shown that patients getting lost can increase mental fatigue and worsen sleep problems for their caregivers [13]. For family or institutional caregivers, it is a considerable physical and psychological load. Therefore, in order to reduce the burden on caregivers and improve or assist the cognitive impairment of patients with dementia, many assistive devices for spatial cognitive impairment have been developed. For example, Liu et al. [14] used a Personal Digital Assistant (PDA) to navigate cognitively impaired patients, to explore whether texts, images, or voice cues could achieve the best guiding effect. The results showed that text was the most helpful index, since text conveys complete information to patients. For some subjects, the information interpreted via images was too complicated, which made subjects feel confused. Although voice cues were not effective, however, combined with other navigation methods, the guiding efficiency could be improved. Some studies added landmarks in their navigation systems to increase the performance of pathfinding in cognitively impaired patients and found that this kind of navigation method can reduce the pathfinding errors of dementia patients compared to giving only left or right turn information [15,16]. Studies have also pointed out that when dementia patients are seeking their way, if the number of turns in the environment is fewer, the patient's pathfinding accuracy can be improved. If using the most familiar places in the environment, such as the kitchen of the nursing home, as a starting point for going out, the chances of patients returning themselves can be increased [17]. Grierson et al. [18] used a belt as a guiding tool when facing forked roads. The belt will vibrate to indicate steering, and the results showed that patients with dementia can follow the correct direction of the belt.

However, most of the guidance aids designed for patients with cognitive impairment mainly used GPS navigation positioning or Wi-Fi positioning. The error value of GPS is approximately 20 m, and the error of Wi-Fi indoors is also up to 5 m [19]. Therefore, even if the above guidance aids are said to have a guidance function, the actual guidance effects are limited due to the large error of the technology used in position determination.

According to this, the main purpose of this study was to develop a home care management and indoor guidance service system that can not only assist cognitive impairment patients with home guidance through a road-finding service, but also be technically positioned within an error range at the centimeter level. Such monitoring and recording of patients' daily behavior can reduce the human burden on care institutions, and family members can understand patients' daily behavior at any time.

2. Methods

The research methods used in this study were a combination of qualitative and quantitative methods, integrated into three service design stages: demand exploration, demand definition, and design execution [20]. Service design integrates user experience into the product design and service in the way of codesign and cocreation, and it emphasizes a human-oriented thinking mode [21]. The service design flow and tools used in this study refer to the four service design processes and tools commonly used in the industry: the IDEO (an American design company) design process, the double diamond design process (4ds), service experience engineering (See), and the idea service design process (Idea SDP). This study integrated the above processes to explore the home care management and indoor guidance system with four service design stages: demand exploration, demand definition, design implementation, and product verification [22]. This study aimed to analyze the behavior of the elderly with cognitive impairment in the daily life of a care organization based on the service experience structure and combine the research results of the above documents to determine the opportunities to assist and guide new product innovation for patients in a care environment.

In the stages of demand exploration and demand definition, potential and unmet requirements were formed, and the design policy and product architecture of the prototype were integrated. In the process of implementation, the contextual inquiry and service molding of the service experience engineering were applied; users and stakeholders were regarded as partners in the process of product development. In the contextual inquiry, the service model and customer journey map were used to determine obstacles and opportunities when the service providers (or stakeholders) were in the environment and when there were activities, interaction, and the use of objects, through the contact points with the main users or service providers. In the demand definition stage, the affinity graph method was used to define the potential requirements. Through the integration, discovery, and exposure of opportunity points, the design policy and product architecture specifications were summarized. In the design execution stage, (1) interdisciplinary teams were recruited to carry out prototype design and functional model production, and (2) technical feasibility experiments were carried out as shown in Figure 1.

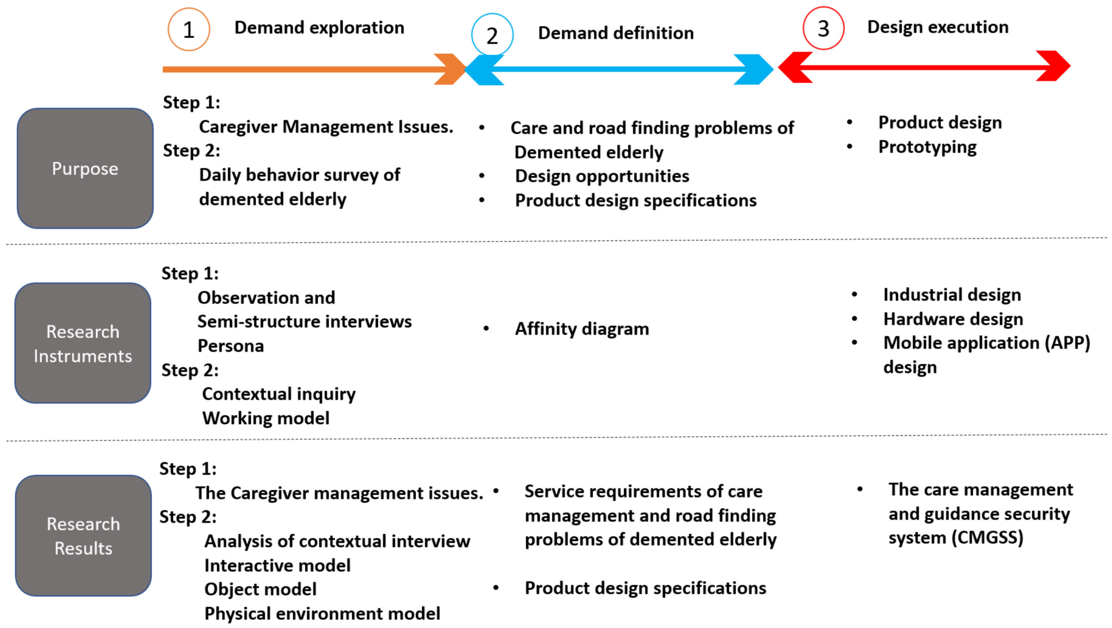


Figure 1. Research methods and process.

All participants gave their informed consent for inclusion before they participated in this study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Research Ethics Committee of National Changhua University of Education (NCUEREC-107-044), 29 October 2018.

2.1. Demand Exploration Stage

2.1.1. Semi-Structured Interview

This study was conducted in a daycare institution for the elderly. There were cognitive impairment patients and other disabled patients in the care environment. The interview was divided into two parts.

The first part was a preliminary interview on the topic of the care environment. Four staff members, one social worker, and three female caregivers were recruited by the care center. The interviews were semi-structured with open-ended questions. The topics of the interview were divided into three parts: (1) the current situation of the care environment and the interaction with patients, (2) spatial cognitive problems (i.e., route-finding problems), and (3) the daily behavior abilities of the patients.

The purpose of the second part of the interview was to establish the persona of participants based on the data collected from the semi-structured interviews and to select representatives of the relevant ethnic group [23]. Five respondents, one male and four females, with an average age of 82 years, were recruited from nursing institutions in Douliu City, Yunlin County. Each interview lasted approximately 40 min. The interview was conducted with open-ended questions. The main purpose of the interview was to find out whether the interviewees had spatial cognitive impairment or route recognition challenges in different functional spaces of the care center, such as the tearoom, restaurant, toilet, or social hall. We sought to determine whether their upper limb strength was used freely and their degree of cognitive impairment (mini-mental state examination (MMSE) score).

2.1.2. Contextual Inquiry

In this study, the participatory observation method was used for natural integration into the study group, and three selected cases were observed. The contextual inquiry observation was to collect information on the participants about their daily life, including eating, toilet, drinking, and sports and leisure activities of the participants in their interactions with their caregivers through five aspects: activities, the environment, interactions, objects, and users, and to explore the participants' unsatisfied care needs and any route recognition barriers.

2.1.3. Working Model

Three working models—the interaction model, object model, and environment model [23]—were used to analyze the contextual data and summarize the participants' various lifestyle behaviors and route recognition barriers in the care centers.

2.2. Demand Definition Stage

In this stage, an affinity diagram [24] was used to summarize user data, identify users' real potential needs, and transform abstract thinking into concrete solutions. This stage summarized the users' behavior patterns (collected in the contextual inquiry research) and the potential demand for products or services, defining the design principles of innovative services to improve care and route recognition problems.

Five experts, including nurses, electronic engineers, product designers, and dementia specialists, were recruited to form the focus group, and using the affinity graph method defined the potential needs of the spatially cognitively impaired in pathfinding and the care needs of patients with mild and moderate cognitive impairment. Firstly, the data obtained from the semi-structured interviews, context surveys, and working model were written on cards one by one and one concept was given priority. Then, cards with similar concepts or of a similar nature were sorted out through card stacking. Similar key points were summed up together and gradually merged into large groups from the bottom up. The summary by the large groups considered the whole contextual inquiry into the behavior patterns of users in the research and evaluated the potential demand for products or services so as to summarize the design policy for innovative services.

2.3. Design Execution Stage

According to the research resulting in the demand definition stage, this study integrated the barriers and demand points to establish the service opportunity and design target for the care management and guidance of the elderly with dementia. The specific product design included two categories: hardware and software. The hardware category included interactive landmarks, wearable devices, indoor positioning modules, and a cloud server. The feasibility of its positioning technology was tested, and the obstacles observed and places that could be improved were listed to observe its benefits.

2.4. Reliability and Validity Measures

In order to improve the reliability and validity of this research, the following strategies were adopted to examine internal validity, external validity, and reliability:

(1) Participatory observation (i.e., field survey) and recording: in the process of contextual inquiry, participatory observation was used to collect data [25,26], the interview content was documented word by word after recording, and the participant feedback method was used to invite the participants to discuss and comment on the interview draft and research conclusion, so as to establish the credibility of the interview content.

(2) The observation data were analyzed by the triangulation method, which combined the AEIOU (activity, environment, interaction, object, and user) analysis method with the interactive model, environment model, and object model to eliminate any contradictory behaviors in the data. In addition, the validity and reliability of this study were examined by prolonging the interview and participation time in the research site and recording the authenticity of the actual observation interview content [27].

(3) External audit mechanism: in order to ensure the validity and confidentiality of the archives, we signed the consent form with the caregiver's family and the participants before the experiment. In the consent form, we mentioned the time limit of the file's existence and the location and time effect of the recording and photo files, so as to protect from data leakage of the subjects' information.

2.5. Data Analysis

The experimental design was divided into three stages: demand exploration, demand definition, and design execution. In addition to product design, the design execution stage also included technical verification. In the demand exploration and definition stage, qualitative research and analysis were used, while quantitative research was used to analyze the technical feasibility.

1. Demand exploration stage

   a. Care management survey: The data collected from the semi-structured interviews of four caregivers were analyzed from human resource allocation, dependence on caregivers, immediate mastery of dementia behavior, spatial cognitive impairment, and daily activity area.
   b. Persona: In this study, we used the method of persona analysis [23] to select a total of three persons (2 mild and 1 moderately cognitively impaired patient) whose upper limbs could be used freely (the Barthel index was mild, provided by the care center). They were represented by cases 1, 2, and 3, respectively.
   c. Analysis of contextual inquiry: In this study, the three selected cases were observed. Through observation and interview of the context survey experiment, the interaction behavior and information about the daily activities in the care center were collected from activities, the environment, interactions, objects, and users.
   d. Behavior modeling analysis: Through the construction of the behavior model [28], the existing daily life behavior information collected from the above cases formed three working models, namely, the interactive, object, and environment models, as follows;

      (1) Interaction model: The interaction model can present a way of contact and interaction between the case, the environment, and others, and it can be simplified into a simple and easy to understand behavior model. In this study, the interaction model between the three cases and other people and the field in the daily activities of the care center was drawn, and the obstacles in the interaction process were displayed.
      (2) Object model: Through the object model, we can see whether there are any obstacles to the tools and implements used in daily life.
      (3) Environment model: It is a field of daily activities in the care center. It can describe the spatial functional layout and structure of daily behavior. According to the purpose and method of use, as well as the activity route of the case in the environment, various related objects are presented. For example, Figure 2 [29] showed the behavior of the patient engaging in gardening activities indoors and outdoors. It included indoor and outdoor planting activities, wheelchairs pushed by patients and caregivers, configuration of various gardening tools, and behavior of the patients observed during the activity.

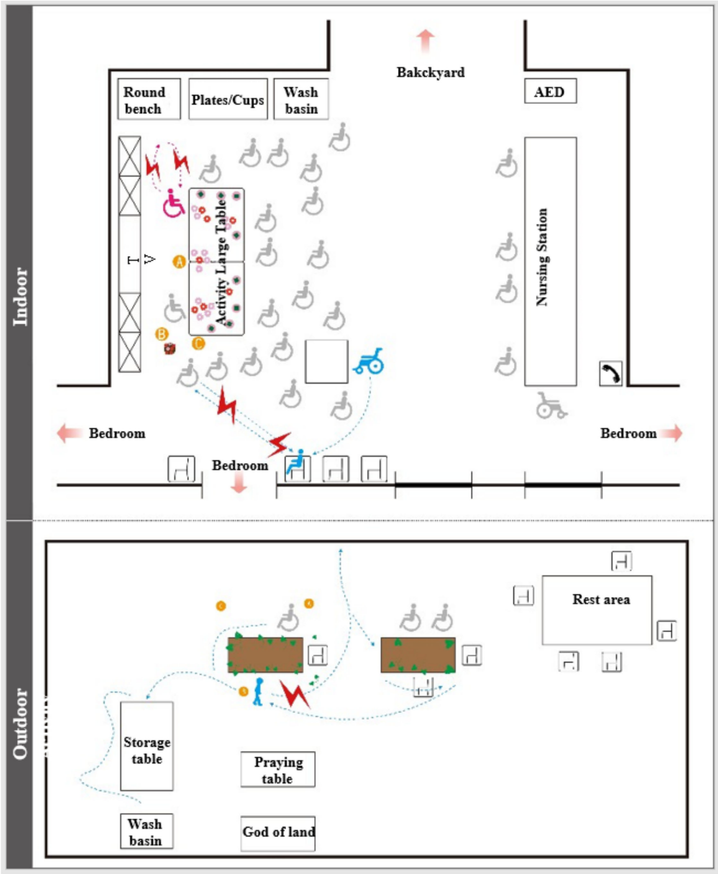


Figure 2. Example of Environmental Model [29].

2. Product verification stage:

The recording method of this experiment was mainly based on Fujiwara et al.'s time difference of arrival (TDOA) indoor positioning method [30]. As shown in Figure 3, the anchor calculates the two-way ranging (TWR) distance with the tag at different times, and the gray memory block in the middle is the area where the measurement tag is located. Due to the indoor configuration and the influence of multipath interference, the distance between the anchor and the tag often changes, just as the distance between circle A and circle B changes as shown on the right of Figure 3.

In this experiment, the position of the tag (x0, Y0) was calculated using the equation of a circle by the trilateral measurement positioning method:

The equation is as follows:

$$(x0 - x1)\ 2 + (y0 - y1)\ 2 = d12, \tag{1}$$

$$(x0 - x2)\ 2 + (y0 - y2)\ 2 = d22, \tag{2}$$

$$(x0 - x3)\ 2 + (y0 - y3)\ 2 = d32, \tag{3}$$

Applying the values of the positions of anchor 1 to anchor 3 in Equations (1)–(3), the following equation can be derived:

$$(x0 - 640)\ 2 + (y0 - 670)\ 2 = d12, \tag{4}$$

$$(x0 - 0)\ 2 + (y0 - 670)\ 2 = d22, \tag{5}$$

$$(x0)\ 2 + (y0)\ 2 = d32, \tag{6}$$

Y0 value was calculated by Equations (5) and (6), and the X0 value was calculated by applying Equations (4) and (5).

$$y0 \cong (d32 - d22 + 6702)/2 \times 670, \quad (7)$$

$$x0 \cong (d32 - d12 + 6402 + 6702 - 2 \times y0 \times 670)/2 \times 640, \quad (8)$$

Finally, Equations (7) and (8) were applied in the program. When the mobile phone receives the distance between each anchor and the tag, it can calculate the tag position (X0, Y0). As shown in Figure 3, when the tag position overlaps with the black dot marked by the floor tile, a black spot is recorded. If the value is within the set range of 60 × 60 cm, a blue dot is recorded. If it is on the boundary line, it is recorded as a red dot; if it is outside the range, it is recorded as a purple point.

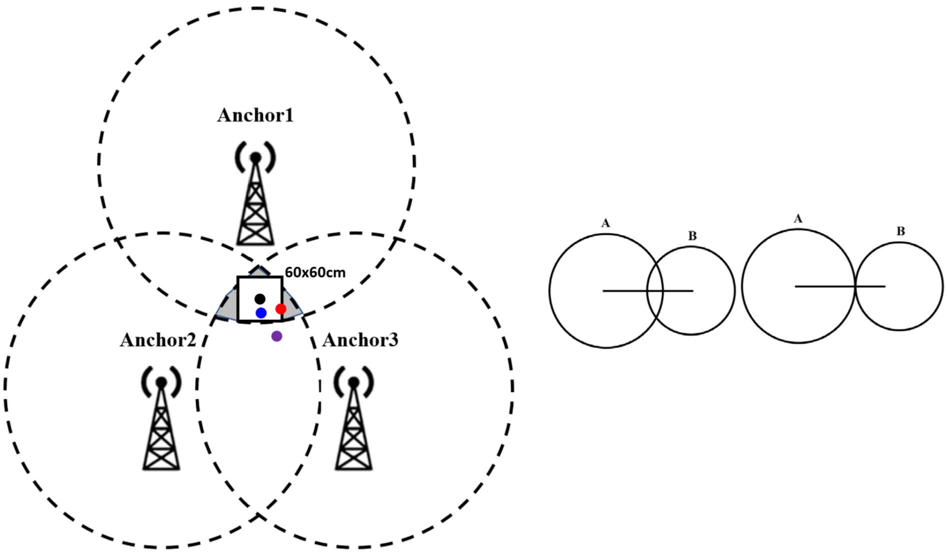


Figure 3. The distance between the anchor and the tag is calculated by two-way ranging, and the gray memory block in the middle is the area where the measurement tag is located. On the right of the figure, the distance between the anchor and the tag will change due to path interference, just as the distance between circle A and circle B changes.

3. Results

3.1. Demand Exploration Stage

3.1.1. Care Management Survey

The first purpose of the interview was to understand the current situation of caregiver management by interviewing the social workers in the caregiver center who are currently taking care of the dementia patients and other elderly patients. The second purpose was to understand the behavior of caregivers in caring for the patients' daily activities such as toileting, drinking water, dining, etc. The four interviewees included three female caregivers and one male social worker. The care management issues noted mainly involved the following five points: (1) insufficient care manpower: each caregiver was required to care for eight patients, and thus the needs of patients were ignored; (2) over-reliance on caregivers; (3) inability to immediately grasp the patient's problems because of human problems, with patients going to the toilet, drinking water, or walking on their own, resulting in care safety problems; (4) guidance labeling problems: some patients with mild dementia went to the toilet or for a drink by themselves, but they were unable to return on their own; (5) active regional cognition: assisting patients in identifying public areas and private areas could reduce the difficulty of care management.

3.1.2. Persona

This study was aimed at patients with mild and moderate cognitive impairment, and their physical and mental functions were only slightly dependent on care. That is to say, patients could use their upper and lower limbs for daily activities on their own. The cognitive impairment scale (tested by MMSE) and Barthel index (provided by the nursing center) were used for 10 participants in the nursing center. After cross-analysis of two tests, we selected three major patients with mild physical dependence and mild-to-moderate cognitive impairment as representatives for the study. The representative patients were selected according to the following four categories: (1) mild-to-moderate cognitive impairment, (2) mild dependence on physical and mental function, (3) ability to respond to speech and words, and (4) enthusiasm to participate in activities.

3.1.3. Contextual Inquiry

The goal of contextual inquiry was to collect information on the participants about their daily life, including eating, toileting, drinking, sports and leisure, and their interactions with their caregivers through five aspects: activities, the environment, interactions, objects, and users, and to explore participants' unsatisfied care needs and route recognition barriers.

Through the use of the MMSE score to measure and screen the elders [19], the study provided an in-depth observation of the patients with mild and moderate dementia and observed their daily behavior in the caregiver center, their interaction with the surrounding environment and people, and using five dimensions, activities (A), environment (E), interactions (I), objects (O), and users (U) analyzed and, finally, summarized their observations and demand points (Table 1).

Table 1. Elderly patients with cognitive impairment: contextual inquiry analysis table.

	Observation	Points of Demand
Activities	1. Wandering from time to time. 2. Needs caregiver to remind them for toileting, drinking, taking medicine. 3. Uses the public area to watch TV or chat after meal. 4. Wheelchair-bound, needs help going into the room. 5. Insufficient caregivers.	1. Prevent elders from reaching the danger zone or inform the caregiver before arrival. 2. Instantly inform the caregiver of the elders' needs.
Environment	1. Wheelchairs are placed freely in the non-parking area. 2. The monitoring of activity space is insufficient. 3. Elders used to using own room toilet. 4. Public areas and rooms are not clearly labeled.	1. Provide real-time location information for elders to care managers. 2. Reduce the attendance time of the caregivers.
Interactions	1. Elders are regularly arranged around or in the middle of the room. 2. Elders call their caregivers with gestures or language. 3. Elders use Taiwanese language to communicate. 4. Elders like to be greeted or praised. 5. When elders are unable to target the location, the caregivers will accompany them to move around.	Whether to use a device to guide the cognitively impaired elders to the place they want to go.

Table 1. *Cont.*

	Observation	Points of Demand
Objects	1. The wheelchair-bound elders are easily obstructed by chairs, wheelchairs, or other obstacles in the environment. 2. Many of the elders cannot understand the signs.	How to improve movement routes in public areas?
Users	1. Elders that rely on wheelchairs still have the ability to move autonomously. 2. Some elders need to speak louder. 3. Elders move slowly and interfere with other people's movements. 4. Elders sometimes cannot find their own rooms. 5. The elders need a caregiver to assist them in going to bed.	Inform the caregivers at any time by means of the device.

3.1.4. Working Model

This study collected data from interviews and observations using contextual inquiry and integrated the behavioral models of the three selected elderly patients with dementia to produce a convergence interaction, object model, and environment model to determine the common obstacles and demand points.

(1) Interactive model: This model integrated and depicted the interaction mode of people and things encountered by the elderly with dementia in their daily life, as shown in Figure 4. In this study, the cognitively impaired subjects sought the help of caregivers because they could not find their destination (such as the living room). In view of the occurrence of wandering events, caregivers made irregular inspections to confirm the position of each elder. However, such decision making could not monitor the movement of the cognitively impaired elderly in a timely manner and prevented the elderly from leaving the care environment uncontrolled.

(2) Object model: This model was based on the objects used by the elderly in the process of route recognition and movement, Table 2. According to the different modes of autonomous action, the walking cognitively impaired elderly rely on crutches and armrests, while others use wheelchairs. It was found that due to the settings of the surrounding corridors in the environment, the actions of the elderly with cognitive impairment were slightly hindered, and they would seek help from caregivers or push them away directly, which caused problems for other elders around them. As a reference for exploring the environment on the route, the various indicators in the care environment were not obvious, and so the caregiver was required to remind or guide the patients from time to time. For example, a pattern on the door of a patient's room, which meant that caregivers could help patients explore themselves by reminding them of the pattern on the door.

(3) Environment model: This model reduced the proportions of the care environment and marked the moving process of objects, people, etc., around them. In this model, we can see the space where the wheelchair was stacked and the rest positions of other elders in the activity space, and how this leads to moving line problems. In the process of exploration, the elderly would leave the activity space, and there were risks of moving and leaving the care environment as shown in Figure 5. (Note that in the middle of the model, there are three caregivers, and the others are in the dormitory to assist in washing, etc.).

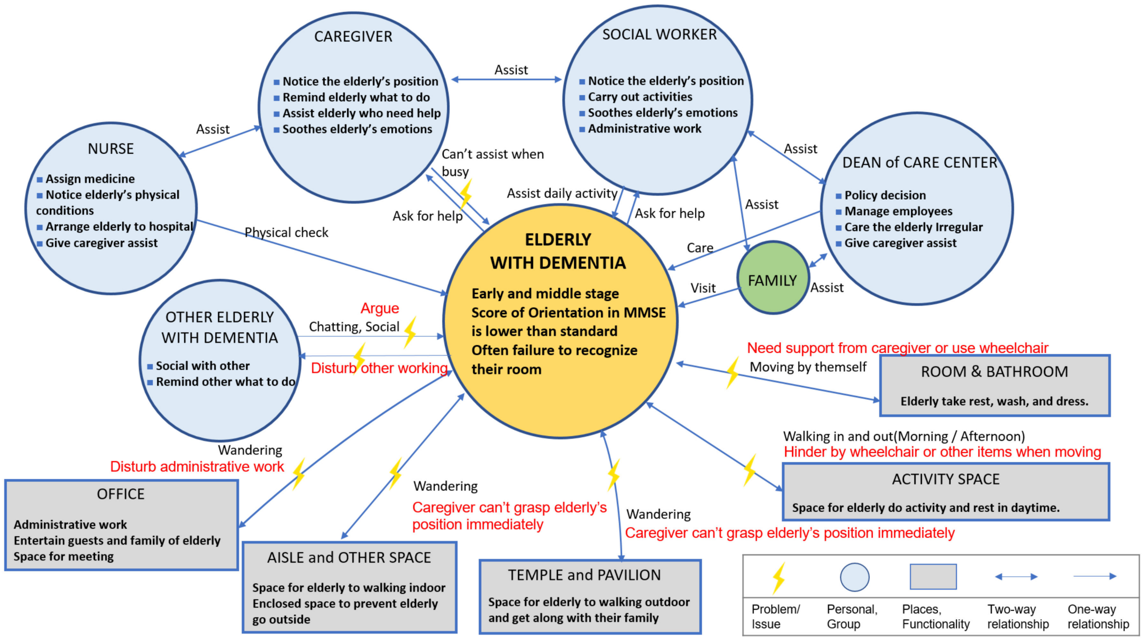


Figure 4. Interactive model.

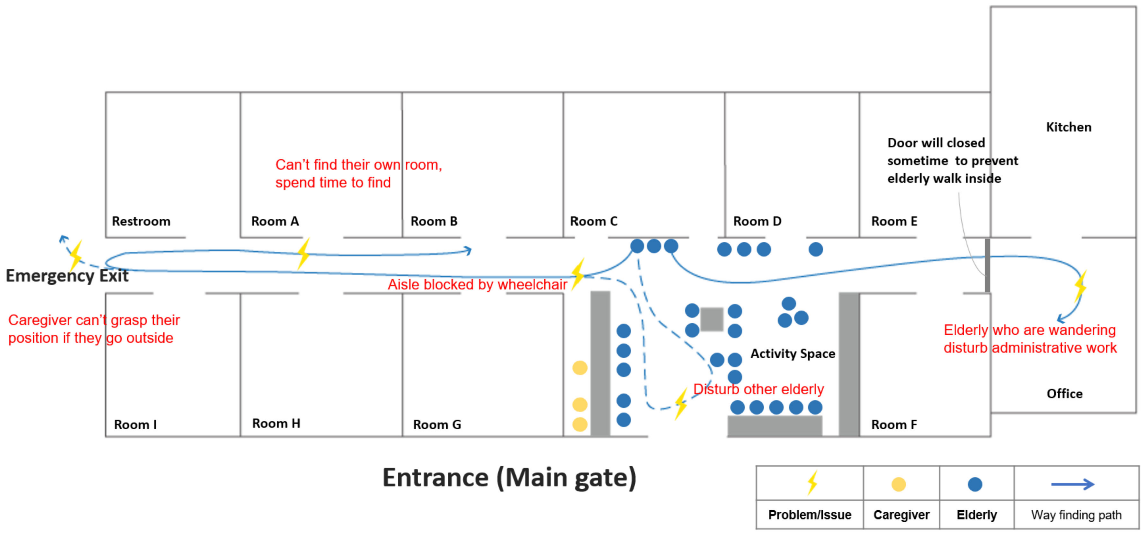
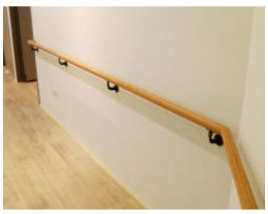


Figure 5. Environmental model.

Table 2. Object model.

Category	Name	Object	Function
Personal belongings	A cane		Used in the process of assisting walking elders to move steadily, the canes have four claw crutches. The elders sometimes forget them and leave them in their seats. Their use is hindered due to the positioning of the wheelchair in the corridor.
	Wheelchair		1. The most common tool in the care environment, used even for the elderly with walking ability during rest time. 2. The movement process was divided into autonomous movement and the assistance of caregivers. 3. The wheelchair was large in size and placed in the corridor when not in use, causing obstruction to the moving line.
Space settings	Indicator		Location-oriented reference: guiding the direction. The elderly with mobility would ask about the location of the toilet, and the caregiver would tell them the location of the sign for the elderly to explore by themselves. The placement of the instructions was combined with information on bulletin boards, which often caused confusion among patients.
	Living room diagram		Location-oriented reference: guiding the location. The elderly with dementia who had the ability to act were unable to judge the location of their own room. The caregiver would make a distinction between the design of the room and tell the elder what the pattern on the door of his room was, so that the elderly could explore by themselves.
	Handrail		The handrail provided the elderly with support, which can help the elderly share their weight during movement. In addition, the range of handrails provides a direction for the elderly to walk.
Problem arrangement		1. Wheelchair placement in the care environment hindered the movement of other patients. 2. Landmarks and indicators in the environment were not obvious. 3. Patients used clues, such as images, as references for exploration.	

3.2. Demand Definition Stage

Caregiver Management Issues

Through the focus group, the demand definition stage integrated and analyzed the conclusions of the literature discussion, AEIOU analysis points, and obstacles of the behavior working model. Through the induction and discussion of experts in the focus group, from the basic card, group affinity card, and large group affinity card, the problems of finding care management and patients' route finding were summarized from complexity to simplicity, Figure 6. A set of guidance services should be provided to assist patients in exploring.

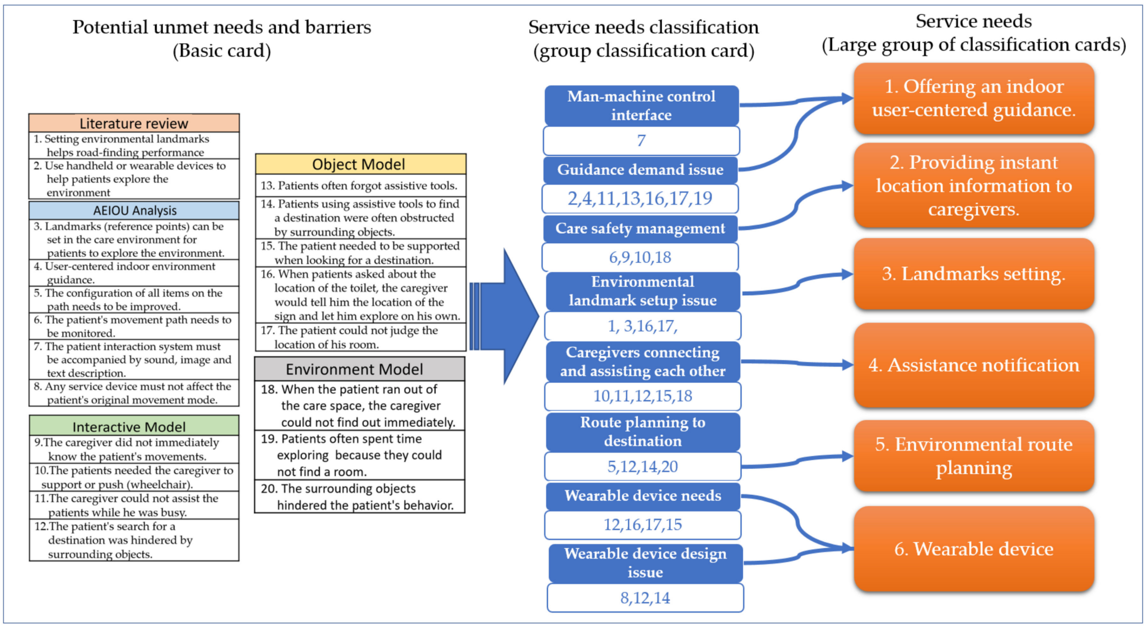


Figure 6. Induction of service needs from dementia care management and route-finding barriers.

Finally, we summarize six service needs and describe them as follows:

1. Offering an indoor user-centered guidance: A user-centered indoor guidance service, combining graphical presentation (such as tablet computers) or voice-cue direction guidance, helps elders with dementia quickly reach their goals and carry out their daily activities, such as toileting, drinking water, taking medicine, etc. It can reduce safety problems occurring during the pathfinding process of patients.
2. Providing instant location information of elders with dementia to caregivers: The caregiver can grasp the position of the self-moving elderly. The device can also combine the indoor positioning function to let the caregiver immediately know the location of elders and determine whether assistance is needed to further prevent the elderly from entering dangerous areas.
3. Landmarks setting: Clear landmarks can reduce errors in pathfinding by placing landmarks in patient's familiar places as a reference for finding their way. The design of the landmarks is presented in the form of text, voice prompts, and images that can improve the accuracy of pathfinding.
4. Assistance notification: Elders will call their caregivers with gestures or language, but they sometimes missed the opportunity for service demand. If the cognitively declined elderly use a device to inform all caregivers, they can immediately complete the needed care requirements.
5. Environmental route planning: For areas where patients often go, such as toilets, restaurants, pantry, etc., special areas for wheelchair placement should be provided to reduce the obstacles and dangers in the path.

6. Wearable device: A wearable device is used as a guide for indoor route guidance. It combines the Wi-Fi's distance signal judgment and sensor module calculation to achieve a higher accuracy of indoor positioning. The device can also work with mobile applications which can calculate the direction and suitable path for optimal route guidance.

3.3. The Design of the Care Management and Guidance Security System (CMGSS)

Based on the potential deficiencies and demands during observation, the care management and guidance security system (CMGSS) was designed for the elderly with cognitive impairments. The CMGSS is mainly used as a wearable device and a guiding tool to interact with landmarks that guide the patient to select a target location, such as toilets, tea rooms, restaurants, and bedrooms, by image, voice cues, or texts displayed on the tablet. The cognitively impaired patient is then guided by the wearable device to the target location he or she has selected. The patient's journey to the destination is recorded and uploaded to the cloud for caregivers and family members to learn about their daily activities such as drinking water, toileting, eating, and going out (caregivers and family members will be notified immediately). The CMGSS includes the following subsystems: (1) indoor guiding system; (2) guiding landmark and interactive system; (3) monitoring system (Figures 7 and 8).

1. Indoor guiding system (IGS): Guiding landmarks are set in the places where patients regularly go (restaurants, toilets, public spaces, etc.) and are linked to the guiding landmark interaction system through the near-field communication (NFC) of the smart watch (Figure 7). Patients can set the destination from the guiding landmarks through voice, image, or text message. Then, the message is sent back to the smart watch, where the near-field component uses the orientation sensor to define the destination and current location of the patients. The screen of the smart watch displays the guiding direction after the path is calculated with the current location. When the patient moves to the destination, the ultra-wide band (UWB) system Esp01S will locate the signal. After the Esp01s signal matches the destination (Figure 7), the device terminates the guidance.
2. Guiding landmark interactive system (GLIS): The GLIS, whether set in the toilet, tearoom, restaurant, bedroom, etc., is composed of a touch screen and an NFC sensor (Figures 7–10). Through the screen interface, it displays daily activities, such as dining, drinking, toileting, resting, for patient selection. The patient connects to the NFC with the smart watch. The screen interface of the GLIS presents the graph with texts options and a voice asks about daily activities. After the patients' select their desired activity by voice or touching the screen, the guiding landmark will transmit a message to the smart watch and guide the patients to their destination. When the patient moves to the destination, the smart watch senses the UWB signal. After the wireless signal matches the destination, the device terminates the guidance.
3. Monitoring system: The system uses multiple ultra-wide band devices, installed in the environment, to detect the patient's smart watch and to transmit the patient's number and position (Figure 11). Through the preset coordinates and the calculation of the triangulation method, the location of the patient in the environment is transmitted back to the monitoring screen of the care manager (Figure 11). The caregiver is notified if the patient does not act in accordance with their chosen purpose, or if they begin wandering in the environment. The monitor screen displays the overall indoor map of the care environment and the number of people in each area (room, corridor, activity space, etc.). The daily activities of the patient are recorded and transmitted back to the family members through the mobile application.

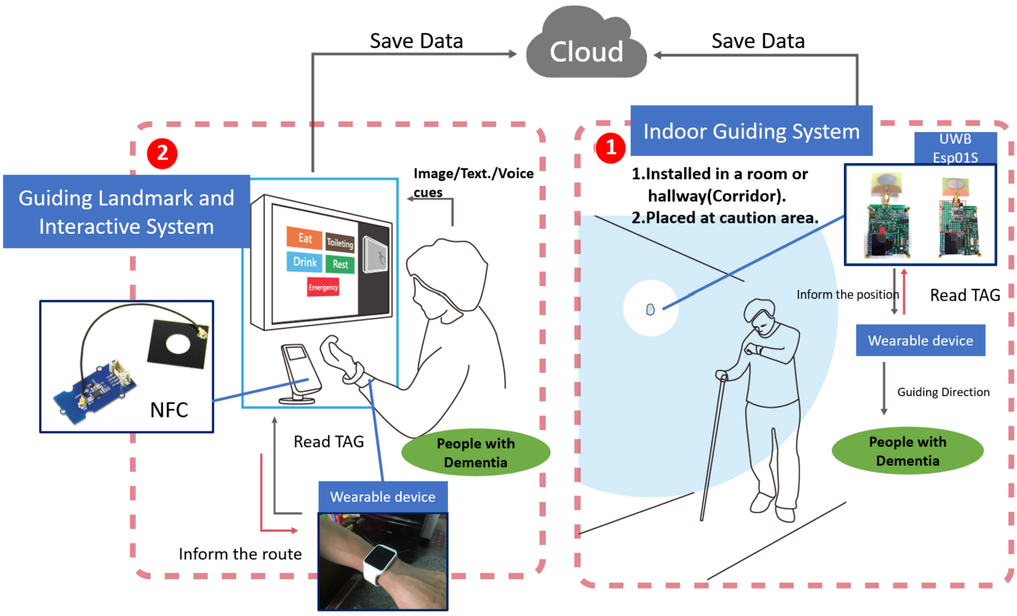


Figure 7. (**1**) The indoor guiding system and (**2**) the guiding landmark and interactive system of the care management and guidance security system (CMGSS).

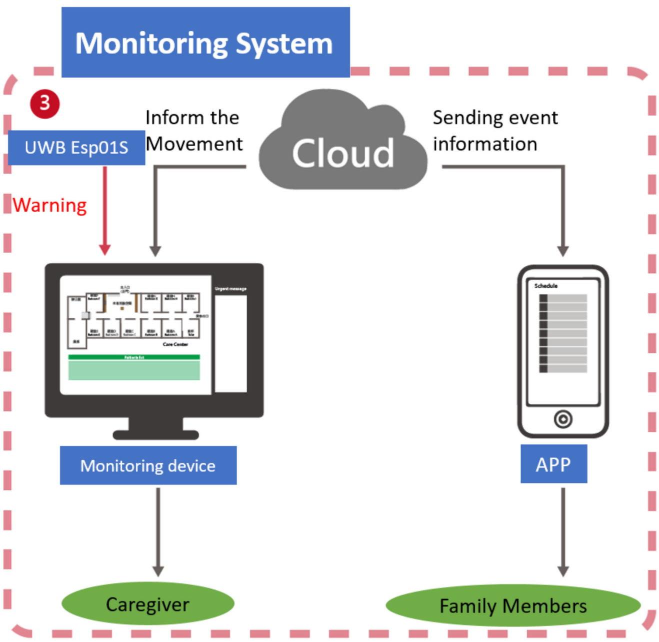


Figure 8. The monitoring system of the care management and guidance security system (CMGSS).

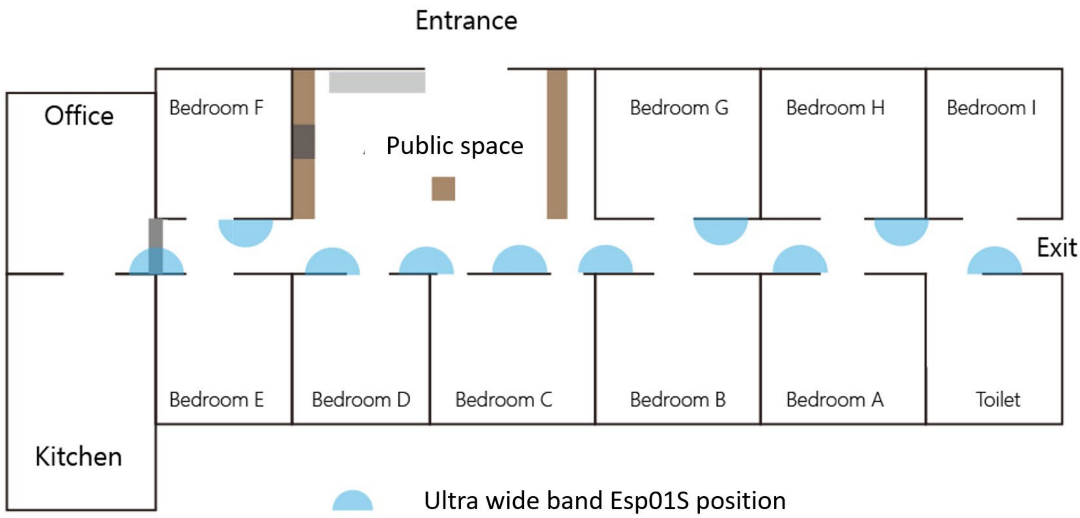


Figure 9. Examples of the ultra-wide band's position settings in the care center.

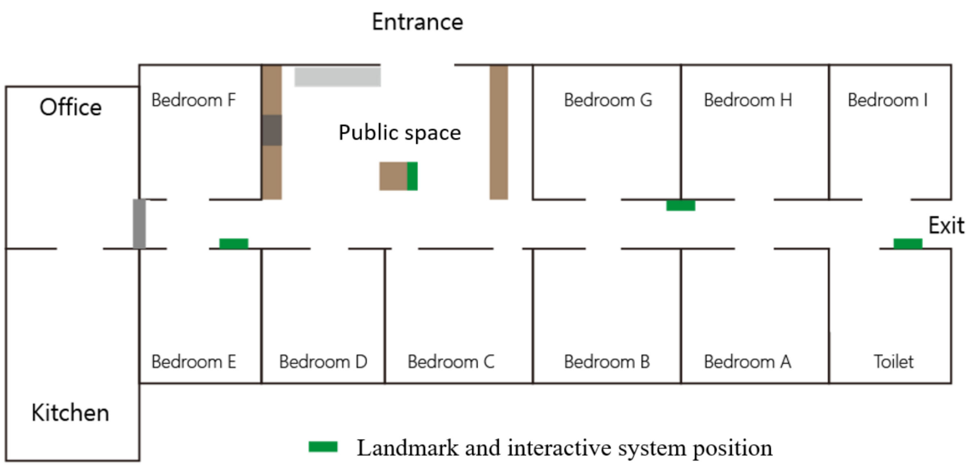


Figure 10. The guiding landmark and interactive systems settings in the care center to guide patients.

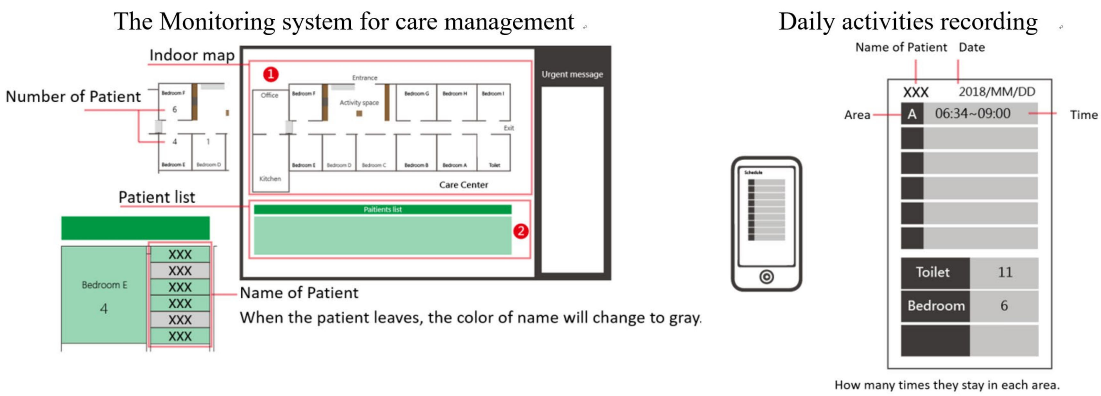


Figure 11. The monitoring system can record the patients' daily activities on screen for caregivers and also be transmitted back to the family members through the mobile application.

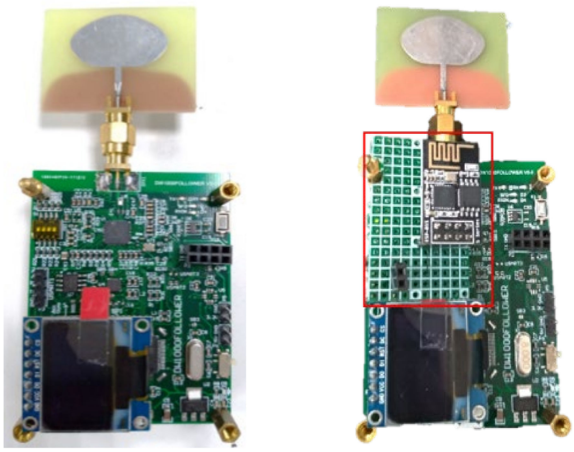
3.4. The Indoor Positioning Technology Verification Experiment

The main purpose of this experiment was to verify the accuracy of ultra-wide band indoor positioning technology and to detect whether the static, dynamic, and wall penetration of the positioning technology would affect its accurate positioning. The noise was filtered through the mobile phone program, and the location and range of each time were recorded. The required characteristics of the resulting location were that the tracking and positioning be accurate to the centimeter level, and the pulse width be far less than the path delay in order to avoid multi-path interference. Therefore, the indoor positioning and range were studied to verify whether this was the case.

3.4.1. Stimulus

1. Ultra-wide band (UWB) indoor positioning equipment

This study used UWB technology positioning system architecture [28], ESP-01S module, as shown in Figure 12. This module can provide wireless network transmission that can be set as an anchor or a tag. The anchor is set-up in an indoor space to detect the location of the tag, which is worn on the patients with dementia. The distance between the anchor and tag is calculated by the two-way ranging method, and then all the data are aggregated to the display terminal for positioning. The UWB software architecture used the Keil MKD-ARM platform, and Keil uVision 4 was recently launched, which provides a good debugging interface to help master related issues. During the experiment, UWB will transmit the positioning value (x, y) to the mobile phone and record it.



Anchor Tag

Figure 12. The ultra-wide band equipment, ESP-01S wireless network transmission module, which can be set as an anchor or a tag.

2. Experimental environment setting

The ESP-01S wireless network transmission module was set-up in the indoor field which was 670 cm in length and 640 cm in width. The three anchors were approximately 200 cm high. The tag was 130 cm above the ground, which was equivalent to the height of the user's chest. It had less multipath interference on the UWB wireless transmission. As shown in Figure 13, the tag was gradually moved back from the transmitter to six meters (six meters is the limit of the side of the experimental space). At the center point of the 60 × 60 cm floor tile, a black positioning sticker with a total of 75 black spots was pasted and acted as the static positioning detection target (Figure 13).

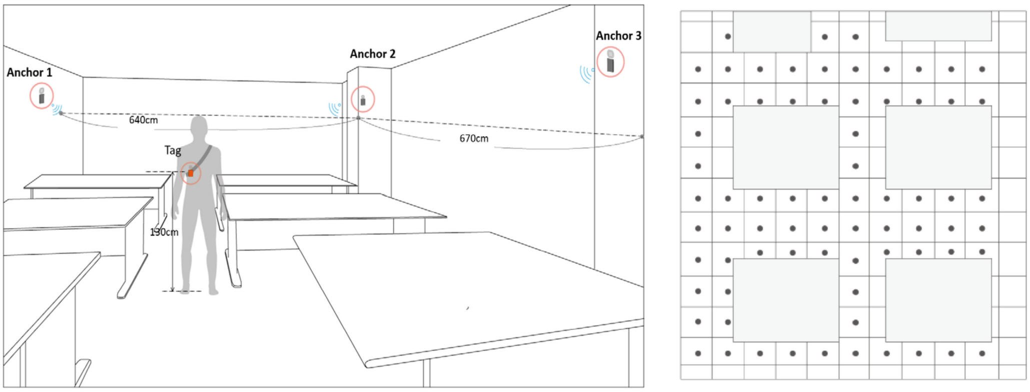


Figure 13. Anchors 1–3 were set-up in the 670 × 640 cm experimental site and installed 200 cm above the ground. The tag was approximately 130 cm above the ground.

3.4.2. Experimental Process

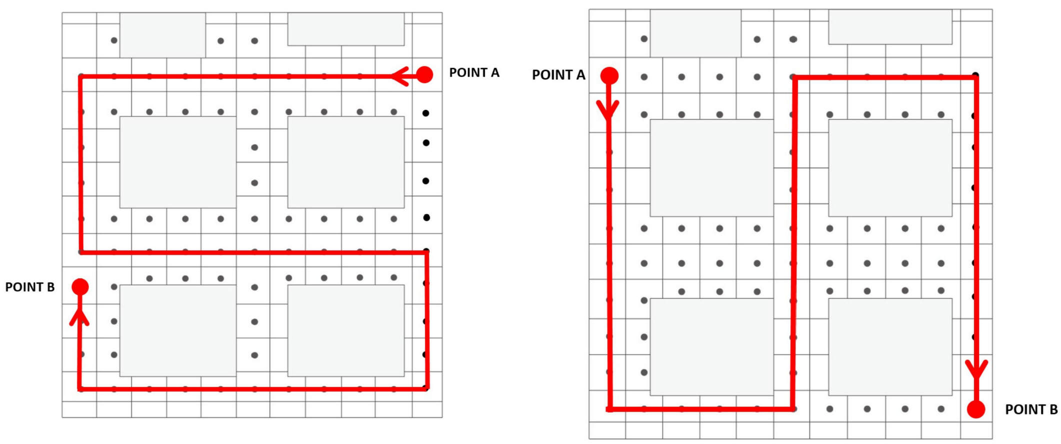
This experiment was aimed at detecting whether the accuracy of the UWB ESP-01S wireless module in indoor positioning was up to 50 cm (width on both sides of the human body). The experimental detection included indoor static positioning detection, indoor dynamic positioning detection, and penetrability detection.

1. Static experiment of indoor positioning

The experiment participant wore a label on their waist (about 130 cm above the ground) and stood on the black spots in Figure 13. They stood on each black spot for about 5 s, with a total of 75 black spots. The difference between the indoor measurement position and the system detection location was recorded.

2. The indoor positioning dynamic experiment

In the indoor positioning dynamic experiment, the experiment participant wore the tag and moved one space every 1 s along the black spots, following the path from point A to B. The three anchors detected the position of the tag passing through each certain point and recorded the indoor dynamic position. The moving path was divided into a horizontal moving path and a longitudinal moving path as shown in Figure 14.



Horizontal moving path Longitudinal moving path

Figure 14. The experiment participant wore the tag and started from point A, moving one space every 1 s, following the black spots until they reached point B. The anchor detected and recorded back the number of points that the dynamic positioning could provide.

3. Ultra-wide band penetration test

In this experiment, the penetration of the UWB was tested with two thicknesses, i.e., a wall thickness of 18 cm and a column thickness of 83 cm. As shown in Figure 15, the tag and anchor were respectively placed on both sides of the wall, approximately 130 cm above the ground, to detect the penetration of the UWB [28].

Figure 15. The UWB penetration test. Left: wall thickness = 18 cm. Right: column thickness = 83 cm. The tag and anchor were placed on both sides of the wall, approximately 130 cm above the ground to test the UWB penetration.

3.4.3. Experiment Results

The main purpose of this experiment was to verify the accuracy of ultra-wide band indoor positioning technology and to detect whether the static, dynamic, and wall penetration of the positioning technology would affect its accurate positioning using the tag and anchor base of the indoor devices.

1. Indoor static positioning results

In the indoor static positioning experiment, the tag was placed at the positioning point until the location information was detected. As shown in Figure 16, the floor size of the solid line frame and the dotted line were a more accurate reference to determine the positioning accuracy. The black points shown in the figure were the preset positions, the blue dots were the measurement positioning within the range (60 × 60 cm), the red dots represent the measured positioning pressing to the boundary line, and the purple dots indicate that the measured positioning exceeded the boundary.

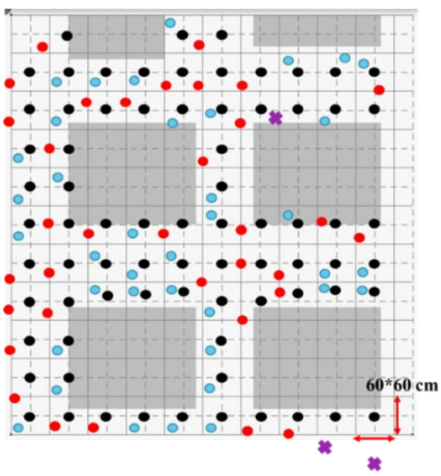


Figure 16. Shows the location detection results of the tag in the indoor static positioning experiment.

According to Table 3, after removing the purple dots, we were left with a total of 72 blue and red dots, which shows that 96% of the tag positioning was within the set range (60 × 60 cm), and the overall error was approximately 42.42 cm. The indoor positioning could be proved to centimeter level indoor positioning in accordance with the detection range set in this experiment.

Table 3. Results of the indoor static positioning detection.

Category	Black Dot	Blue Dot	Red Dot	Purple Dot
Quantity	75	38	34	3

2. Indoor dynamic positioning results

In the dynamic experiment, the experiment participant wore a tag and moved one space every 1 s along the black spots, from point A to point B along the path. The position of the tag passing through each specific point was detected by three anchors and the indoor dynamic position information was recorded. Table 4 shows the experimental results of the indoor positioning dynamics. The results show that the average detection result was 63 red dots horizontally and 73 red dots longitudinally. The results show that the UWB indoor positioning technology can still be detected within 60 × 60 cm even under dynamic movement, and that the number of positioning points in each test was more than 55.

Table 4. The positioning results of the horizontal and longitudinal moving path detection experiments.

	First	Second	Third	Average
Horizontal moving path	63	57	66	62
Longitudinal moving path	76	83	60	73
Unit: cm.				

3. Ultra-wide band penetration testing results

The thickness of the column was 83 cm, and the wall thickness was 18 cm. As shown in Table 5, no matter whether the door was closed, the measured data of UWB under the wall thickness of 18 cm were not too different, which shows that the penetration of the UWB under a wall thickness of 18 cm is not a problem. However, when the wall thickness is 83 cm and the label distance is approximately 50 cm, the weaker the penetration, that is, the greater the error between the measured value and the actual distance (Table 5). Therefore, in this case, anchor detection and positioning can be installed to improve the accuracy.

Table 5. Ultra-wide band penetration test results.

Category		Original Distance (cm)	Error Range (cm)
Wall thickness of 18 cm	Open door test	63~70	2.4~2.6
	Closed door test	63~69	2.4~2.7
Wall thickness of 83 cm		600~642	−503~−504
		260~520	−244.6~−249.6
		254~269	−122~−122.6

The experimental results show that the use of the UWB in the indoor guiding system can accurately guide the behavior of patients with dementia to the right position, provide accurate information for caregivers, and record their daily behavior. The error range of this technology is not only within 42.42 cm in indoor static positioning but also within 55 cm in dynamic positioning, even with 18 cm of wall thickness. However, when the wall thickness is 83 cm, the positioning accuracy is reduced.

4. Discussion

In this study, we conducted in-depth research into the service needs of patients with cognitive impairment in institutions through the context insight stage. Their daily behavior was observed and recorded, and interviews were presented through the five dimensions of AEIOU. Through the interaction model, object model, and environment model, and the potential demands and route recognition of the elderly with dementia in care and were deduced. This section discusses the necessity of a home-based care management and indoor guidance service system from two aspects: the need to assist with route finding for cognitively impaired elders and to reduce the burden of care management for caregivers.

4.1. Guidance on Route Finding

From the perspective of the daily activities of the three cases in the care center, it could be seen that patients with mild-to-moderate cognitive impairment do have spatial cognitive impairment [4,5], and they were unable to reach their destination [31]. This was demonstrated in scenarios such as patients wanting to go to the toilet but not knowing how to go, wanting a drink of water but not knowing how to get to the tea room (Figure 4), or wandering in the hallway as they didn't know where their destination was (Figure 4). These abnormal behaviors included walking and even getting lost due to obstacles on the route leading to loss of path recognition [4]. In the early stages, cognitively impaired patients are purposefully wandering, driven by goal-directed behavior [32]. They can identify landmarks, but they cannot effectively find their destination. Therefore, this study used texts, images, and sounds to achieve the best guidance effect [14], such as landmark and interactive systems, which can interact with landmarks via screens through wearable devices and present daily life events, such as eating, drinking, resting, and going to the toilet, so as to guide them to the corresponding known places (restaurants, tea rooms, toilets, public spaces, etc.), improving route finding performance [15,16].

4.2. Care Monitoring and Management

From the interviews with caregivers and insights into the context (refer to the care management survey), the spatial cognitive impairment of dementia patients, resulting in route recognition problems, and even loss of way, often leads to an additional burden of care on caregivers or their families, resulting in mental distress for their family members [33] and excessive dependence on caregivers who need to monitor patients at all times. The mobile phone app and the wireless positioning system create an environment in which the patient location can be detected via the patient's smartwatch. The triangulation method was used to calculate the position of the patient in the environment and this information was sent back to the monitoring screen of the nursing manager.

If the patient did not move forward according to the selected purpose or walk in the environment, the caregiver would be informed. The app provided family members of the patient with the patient's daily schedule. The main screen would list the time and area where the patient had been and the number of times the patient had used the interactive device. The monitoring system used ultra-wide band indoor positioning technology that can improve the precision of indoor static positioning to within 50 cm, and dynamic positioning to within 60 cm. Even where the wall thickness was 18 cm, it can still be accurately positioned. This monitoring system can reduce the burden of care and can be used not only for institutional care but also for home care.

5. Conclusions

The purpose of this study was to improve the burden on caregivers and assist the spatial cognitive impairment of patients with dementia. According to the six requirements, we developed and produced a prototype of home care management and indoor guidance system and verified it. We used a more accurate indoor guidance and positioning technology (ultra-wide band) and guided patients to their own destination through indoor guidance services, helping caregivers to monitor their actions so as to reduce their care burden. This system mainly used smart watches as a guide interactive tool, which could connect to guiding landmarks to select target sites and directed them to reach their goals via the smart watch. The process of patients arriving at the target place was recorded and uploaded to the cloud for caregivers and family members to understand their family member's daily life behavior.

However, the research was only aimed at the accuracy of indoor technology positioning and did not conduct a verification experiment to apply this technology to a developed care management and indoor guidance system. An actual experiment of the wearable device used with patients with cognitive impairment has not been formally conducted. Actual clinical practice will be carried out in the future to verify the effectiveness of the care management and indoor guidance system. Although the device has been designed for institutional care, it can also be applied to the management and care of general home-based patients with cognitive impairments.

Author Contributions: All authors contributed to the paper. C.-C.S. investigated and analyzed data; W.-K.W. and Y.-S.S. designed and developed the wayfinding system and the implementation of the UWB positioning experiment; W.S.-W.T. supervised, planned, and wrote the original manuscript, and acted as a corresponding author. All authors have read and agreed to the published version of the manuscript.

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