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Research on Indoor Spatial Behavior Perception IoT Smart System for Solitary Elderly at Home

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Abstract: This research aims at contributing to a seamless, integrated technology intelligent living system for solitary older adults at home. The capacitive intimate sensing module, that can be easily pasted to the existing home space element surfaces, daily objects, or home furniture, such as a wall, door, stairs, a chair, cabinet, table, sofa, etc, is developed in this research. This 30 × 30 cm sensing module can actively sense people's physical behaviors and body movements in spaces. The signals acquired from the sensing modules in indoor spaces will then integrate into the controller system through the IoT application and logically define the behavior classification. From the preliminary analysis of observing the 80-year-old elderly subject's daily activities, the movement trajectory of the 'Move–Stop' pattern is found. There will be a touch (T) and a touchless (TL) relationship between the body and the space elements or objects. The touchless or non-contact intimate relationship also can be divided into two types: 1. the body 'Passes by' (P) the spatial elements or objects, and 2. the body 'Stays' (S) in front of the object and performs activities. This research pasted eight sensing modules on nine objects in six spaces. Finally, the specific actions and life pattern can be recognized and analyzed through the developed IoT spatial behavior smart system and provide the customized intelligent application function for the elderly.

Keywords: elderly; smart home system; IoT application; spatial behavior; NUI-based sensing system; ubiquitous design; interaction design; capacitive sensing

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1. Introduction

1.1. Background

With the rapid development of the Internet of Things (IoT) and Information and Communication Technology (ICT) technologies in the digital age, many smart living products or smart home integration systems have been applied in daily life. The application of technologies or products such as wearable devices, smart home systems, and the IoT has changed the living behaviors and functions of the original home objects. The main tasks of developing these smart products or IoT systems include a remote control or daily life information collection to provide intelligent feedback. The primary purpose is to improve the quality of life or health care application. Wu and Pillan [1] analyzed successful smart product cases on the market. They concluded that the factors to be considered in the user experience of smart products include: the physical design of product objects, material quality, usability, service technology, and interface design. At the same time, researchers [1] proposed that three essential design strategies must be considered when designing next-generation smart products: connecting existing life behaviors, simplifying operation methods, and customizing function settings. Especially when creating a technology product suitable for the elderly, maintaining the original life behavior or habits in design, and providing intelligent life assistance by the technology attached to the actual living object will cause a good user experience and improve quality of life [1,2]. Therefore, as to how to integrate seamlessly, based on the elderly person's original living behaviors or habits at home, integrating smart assistive technology into daily life and improving the quality of life are the critical issues for this research.

At present, the smart life technology assisting products on the market often only focus on technology and ignore user experience. In fact, in the design of technology-assisted products, in addition to technical or functional considerations, we should also care about the interaction and usability between "people" and "objects". In the book "The Meaning of Things", well-known psychologists Csikszentmihalyi and Rochberg-Halton [3] combined the theoretical basis of psychology and the analytical tools of sociology and pointed out that people will like objects in daily life. Because an object is related to one's living memory, it will cause people to recall the past, association, or memory. "Home" is the origin of human memory construction, and the "objects" in daily life become the vehicle of these living memories. However, many technological auxiliary products of smart homes are still mainly based on functional considerations and are less designed from humanistic care, such as living habits, emotions, and memory.

In 2015, the author proposed the design concept of "Memory of Things" (MoT), which was mainly aimed at the elderly who are used to old life objects and explored the relationship between people, objects, and spaces. Then, through daily-life objects familiar to the elderly and rich in living memory, with the assistance of social networks and technology, the author aimed to strengthen emotion, memory, and narrative, and finally propose a thoughtful interactive product design that is more adaptable to the elderly [4]. This research will extend the concepts of people, objects, and spatial relationships emphasized in the author's previous research, and then more rigorously explore the relationship between "human body" and "everyday objects" when carrying out different life behaviors in the home living space. More in-depth analysis and research is appropriate concerning the relationship between "spatial elements" and the hope to further propose home smart living technology-assisted solutions that are more suitable for the elderly, especially in discussions of the interactive mode.

The Natural User Interface (NUI) advocated by Professor Steve Mann mainly emphasizes interacting with computer information in the most natural way of human beings, rather than using a keyboard or mouse as an input interface. These natural behaviors include gestures, body postures, facial expressions, touches, sounds, etc. [5]. NUI has become an essential interactive interface design trend in interactive design research since 2006 [6]. In the tactile interaction design of these natural behaviors, the Tangible User Interface (TUI) emphasizes the interactive behaviors generated by the physical environment and digital information and the tactile relationship with objects through more natural grasping, operation, assembly, etc. It can operate between a virtual domain and reality more freely and intuitively [7]. The Organic User Interface (OUI) proposed by Holman et al. in 2008 emphasizes a flexible and tactile interface and an interactive interface that includes sensing and actuation capabilities, combined with the daily environment and behavioral patterns. It can provide a more intuitive interaction [8]. For the future home design of Ubiquitous Computing, Nabil proposes OUI interiors through OUI design combined with interior space, which mainly converts daily objects in interior space, such as lamps and mirrors, into interactive artifacts [9].

In addition to the tactile interaction of direct contact with physical objects, there is also a non-contact distance relationship between body motion behaviors and physical objects. Based on the concept of Proxemic between people proposed by Hall, Greenberg et al. [10] extended the idea to the distance relationship between people and physical objects (digital and non-digital carriers). They emphasize the close relationship between people and physical objects in the Ubiquitous Computing (Ubicomp) interaction research and propose the concept of intimate interaction, called Ubicomp Proxemics. This concept has five dimensions: Distance, Orientation, Movement, Identity, and Location. Non-contact or touchless interactive interfaces have flourished in recent years and are primarily used in public places. Touchless interfaces are gradually becoming necessary to avoid physical contact, especially during the COVID-19 epidemic of the past two years [11].

1.2. Aims

Based on the concept of NUI, this research explores how we effectively use the natural contact or non-contact interaction between the physical behavior and object relationship in daily life as an interactive mode of sense, despite using the existing input technology. There is a close relationship between the human body and space or objects, but what are these close relationships? How to activate the current space or object so that it can detect the presence and behavior of people from contact to non-contact interaction is the question that this research hopes to explore.

In addition, from the perspective of Ubicomp, this research analyzes the contact and non-contact close interaction between people and objects in the room through the natural movements and activities of the body in everyday life. Based on the dimensions of Ubicomp Proxemics research proposed by Greenberg [10], this research explores how to combine spatial surfaces and living objects with additional sensing functions to perceive body movements and behaviors in space and provide feedback to smart living assistance. This research hopes daily life can be implemented into smart assisting functions through simple easier-to-use sensor elements or modules embedded into spatial interfaces or living objects without changing living behaviors or replacing household objects.

The aim of this research is to design a smart living system that solitary older adults can easily use through touch/touchless interface design.The sensing system can be seamlessly integrated into an older adult's home and improve life assistance. A sensing module, namely Presence Stickers, is developed. These can be easily pasted to the existing space elements (wall, floor, door, stairs) or home furniture (chair, cabinet, bed, table, sofa, etc.). These 30 $\times$ 30 cm sensing modules can actively sense people's physical behaviors and body movements in spaces. The signals acquired from the sensing modules in spaces will then integrate into the controller system through the IoT application and logically define the behavior classification. Users can define their feedback, such as switching on/off home appliances, lights, electric fans, air-conditioning, and other daily applications.

2. Related Works

2.1. Spatial Behavior Perception Interaction Design

In the Human–Computer Interaction (HCI) design applications, the sensors collect environmental information or perceive human behavior, such as environmental information, location, activities, behavior, etc. Most interactive design applications of spatial behavior perception collect, analyze, and calculate information from the object-oriented and activity-oriented aspects and give responses or assistance. Localization sensing is one of the applications of environmental information sensing; it focuses on the design and application of finding, identifying, and perceiving between "people" and "objects" [12,13]. In addition, the research on activity-oriented sensing design focuses on auxiliary information in activities. It uses various interactive sensing devices throughout the space to sense human spatial behavior and then integrate and identify through this sensing information. Feedback, response, and control concerning users' living are needed to form an intelligent home space [14,15]. Whether it is the spatial behavior interaction design of position sensing or activity assistance information, it is the application of sensors to combine life events in the space in living space automation and intelligence.

The Sensible Energy System (SENS) by Chang et al. [16] is designed primarily through the behavior perception of users in space. Using the Network Sensor Fusion Approach, the collected users' behavior data from their coming in and out of the factory environment and their use of various machinery, as well as sensing values such as energy consumption in space, are provided to a visualized information application for users' plant energy consumption. This is achieved by integrating and computing the information of the user behavior and energy consumption from IoT. A Smart Energy Environment based on user behavior is thus built to achieve a usage scenario for efficient use of space energy.

Chang et al. [17] also developed a slow sensor for the behavior of the elderly in home gardening. The study suggested three steps to develop a slow sensor: 1. identifying everyday objects and behaviors as behavior settings; 2. placing sensors in the objects related to behavior activities for creating an information collection and system model for behavior sensing; 3. information processing and behavior classification. The study collects the information by using the behavior of the elderly in gardening and making plants as objects embedded with sensors. Long-term behavior observations and collections of the data being sensed are used to test the slow sensor system under development and verify its feasibility.

2.2. IoT-Based Smart Environment for the Needs of the Elderly

Smart Home Assistance developed with IoT technology has already received many results, systems, or products from relevant research and development. It is more commonly used in the control of living conditions in interior space, such as air quality, temperature and humidity, energy consumption, lighting, control of household appliances, etc. [18–20]. Many studies on interior space quality monitoring systems have been developed by linking IoT applications through Arduino and Raspberry Pi Microcontroller boards for home monitoring, improving the quality of life at home, and physical and mental health [19–21].

As the world is moving toward an aging society, IoT-based smart home applications for the elderly's needs are becoming an important research issue. Fall detection is the most common design for indoor living behavior-monitoring systems [22–24]. Gharti [24] utilized wearable devices and cameras for AI image pose recognition and object detection. The posture of movement of the elderly is computed to determine the posture of fall. The emergency rescue message is then pushed to a cell phone. The need for "aging in place" also makes research on home safety more important. Research on indoor localization based on IoT system integration includes application research using the technologies such as infrared sensing, ultrasonic, floor pressure sensing, camera image recognition, wearable devices, etc. [12,13,18,22,25]

Nath and Thapliyal [22] proposed a voice-based location detection system to assist in the recognition and positioning of multiple elderly people in nursing organizations. Such a system sets up multiple ultrasonic sensors in space to sense the position of the human body. In addition, the tags worn by the elderly are used for personal identification. When ultrasound senses a human body, position signal and personal tag information are sent simultaneously with IoT integrating the information being sensed. The caregiver can simply ask the voice assistant, Amazon echo, for the position of a specific elderly person, and the relevant information can be given by Alexa voice assistant.

2.3. Capacitive Sensing Study on Behavioral Motion Sensing

For the sensing technology, the most commonly used touch sensing on the market today is pressure sensors, non-contact infrared sensors, capacitive sensors, image recognition, etc. Capacitive sensing not only can sense the contact of the human body, but also non-contact body posture at a certain distance. Compared to other sensing technologies, capacitive sensing offers the advantages of low cost, low energy consumption, being tag-less, being wearable-less, long-term sensing, and easy implementation. It is also often used in gesture-sensing research and applications for long-range capacitive indoor localization [25].

Touché [26], developed by the Disney Research team Sato et al. in 2012, is an innovative design that uses capacitive sensing technology as human touch sensing and can perceive subtle body movements. Touché can have the same sensing sensitivity for objects of different scales, such as pens, doorknobs, mobile phones, and tables. Gesture recognition can also be recognized through these objects.

Buck and Aherin [27] applied Capacitive Proximity sensors to conduct research on human presence sensing, and pointed out the scope of application. Experiments implemented through the sensor are used to study the following sensing characteristics: 1. sensing sensitivity of different materials, 2. sensing distance, 3. the sensitivity influence of different sensing configuration designs, 4. the sensing effect when water or dust is on the sensor. Through the research of these Capacitive Proximity sensing characteristics, Buck and Aherin proposed that Capacitive Proximity sensors can be applied to the farm tractor as a safety device such as emergency switch control. The sensor can be placed on the user's seat cushion, floor mat, and other places where the user makes contact with the tractor to control the safety control mechanism such as engine shutdown.

Strohmeier et al. [28] used capacitive and resistive sensing ability to develop a zPatch sensor, which is made of soft fabrics and can provide close-range hover sensing, touch sensing, and pressure sensing for various applications. zPatch can be attached to body clothing for motion behavior detection. The research application of the zPatch sensing system is for text input, game motion input, and music player motion input.

Porins and Apse-Apsitis [29] conducted research on the geometric and size design of Capacitive Proximity sensors, and discussed the influence of the sensor's configuration design on the sensing distance. The research used different shapes for sensing value, including circle, square, and rectangle. Research results show that the square with area 0.05 m^2 and a separate distance of 27 mm can sense up to a distance 48 cm. If the sensing distance wants to be at least 50 cm, the surface area of the sensor should be smaller and the plate separation distance should be as low as possible.

Tariq et al. [30] developed a 16 m $\times$ 16 m long-range capacitive sensor that can sense the position of the human body within a 3 $\times$ 3 m space. Meanwhile, the spatial data collection and the filtered dataset can be trained by a neural network to address the problem of computational performance that capacitive sensing inherently faces in long-range sensing.

This research will take advantage of capacitive sensing, which can sense from proximity to contact, and develop an IoT sensing system that interacts with natural behavior.

3. Materials and Methods

This research develops an NUI-based sensing system design by analyzing behavior patterns. It uses interactive natural daily behaviors to painlessly integrate technology into the existing living space of the elderly to provide intelligent assistance and improve quality of life.

In the previous study, the author of this paper proposed the design process of the Emotional Tactile Interaction [2], emphasizing that human daily activities in the spatial environment can be understood in more detail and with greater insight by observing the associativity among five dimensions: Activities, Environment, Interaction, Object, and User. Such a method of observation and documentation is called A.E.I.O.U. Technology can then be attached to or embedded into these associated and familiar objects or spatial elements that appear in daily life. These objects and elements are then activated into smart objects as input sensor devices while human interactive behaviors become natural, intuitive and initiated actions. At the same time, from the author's previous research on MoT [4], it is understood that the elderly have an intimate relationship with their familiar household objects in daily life. Based on the above-mentioned research, this study also uses the observation and documentation method of A.E.I.O.U. The focus of the study is on the close relationship between objects and the body of an elderly person living alone who performs various regular daily activities in the home environment. The main points of interest for each dimension are shown in the following A.E.I.O.U framework diagram of this study (Figure 1):

- **A**—Activity: The daily activities of the elderly, including sleeping, eating, cooking, washing dishes, watching TV, sports, gardening, going to the toilet, bathing, etc.
- **E**—Environment: Various spaces in a home environment, such as entrance hall, living room, kitchen, dining room, rooms, toilet, study room, stairs, etc.
- **I**—Interaction: Frequent interactions between the body of the elderly and the objects or spatial elements; intimate interactions at various distances (touch, touchless) and under various situations. Based on the intimate relationship of the elderly with familiar objects/spaces, and the characteristics of his/her daily, repetitive, and regular life behavior, the study explores the characteristics of these intimate interactive relationships as criteria for triggering sensing action.

- **O**—Object: The objects in a home environment which are associated with the activities the elderly participate in, such as daily living objects (furniture) or spatial elements (walls, doors, stairs, etc.). These objects will be embedded with the technology of sensing and activated as smart objects.
- **U**—User: The elderly (body).

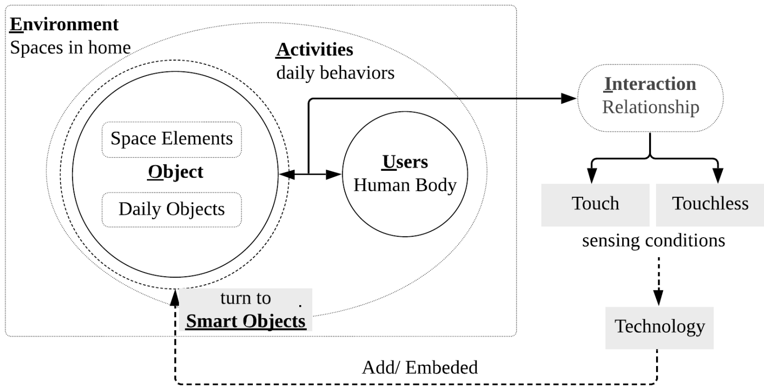

Figure 1. The A.E.I.O.U framework diagram.

This research mainly focuses on capacitive sensing technology from contact to non-contact sensing in developing and designing behavior-sensing modules and IoT smart system. With the advantages of low cost, low energy consumption, and easy operation of capacitive technology, it is hoped that a simple-to-operate and ready-to-use presence-sensing module can be developed. As shown in the A.E.I.O.U framework diagram in Figure 1, this research explores the intimate interaction between the body and spatial objects in the daily life behaviors that occur in the home space: 1. Intimate sensing including contact and non-contact relationships as a sensing condition for spatial behavior sensing and IoT system development. 2. Emphasizing the daily life behaviors and habits as the input trigger of capacitive sensing in the intimate interaction, as a friendly introduction strategy for the smart life of the elderly at home, to solve the dilemma that technology products are challenging to apply at the home of the elderly practically.

There were three main research steps conducted to complete an iteration design process for spatial behavior research exploration analysis and sensor system development, including the research work of behavior research, sensor fabrication, and user field test (Figure 2).

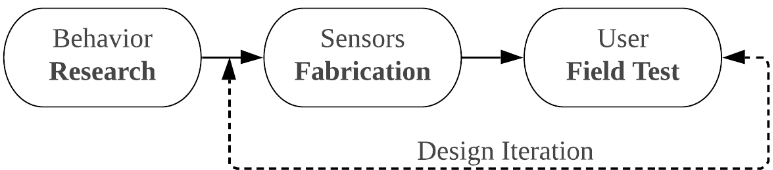

Figure 2. Research steps for the development of Presence Sticker IoT system.

First, interviews, questionnaires, and participatory observation methods were conducted to analyze the close relationship between the body and space or objects in the daily life of the elderly, then the sensing conditions for the analyzed intimate relationship were summarized.

In the second step, the sensor module was fabricated and experiment-tested based on the sensing conditions from the first step. The fabricated process explored how to activate existing space elements or living objects to sense the existence of the human body and judge behavior from contact to non-contact interactions.

Finally, the actual user field verification was carried out in the third step based on the previous two stages' behavior analysis and sensor fabrication. The user test experiment was carried out first in the home space of the experimental subjects. The use of the sensor system was tested to conduct user testing and evaluation research. The design iterations of the presence-sensing module were carried out from the users' feedback and experiment data analysis results. Finally, the modified sensing system was again integrated into the home space for verification.

3.1. Step 1: Behavior Research—Activities and Intimate Relationship between Body and Objects

This research derived the design guidelines for the Presence Sticker sensing module from a review of literature research on interaction theory Ubicomp Proxemics and Capacitive Proximity sensing technology. The notion of Ubicomp Proxemics proposed by Greenberg [10] pointed out that the close relationship between the human body and physical objects has five different dimensions, including distance, orientation, movement, identity, and location. This research aims to perceive people's existence and behavior in space through objects. In the Presence Stickers design framework shown in Figure 3, the first step was to observe and interview the elderly's home life pattern to understand the elderly's daily behaviors and activities. Then the research discerned relevant living objects and relationship attributes and then used the appropriate Ubicomp Proxemics dimension to analyze the intimate relationship between the body and objects.

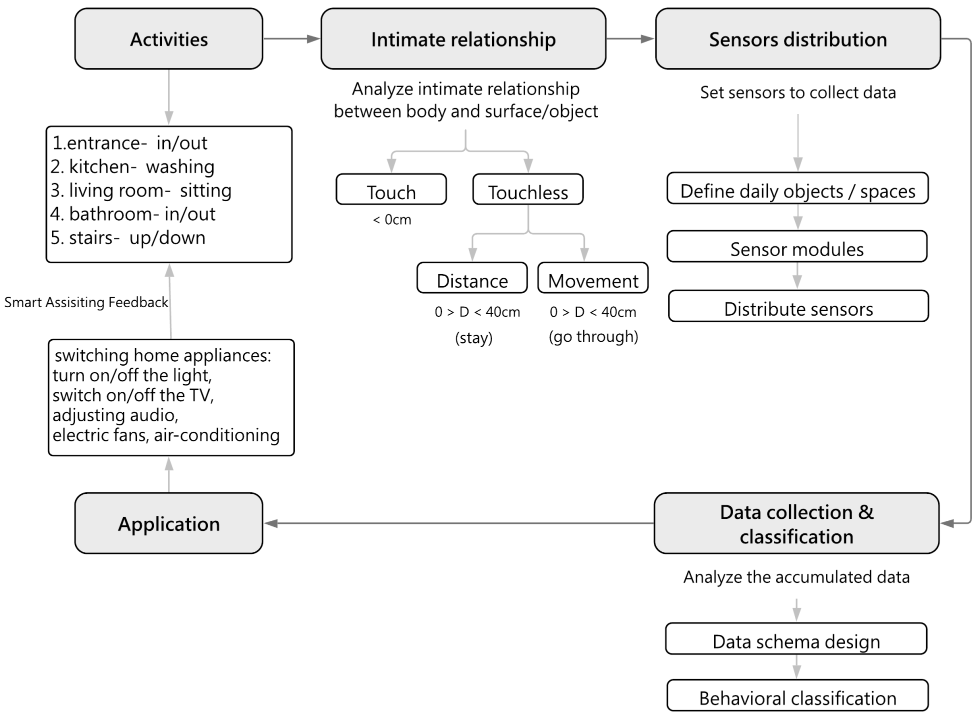

Figure 3. The design framework of Presence Stickers.

A solitary 80-year-old male older adult was interviewed in the experiments, and the research team recorded the subject's daily life behaviors and activities at home within 24 h. Table 1 shows the subject's life behavior record, including time, activities, spaces, relevant objects, and interactions. From the preliminary analysis of observing the activities of this elder at home over one day (Table 1), it is evident that the subject will perform different activities in different spaces (living room, kitchen dining room, room, bathroom, outdoors). In response to changes in activities caused by different times, the subject will first walk through the aisle space to the next space. It can be seen that the subject will have a 'Move' and 'Stop' activity trajectory when switching between different activities.

Due to this phenomenon, this research only focuses on the following two dimensions of the Ubicomp Proxemics concept—distance and movement—to explore the distance and movement relationship between body and spaces/objects when the human body moves in space.

Table 1. Twenty-four hours of daily life behaviors and activities of the elderly subject.

Time	Space	Object	Activities (Move–Stop)	Interaction (T) (TL) (S) (P)
07:15	Bedroom	bed, quilt, pillow, switch	(Stop) wakeup	(T) laying on the bed (T) covering the quilt (T) sleep on the pillow (T) sitting on the bed (T) turn off the light/ aircon
07:20	Bathroom	switch, door, toilet, toilet paper, sink, cabinet	(Stop) brush the teeth, wash the face, toilet	(T) turn on the light (TL-P) open/close the door (TL-S) standing near/ in front of the sink cabinet (T) sitting on the toilet (T) holding toilet paper, flushing
.	Bedroom	door	(Move) pass by	(TL-P) open/close the door
.	Corridor	wall	(Move) Walking to	(TL-P) walking
08:00	Kitchen Dining room	table, chair, tableware (plate, fork, bowl, spoon, fork, bowl, spoon, chopsticks), sink, kitchen counter	(Stop) breakfast, washing dishes	(T) sitting on the chair (T) touching the table (T) holding the tableware (TL-S) standing near/in front of the sink cabinet/counter (T) turning the faucet
.	Corridor	wall	(Move) Walking to	(TL-P) walking
09:00	Garden	main door, water pipe, tools, broom	(Stop) watering, gardening	(TL-P) open/close the door (T) turn the faucet (T) holding the toiletries (TL-S) standing in front of the cabinet, take out the cloth
11:00	Garden Living room	main door, chair/ sofa, cushion, cell phone	(Stop) playing on a cell phone (Facebook, games)	(TL-P) open/close the door (T) sitting on the chair/sofa (T) holding the cushion (T) holding the cell phone
.	Corridor	wall	(Move) Walking to	(TL-P) walking
12:00	Bathroom	door, faucet, toiletries, cabinet	(Stop) taking a bath	(TL-P) open/close the door (T) turn the faucet (T) holding the toiletries (TL-S) standing in front of the cabinet, take out the cloth
.	Corridor	wall	(Move) Walking to	(TL-P) walking
12:30	Bedroom	door, bed, cell phone	(Stop) playing on a cell phone (games)	(TL-P) open/close the door (T) sitting on the bed (T) holding the cell phone
. 13:00	Corridor Kitchen Dining room	wall table, chair, tableware (plate, fork, bowl, spoon, chopsticks), sink, kitchen counter	(Move) Walking to (Stop) lunch, washing dishes, doing chores	(TL-P) walking (T) sitting on the chair (T) touching the table, holding the tableware (TL-S) standing near/ in front of the sink cabinet/counter (T) turning the faucet
.	Corridor	wall	(Move) Walking to	(TL-P) walking
14:00	Bedroom	door, bed, quilt, pillow	(Stop) snap	(TL-P) open/close the door (T) laying on the bed

Table 1. *Cont.*

Time	Space	Object	Activities (Move–Stop)	Interaction (T) (TL) (S) (P)
16:00	Bathroom	door, toilet, sink	(Stop) wakeup, go to the toilet	(TL-P) open/close the door (T) sitting on the toilet (T) holding toilet paper, flushing (TL-S) standing near/ in front of the sink cabinet
.	Bedroom	door	(Move) Pass by	(TL-P) open/close the door
.	Corridor	wall	(Move) Walking to	(TL-P) walking
16:10	Living room	chair/ sofa, cushion, cell phone	(Stop) playing on a cell phone (Facebook, games)	(T) sitting on the chair/sofa (T) holding the cushion (T) holding the cell phone
16:30	Living room	Treadmill, towel	(Stop) exercise (Treadmill)	(T) running on the treadmill (T) wiping sweat
17:00	Second floor	Stairs, bloom	(Stop) do chores (sweeping the floor)	(TL-P) climbing up/down the stairs (T) holding the bloom
. 18:00	Corridor Bathroom	wall door, faucet, toiletries, cabinet	(Move) Walking to (Stop) take a bath; rest/ do chores	(TL-P) walking (TL-P) open/close the door (T) turn the faucet (T) holding the toiletries (TL-S) standing in front of the cabinet, take out the cloth
.	Corridor	wall	(Move) Walking to	(TL-P) walking
19:00	Kitchen Dining room	table, chair, tableware (plate, fork, bowl, spoon, chopsticks), sink, kitchen counter	(Stop) dinner	(T) sitting on the chair (T) touching the table (T) holding the tableware (TL-S) standing near/ in front of the sink cabinet /counter (T) turning the faucet
.	Corridor	wall	(Move) Walking to	(TL-P) walking
20:00	Living room	chair/ sofa, cushion, remote control	(Stop) watching TV (news)	(T) sitting on the chair/sofa (T) switch on the TV (T) holding the cushion (T) holding the remote control
.	Corridor	wall	(Move) Walking to	(TL-P) walking
21:00	Bedroom or Study room (2nd floor)	door, switch, bed	(Stop) playing on a cell phone (Facebook, games) reading	(TL-P) open/close the door (T) turn on the light, aircon (T) sitting on the bed (T) sitting on the chair
22:00	Bedroom	quilt, pillow, switch	(Stop) sleep	(T) laying on the bed (T) covering the quilt (T) sleep on the pillow (T) turn off the light
03:00	Bathroom	door, toilet, toilet paper, sink, cabinet	(Stop) toilet	(TL-P) open/close the door (T) turn on the light (T) sitting on the toilet (T) holding toilet paper, flushing ((TL-S) standing near/ in front of the sink cabinet
03:10	Bedroom	bed, quilt, pillow, switch	(Stop) sleep	(T) laying on the bed (T) covering the quilt (T) sleep on the pillow (T) turn off the light

Table 1. *Cont.*

Time	Space	Object	Activities (Move–Stop)	Interaction (T) (TL) (S) (P)
05:00	Bathroom	door, toilet, toilet paper, sink, cabinet	(Stop) toilet	(TL-P) open/close the door (T) turn on the light (T) sitting on the toilet (T) holding toilet paper, flushing (TL-S) standing near/ in front of the sink cabinet (T) turn off the light
05:10	Bedroom	bed, quilt, pillow, switch	(Stop) sleep	(T) laying on the bed (T) covering the quilt (T) sleep on the pillow (T) turn off the light

Based on the movement trajectory of the Move–Stop pattern, the second step in the design framework (Figure 3) of this research is to analyze the intimate relationship between the human body and the space surface or object. There will be a touch (T) and a touchless (TL) relationship between the body and the space elements or objects. The touch or contact relationship is the behaviors for which an object must be touched, such as sitting on a chair or laying on a bed. Furthermore, touchless or non-contact intimate relationships can be divided into two types: 1. the body 'Passes by' (P) the spatial elements or objects, and 2. the body 'Stays' (S) in front of the object and performs activities. The definitions are as follows:

- The first type, the 'Pass by' (P) relationship between the body and the object, is a very short time (less than 1 min) and directional movement, such as the movement of climbing stairs, passing through a door/corridor; the distance relationship between the body and handrails or walls will be less than 40 cm.
- The second type, the 'Stay' (S) relationship between the body and the object, is a longer time (more than 1 min) activity. The body will remain at a certain distance (less than 20 cm) for continuous activities, such as the behaviors of washing hands/ teeth/ dishes; it will maintain an intimate relationship of less than 10 cm between the body and the surface of the cabinet under the sink.

Based on the analysis of the intimate relationship mentioned, this study encodes the elderly subject's daily life behaviors and activities according to three interaction modes: touch (T), 'Pass by' mode of touchless interaction (TL-P), and 'Stay' mode of touchless interaction (TL-S). From the coding data, Table 1 shows that the interaction between the body of the elderly subject and the object is primarily direct contact behavior, and it is mainly in the 'Stop' activity trajectory regarding the Move–Stop pattern.

In addition, non-contact relationships mainly occur in the 'Move' activity trajectory. This includes body behaviors, such as passing by the wall between the aisle space or passing through the door when entering different rooms. Furthermore, an intimate non-contact relationship between the body and the surface of the cabinet was observed when the elderly subject was using the sink.

The three dimensions of the intimate relationship between the body and objects in the home space of the elderly in this study are distance, movement, and touch. From the observation and analysis, the elderly subject will keep a certain distance between the body and the object in the different intimate relationships. There is a distance less than 20 cm and 'Stay' behavior in the distance dimension activities. The movement dimension activities show 'Pass-by' movement behavior and a distance less than 40 cm. The touch dimension activities show a contact relationship with a distance less than 0 cm. Figure 4a shows the relative behaviors of the elderly subject in these three intimate relationship dimensions, which the Presence Stickers will examine in the next further steps.

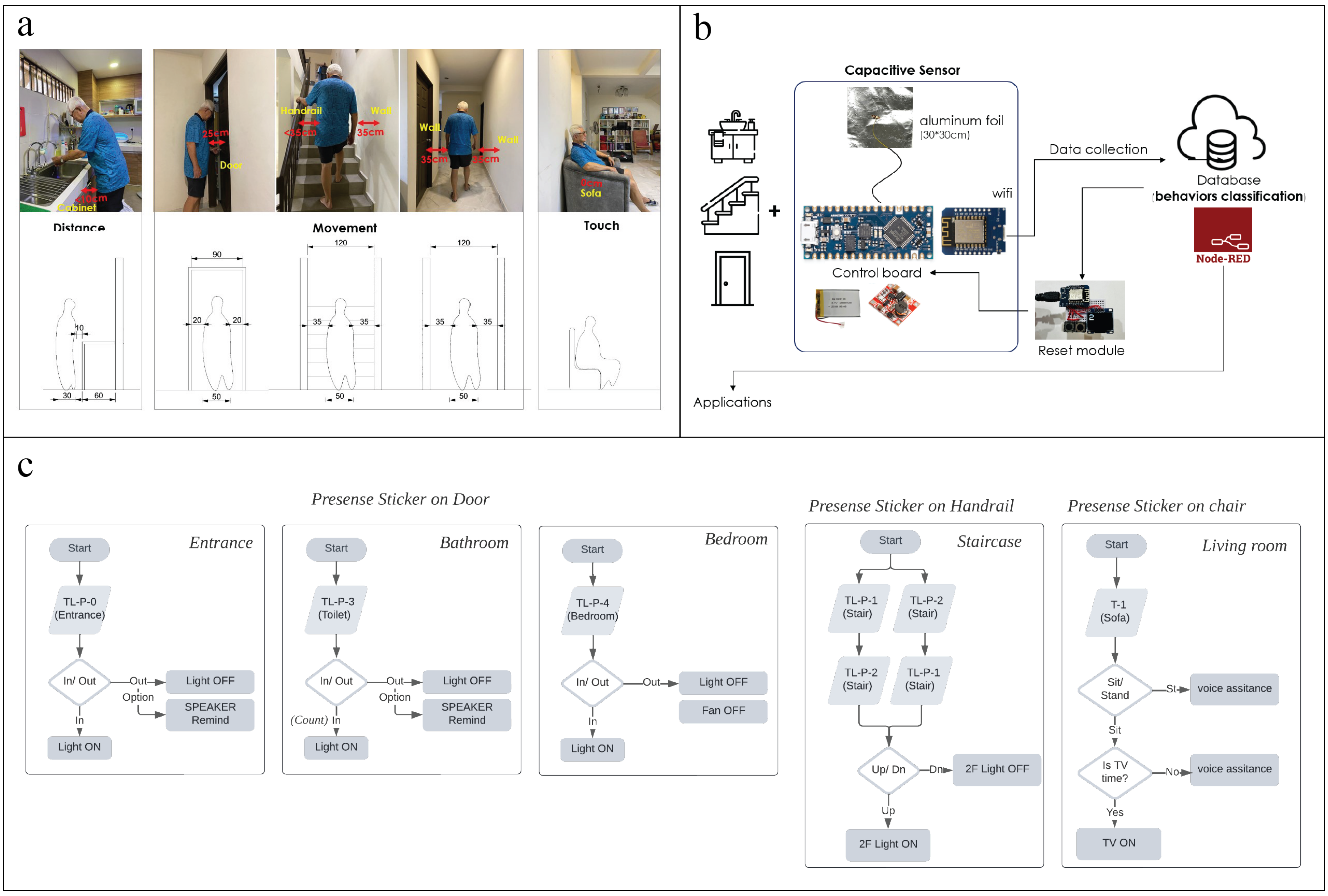

Figure 4. (**a**) (Top Left). The behaviors of the elderly subject in three dimensions. (**b**) (Top Right). The information framework of the Presence Stickers. (**c**) (Bottom). Application: flow charts of smart life assistance.

3.2. Step 2: Sensor Fabrication-Presence Stickers Sensing Module

Based on the above analysis, the three types of intimate relationships between bodies and objects—T, TL-P, and TL-S—will be used as the primary sensing conditions to develop the Presence Stickers sensing module. Then this study experimented with the design and development of Presence Stickers. At the same time, the sensing module will be tested regarding the activity behaviors of the elderly subject in the three relational dimensions: distance, movement, and touch (Table 2).

Table 2. Sensing conditions and the relative activity behaviors.

Ubicomp Proxemics	Types of Intimate Relationship (Sensing Conditions)	Relationship between Body and Daily Objects	Activities/Behaviors	Interior Space
Touch	Touch (T)	sitting on the chair	playing on a cell phone (Facebook, games)	living room
Movement	Touchless-Pass by (TL-P) d < 40 cm; t < 1 min	facing the door, walking/pass through the wall/handrail	enter/leave the rooms, climbing updown the stairs	all rooms, aisle, corridor, stairs
Distance	Touchless-Stop (TL-S) d < 20 cm; t > 1 min	standing near/in front of the sink cabinet/counter	washing hands/dishes	kitchen, bathroom

From the research literature, capacitive sensing as a sensing interaction application between the human body and objects was initially proposed in 1995 by the MIT Media lab research team Zimmerman et al. Zimmerman et al. [31] pointed out that the human–computer Interaction design can use low cost, low power consumption, and a simple realization electric field sensing method to allow objects to sense the human body as an intuitive and natural interaction. Braun et al. [32] also analyzed the research and application of capacitive sensing. They believed that Capacitive Proximity sensing in a smart environment has advantages and proposed a design guide for this application. In order to have both contact and non-contact proximity-sensing functions, this study adopted Capacitive Proximity sensing as the sensory design of the Presence Stickers module.

Figure 4b shows the information framework of the Presence Stickers sensing module. The Presence Stickers module is equipped with a breadboard with Arduino Nano, coupled with a 30 $\times$ 30 cm aluminum foil as the electrode-sensing plate. This research uses the ADCTouch library to compute and control capacitive sensing. In order to integrate the data of multiple sensors placed in the different spaces and objects, the module is coupled with the WEMO Wi-Fi module to transmit the accumulated sensor data to the cloud. This module is powered by a lithium battery. A voltage regulator module is added to stabilize the current of the sensor module. Since the value of the capacitive sensor will be affected by environmental factors such as temperature, humidity, object materials, human conditions, etc., this research added a reset module that can reset the sensors through Wi-Fi. It was used as a remote adjustment in the research experiment.

As mentioned, this study uses the ADCTouch library as the program algorithm for capacitive sensing. This library can only be applied to AVR microcontrollers. ADCTouch is a library that allows users to create a capacitive sensor without external hardware. This library uses AVR internal wiring to obtain decent resolution with a single pin. As the design of Presence Stickers in this study means they need to be put on or stuck on objects or surfaces, the module design needs to be very simple and light; the simple circuit design of ADCTouch meets the needs of the design and is adopted.

This research aims to easily stick multiple Presence Stickers on different spaces and objects, sense human behaviors in space, collect data for a long period for the computation of behavior classification, and finally provide the customized intelligent application function for the solitary elderly at home. Therefore, Wi-Fi is used as the wireless network information-integration method. With the WEMO Wi-Fi module and the lightweight Message Queuing Telemetry Transport (MQTT) publish–subscribe network protocol, all the Presence Sticker sensors become IoT devices.

In the computational process of behavior classification, the sensing data from the Presence Sticker module are transmitted to the Node-RED platform through IoT; then, the spatial behaviors are classified through the Artificial Intelligence (AI) training algorithm.The K Nearest Neighbor (KNN) AI algorithm is used to train the datasets. The data are first collected through the collection of behavioral sensing information through the presence-sensing modules, and then the collected dataset is segmented to capture behavioral feature information, after the process of data filtering and sorting; finally the classification and labeling of spatial behavior will be trained. It is hoped that the system can determine the spatial behavior trajectories of the subjects in different spaces and different behaviors from the long-term collected sensing information.

In addition to researching and testing the functional requirements of Presence Stickers for collecting behavioral data, the IoT system developed in this study also provides users with a life-assist feedback function. The information collected from the Presence Stickers for different spaces and different objects is classified by the cloud computing, and then the feedback of auxiliary functions is given. Figure 4c shows the life-assistance flow chart based on the different behavior classifications in the different spaces. For example, the perception information of Presence Stickers attached to the entrance door will be trained to recognize whether the user is entering or leaving, and then turn on or off the light according to the time and spatial behavior trajectories of the users.

3.3. Step 3: Experimental Setup and Sensor Distribution

The capacitance sensing values of the Presence Stickers which are put on the objects (chair, door, wall, handrail) were tested based on the three intimacy behaviors between bodies and objects, T, TL-P, and TL-S, analyzed in this study. From the testing results of the sensing values, as shown in Figure 5, it is known that different value patterns will appear under three different sensing conditions of intimacy. The same behavior and action will be tested repeatedly 4 to 6 times. The sensing value patterns obtained under the same action test will remain similar, which means that the sensing function is stable and reliable. After completing the sensor test, the sensor contribution and data collection experiment was conducted in five places in the elderly's home, including the entrance, living room, kitchen, bedroom, bathroom, and staircase. Seven Presence Stickers were pasted on the surfaces of different objects or space elements, including entrance door, toilet door, stair handrail 1 (lower step), stair handrail 2 (higher step), sink cabinet, bedroom door, and corridor wall. After the sensors were set up, this research conducted a one-week test and collected the accumulated sensing data of the elderly subject's behaviors and activities at home.

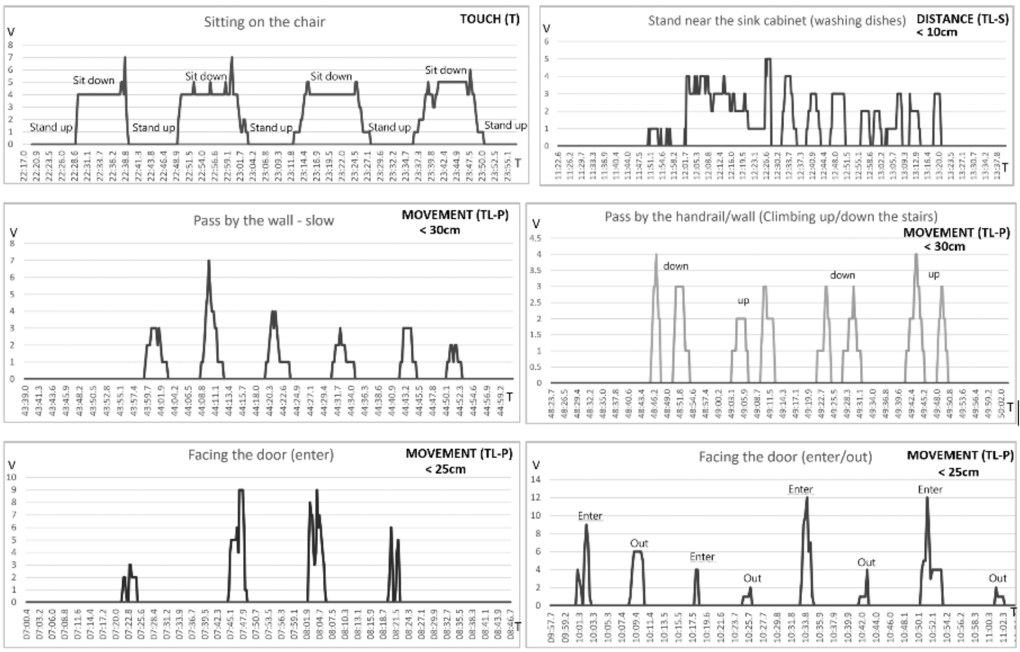

Figure 5. The sensing value patterns in different behaviors.

4. Results

The cumulative performance data of all the sensors collected from the experiment are first distinguished by "space name ID", and then classified by three types of intimacy (T-*, TL-P-*, TL-S-*), and at the same time, the date and time are recorded. Based on the record and analysis of the life pattern of the elderly subject as shown in Table 1, the collected accumulated sensing data will be logically defined according to the time and relationship when different sensors are triggered to determine the daily life behavior of the elderly subject. Figures 6 and 7 show the sensor data schema and behavior classification for two periods of the accumulated data on different days:

- Date: 2021.12.8 (Figure 6)
  The sensor data schema: Corridor (TL-P-0) > Living (T-1) > Corridor (TL-P-0) > Bedroom (TL-P-4) > Bathroom (TL-P-3) > Bathroom (TL-P-3) > Bedroom (TL-P-4) > Corridor(TL-P-0) > Living (T-1). The behavior classification: Walking (Pass by) > Sit > Walking (Pass by) > Enter Bedroom > Enter Bathroom > Leave Bathroom > Leave Bedroom > Walking (Pass by) > Sit

The actual behavior and activities: After three o'clock in the afternoon, the subject got up from a nap, went to the living room, sat in a chair and played with a phone, and then did some housework. After that, he went to the bathroom in the bedroom to shower and then walked to the living room and sat on a chair for a rest.

- Date: 2021.12.10 (Figure 7) The sensor data schema: Kitchen (TL-S-1) > Stair1 (TL-P-1) > Stair2 (TL-P-2) > Corridor (TL-P-0) > Study (T-2) The behavior classification: Washing (Standing near the sink) > Climb upstairs (lower step) > Climb upstairs (higher step) > Walking (Pass by) > Sit (Reading).

  The actual behavior and activities: After seven o'clock in the evening, the subject stood in front of the sink to wash the dishes after he had had dinner.

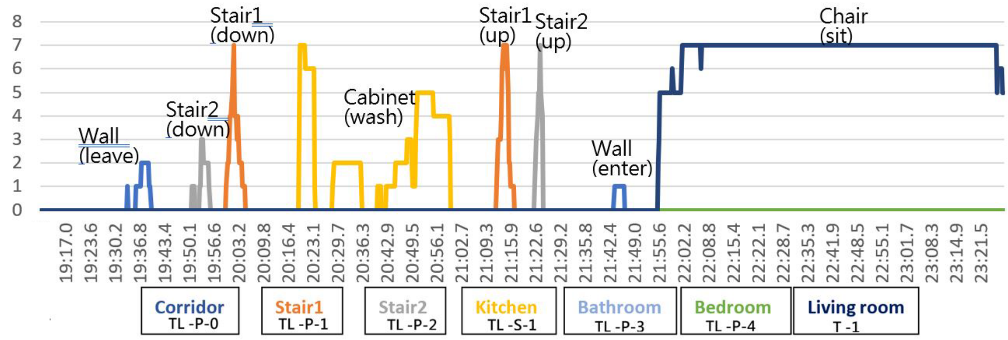

Figure 6. Behavior classification of the accumulated data (8 December 2021).

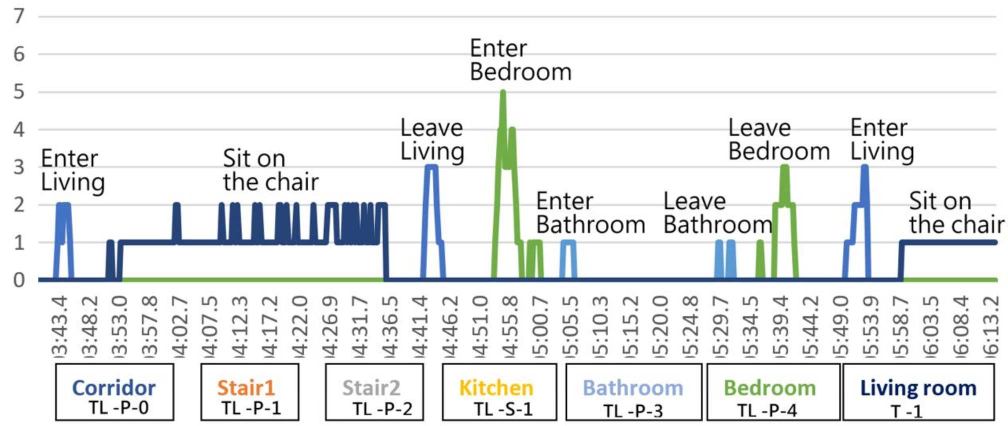

Figure 7. Behavior classification of the accumulated data (10 December 2021).

When the behavior classification can be successfully defined completely, it can be connected to the Presence Stickers system through the IoT switch device to provide life assistance, such as switching lights, air conditioning, and other smart applications. Figure 4c shows the life-assistance flow chart based on the different behavior classifications in the different spaces. From the coding data, this study concludes three interaction modes: touch (T), 'Pass by' mode of touchless interaction (TL-P), and 'Stay' mode of touchless interaction (TL-S). The TL-P sensors can sense the 'Pass by' behavior, so the system enables prediction of the next space the subject will go to and triggers the customized smart assistance function, such as turn on the light/fan. The smart assistance provided by the IoT system can be customized, and the subjects can set it according to their daily living habits.

Moreover, a data visualized dashboard has also been developed along with the IoT system. Figure 8 (top) shows the visualization of each sensor data item in the form of charts and gauges instantly. Figure 8 (bottom) shows the movement trajectory of the 'Move–Stop' pattern of the subject through the house plan representation. It can show the movement and life pattern in different spaces very clearly.

Figure 8. Dashboard application of the visualization sensor data and the movement trajectory of the 'Move–Stop' pattern.

5. Discussion

The experiment in this research is limited to only one 80-year-old elderly person, mainly because of the longer duration of the experiment under this study, plus the need for the research team members to enter the home of the elderly for system set up. Acceptance by the subject and the condition constraints of the subject's home network environment become the challenges for this experimental study. It is therefore hoped that the experiment process could be further optimized and simplified in future research and that more elderly people can be recruited as the subjects of the experiment to obtain more experimental data and user evaluation results. In addition, the current position where the sensor module is affixed is mainly based on the furniture or spatial elements that the subject may come into contact with in the event of more repetitive motion behavior that occurs in the daily home living space. Therefore, the distribution of the sensing modules must be customized to the user's daily life behavior.

Based on interviews and daily life observation for the subject, this study found that there is a 'Move–Stop' pattern when various living behaviors are performed in different spaces at home. The research deeply analyzes the intimate relationship between the human body and the surface elements or objects within the 'Move–Stop' activities. This research concludes that there will be a touch and a touchless relationship between the body and the space elements or objects. In the 'Move' activity pattern, there are the touchless or non-contact intimate relationships between the body and the door or wall. In this research, these are defined as the body 'Passes by' the spatial elements or objects. On the other hand, there will occur both touch and touchless relationships between the body and the space elements or objects in the 'Stop' activity pattern. The touch or contact relationship is the behaviors concerning which an object must be touched. Touchless relationships are behaviors where the body stays in front of or near an object for a while. The body will remain at a certain distance from the object for continuous activities. An intimate relationship of less than 20 cm will be maintained between the body and the surface of the cabinet/wall. In this research, this is defined as the body 'Stays' in front of the object and performs daily activities. These features are used as the sensing conditions to develop the spatial behavior-sensing module. The Presence Stickers use proximity capacitive sensing technology; it has the advantage of stability of sensing function in the sensing conditions (sensing distance less than 40 cm), as described above.

In order to improve the user experience, the Presence Stickers developed by this research can be used as home decoration, because the thin patch sticker can be printed as a decoration pattern or a photo. The research hopes the Presence Stickers are not just a sensor with IoT smart assistance, but a special home decoration attached to a wall or home furniture at home, just the same as a wall picture.

6. Conclusions and Future Research Orientation

In the discussion of 'Move–Stop' pattern behavioral interactions, this research mainly focused on analyzing the intimate interactions between space elements, daily objects, and the body, hoping to summarize these close relationships from touch to touchless ('Stay' and 'Passes by') and organize them into indoor spatial behavioral sensing design conditions. It is hoped that more accurate indoor activities can be derived from the intimate relationship between body and objects. The importance of the discussion and results of this interaction model research are expected to be used as an essential design condition guide or reference index for the interaction research of natural behavior and the design of technology products of friendly and elderly-friendly smart living assistance.

This research's Presence Stickers sensing module is fabricated with low-cost capacitive sensing components. The feedback settings can also be customized, suitable for the home life of different elderly people. At the same time, more importantly, users can emply the smart living mechanism without changing any items in the home so that the elderly can enjoy the convenience of technology-assisted life in the original familiar environment. Furthermore, the collected sensing data and behavior classifications can also be used as a record of the elderly's life patterns. It can also be provided as a reference for smart medical treatment.

The design and systems of the sensing process in this study can effectively address privacy issues arising from using a camera for image recognition of daily life behavior. The application can also be extended to other design applications that require specific behavior-perceptive interactions, especially research or assistance for specific behavior of specific groups, such as analysis of behavioral patterns of the elderly suffering from dementia, and behavioral pattern analysis for patients with depression or children, etc. At the same time, the sensors developed in this study are easy to use, both hardware and software, and can be quickly used in the research phase by interactive design developers who want to explore behavior perception.

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