PRESENCE STICKERS

A seamlessly integrated smart living system at a solitary elderly home

CHOR-KHENG LIM[1]
[1]*Department of Art and Design, YuanZe University*
[1]*kheng@saturn.yzu.edu.tw, 0000-0003-0990-5191*

Abstract. This research develops Presence Stickers, the capacitive sensing module that can be easily affixed to the existing space element surfaces (such as a wall, door, stairs), and daily objects or home furniture (such as a chair, cabinet, table, sofa, etc.). These 30*30 cm Presence Stickers can actively sense people's physical behaviors and body movements in spaces. 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 Touchless (TL) relationship between the body and the space elements or objects. Furthermore, the touchless, or non-contact, intimate relationship can also be divided into two types: 1. The body that 'Passes by' (P) the spatial elements or objects, and 2. The body that 'Stays' (S) in front of the object and performs activities. These three types of the intimate relationship between bodies and objects, i.e., T, TL-P, and TL-S, were used as the main sensing conditions to develop the Presence Stickers sensor module. We affixed 8 Presence Stickers on 9 objects in six spaces and finally, the life pattern can be analyzed and the sensors provide the customized intelligent application function for the elderly.

Keywords. Intuitive Interaction Design; Capacitive Sensor; Daily Object; Touchless; Body Movement; Smart Home; SDG 3.

1. Introduction

In the field of Human-Computer Interaction design, user interfaces that interact with natural human abilities such as gestures, touch, or voice are often referred to as Natural User Interfaces (NUI). In tactile interactive design, Tangible User Interface, TUI emphasizes the interaction between the physical environment and digital information, through the more natural grasping, operation, assembly, and other tactile relationships with objects as an interactive interface design, which can more freely and intuitively operate between the virtual and the physical (Ishii & Ullmer, 1997). The Organic User Interface, OUI proposed by Holman et al. in 2008, emphasizes flexible, tangible interface, and interactive interface that includes sensing and actuation capabilities. It combines daily life environment and behavior patterns to provide more intuitive

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 1, 445-454.

interaction (Holman & Vertegaal, 2008). For the future home based on the design of Ubiquitous Computing, Nabil (2017) proposed Organic User Interfaces Interiors, by applying Organic User Interface Design to interior spaces design. 'OUI Interiors' mainly turns the daily objects into interactive artefacts. In this sense, interior spaces, surfaces (walls, floors, tables, and ceilings), interior objects such as furniture, and decorative accessories can become computationally-driven interactive artefacts, potentially changing their physical appearances, i.e., shape, colour, pattern or texture.

In addition to the Tangible Interaction of direct contact with physical objects, there is also a non-contact distance relationship between human behavior and physical objects. Greenberg (2011) used the concept of 'Proxemic' proposed by Hall (1969) as a basis and extended it to the distance relationship between humans and physical objects (digital and non-digital devices). In the Ubicomp interaction, the intimate relationship between the human body and physical objects is emphasized and the concept of 'Proxemic Interaction' is proposed. Greenberg (2011) points out that there are five dimensions of proxemics for Ubicomp: Distance, Orientation, Movement, Identity, and location. Non-contact or touchless interactive interfaces have flourished in recent years and are mostly used in public places. To avoid physical contact, touchless interfaces are even more critical in the era of the COVID-19 pandemic. In fact, this research aims to explore how we should make better use of the touchless interface provided by the products of technology in daily life, instead of just relying on existing input technology. This is because there is an intimate relationship between the human body and space (or objects). How to activate an existing space or objects to detect the presence of human beings, even if there is no contact.

From the perspective of Ubiquitous Computing's smart home design, the subject of this study is to explore how to interact with spaces or objects through intuitive body behaviors and to obtain digital information. And the result will be used or as a user interface design for smart home products. At the same time, the research scope includes the intimate relationship between physical behavior and daily-life objects in spaces. Through intuitive body movements and activities in daily life, this research analyzes the intimate relationship including contact and non-contact, between people and objects.

This study is based on the Ubicomp Proxemics dimensional study proposed by Greenberg (2011) and explores how to integrate the capabilities of sensors and actuators into the spatial surfaces (such as walls, floors, doors, and windows) and everyday objects (such as furniture, decorations) that are closely related to the body; how to perceive body movements and behaviors in the space and provide feedback for intelligent life assistance. This research aims to introduce smart auxiliary functions through simple sensing components or modules implanted in space surfaces or everyday objects without changing life behaviors or replacing household objects.

Regarding the sensing technologies, the most commonly used currently includes pressure sensors or capacitive sensors; the non-contact sensing ones include infrared sensors, capacitive sensors, and image recognition. An innovative sensor design, Touché, which is developed by the Disney Research team (Sato et al. in 2012) uses capacitive sensing technology to sense human body touch and perceive subtle body movements. Moreover, the Touché capacitive touch sensing can reflect on objects of different scales (pens, doorknobs, mobile phones, tables), all with the same sensitivity.

And different body gestures can also be distinguished (Sato, Poupyrev, & Harrison, 2012). In addition to capacitive sensing that can sense the touch of the human body, Capacitive proximity sensors can sense the non-contact body gestures at a certain distance. Compared to other sensing technologies, capacitive sensing has the advantages of low cost, low power consumption, and simple realization, so it is also used as an indoor human localization sensing application (Arshad et al., 2017).

This research will take advantage of capacitive sensing, which can sense from proximity to contact, and develop a sensing system that interacts with natural behaviors. The goal of this research is to design a smart living system that can be used by solitary elderly people through touch/touchless interface design. It is hoped that the sensing system can be seamlessly integrated into the home of elderly people and improve life assistance. This research develops Presence Stickers that can be easily affixed to the existing space elements (wall, floor, door, stairs) or home furniture (chair, cabinet, bed, table, sofa, etc). These 30*30 cm Presence Stickers can actively sense people's physical behaviors and body movements in spaces. The signals acquired from the Presence Stickers in spaces will then integrate into the controller system through the MQTT technology and logically define the behaviors classification. Users can define their own feedback, such as switching home appliances, lights, electric fans, air-conditioning, and other daily applications. Figure 1 shows the design framework of Presence Stickers.

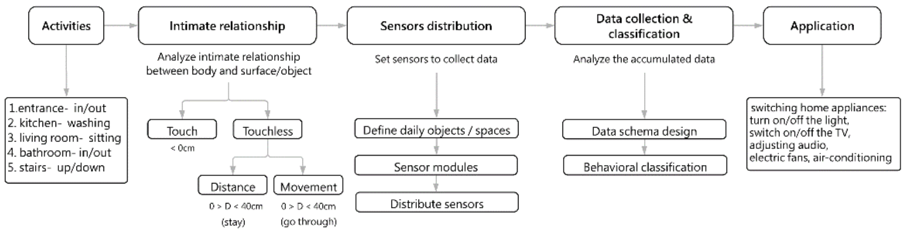

Figure 1. The design framework of Presence Stickers

2. Activities and intimate relationship between body and object

This research derives the design guidelines for the sensor module of Presence Stickers from the review of literature research on interaction theory Ubicomp Proxemics and Capacitive Proximity sensing technology. The notion of Ubicomp Proxemics proposed by Greenberg (2011) points out that the close relationship between the human body and physical objects has five different dimensions, including Distance, Orientation, Movement, Identity, and Location. However, because the purpose of this research is to perceive the existence and activity behavior of people in space through objects, the first step in the design framework (Figure 1) is to observe and interview the elderly's home life pattern to understand the elderly's daily behaviors and activities and find out relevant everyday objects and relationship attributes, and then use the appropriate Ubicomp Proxemics dimension to analyze the intimate relationship between the body and objects.

In this study, a solitary 80-year-old male older adult was interviewed, and we recorded his daily life behaviors and activities at home spaces within 24 hours. Table 1 shows his life behaviors record, including the time, activities, spaces, relevant objects, and interaction behaviors. From the preliminary analysis of observing the activities of this elderly at home in one day (Table 1), it is obvious that he performed different activities in different spaces (living room, kitchen dining room, room, bathroom, outdoor). In response to changes in activities at different times, he first walked through the aisle space to the next space. It can be clearly seen that he had a 'Move' and 'Stop' activity trajectory when switching between different activities. Due to this phenomenon, this research only focuses on the 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.

Based on the movement trajectory of the Move-Stop pattern, the second step in the design framework (Figure 1) 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 relates to the behaviors that must touch the object, such as sitting on a chair; Furthermore, a touchless or non-contact intimate relationship can be divided into two types: 1. The body that 'Passes by' (P) the spatial elements or objects, and 2. The body that 'Stays' (S) in front of the object and performs activities.

- The first type, the 'Pass by' (P) relationship between the body and the object, is a short-time (<1 minute) and directional movement. There will be a distance of less than 40 cm between the body the spatial elements or objects, such as the movement of going up and down the stairs, the relationship between the body and handrails or walls.
- The second type, the 'Stay' (S) relationship between the body and the object is longer (>1 minute), and the body will remain at a certain distance (<20cm) for continuous activities, such as the behaviors of washing hands and teeth, it will maintain a intimate relationship of <10cm 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 'Stays' 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 mostly 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 'Move' activity trajectory. It includes the body behaviors, such as passing by the walls between the aisle space or passing through the door when entering different rooms. Furthermore, the 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 include: Distance, Movement, and Touch. Figure 2 shows the relative behaviors of the elderly subject in these three intimate relationship dimensions which will be examined by the Presence Stickers.

Table 1. 24 hours daily life behaviors and activities of the elderly subject

Time	Activities (Move-Stop)	Space	Object	Interaction (T) (TL) (S) (P)
07:15	waking up	bedroom	bed, quilt, pillow, switch	(T) lying on the bed, (T) tucking in the quilt, (T) sleeping on the pillow, (T) sitting on the bed, (T) turning off the light, aircon *
07:20	brushing the teeth, washing the face, toilet	bathroom	switch, door, toilet, toilet paper, sink, cabinet	(T) turning on the light * (TL-P) opening/closing the door, (TL-S) standing near/in front of the sink cabinet, (T) sitting on the toilet (T) holding toilet paper, flushing
		bedroom	door	(TL-P) opening/closing the door
	Walking to	corridor	wall	(TL-P) walking
08:00	breakfast, washing dishes	kitchen, dining room	table, chair, tableware (plate, fork, bowl, spoon, chopsticks), sink, kitchen counter	(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
	Walking to	corridor	wall	(TL-P) walking
09:00	watering, gardening	garden	main door, water pipe, tools, broom	(TL-P) opening/closing the door, (T) holding the pipe, tools
11:00	playing on a cell phone (Facebook, games)	garden or living room	main door, chair/sofa, cushion, cell phone	(TL-P) opening/closing the door, (T) sitting on the chair/sofa (T) holding the cushion, (T) holding a cell phone
	Walking to	corridor	wall	(TL-P) walking
12:00	taking a bath	bathroom	door, faucet, toiletries, cabinet	(TL-P) opening/closing the door, (T) turning the faucet, (T) holding the toiletries, (TL-S) standing in front of the cabinet, taking out the cloth
	Walking to	corridor	wall	(TL-P) walking
12:30	playing on a cell phone (games)	bedroom	door, bed, cell phone	(TL-P) opening/closing the door, (T) sitting on the bed, (T) holding a cell phone
	Walking to	corridor	wall	(TL-P) walking
13:00	lunch, washing dishes, doing chores	kitchen, dining room	table, chair, tableware (plate, fork, bowl, spoon, chopsticks), sink, kitchen counter	(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
	Walking to	corridor	wall	(TL-P) walking
14:00	napping	bedroom	door, bed, quilt, pillow	(TL-P) opening/closing the door, (T) lying on the bed
16:00	waking up, going to the toilet	bathroom	door, toilet, sink	(TL-P) opening/closing the door, (T) sitting on the toilet, (T) holding toilet paper, flushing (TL-S) standing near/in front of the sink cabinet
		Bedroom	door	(TL-P) opening/closing the door
	Walking to	corridor	wall	(TL-P) walking
16:10	playing on a cell phone (Facebook, games)	living room	chair/sofa, cushion, cell phone	(T) sitting on the chair/sofa (T) holding the cushion, (T) holding a cell phone
16:30	exercising (Treadmill)	living room	Treadmill, towel	(T) running on the treadmill (T) wiping sweat
17:00	doing chores (sweeping the floor)	second floor	stairs, bloom	(TL-P) climbing up/down the stairs (T) holding the bloom
	Walking to	corridor	wall	(TL-P) walking
18:00	taking a bath, resting/doing chores	bathroom	door, faucet, toiletries, cabinet	(TL-P) opening/closing the door, (T) turning the faucet, (T) holding the toiletries, (TL-S) standing in front of the cabinet, taking out the cloth
	Walking to	corridor	wall	(TL-P) walking
19:00	dinner	kitchen,	table, chair,	(T) sitting on the chair,

		dining room	tableware (plate, fork, bowl, spoon, chopsticks), sink, kitchen counter	(T) touching the table, (T) holding the tableware, (TL-S) standing near/in front of the sink cabinet/counter (T) turning the faucet
	Walking to	corridor	wall	(TL-P) walking
20:00	watching TV (news)	living room	chair/sofa, cushion, remote control	(T) sitting on the chair/sofa (T) switching on the TV* (T) holding the cushion, (T) holding the remote control
	Walking to	corridor	wall	(TL-P) walking
21:00	playing on a cell phone (Facebook, games) reading	bedroom or study room (2nd floor)	door, switch, bed	(TL-P) opening/closing the door, (T) turning on the light, aircon* (T) sitting on the bed (T) sitting on the chair
22:00	sleeping	bedroom	quilt, pillow, switch	(T) lying on the bed, (T) tucking in the quilt, (T) sleeping on the pillow, (T) turning off the light
03:00	toilet	bathroom	door, toilet, toilet paper, sink, cabinet	(TL-P) opening/closing the door, (T) turning 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	sleeping	bedroom	bed, quilt, pillow, switch	(T) lying on the bed, (T) tucking in the quilt, (T) sleeping on the pillow, (T) turning off the light
05:00	toilet	bathroom	door, toilet, toilet paper, sink, cabinet	(TL-P) opening/closing the door, (T) turning on the light (T) sitting on the toilet, (T) holding toilet paper, flushing (TL-S) standing near/in front of the sink cabinet (T) turning off the light
05:10	sleeping	bedroom	bed, quilt, pillow, switch	(T) lying on the bed, (T) tucking in the quilt, (T) sleeping on the pillow, (T) turning off the light

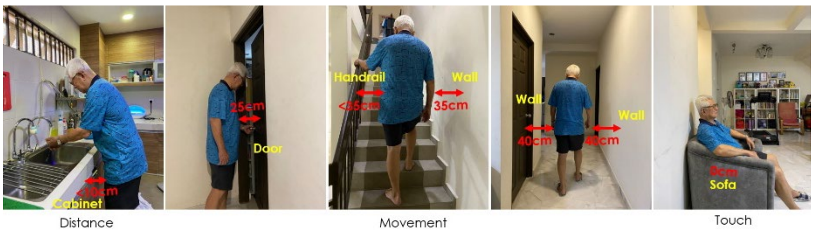

Figure 2. The behaviors of the elderly subject in three dimensions of intimate relationship

3. Presence Stickers sensing module

Based on the above analysis, the three types of the intimate relationship between bodies and objects (T, TL-P, and TL-S) will be used as the main sensing conditions to develop the Presence Stickers sensor module. Then this study carried out the experiment of the design and development of Presence Stickers. At the same time, the sensing module would be tested regarding the activity behaviors of the elderly subject in the three relational dimensions: Distance, Movement, and Touch (Table 2).

From the research literature, the use of capacitive sensing as a sensing interaction application between the human body and objects was originally proposed in 1995 by the MIT Media lab research team Zimmerman and others. Zimmerman et al. (1995)

pointed out that The Human-Computer Interaction design can allow objects to sense the human body as an intuitive and natural interaction by using the electric field sensing method that costs less, consumes less power, and can be simply implemented. Braun et al. (2015) also analyzed the research and application of capacitive sensing and believed that the use of capacitive proximity sensing in a smart environment has its 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.

The Presence Stickers module is equipped with a breadboard with Arduino Nano, coupled with a 30*30 cm aluminum foil as the electrode sensing plate. ADCTouch library is used as the main computation and control of capacitive sensing. To integrate the data of multiple sensors placed in the different spaces and objects, the module is coupled with the WEMOs Wi-Fi module to transmit the accumulated sensor data to the cloud. This module is powered by a lithium battery. To stabilize the current of the module, a voltage regulator module is added. Since capacitive sensing will be affected by environmental factors such as temperature and humidity, object materials, human conditions, etc., this research had added a Reset module that can reset the sensors through Wi-Fi connection, can be used as a remote adjustment in the research experiment. Figure 3 shows the information framework of the Presence Stickers sensing module.

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

This research aims to easily stick multiple Presence Stickers on different spaces and objects, to sense human behaviors in the space, to collect data for a long time for the computation of behaviors classification, and finally to 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 WEMOs Wi-Fi module and the lightweight MQTT publish-subscribe network protocol, all the sensors, Presence Stickers, have become IoT devices.

Table 2. Sensing conditions and the relative activity behaviors

Ubicomp Proxemics	Types of intimate relationship	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; $t < 1$minute	facing the door, walking/passing through the wall/handrail	entering/leaving the rooms climbing up/down the stairs	all rooms, aisle/corridor stairs
Distance	Touchless- Stay (TL-S) $d < 20$cm; $t > 1$minute	standing near/ in front of the sink cabinet /counter	washing hands/ dishes	kitchen/ bathroom

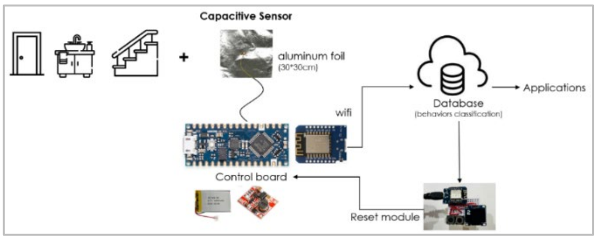

Figure 3. The information framework of the Presence Stickers

4. Experimental setup and sensors distribution

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

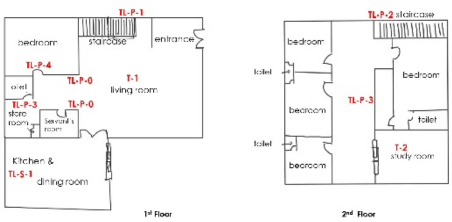

Figure 4. Sketch of the subject's house floor plan and sensors distribution

5. Behaviors classifications from accumulated data

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 recorded with the Date and Time. 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 the relationship when different sensors are triggered to determine the daily life behavior of the elderly subject. Figure 6 shows 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)→Sitting→Walking (Pass by)→Entering Bedroom→ Entering Bathroom→Leaving Bathroom→Leaving Bedroom→Walking (Pass by) → Sitting

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 the phone, and then did some housework. After that, he went to the bathroom in the bedroom to take a shower, and then walked to the living room, and sat on a chair for a rest.

Date: 2021.12.10 (Figure 6)

The sensor data schema: Kitchen (TL-S-1) → Stair1 (TL-P-1) → Stair2 (TL-P-2) → Corridor (TL-P-3) → Study (T-2)

The behavior classification: Washing (Standing near the sink) → Climbing upstairs (lower step)→ Climbing upstairs (higher step)→ Walking (Pass by) → Sitting (Reading)

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

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. Since this research has just completed the sensing module and behavior definition, it was just tested in the laboratory and it worked well, but the application of the feedback mechanism in the subject's home has not yet been tested.

6. Conclusion

The Presence Stickers sensing module in this study is made with low-cost capacitive sensing components. The feedback settings of the module can be customized, which is suitable for the home life of different elderly people. Meanwhile, more importantly, users can reach 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. Moreover, the collected sensing data and behavior classification can also be used as a record of the elderly's life patterns, and can also be provided as a reference for smart medical treatment.

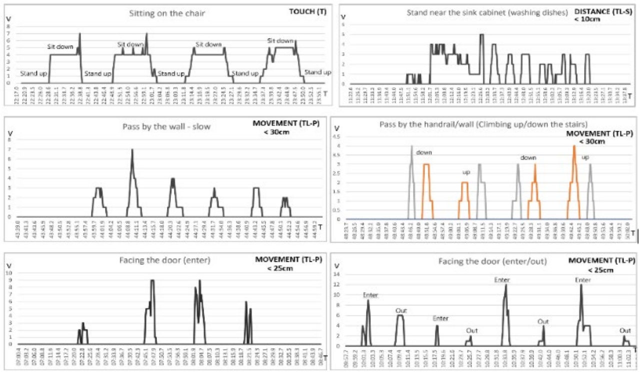

Figure 5. The sensing value patterns in different behaviors

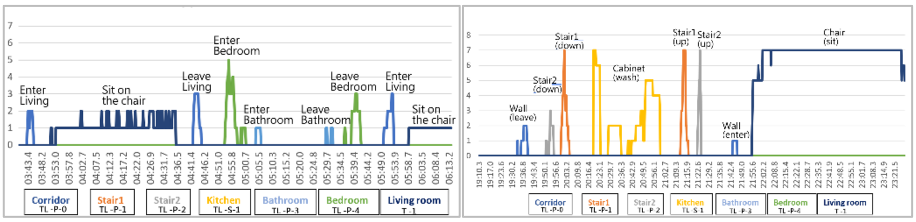

Figure 6. Sensor data schema and behavior classification

References

Arshad, A., Khan, S., Zahirul Alam, A. H. M., Abdul Kadir, K., Tasnim, R., & Fadzil Ismail, A. (2017). A capacitive proximity sensing scheme for human motion detection. *Paper presented at the 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC).*

Braun, A., Wichert, R., Kuijper, A., & Fellner, D. W. (2015). Capacitive proximity sensing in smart environments. *Journal of Ambient Intelligence and Smart Environments, 7*(4), 483-510. doi:10.3233/ais-150324

Greenberg, S., Marquardt, N., Ballendat, T., Diaz-Marino, R., & Wang, M. (2011). Proxemic interactions. *Interactions, 18*(1), 42-50. doi:10.1145/1897239.1897250

Hall, E. T. (1966). *The Hidden Dimension*: Anchor Books.

Holman, D., & Vertegaal, R. (2008). Organic user interfaces: Designing computers in any way, shape, or form. *Communications of the ACM, 51*(6), 48-55. doi:10.1145/1349026.1349037

Ishii, H., & Ullmer, B. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. *Paper presented at the CHI.*

Nabil, S., Kirk, D. S., Ploetz, T., & Wright, P. (2017). Designing Future Ubiquitous Homes with OUI Interiors: Possibilities and Challenges. *Interaction Design and Architecture(s) Journal*, 28-37.

Sato, M., Poupyrev, I., & Harrison, C. (2012). Touché: Enhancing Touch Interaction on Humans, Screens, Liquids, and Everyday Objects. Paper presented at *the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.*

Zimmerman, T. G., Smith, J. R., Paradise, J. A., Allport, D., & Gershenfeld, N. (1995). Applying Electric Field Sensing to Human-Computer Interfaces. Paper presented at *the CHI Mosaic of Creativity.*