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Understanding the Interaction between Older Adults and Soft Service Robots: Insights from Robotics and the Technology Acceptance Model

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Abstract:

As the world's population increasingly ages, we need technological solutions such as robotics technology to assist older adults in their daily tasks. In this regard, we examine soft service robots' potential to help care for the elderly. To do so, we developed and tested the degree to which they would accept a soft service robot that catered to their functional needs in the home environment. We used embodied artificial to develop an in-house teleoperated human-sized soft service robot that performed object-retrieval tasks with a soft gripper. Using an extended technology acceptance model as a theoretical lens, we conducted a study with 79 older adults to examine the degree to which they would accept a soft service robot in the home environment. We found perceived ease of use, perceived usefulness, and subjective norms as significant predictors that positively influenced older adults' intention to adopt and use soft service robots. However, we also found that perceived anxiety and perceived likability did not significantly predict older adults' intention to adopt and use soft service robots. We discuss the implications, limitations, and future research directions that arise from these findings.

Keywords: Older Adult, Robotics, Technology Acceptance, Soft Service Robot.

Bansal Gaurav was the accepting senior editor for this paper.

1 Introduction

The world's increasingly aging population has created new issues for humanity to solve. Most countries have rising life expectancy and an aging population. In fact, the aged population today has reached the highest trajectory in human history with the combined senior and geriatric population expected to reach two billion people by 2050 (United Nations, 2019). Researchers have forecasted an increase in healthcare costs and a shortage in caregivers (Lazar, Thompson, Piper, & Demiris, 2016); thus, planning for aging has imperatively become a collective responsibility for academics, civil society, industry, and policy makers alike.

Given the world's aging population, the gerontechnology field has emerged. In particular, gerontechnology combines insights from gerontology and technology to innovatively develop assistive technologies to improve older adults' way of life by helping them to live independently (Teh et al., 2017). In recent times, many gerontechnologists have explored whether robotics can support older adults (Mitzner, Chen, Kemp, & Rogers, 2014; Mois & Beer, 2020). For example, Allaban, Wang, and Padir (2020) and Christoforou, Panayides, Avgousti, Masouras, and Pattichis (2019) reviewed assistive robotics and technologies for elderly care, such as ambient assisted living and robotic nursing, whereas Gessl, Schlögl, and Mevenkamp (2019) shed light on the degree to which the future elderly (i.e., people aged 20 to 60 today) will accept artificially intelligent robotics. Yet, most gerontechnologists agree that implementing robotics for elderly care may actually be easier said than done in reality (Allaban et al., 2020; Christoforou et al., 2019).

In line with existing literature, we concur that gerontechnologists will need to develop service robots that offer functional support to older adults in order for them to independently operate in the home environment (Bedaf, Marti, & De Witte, 2019; Diaz-Orueta, Hopper, & Konstantinidis, 2020). Building on the existing literature, we contend that gerontechnologists will also need to ensure successful human-robot interaction to realize the potential of robotics technology in elderly care, which means we need to understand the degree to which older adults will accept service robots. Unlike the existing literature that has forecasted the future elderly will accept gerontechnology (e.g., Gessl et al., 2019) or surveyed older adults without prototypes (e.g., Bedaf et al., 2019), we focus on accelerating the translation of gerontechnology theory into practice by developing and testing an original prototype of a service robot with actual older adults (i.e., people aged 60 and above).

From a technical perspective, we develop and report on an in-house teleoperated human-sized soft service robot that performs object-retrieval tasks with a soft-jamming granular gripper. In essence, the soft-jamming granular gripper is a contemporary, universal gripper that overcomes the hardware and software complexities of conventional multi-fingered grippers, such as reducing computational overhead and eliminating the need for force sensing and large numbers of controllable joints (Brown et al., 2010). In particular, rather than individual fingers as in the conventional gripper, the contemporary gripper features a single mass of granular material and uses vacuum to rapidly contract and harden to pinch and hold onto target objects without requiring sensory feedback. While existing studies have treated grippers as an independent prototype (e.g., Brown et al., 2010; Deebekaa, Priya, & Kalaiarassan, 2018), we contend that we need to consider grippers as an integral component alongside other components, such as a tablet interface and a human-sized base, in a given technology to comprehensively evaluate its feasibility for implementation in practice and, in this case, as part of a soft service robot that can serve as an independent living solution for older adults.

From a human-computer interaction perspective, we test and report on the degree to which older adults would accept a soft service robot after interacting with it in the home environment. As such, our results should offer important implications on how one should design and develop soft service robots for older users. Moreover, theory in general and the technology acceptance model (TAM) (Davis, 1989) in particular guides our paper. The TAM offers a theoretical lens to examine how older adults evaluate the soft service robot that we developed for this study after interacting with it. Unlike most studies that use the TAM, we apply it in its extended form by including additional considerations that the existing literature has proposed, such as perceived anxiety (Yap & Lee, 2020), perceived likability (Haring, Silvera-Tawil, Watanabe, & Velonaki, 2016), and subjective norms (Venkatesh & Davis, 2000).

This study's novelty resides in our comprehensive two-stage approach to human-computer interaction validation. First, we developed an original soft service robot via integrating state-of-the-art components, such as the soft-jamming granular gripper that one can easily and quickly assemble using readily accessible and available parts in the marketplace. Second, we tested the degree to which older adults accepted this robot based on the TAM, a widely accepted theoretical lens.

This paper proceeds as follows. In Section 2, we discuss the study's theoretical background. In Section 3, we explain how we designed and developed the soft service robot. In Section 4, we discuss the procedure we followed to conduct the study and our findings. Finally, in Section 5, we discuss the study's implications and limitations and present future research directions.

2 Theoretical Background

2.1 Robotics

Rapid technological development continues to steadily bring the futuristic service robots we see helping people on screen into real life. A key advance involves the integration of robot manipulator arms with mobile platforms. Commonly referred to as mobile manipulators, robot manipulator arms' ability to interact with their surroundings make them highly suited for service robot applications in human-centric social environments (Khatib, 1999). Nonetheless, many service mobile manipulators are only marketed for and used in research (Marvel & Bostelman, 2013; Srinivasa et al., 2012; King, Chen, Fan, Glass, & Kemp, 2012). However, one cannot easily implement these robots in practice given that they need to operate in highly uncertain environments and to adapt to various task permutations, such as retrieving household objects with different geometries, sizes, and makes (King et al., 2012).

At the same time, researchers have widely expanded on another robotics field in recent years: soft robotics. Soft robotics, which generally refer to robotic systems made at least partially out of soft materials, have seen growing adoption due to their compliant and shape-adaptive nature, low implementation costs, and energy efficiency (Nurzaman, Iida, Margheri, & Laschi, 2014; Wang, Nurzaman, & Iida, 2017; Katiyar, Kandasamy, Kulatunga, Mustafizur, Iida, & Nurzaman, 2018; Laschi, Mazzolai, & Cianchetti, 2016). In lieu of the barriers that we mention above, soft grippers could represent a solution for improving mobile manipulator-based social service robots due to their adaptability in grasping myriad household objects (Shintake, Cacuciolo, Floreano, & Shea, 2018).

Barring challenges such as cost and social acceptability, older adults today will likely be the first individuals to use assistive robots in some form. Current on-site human caregivers may potentially be a traditional alternative as researchers have shown relatively low-cost service robots to be able to help older adults at home to a decent effect (Mucchiani et al., 2017). However, this shift may be difficult to achieve in practice due to preconceived notions of complexity and an inevitable technological learning curve that may drive older people away from assistance via technology (Czaja et al., 2006; Demiris et al., 2004). Recent studies have also noted that many older people view current autonomous robotic assistants as lacking practicality and as frustrating and slow to use (Pripfl et al., 2016). These signs suggest the need to analyze the degree to which users (particularly the elderly) accept these robots such that future iterations may take directions that fit the bill for general users.

2.2 Technology Acceptance Model

The TAM constitutes one among many widely used theoretical models that helps explain people's perceptions and behaviors toward new technology (Davis, 1989; Bagozzi, 2007; Wang, Chen, & Chen, 2017; Schwalb & Klecun, 2019). While the original TAM explains users' perceptions about how easy to use and useful they found a given technology and their intentions toward it, recent studies have called for extensions to the original TAM to account for peculiarities that could better explain technology acceptance for different individuals who use myriad technologies (Lim, 2018a, 2018d), including in humanoid robots settings (Stock & Merkle, 2017).

In this paper, we used an extended TAM to examine the degree to which older adults accept a soft service robot that we developed to help them live independently in the home environment. The extended TAM postulates five antecedents that older adults may consider when deciding to adopt or not to adopt a soft service robot. Two antecedents (i.e., perceived ease of use and perceived usefulness) have their roots in the original model (Davis, 1989), whereas we include the other three antecedents (i.e., subjective norms, perceived anxiety, and perceived likability) due to recommendations from the existing literature (Haring et al., 2016; Venkatesh & Davis, 2000; Yap & Lee, 2020).

When one applies the original TAM to soft service robots, perceived ease of use encapsulates the degree to which one believes that using a soft service robot does not require effort (Davis, 1989). That is, older adults will likely adopt a soft service robot when they find it easy to learn and use (Davis, 1989; Heerink, Kröse, Evers, & Wielinga, 2010; Lim et al., 2015). In contrast, perceived usefulness refers to the degree to which one believes that using a soft service robot would be assistive (Davis, 1989). That is, older adults will likely adopt a soft service robot when they find it convenient, helpful, and useful (Davis, 1989; Heerink et al., 2010; Lim et al., 2015).

When one applies the extended TAM to soft service robots, subjective norms accounts for the degree to which one perceives that significant others think that one should or should not use a soft service robot (Heerink et al., 2010; Niknejad, Ismail, Mardani, Liao, & Ghani, 2020). That is, older adults will likely adopt a soft service robot when others, such as their family and friends, approve their doing so (Heerink et al., 2010; Talukder, Sorwar, Bao, Ahmed, & Palash, 2020). The extended TAM also considers two other perceptions: perceived anxiety and perceived likeability. Perceived anxiety considers the degree to which one feels anxious or experiences an uncomfortable emotional reaction when using a soft service robot (Heerink et al., 2010; Tsai, Lin, Chang, Chang, & Lee, 2020). That is, older adults will not likely adopt a soft service robot when they fear that they will break something or make mistakes while using it or when they find it intimidating or scary (Fridin & Belokopytov, 2014; Heerink et al., 2010). Perceived likability refers to the degree to which one believes that a soft service robot is likable (Haring et al., 2016; Troncone et al., 2020). That is, older adults will likely adopt a soft service robot when they like its appearance, design, or look (Haring et al., 2016; Krägeloh, Bharatharaj, Kutty, Nirmala, & Huang, 2019; Mohammad & Nishida, 2015).

More importantly, one can observe whether older adults will adopt a soft service robot through the notion of intention, a predictor or proxy of actual behavior that technology acceptance studies often use (Davis, 1989). That is, one can observe older adults' intention to adopt a soft service robot through their intention to purchase, upgrade, use, or recommend it (Teh et al., 2017).

Given this theoretical underpinning, we propose the following hypotheses:

H1: Perceiving a soft service robot as easy to use positively influences older adults' intention to adopt it.

H2: Perceiving a soft service robot as useful positively influences older adults' intention to adopt it.

H3: Perceiving a soft service robot as adhering to subjective norms positively influences older adults' intention to adopt it.

H4: Perceiving anxiety about using a soft service robot negatively influences older adults' intention to adopt it.

H5: Perceiving a soft service robot as likeable positively influences older adults' intention to adopt it.

We present our model in Figure 1.

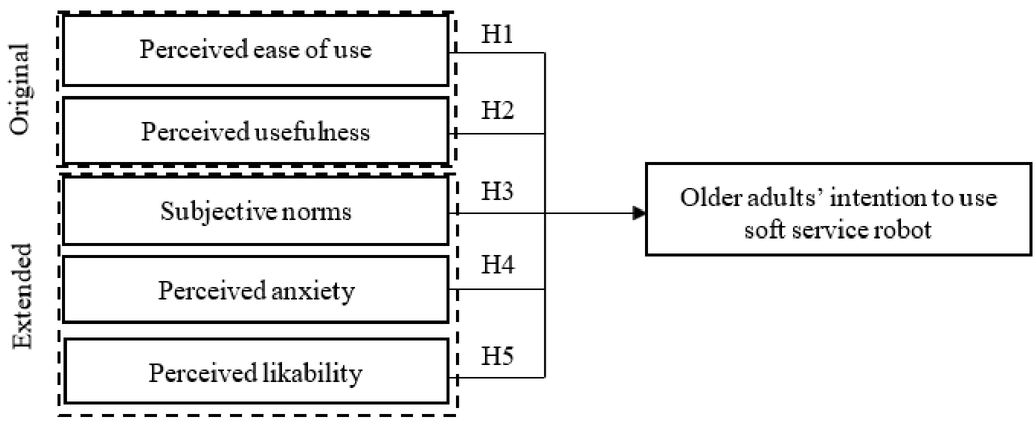

Figure 1. Technology Acceptance of Older Adults towards Soft Service Robots

3 Design and Development of Soft Service Robot

In this section, we describe the soft service robot's technical features and operating principles. We provide a full view of the robot system in Figure 2.

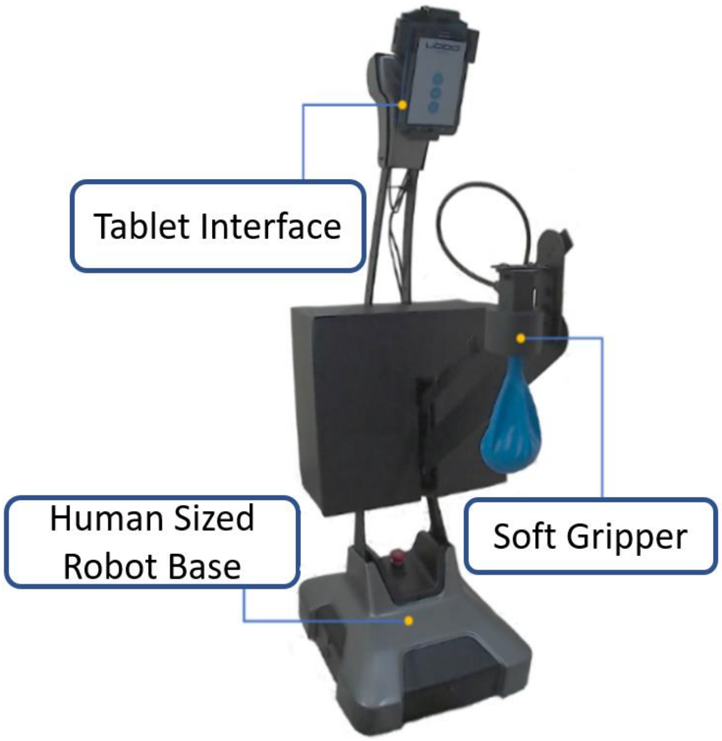

Figure 2. Full View of the Soft Service Robot

3.1 Hardware

3.1.1 Human-sized Robot Base

To accelerate the build process, we used the UBBO maker telepresence Robot by AXYN Robotique as a platform to develop the soft service robot (AXYN Robotique, 2018). We chose this platform because we could easily adapt it since it has an open source kit that one can assemble on arrival. Moreover, researchers have suggested a properly designed teleoperated robot system to be socially acceptable (Nakanishi, Murakami, Nogami, & Ishiguro, 2008). The robot stands 1.3 meters tall and has a 35 cm by 45 cm base. The robot kit features a highly mobile drive system that uses mecanum wheels and IR sensors on its base to detect obstacles. The robot also comes equipped with Bluetooth connectivity for communication and a tablet at the top, which affords remote control and telepresence functionality. One can expand the robot's I/O options with an Arduino MEGA microcontroller built in, and a large battery capacity should help the robot to maintain an efficient run time even when one adds new functionality to it.

In relation to our study's goals, we implemented a soft gripper with a simple one-degree-of-freedom arm with the robot platform along with supporting electronics to turn the robot into a mobile manipulator, which we explain in Section 3.1.2.

3.1.2 Robot Arm

A one-degree-of-freedom manipulator enables the robot to perform pick and place operations from ground level. Two stepper motors in parallel connection to a gear train with a reduction of 7.1:1 drive the arm (see Figure 3a). The arm can pick up objects up to 2.5 kg from the floor with an arm length of 50 cm. The robot base integrates stepper motor drives that the on-board Arduino MEGA controls.

3.1.3 Soft Gripper

Since household objects come in all shapes and sizes, the robot enabled compliant grasping via a "granular-jamming" soft gripper as the end effector of the robot arm. The gripper design (see Figure 3b) built on the universal gripper design (Brown et al., 2010) and operated in a similar manner. Factors behind our decision to choose this soft gripper design reference included low cost, ease of fabrication, simple operation, and sufficient adaptability in grasping various objects.

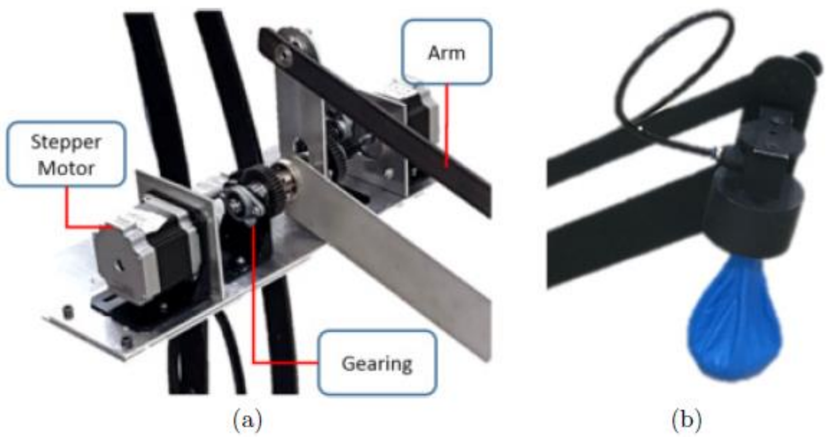

Figure 3. Robot Arm Drivetrain (A) and Soft Gripper (B)

At the core of its design, the soft service robot version of the universal gripper used a 3D-printed base that connected the vacuum line to a balloon filled with 1 mm in diameter plastic beads. Thus, the gripper had a shorter and simpler fabrication process compared to a silicone pneumatic networks (PneuNets) gripper, another soft gripper that we considered for this study. We used an air pump in the robot base to generate the vacuum, which stiffened the bead-filled balloon as it conformed to an object. The Arduino MEGA controlled the pump via a relay. The gripper applied force evenly around the grasp surface when grasping, which prevented pinching, high pressure, and impact points that could have damaged items.

Despite the fact that we did not focus on improving the universal gripper's grasping ability in our study, we conducted an experiment using the developed soft gripper to evaluate its viability to grasp various household objects as part of the decision-making process in selecting this design. In Figure 4, we show the gripper's success rate in picking up various objects with 20 trials. In particular, in the trials, we tested whether the arm could lift up various objects from the ground and keep them suspended for 10 seconds. The data shows that the gripper had trouble with thin objects such as coins and large objects such as the handle or rim of a mug—a result that we expected given the outlined advantages and disadvantages of this type of soft gripper.

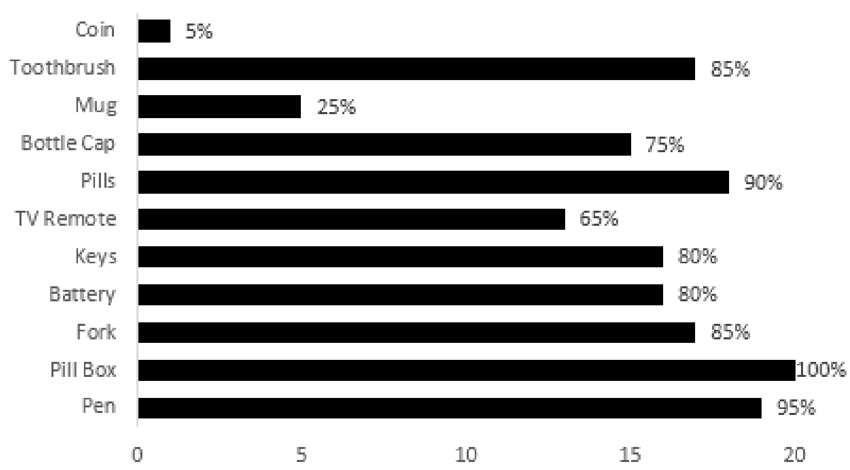

Figure 4. Grasping Success Rate for Household Objects

3.2 Software

3.2.1 Robot Programming

Due to the open source nature of the Arduino program that the UBBO Maker telepresence robot used, we could easily add additional features to the soft service robot's code. The robot also had a tablet running the UBBO Maker application that handled its telepresence functionality and Web communication. The application allowed the tablet to communicate with the Arduino MEGA via Bluetooth to send remote control instructions to or acquire status data from the robot base.

3.2.2 User Interface

Due to the robot's telepresence functionality, either older adults themselves or remotely located caregivers who assist older adults could operate it. A webRTC based graphical user interface (GUI) that AXYN Robotique developed allowed users to perform video calls through the robot tablet and control the robot. One could access the platform through various electronic devices (see Figure 5). Only users with the correct login credentials could access the robot, and communication to the tablet required a security identifier tied to the login.

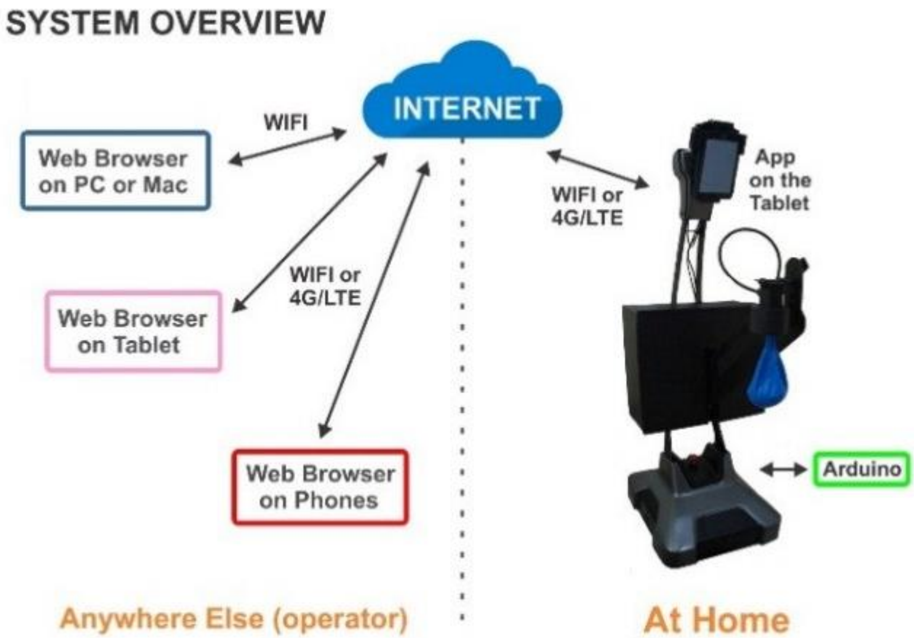

Figure 5. System Connectivity Overview

Users could initiate the connection between the tablet and the operator once they logged in by launching an application on the tablet and initiating a video call from it. The user could then receive the call via the Maker.Ubbo.io website interface to establish the connection. Afterwards, the user would see the GUI to operate the robot, which the user could customize based on the robot's function (see Figure 6), and a legend for the controls for movement and actuation. By using the interface, users could control the robot remotely using on-screen controls or with the keyboard.

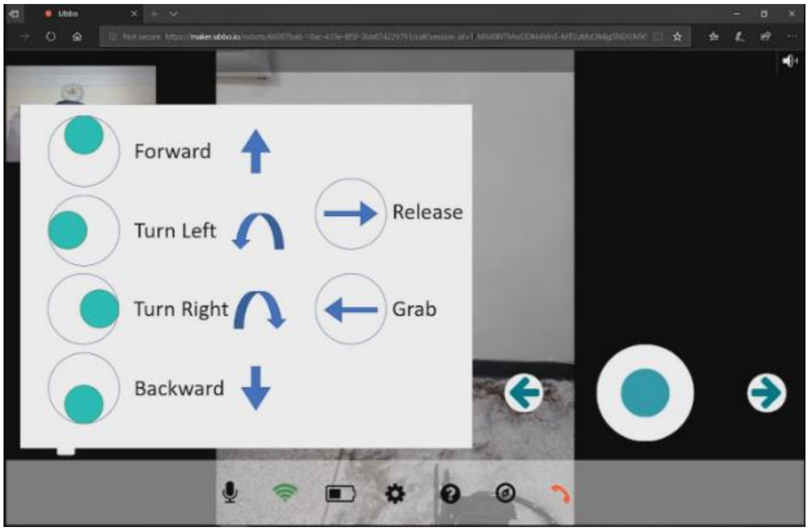

Figure 6. Operator User Interface Appended with Control Legend

4 Study

4.1 Methodology

4.1.1 Instrumentation

We conducted a survey via a questionnaire to examine the degree to which older adults would accept the aforementioned soft service robot that would cater to their functional needs in the home environment. In particular, the questionnaire in the survey comprised close-ended questions that measured each construct that we hypothesized. We adapted the questions measuring perceived ease of use, perceived usefulness, subjective norms, perceived anxiety, perceived likability, and intention toward the soft service robot from past studies (Davis, 1989; Heerink et al., 2010; Lohse et al., 2007; Teh et al., 2017) (see Table 1 on the next page). We pretested the questions, which we measured on a seven-point Likert scale and modified to suit our study context, with five subject-matter experts (with minor changes for clarity) to establish content validity (Beck & Gable, 2001).

4.1.2 Sampling

We employed typical case sampling to recruit older adults for this study. In essence, typical case sampling is a form of purposive sampling that one can use to study general (or average) members of a target population (Etikan, Musa, & Alkassim, 2016). We considered this sampling method ideal for this study because we targeted the general—and not any specific—population of older adults with which to test the soft service robot that we developed. We chose this target population and, therefore, the sampling method for three primary reasons. First, older adults are generally less mobile compared to younger adults due to a natural decline in bodily strength, which suggests a potential need for mobility solutions (Gordon, 2018). Second, older adults have a general tendency to stockpile essentials since it can help them relieve anxiety and reassure their quality of life and dignity, which indicates a potential demand for mobility solutions to retrieve these items even when older adults only marginally require them (Andersen, Raffin-Bouchal, & Marcy-Edwards, 2008). Third, older adults with serious health (e.g., dementia) and mobility (e.g., stroke) issues will likely require caretaker support and/or robotics rehabilitation rather than soft service robots (which we developed as a general—and not a chronic—mobility solution) in the home environment (Krishnan et al., 2018; Weber & Stein, 2018).

Table 1. Measurement Items

Construct	Conceptualization	Operationalization	Sources
Perceived ease of use	The degree to which one believes that using a soft service robot does not require effort (Davis, 1989; Heerink et al., 2010).	1. I find the soft service robot easy to use. 2. I think I will know quickly how to use the soft service robot. 3. I think I can use the soft service robot without any help. 4. I think I can use the soft service robot when there is someone around to help me. 5. I think I can use the soft service robot when I have a good manual.	Davis (1989), Heerink et al. (2010)
Perceived Usefulness	The degree to which one believes that using a soft service robot would be assistive (Davis, 1989; Heerink et al., 2010).	1. I think the soft service robot is useful to me. 2. It would be convenient for me to have the soft service robot. 3. I think the soft service robot can help me with many things.	Davis (1989), Heerink et al. (2010)
Perceived anxiety*	The degree to which one feels anxious or uncomfortable emotional reactions when using a soft service robot (Heerink et al., 2010).	1. If I should use the soft service robot, I would be afraid to make mistakes with it. 2. If I should use the soft service robot, I would be afraid to break something. 3. I find the soft service robot scary. 4. I find the soft service robot intimidating.	Heerink et al. (2010)
Perceived likability	The degree to which one believes that a soft service robot is likable (Lohse et al., 2007).	1. I like the design of the soft service robot. 2. I like the appearance of the soft service robot. 3. I like the look of the soft service robot.	Lohse et al. (2007)
Intention	The intention that one has about a soft service robot (Teh et al., 2017).	1. If available, I intend to purchase the soft service robot for activities of daily living in my home. 2. If available, I intend to use the soft service robot for activities of daily living in my home. 3. If available, I intend to recommend to others the soft service robot for activities of daily living in their homes. 4. If I own an older model of the soft service robot, I am likely to upgrade to the newer model of the soft service robot.	Teh et al. (2017)

Note: * we measured perceived anxiety using negatively worded questions.

We recruited a typical case sample of the general older adult population through a call for participation advertisement that we disseminated to non-governmental associations for the elderly in Klang Valley, Malaysia. We followed this procedure for two primary reasons. First, non-governmental associations for the elderly typically regularly engage with older adults as they often organize events and activities that older adults find interesting and relevant in a safe and secure environment that features mutual trust, support, and respect. Second, to increase the study's generalizability, we chose Klang Valley as the sampling location since only it comprised residents who come from all the 14 states in Malaysia (Lim & Ting, 2012a; Lim & Ting, 2012b).

We required all participants who agreed to voluntarily participate (i.e., they received no remuneration, though we did provide a lucky draw of US$25 for 10 random participants) to provide consent before they could participate in the survey. Following that, we required participants to watch a short video that demonstrated the soft service robot in operation (i.e., retrieving and moving dropped objects such as a pillbox, spoon, keys, and eye-glasses in a home setting). The video that we showed to participants followed the outline that we present in Figure 7c (readers can find the compressed but high resolution video that we showed to the participants in Lee (2018)). In the video, a narrator explains each section alongside relevant pictures and video. The user interface that we show in Figure 6 represents an example picture that the video uses to explain how to use the robot. Figure 7a shows a screenshot from the video that demonstrates a full pick-and-place sequence for an object, and Figure 7b shows for a screenshot from the video that demonstrates objects that the robot can pick up to give viewers an idea about its capabilities. The direct-indirect experience spectrum (Mooy & Robben, 2002) in which participants acquire indirect experience from viewing a video about something (in this case, the soft service robot) supports our research design. Finally, after watching the video, participants completed a questionnaire on their views about the soft service robot. In total, 79 older adults completed the survey. The small sample size, which we can attribute to the fact that we did not provide remuneration to participants, concurs with past gerontechnology studies (e.g., Lim et al., 2015; Teh et al., 2017). We recorded no participant dropout, which we can credit to the survey's straightforward nature (e.g., concise and relevant to older adults' daily lives). However, we do not disclose the non-governmental organizations' names or the total number of older adults who participated in the survey and viewed the call for participation advertisement due to ethical considerations in the ethics approval that we obtained for the study.

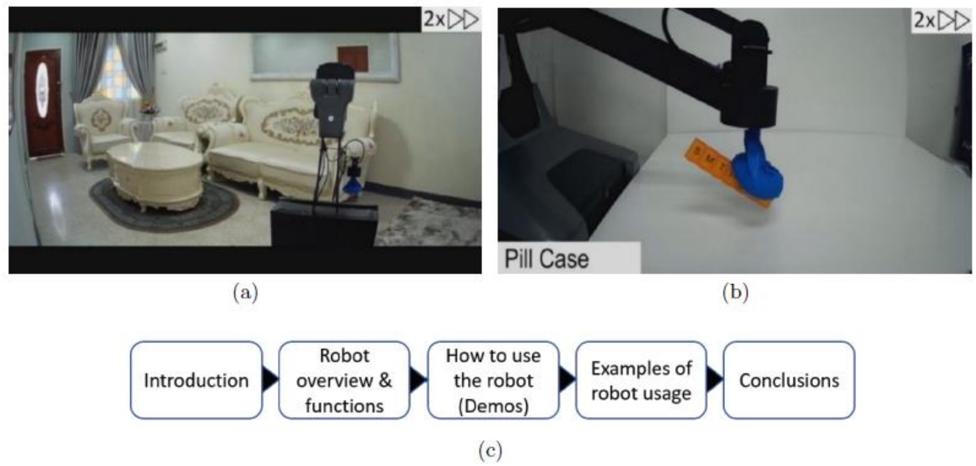

Figure 1. Full Robot Demonstration Sequence Screenshot (A), Object Pickup Demonstrations Screenshot (B), and Outline of Survey Video (C)

4.2 Results

4.2.1 Sample Profile

Our sample comprised 79 older adults (67% females and 33% males) (see Table 1). Furthermore, almost all participants were Asians (97.5%) and had completed at least primary education (97.5%). Most were between 60 and 69 years old (86%), while the remaining 14 percent were over 70 years old. Also, 82.3 percent of participants were married, 6.3 percent were single, 6.3 percent were widowed, and 5.1 percent were divorced or separated.

Most participants reported their economic status as general or adequate (i.e., neither rich nor poor) (94.9%); only a handful regarded themselves as rich (2.5%) or poor (2.5%). Furthermore, 27.8 percent of participants relied on the pension; 21.5 percent had a retirement fund; 21.5 percent received a salary or wage; 16.5 percent depended on monetary support from a spouse, child(ren), grandchild(ren), or relative(s); and the remaining 12.6 percent reported that they relied primarily on other monetary sources (e.g., savings).

Most participants lived with family member(s) (67.1%). The remaining participants lived with only a spouse (25.3%) or alone (7.6%). Furthermore, most participants lived on a landed property such as a single- and double-story terrace or linked house, semi-detached house, or bungalow (86.6%), whereas the remaining participants lived on a non-landed property such as an apartment, flat, or condominium (11.4%).

Most participants felt that they were in good to excellent health (77.2%). The remaining participants reported fair health (22.8%), and no participants reported poor health. Nevertheless, most participants reported that health conditions associated to aging (e.g., mobility) limited their routine activities (73.4%), which indicates the potential demand for soft service robots (even among healthy older adults). Finally, 75.9 percent of participants were independent, whereas 24.1 percent required some form of assistance from others (i.e., from limited assistance from others to total dependence on others). This figure concurs with the growing trend of older adults who wish to age with dignity (Bayer, Tadd, & Krajcik, 2005; Gilleard, 2018).

When we considered the constructs in the study, the skewness and kurtosis values of perceived ease of use, perceived usefulness, subjective norms, perceived anxiety, perceived likability, and intention of our sample were between the recommended range of -2 and +2 for an acceptable normal distribution (George & Mallery, 2010) (see Table 3). More importantly, the mean ($\bar{x}$) ranges for the constructs suggest that most older adults in our sample believed that the soft service robot was easy to use ($\bar{x} > 3.5$ = 82.3%), useful ($\bar{x} > 3.5$ = 69.6%), socially acceptable ($\bar{x} > 3.5$ = 69.6%), and likable ($\bar{x} > 3.5$ = 65.8%). They also believed that the robot would not likely cause them anxiety ($\bar{x} \leq 3.5$ = 59.5%; negatively worded questions).

Table 2. Participant Profile

Categorical construct / sociodemographic characteristic		Frequency (n = 79)	Percentage (%)
Gender	Female	53	67.1
	Male	26	32.9
Ethnicity	Asian	77	97.5
	Non-Asian	2	2.5
Education	Informal (i.e., no schooling or self-learning)	2	2.5
	Primary school	6	7.6
	Secondary school	16	20.3
	Vocational certification	2	2.5
	Diploma	12	15.2
	Bachelor degree or professional qualification (e.g., ACCA, CPA)	23	29.1
	Master degree	11	13.9
	Doctoral degree	7	8.9
	Other	0	0.0
Age	< 60	0	0.0
	60-64	45	57.0
	65-69	23	29.1
	70-74	7	8.9
	75-79	2	2.5
	≥ 80	2	2.5
Marital status	Single	5	6.3
	Married	65	82.3
	Widowed	5	6.3
	Divorced or separated	4	5.1
Economic status	Rich	2	2.5
	General or adequate (i.e., neither rich nor poor)	75	94.9
	Poor	2	2.5
Primary means of living	Salary or wages	17	21.5
	Business income	3	3.8
	Property income	2	2.5
	Pension	22	27.8
	Retirement fund	17	21.5
	Income support from family members (e.g., spouse, child, grandchild, relative)	13	16.5
	Other	5	6.3
Living arrangement	Live alone	6	7.6
	Live with a spouse only	20	25.3
	Live with family member(s)	53	67.1
Housing	Apartment or flat	4	5.1
	Condominium	5	6.3
	Single-story terrace or linked house	20	25.3
	Double-story terrace or linked house	29	36.7
	Semi-detached house	7	8.9
	Bungalow	14	17.7

Table 2. Participant Profile

Health	Poor	0	0.0
	Fair	18	22.8
	Good	38	48.1
	Very good	21	26.6
	Excellent	2	2.5
Independence	Independent	60	75.9
	Supervised	2	2.5
	Limited assistance	15	19.0
	Extensive assistance	1	1.3
	Total dependence	1	1.3

4.2.2 Factor, Reliability, and Correlation Analyses

We analyzed the data using Microsoft Excel and SPSS 23. We measured the survey items' reliability and validity using Cronbach's alpha, composite reliability, and average variance extracted. As Table 3 shows, all Cronbach's alpha and composite reliability values were above 0.70. Accordingly, they met the desirable value that Nunnally and Bernstein (1994) and Bagozzi and Yi (1998) recommend and, thus, demonstrated good internal consistency or reliability. We also established convergent validity as all average variance extracted values were greater than 0.50, a threshold value that Fornell and Larcker (1981) recommend. As Table 3 showed, all square root values of average variance extracted were greater than the off-diagonal values in the correlation matrix, which indicates evidence of discriminant validity.

Table 3. Results of Reliability and Validity Analyses

Construct	Perceived ease of use	Perceived usefulness	Subjective norms	Perceived anxiety	Perceived likability	Intention
Perceived ease of use	*0.874*					
Perceived usefulness	0.452**	*0.960*				
Subjective norms	0.374**	0.717**	*0.950*			
Perceived anxiety	-0.462**	-0.437**	-0.367**	*0.828*		
Perceived likability	0.213	0.586**	0.619**	-0.263*	*0.969*	
Intention	0.477**	0.754**	0.733**	-0.356**	0.515**	*0.934*
$\bar{x}$	4.623	4.430	4.203	3.332	4.232	4.092
σ	1.367	1.620	1.604	1.268	1.561	1.633
$\sigma\bar{x}$	0.1272	0.1823	0.181	0.143	0.176	0.184
$\bar{x}$ range (≤ 3.5)	n = 14 (17.7%)	n = 24 (30.4%)	n = 24 (30.4%)	n = 47 (59.5%)	n = 27 (34.2%)	n = 29 (36.7%)
$\bar{x}$ range (> 3.5)	n = 65 (82.3%)	n = 55 (69.6%)	n = 55 (69.6%)	n = 32 (40.5%)	n = 52 (65.8%)	n = 50 (63.3%)
Skewness	-0.707	-0.130	-0.061	0.011	0.042	-0.218
Kurtosis	0.188	-0.972	-0.666	-0.930	-0.867	-0.686
α	0.719	0.957	0.945	0.837	0.966	0.951
AVE	0.764	0.921	0.921	0.685	0.938	0.872
CR	0.941	0.972	0.972	0.897	0.979	0.965

Note: $\bar{x}$ = sample mean; σ = standard deviation; $\sigma\bar{x}$ = standard error; α = Cronbach's alpha; AVE = average variance extracted; CR = composite reliability; *correlation was significant at the 0.05 level (2-tailed); **correlation was significant at the 0.01 level (2-tailed); italicized values in the diagonal row are square roots of the average variance extracted.

To check for construct validity, we conducted principal component factor analysis (see Table 4). We show the factor loadings, Kaiser-Meyer-Olkin statistic, Bartlett's test of sphericity statistic, and eigenvalues in Table 4. In particular, each item exhibited good factor loading (i.e., more than 0.50). In addition, the Kaiser-Meyer-Olkin statistics ranged from 0.629 to 0.812 and, thus, met the cut off criteria of 0.50 that Hair, Black, Babin, and Anderson (2010) suggest. The Bartlett's test of sphericity statistics were also significant for all scales and ranged from 197.220 (perceived ease of use) to 373.177 (intention). Moreover, we retained the six constructs under study when we considered the latent root criterion of retaining factors with eigenvalues greater than one—the unidimensional one-factor structure of each construct attained eigenvalues that ranged from 2.709 to 3.488 (see EV Factor 1). Taken together, we confirmed the constructs perceived ease of use, perceived usefulness, subjective norms, perceived anxiety, perceived likability, and intention to be valid and reliable in this study.

Table 4. Results of Factor Analyses

Variables	No. of items	KMO	BTS	EV factor 1	EV factor 2	Factor loadings				
						Item 1	Item 2	Item 3	Item 4	Item 5
Perceived ease of use	5	0.746	197.220**	2.895	0.672	0.862	0.942	0.903	0.968	0.663
Perceived usefulness	3	0.774	249.413**	2.762	0.139	0.959	0.966	0.954	NA	NA
Subjective norms	3	0.721	266.725**	2.709	0.246	0.967	0.971	0.911	NA	NA
Perceived anxiety	4	0.629	224.769**	2.738	0.924	0.776	0.798	0.888	0.844	NA
Perceived likability	3	0.727	313.597**	2.813	0.147	0.951	0.984	0.971	NA	NA
Intention	4	0.812	373.177**	3.488	0.297	0.961	0.967	0.928	0.877	NA

Note: **p-value < 0.01; KMO = Kaiser-Meyer-Olkin statistic; BTS = Bartlett's test of sphericity statistic; EV = eigenvalue; NA = not applicable.

4.2.3 Multiple Regression Analysis and Hypothesis Testing

We performed multiple regression analysis to test the hypothesized model (see Table 5). The predictors explained 66.3 percent of intention's variance in the model. In this evaluation, perceived ease of use (β = 0.163; p-value < 0.05), perceived usefulness (β = 0.421; p-value < 0.01), and subjective norms (β = 0.380; p-value < 0.01) jointly determined older adults' intention. Our findings show a non-significant relationship between perceived anxiety (β = 0.046; p-value = 0.568) and perceived likability (design) (β = 0.011; p-value = 0.901) to intention in the model. Thus, we found support for H1, H2, and H3 but not H4 and H5.

Table 5. Results of Multiple Regression Analysis

Hypothesis	Beta coefficient	Standard error	Hypothesis testing
H1: Perceived ease of use → intention	0.163*	0.117	Supported
H2: Perceived usefulness → intention	0.421**	0.108	Supported
H3: Subjective norms → intention	0.380**	0.107	Supported
H4: Perceived anxiety → intention	0.046	0.103	Not supported
H5: Perceived likability → intention	0.011	0.094	Not supported
R^2	0.663		
Adjusted R^2	0.640		
F	28.705		
Significance	0.000**		

Note: dependent construct = intention; *p < 0.05; **p < 0.01.

5 Conclusion

Gerontechnologies using robotics have attracted increasing research interest, but few solutions have found common use because we do not adequately understand human-computer interaction between older adults and service robots. By involving older adults in developing and testing soft service robots that may help them live more independently, we make several pertinent contributions.

From a technical standpoint, we contribute fresh insights into developing an original gerontechnology for older adults—an in-house teleoperated human-sized soft service robot that performs object-retrieval tasks with a soft-jamming granular gripper. More specifically, we demonstrate the ease in building this robot from the UBBO Maker telepresence robot system and the extent to which the robot can successfully grasp numerous objects in the home environment. In particular, the user interface allows older adults themselves or remote caregivers to control the robot and retrieve and move dropped items (e.g., pillbox, spoon, keys, and eye-glasses) from one location to another in the home.

From the human-computer interaction standpoint, with this paper, we enrich our understanding about the degree to which older adults accept gerontechnologies such as the soft service robot we considered. More specifically, we used the extended TAM and uncovered important insights that others can use to encourage older adults to adopt the soft service robot. That is, we found that perceived ease of use, perceived usefulness, and subjective norms positively and significantly predicted older adults' intention to adopt and use the soft service robot we developed. These findings reaffirm the findings from two studies: Heerink et al. (2010) and Wang et al. (2017). In particular, Heerink et al. (2010) emphasized that, to encourage older adults to use robots, one needs to design them mindfully so that older adults find them useful and easy to use, and Wang et al. (2017) highlighted that robots could help older adults to mitigate social isolation arising from non-conformance to societal expectations as its adoption enables them to demonstrate their ability to embrace modern technologies to their younger counterparts.

Nonetheless, the older adults in our study weighed perceived anxiety as insignificant in predicting their intention to use the soft service robot. A possible reason why concerns the fact that many older adults today have increasingly adapted to using contemporary technology, such as smartphone and social media, in their daily lives and, thus, do not feel anxious in using technology as they have already become acquainted with technological interaction. Likewise, we found perceived likability found to be insignificant in affecting older adults' intention to adopt the soft service robot. This finding, when considered alongside the significant influence of perceived ease of use and perceived usefulness, suggests that older adults care more about the soft service robot's utilitarian rather than hedonic aspects to help them live more independently. Thus, when encouraging older adults to adopt gerontechnologies such as the soft service robot, gerontechnologists and marketers should focus on its utilitarian benefits, such as ease of use and usefulness, and on subjective norms. More importantly, gerontechnology manufacturers will need to ensure that older adults can afford the soft service robot in order to mitigate the intention-behavior gap, which may occur when older adults who intend to adopt the soft service robot cannot do so due to its price. Large gerontechnology enterprises may have a more privileged position to offer the soft service robot at a lower price due to economies of scale as compared to small and medium-sized gerontechnology enterprises that could nevertheless compete using a rent-to-own pricing strategy to weather through the competition in their journey to reach economies of scale.

This study has four main limitations that could pave the way for further research. First, our results build on responses that participants who had indirect experience with the soft service robot provided. Therefore, future research can include technology-based intervention to assess participants who have direct experience with the soft service robot (see direct versus indirect experience of technology-based intervention in Lim et al. (2018)). Second, we relied on cross-sectional data instead of longitudinal data in our analysis. Researchers need to conduct future work in which they measure user experience with the soft service robot from prototype testing to post-implementation assessment (see longitudinal assessment in Berner et al. (2019)). Third, we relied on proxies, such as education and independence, to describe the cognitive ability of older adults who participated in the survey. In general, we found an indirect indication that older adults in the sample had good cognitive ability as almost all participants completed at least primary education (97.5%) and most participants were independent (75.9%) (i.e., did not require assistance from others). In addition, we encountered no illogical or inconsistent responses in the survey sample. Nonetheless, future research should use direct measures of cognitive ability to ensure (with greater confidence) that they include only older adults who can understand and answer the survey well (e.g., no dementia) in the analysis. Finally, we conducted our study using self-reported measures. Thus, future research could enhance our investigation's rigor via experimenting with and using neuroscientific methods to supplement and validate self-reported measures (see experimentation in Lim (2015) and Lim, Ahmed, and Ali (2019) and neuroscientific methods in Lim (2018b, 2018c)).

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