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Deployment of a Service Robot to Help Older People

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Abstract— **This paper presents the first version of a mobile service robot designed for older people. Six service application modules were developed with the key objective being successful interaction between the robot and the older people. A series of trials were conducted in an independent living facility at a retirement village, with the participation of 32 residents and 21 staff. In this paper, challenges of deploying the robot and lessons learned are discussed. Results show that the robot could successfully interact with people and gain their acceptance.**

I. Introduction

During the last half-century, robotics research has evolved as a result of changing human needs. The dominant robotic application areas evolved from replacing human operators in factories to more service oriented applications in proximity to humans [1]. A service robot is a robot which operates autonomously or semi-autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations [2].

Internationally, the proportion of older people is increasing. Looking after the increasing high–care community is a strain on diminishing staff and resources [3], [4]. Robotic technology for older care may be a technical solution to this challenge. There have been several attempts to build service robots for older care [5].

In order to develop useful service robots, it is necessary to consider the social and personal viewpoint rather than an industrial viewpoint. This paradigm shift is more prominent when robots are designed for older care. Service robots for older people must satisfy several additional requirements, including safety and user preference. Broadbent *et al.* conducted a retirement home study of staff and residents' preferences for robots [6]. Study participants identified their preferences for a healthcare robot in relation to size, color, appearance, and gender. Results of that study were used as key inputs in the development of the work presented in this paper.

Most previous human robot interaction (HRI) research has focused on different technical aspects in the development of service robots for older people. The pioneering retirement home robot, Pearl, provided reminders and guidance for elderly residents [7], [8]. The Care-O-bot project [9] focused in the same application area. In [10] authors implemented an automated transportation task in a hospital. Shibata *et al.* developed a seal robot (PARO), and studied psychological, physiological and social effects on older people [11]. The uBot project [12] was mainly focused on performing diagnostic checks after a detected fall event. The MATS project robot [13] is a manipulator that could move inside a house. The main focus was locomotion and manipulation, rather than older care. Robots such as T-Rot [14] are general service robots rather than robots designed for elderly.

Unlike the earlier studies, this work is user oriented and does not focus only on technical aspects. The long term objective of this work is to develop a robotic assistant for older people. An older care robot could provide a variety of services such as vital signs measurement, reminding, entertainment, communication, falls detection, and security. It could also support care givers by providing scheduling, medication management, telepresence, and monitoring services. In addition to technological inputs, a considerable research effort was exerted in the areas of health psychology and gerontology.

This paper presents the deployment of the first version of the service robot, designed for older people in a retirement village environment. This study assessed people's reactions to an interaction with an older care robot to determine which human and robot factors predict a successful HRI. For the study purposes it was not necessary for the robot to provide comprehensive functionality; however the robot was required to maintain an effective interaction for some 30 minutes in order to evaluate people's reactions. The key requirements considered in the development process were:

- Low cost: Since this robot is intended to be a personal robot, cost is a primary consideration. Therefore, simpler and cheaper technologies were used.
- Simple user interface: Since the target user group was older people, with little or no experience with computers, simple user interfaces were used.
- Simple operation: All services provided by the robot could be accessed via a touch screen. Speech synthesis was used, but speech recognition was not used.
- Customizability: In the domain of personal robotics, customizability of the user interface is critical. Different users may have different requirements and preferences.
- Robustness: The working environment of the service robot is a domestic setting, where technical support is not readily available. Therefore, special attention was paid to the robustness.

Section II gives a brief overview of the system and in section III, implementation details are presented. Details of the study and results are presented in section IV. In section V, interpretation of results, lessons learned, and

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Fig. 1. HealthBot robot

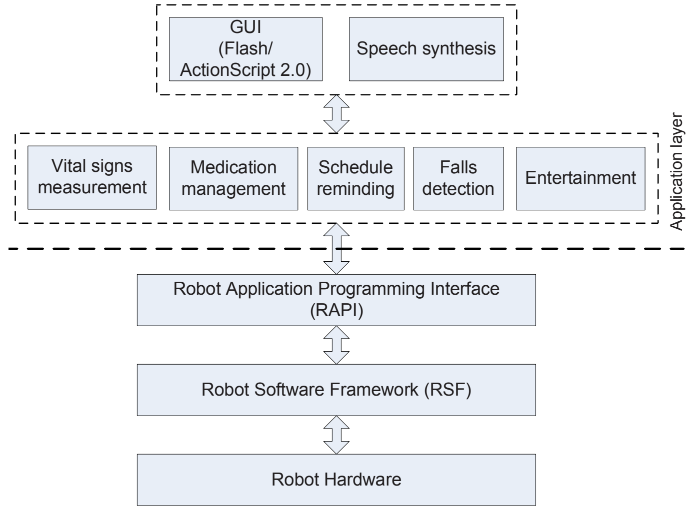

Fig. 2. Overview of the architecture of the HealthBot Robot.

future directions of the research are discussed.

II. System overview

The robot developed in this work is shown in Fig. 1. It consists of a tiltable head, rotatable torso, and a mobile platform. Low level control functions and navigation are handled by a single-board computer running the Linux operating system. Service applications are running on a similar computer running the Windows XP operating system. The two computers are connected via Ethernet.

Ultrasonic sensors for obstacle avoidance are located in the mobile platform (the lower part of the robot in Fig. 1). A tray is fixed to the torso in order to carry measuring devices used by some of the service applications. These external devices are connected to the robot via a USB hub.

The main characteristics of the robot are as follows:

- Interactive: The robot can interact with people via touch screen and synthesized speech. In addition to dialogs, it can use images and short videos to make interactions more meaningful.
- Semi-autonomous: The robot needs minimal user intervention for its operation. It can perform navigation, localization and obstacle avoidance.
- Common theme for GUI: All screens have similar background, colors, button styles, and fonts.
- Dialog management: Appropriate dialogs for user interactions are generated by a dialog manager. In the current version of the robot, the dialog manager consist of a set of pre-defined dialogs.
- Reactive: In addition to user inputs received via the touch screen, it can react to other inputs of users. For example, it can show a friendly gesture when patted on the back.

In addition to these main features, the robot consists of several service modules. They are,

- Vital signs measurement,
- Medication,
- Falls,
- Schedule reminding, and
- Entertainment.

The vital signs measurement module provides two services; blood pressure measurement and blood oxygen saturation (SPO2) measurement. The medication, falls and schedule reminding modules collect data from users via conversations. These data will be used for the development of the next version of the robot, for which medication reminding and fall detection functions will be fully developed. Users can listen to jokes and songs using the entertainment module.

III. Implementation

The robot used for this study is a joint development of the University of Auckland/Auckland UniServices in New Zealand, with ETRI and Yujin Robot Co. Ltd., in South Korea.

The architecture of the robot consists of 4 layers; robot hardware, robot software framework (RSF), robot application programming interface (RAPI), and service applications, as shown in Fig. 2. Robot hardware, RSF, and RAPI were developed by Yujin Robot Co. Ltd. and service applications were developed by a research team at the University of Auckland/Auckland UniServices based on their former research work in the area of health psychology and HRI [6], [15], [16].

The robot hardware consists of a differential drive mobile platform, two single board computers, sonar sensors, microphone, speakers, touch screen mounted on an actuated head, camera, and USB ports.

A. Software architecture

Low level control and navigation are handled by RSF. RAPI hides the complexities of the lower-layers from the service application layer. The work presented in this paper is mainly related to the service applications. Details of other layers are not discussed.

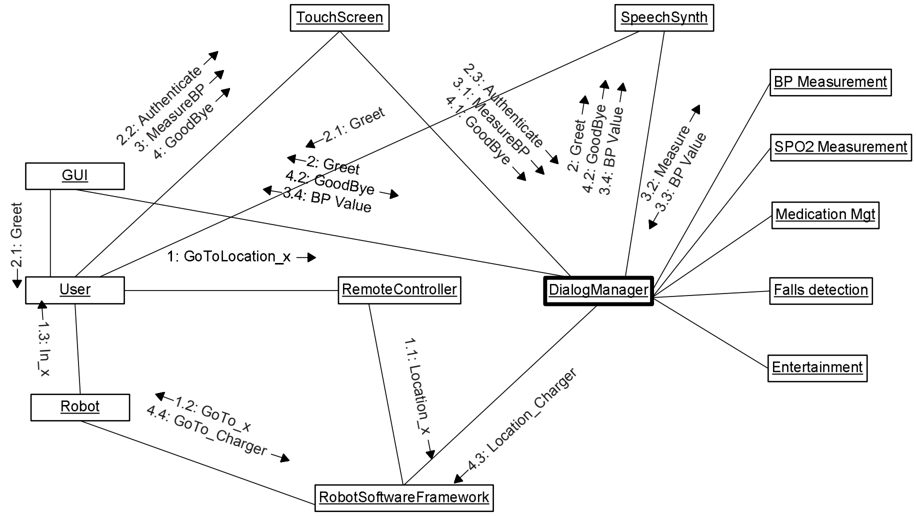

Fig. 3. Collaboration diagram showing the relationship between the different components of the robot architecture.

The service application modules were developed in C++. The application front end was written in Flash and Action Script 2.0.

The collaboration diagram shown in Fig. 3 illustrates the relationships between the main components of the architecture. Messages shown in the diagram are described below.

Message 1 through 1.3 are related to bringing the robot into a user desired location. By entering the destination identifier (discussed in Section III-D) using a remote controller, a user can command the robot to go to a pre-defined place within the work space. Message 2 through 2.3 are related to the initial interaction between the robot and the user. As a part of the greeting, the robot asks for authentication. In the current implementation, an open system authentication method is used; i.e. a user can authenticate by simply entering the name. Messages 3 through 3.4 are related to blood pressure measurement. When the user requests the service, the dialog manager invokes the blood pressure measurement service and provides the results to the user via a synthesized voice as well as the GUI.

Behaviours of other service modules are similar to the behaviour of the blood pressure measurement module.

B. Speech synthesis

The speech synthesis module of the robot is based on the Festival Speech Synthesis System [17]. It was implemented on the robot in server mode, and the application modules interacted with it using socket communication. The standard Festival distribution comes with two diphone voices; US and UK accented English. For this study a New Zealand English voice was used; it was newly developed by the University of Auckland. It contains diphones recorded by a male speaker and a New Zealand English lexicon with 500 common Maori words [18].

C. User interface design and dialog management

The main interface of the robot is shown in Fig. 4. Each screen was carefully designed considering the needs of older people. Aside from the main interface screen, the maximum number of buttons per screen was limited to 4 and in most screens it was limited to 2 or 3. When the robot speaks, the same sentence is displayed on the screen as subtitles. The dialog manager is the main component of the software architecture as shown in Fig. 3. In the current version of the robot, all dialogs are pre-defined. Once a dialog is initiated, the robot guides the user through the dialogs in a deterministic manner. Each service module has a pre-defined dialog flow. A sample dialog pertaining to vital signs measurement is shown in Fig. 5. It shows which words are spoken and what is displayed in each and every screen within the blood pressure measurement module. In the figure, shaded boxes represent buttons. Sentences within quotes are spoken by the robot and are displayed on the screen as subtitles. Instructional videos are shown prior to and during the vital signs measurement process.

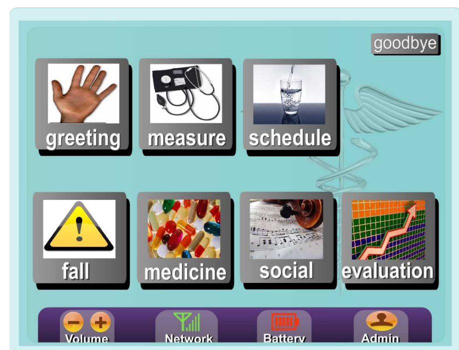

Fig. 4. The main interface used in the robot trial. Note the large font and buttons.

For each service module, similar flowcharts were developed and were circulated among experts in HRI, gerontology, psychology, and programming, to elicit feedback and modifications. A final design was reached after several iterations of this process.

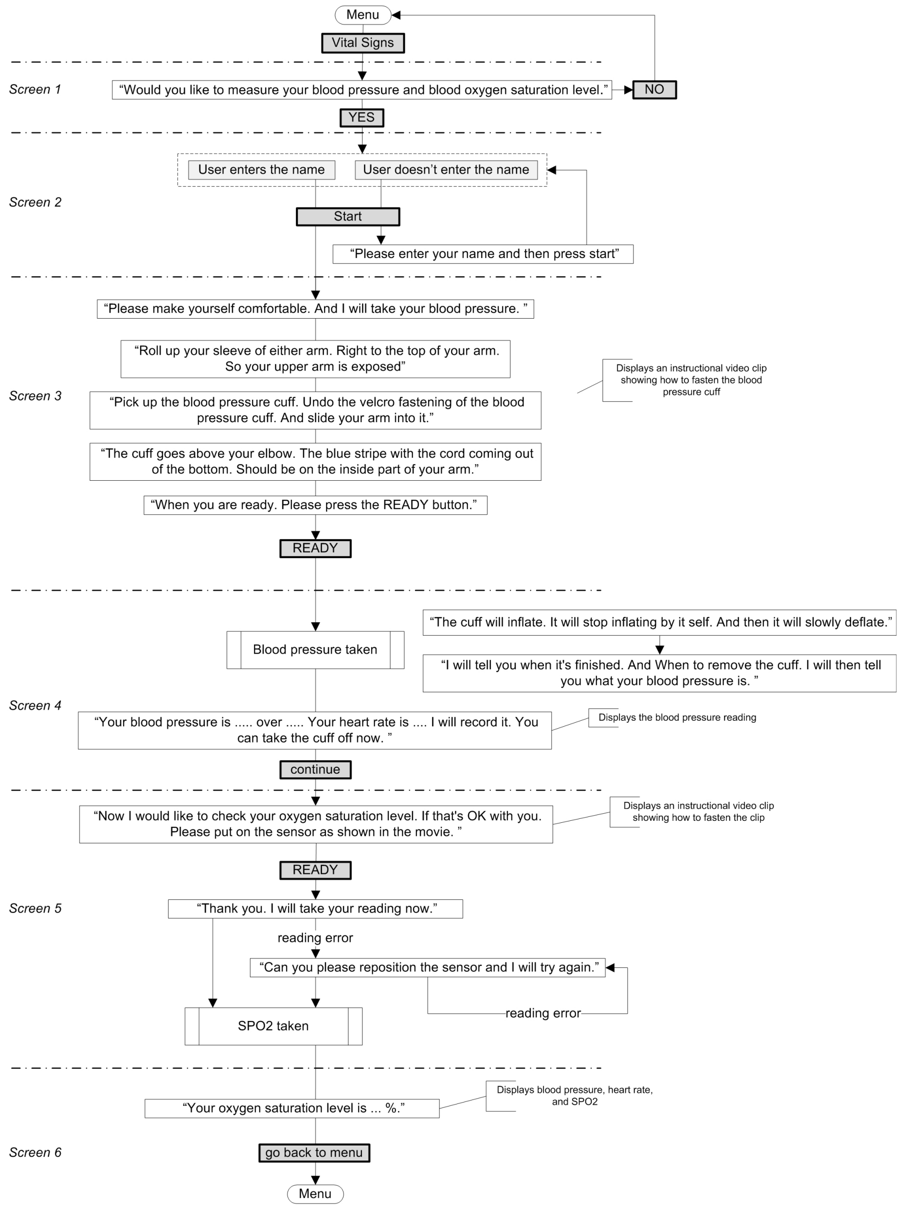

Fig. 5. A sample dialog — vital signs measurement. Shaded boxes represent buttons on the screen.

D. Navigation

The StarGazer localization system [19] was used as the main navigation component. It is a robust commercial localization system. StarGazer requires passive landmarks installed on the ceiling, covering the entire robot work space. The distance between landmarks depends on the robot height and the ceiling height.

In the study environment (discussed in Section IV-A), landmarks were installed with a separation of approximately 1m. Then a map was created by executing the map building module, which comes with RSF. It was possible to assign numbers to important places in the map as location identifiers. Later, these location identifiers were used to navigate the robot to different places within the apartment.

IV. Study and Results

The implemented system was tested with 53 volunteers recruited from a retirement village in Auckland, New Zealand. Participants were 32 residents and 21 staff members. The study was conducted over two months. Each participant took approximately one hour to complete the study, including obtaining consent, robot instruction, interaction with the robot and administration of questionnaires. The trial was conducted by a health psychology researcher in a controlled environment. Results pertaining to participants' changes in attitudes and emotions towards the robot from before to after the interaction are presented elsewhere [20]. Here we report the results of the module appraisals, technical faults that occured in each module, and lessons learned from the trial.

Fig. 6. The robot assisting a user take his blood pressure.

A. Study setup

The trial was carried out in an apartment specially built for older people. It consists of two bedrooms, a kitchen and a living area. The steps of the study were:

1) The researcher welcomed the participant to the apartment
2) Initial discussion and first questionnaire
3) The researcher signalled to the robot (using a remote control) that the participant was ready
4) The robot navigated from the charging station (which was hidden from the participant) toward the participant
5) The robot greeted the participant
6) The participant interacted with all the functionalities of the robot with minimal intervention from the researcher
7) The participant completed another robot evaluation questionnaire
8) End

In the questionnaire, participants were asked to rate each module on a 4 point scale; poor (1), acceptable (2), good (3), and excellent (4). They were also asked to rate the robot's performance overall by giving a number between 0 (poor) and 100 (excellent). On average, each trial took 39 minutes.

B. Results

Figure 6 shows the robot assisting a participant take his blood pressure. A summary of results is shown in Table. I. Percentage values given under 'Technical faults' represent the number of trials in which technical problems were encountered in the particular module, out of total number of trials. A mixed ANOVA showed there was a significant difference between ratings for each module($F(3.34) = 7.25$, $p < 0.001$), but no difference in ratings between staff and residents across modules and no interaction effect ($p > 0.05$). The joke module was rated significantly lower than all the other modules.

There was no significant difference between the mean interaction time of the two groups, suggesting the time taken to go through all the service modules was not associated with the age of participants. This is an indication of the success of service applications, which were developed targeting older users.

TABLE I
SUMMARY OF EXPERIMENTAL RESULTS

	Residents	Staff
Number	32	21
Mean age	81 y	46 y
Mean interaction time	39 min	38 min
Overall robot rating	81.88%	77.86%
Module ratings		
—Greeting	3.23	3.05
—Blood pressure	3.31	3.18
—SPO2	3.29	3.00
—Joke	2.52	2.62
—Song	3.21	3.14
—Hydration reminder	3.48	3.26
—Instructions	3.54	3.30
Technical faults		
—Greeting	0%	0%
—Blood pressure	10%	10%
—SPO2	5%	5%
—Joke	0%	0%
—Song	0%	0%
—Hydration reminder	0%	0%

V. CONCLUSION

This paper presented a mobile robot specially designed for older people. The robot was extensively tested by conducting a study in an independent living apartment of a retirement village. In this research, the robot interacted with users via synthesized speech and a touch screen, and provided various services and collected data. This is an ongoing research project and the collected data will be used for the design of the next trial version of the robot.

The findings suggest it is feasible to use appropriately designed robots to help older people. 53 participants interacted with the robot for approximately 30 minutes and the study setup was a real world environment. During the entire period, the robot was permanently stationed in the apartment used for the research and it was used almost daily for long hours. At the end of the study, an open day was organized, giving the retirement home residents and the staff an opportunity to informally interact with the robot.

The technical results give an indication of robot reliability. The results suggest it is feasible to station a robot permanently in a retirement village for longer periods. This finding is further strengthened by the results shown in Table. I. The participants gave the robot high overall ratings in addition to satisfactory ratings in each service module. Only the joke part of the entertainment module received an average rating lower than 3 (good) and it was still rated acceptable.

By developing the robot and running trials, we learned several lessons including:

- *The importance of developing techniques that can satisfy individual needs.* This is especially true for service robots for older people. The data collected shows that different people have different preferences and requirements. Therefore, customizability will be one of the main requirement in the next version of the robot. For example, screen layout, voice parameters, and word choice should be customizable.

- *Interface design improvements.* Although a great effort was taken to design interfaces considering the needs of older people, some of them experienced some difficulties interacting with the touch screen. Due to some people's shaky hands, some participants accidentally double clicked buttons when a single click was expected. These problems can be programatically eliminated and will be incorporated in the next version. Also, proper feedback method for older people should be incorporated.
- *The need for customization of specific instructions.* The robot's instructions were very specific, simple, and sometimes repetitive, as directed by the feedback we received during software development as necessary for older people. However, relatively younger users sometimes found the instructions cumbersome. Therefore, the context awareness of the robot is a key requirement in the next version.
- *The need for multimodal interaction.* The robot should be equipped with more methods for communication, to interact with people with physical and sensory limitations, such as shaky hands, and poor eyesight. The touch screen alone is not sufficient for user inputs.
- *Wireless connection for measuring devices.* Blood pressure and blood oxygen saturation measuring devices were connected to the robot via a USB hub. During the trials, some participants found it difficult to reach the robot to connect to the devices and sometimes cables were disturbed. Therefore, the most appropriate method is to connect measuring devices as wireless devices (such as Bluetooth).
- *Proximity to the user.* The robot's ability to maintain a safe distance from the older person, while staying close enough to allow a clear vision and to perform tasks such as vital signs measurement is important.
- *Wireless infrastructure.* This type of robot should be able to communicate with existing systems in retirement villages such as pharmacy software, dispensing systems, security systems as well as with Internet, using wireless technologies. However, the availability of necessary infrastructure is not guaranteed.
- *Tools for faster product development.* Prior to the study, a large amount of work was spent on modifying or sometimes even redesigning the user interfaces and dialogs. Since the project is inherently multidisciplinary, faster methods are required to incorporate suggestions of experts of different disciplines, at various points of product development and testing.

VI. ACKNOWLEDGMENT

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