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PATIENT FACING SYSTEMS

Evaluation of an Assistive Telepresence Robot for Elderly Healthcare

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Abstract In this paper we described the telepresence robot system designed to improve the well-being of elderly by supporting them to do daily activities independently, to facilitate social interaction in order to overcome a sense of social isolation and loneliness as well as to support the professional caregivers in everyday care. In order to investigate the acceptance of the developed robot system, evaluation study involved elderly people and professional caregivers, as two potential user groups was conducted. The results of this study are also presented and discussed.

Keywords Telepresence robot · Elderly care · Shared control · Technology Acceptance Model (TAM)

Introduction

Telepresence refers to a set of technologies used to create a sense of physical presence at a remote place. Telepresence robots, in particular, allow human operators to be virtually present and to interact in a remote location through the robot mobility and bidirectional live audio and video feeds.

Recently there is a growing interest for developing telepresence robot systems for healthcare of elderly people. This is not surprising if we take into consideration that the world population is rapidly ageing. Each year the number of elderly in the world is increasing, and the percentage of total population represented by the older people is growing. According to World Health Organization (WHO) the absolute number of people aged 60 years and over is expected to increase from 605 million to 2 billion between 2000 and 2050 (meaning that the world's population over 60 years will double from about 11 to 22 %).

Population ageing presents social, economic and cultural challenges to individuals, families, societies and global community. It leads to increased health care for elderly, as well as social care service. This will increased burden in the health-care sector for this category of people. In near future, it will become more difficult to provide quality care service for elderly, because of the insufficient health care personnel, and the high level of expectancy of these services that should meet the demands for the elderly in order to prolong their independency.

Telepresence robot systems could be possible solution for resolving this bottleneck in the healthcare system, supporting independence of elderly people.

A robot proactively engages users in a social manner creating an interaction with the person for the purpose of giving assistance and support in certain activities of daily living and care [1, 2].

Some robot systems can also collect medical data about vital signs of person that are important for doctors and caregivers. Telepresence robot can also be used for social interaction with other people (family members, friends, doctors or caregivers). The mobility that a robot provides

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yields a stronger feeling of presence at both sides. Several studies have shown that people interact with robots in the same way they might interact with other people, establishing social relationships and emotional ties with them [3–6]. Telepresence robot systems can also help elderly to overcome a sense of social isolation and loneliness, affecting physical, mental, and emotional health of older people [7].

One of the first telepresence robot systems allowing care assistance for elderly, was "Physician-Robot" system, developed by the cooperation of the InTouch Health Company and the Johns Hopkins University. This system allows physicians to visit more frequently their hospitalized patients. Results from an evaluation of Johns Hopkins University showed that 80 % of the patients felt that this robot system increases the interaction between physicians and patients [8].

Recently InTouchHealth has developed the RP-VITA platform, a successor of the RP-7 that combines autonomous navigation and mobility allowing doctors to remotely monitor patients (to talk with them and even plug in various monitoring devices to check patient's vital signs [9]. Some other examples of telepresence platforms are: TRIC [10] (Telepresence Robot for Interpersonal Communication), TeCaRob [11] (provide customized, on demand remote assistance for people with special needs), Care-o-Bot [12] (mobile robot assistant to actively support humans in domestic environments), VGO [13] (remote controlled mobile telepresence robot designed for establishing your physical presence in a distant location), Giraff [14] (remotely controlled mobile robot designed with features enabling social interaction from a domestic environment to the outside world-caregivers or friends/ family).

The basic idea in our research is to develop a telepresence robot system, which purpose is to improve the well-being of elderly by supporting them to do daily activities independently, to facilitate social interaction of people potentially isolated (in their home or in eldercare institution/ nursing home) thus diminishing the sense of loneliness; to improve the well-being of family members by bridging physical distances, that usually exist between them and the elderly, by enabling interaction and communication through the implemented robot functionalities; to support the professional caregivers in everyday care.

In this paper we investigate the use of this robot system and its acceptance by two potentially user groups: elderly and professional caregivers. We were interesting in their general opinion about this system, as well as system functionalities used during the experiments, in relation to perceived usefulness and perceived ease of use. Results have shown a good acceptance and willingness of potential users for using this kind of robot system in both social and medical contexts, which is important for further research in the field of assistive robots for elderly.

Description of the developed robot

Hardware structure of the developed robot

The developed assistive telepresence robot is shown in Fig. 1.

It is composed of mobile robot base, robot body which on its side comprises linear actuator and robot manipulator and robot head represented by a tablet.

The mobile base is made of two gusseted aluminum frames rigidly. The base is driven by 4 pneumatic wheels with 10 in. diameter. Wheel's axles are driven by four brushed permanent magnet DC planetary gear motors. Left and right motors are coupled/wired in a manner which enables them to spin together synchronously. The robot is powered by two 12 V $LiFePO_4$ (Li-ion) batteries with 20 Ah. The robot base has a special placeholder and also bears the linear ball-screw actuator from IGUS which is vertically positioned.

For safety reasons the effective stroke is limited to 80 % of the actuator's length i.e. upper and lower 10 % of the stroke are defined as a dead zone by two mechanical end-stop switch modules. The aim of the actuator is to move the robot arm vertically. The mounted robot arm is a lightweight (3.5 kg) serial six axis kinematic. All six joints are driven by servos and four of them are equipped with encoders which enables accurate position control. The arm has a reach of 500 mm and could lift objects up to 200 g.

The robot manipulator with the two finger end-effector, could grasp and hold a specially designed proprietary sensor for measurement of a three channels ECG, temperature and respiration rate. The 10" tablet with integrated

Fig. 1 Developed assistive telepresence robot

camera is mounted at the top end of the linear actuator by the means of a supportive element that has two (currently un-motorized) rotational joints and two degrees of freedom (up-down, left-right). Moreover the robot is equipped with 12 ultrasound sensors placed laterally that should facilitate the robot's autonomy.

The entire robot system weights 42 kg, has physical dimensions of 48 cm × 52 cm × 180 cm (L × W × H) and can reach a movement speed up to 2.2 m/s. Robot's human like height will enable more natural eye contact. The adaptable robot speed is important for navigation in dynamic environments and with its heavy structure the robot can push away small obstacles encountered during navigation with a minimum danger of being entrapped.

Human-robot interaction

Generally speaking robot's autonomy could be defined as a measure of its independency. Assistive robots nowadays tend to increase their level of autonomy and their efficiency mainly due to the variety of cheap sensors that permit them to perceive the environment. Despite the increased level of autonomy, some complex tasks such as door-crossing, sharp turns, or cognitive demanding tasks still require human guidance in order to guarantee safety and efficiency. This is especially important when the assistive robots are involved in applications including interaction with elderly and disabled persons.

Depending on the level of robot's autonomy human-robot interaction could range from: *teleoperation* where operator has complete and permanent control of the robot, *safeguarded operation* in which the operator guides the robot and it evaluates its own conditions as well as the environment and could perform tasks to protect itself or the environment, *shared control* in which both the operator (on high-level) and the robot (mainly on low-level) direct the robot towards accomplishment of a certain goal and *autonomous control* in which the robot performs both the low-level control as well as the high level reasoning transmitting to the operator the measured environmental data giving him the opportunity to analyze them as well as to react with high-level commands in exceptional situations.

Implemented control architecture is depicted in Fig. 2. It is based on a Model-View-Controller pattern. This architecture model enables application of a shared control paradigm. More specifically, the operator instructs or directs the robot at higher level and leaving the responsibility to the robot for accomplishing the task. The operator instructs the robot in two ways:

- by giving a general direction of movement or by specifying a destination;
- by selection of one or more primitives ordered in a sequence from a set of pre-defined high level primitives such as: TakeVitalSignsSensor, WallFollowing, DoorPasing etc.;

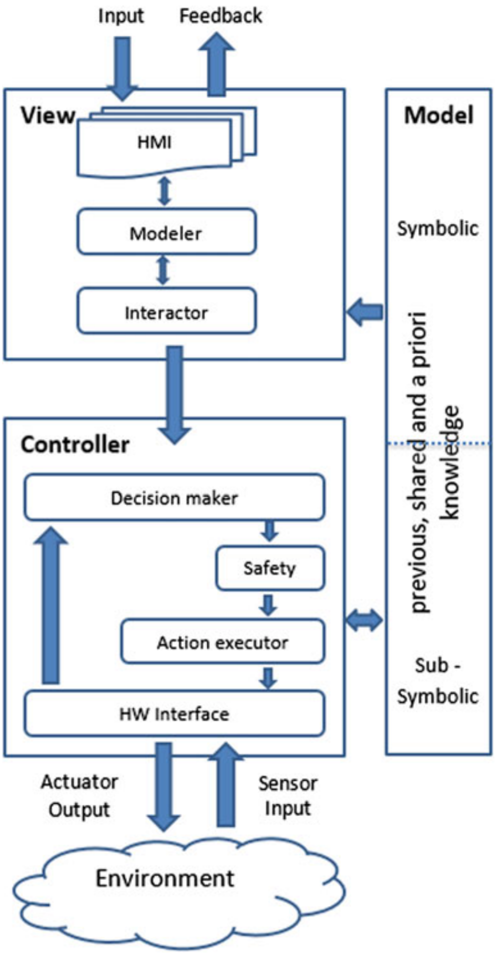

Fig. 2 System architecture

However, the operator can at any moment interrupt the robot's behavior and takes over the control. Regardless of who has the responsibility at a certain time point, all the commands are transmitted through the safety module, which is permanently active and has highest level of priority. The safety module transforms all the commands into safe low-level actions.

Proposed architecture enables reactive control i.e. closed control loop and authonomous behavior. Namely, the decision maker module is directly consuming the input from the sensors, processing it and reacting in a safety manner on the dynamic environmental changes via the actuators. This means that even in the case when the communication channel between the operator and the robot is interrupted (due to network failure for example) the decision maker could act independently and perform the operations safely.

To enable the patient safety in cases of emergency, in addition to the enabled reactive control, mechanical stops are implemented (various switches, push buttons, touch and pressure sensors, etc.). For example the manipulator has limited vertical movement, each of its joints have pre-defined rotation angles, for the mobile platform a limited safety zone is defined. Moreover, the entire system as well as various sub-systems (e.g. mobile platform, robot manipulator, linear actuator) have their own "red buttons", by the means of which they could be deactivated by the patient, in the case of unwanted behaviour.

The user control interface, for robot navigation and manipulator movement, is shown on Fig. 3. The interface contains several frames, each of them providing a panel with various controls for handling different tasks. Controls can be accessed via keyboard or touch.

The large frame on the upper left side of the screen contains a video image from the integrated tablet camera, or a video image from the camera mounted on robot manipulator (depending on the task performed at the moment: navigation, or vital signs measurement).

In the upper right frame, a floor plan representation of the place where the robot is navigating, and the robot trajectory (drawn with a red color), are shown.

The lower left frame provides buttons for controlling the robot movement, as well as buttons for turning on/off the robot sensors. The operator can press "left", "right", "forward" or "back" button in order to move the robot in desired direction. While the action is performed, the operator can stop the robot unwanted movement by pressing the "stop" button.

The lower right frame provides controls for the actuator and manipulator movements. The manipulator joints (shoulder, elbow and wrist), as well as the end-effector, can be controlled by means of these controls. The "stop" button which can be used in order to stop the robot to perform some unwanted movement, is also available in this panel.

Evaluation study

This evaluation was aimed to measure user perceptions and acceptance of developed telepresence robot system. Technology Acceptance Model (TAM) [15], which is the most accepted theoretical model used to evaluate the acceptance of many different types of technology, was used. This model presupposes, that two particular constructs determine the user's acceptance of a technology: perceived ease-of-use (PEOU) and perceived usefulness (PU). Both factors affect a user's attitude towards the technology, which in turn influences the intention to use the technology that leads to its actual use [16].

A modified questionnaire based on TAM model was used to determine the PU and PEOU of different types of functionalities of a developed telepresence robot system. The statements from questionnaire was translated in Macedonian language (the mother language of all participants). Participants could indicate their agreement with the statements using a five point Likert scale (from totally agree- score 5, to totally disagree- score 1).

Fig. 3 Control user interface

This questionnaire was given to the participants at the end of the evaluation process.

Additional comments on the telepresence robot system, its behaviors and applications were also solicited during the interviews conducted after the evaluation. Participants were asked to express their general opinion about the robot system, as well as willingness to use it.

Participants

In total, 35 persons participated in the study, grouped in two focus groups: professional caregivers and elderly people. The pilot study was conducted in one nursing home where the elderly lived at least 1 year. 30 elderly participants (17 man and 13 women) with a mean age of 71 years (65 to 78) with no severe disability problems (e.g. severe dementia, bedridden) were included in a study. 5 professional caregivers currently employed in the nursing home were also participating in the study.

All participants had some previous knowledge in using technology (e.g. mobile phones, video conference application) and had an open mind towards it, which was very important for us in order to obtain valuable results about the functionalities of the system, as well as to express their attitudes and feelings freely.

Procedures

Because none of the participants had prior experience with this kind of robot system, they have a training session before each experiment. First, the experimenter has described to participants a general idea of designed telepresence robot system as well as the goal of the study. Then participants were introduced with the functionalities of the telepresence robot system. They were given instructions on how to drive the robot (forward, backward and make turns), how to manipulate the robot manipulator to grasp and drop the objects, how to use the video conference application and other functionalities used during the experiments. During the training session, participants also had a practice time, during which they were free to use the introduced robot functionalities. After the practice time, the robot was re-positioned in order to start the testing session.

Experiments

A testing session consist of four types of experiments that were identified during the analysis.

> *Experiment 1* – the first experiment was designed to evaluate the robot navigation functionality, as well as video conference application. The task that elderly needed to complete, was driving the robot from one starting point to the nursing room, avoiding possible obstacles, and realizing a video conference session with a professional caregiver. The participants were instructed to take care of the speed as well as precision while performing the task. During the experiment, the experimenter was present to assist the participant in navigation if needed (e.g., avoiding obstacles).
>
> *Experiment 2* – the second experiment was similar to previous one, except that professional caregiver were driving the robot. Also they needed to evaluate one more functionality of the robot system that is the electrocardiograph (ECG) measurement functionality. After entering the room of an elderly a professional caregiver should make an electrocardiograph (ECG) of the elderly person. For that purpose the caregiver had to manipulate with a robot manipulator, for properly placing the electrodes on the patients' body. For better perception of the patient's body and more precise sensor application a camera mounted on robot manipulator was used.
>
> *Experiment 3* – in this experiment a robot manipulator was used by the elderly. In particular they were using it for fetch and carry some small object (eg. to bring them a glass of water). Experiment was conducted in elderly's room.
>
> *Experiment 4* – in this experiment the focus was put on evaluation of the reminder functionality (e.g. robot should remind the elderly to take or caregiver to give the right medication at the right time), and a calendar functionality (e.g. days when there is some appointment or a visit are marked, or holidays during the months etc.)

All the experiments were conducted during the period of 1 month after which a questionnaire was administered to the participants of the study. There were no time limits for performing the tasks.

Results

All participants successfully finished the given tasks, although there were trials in which the participants received assistance for task completion.

The results of the robot acceptance questionnaire showing the mean scores of the used functionalities (by groups), in relation to PU and PEOU constructs are shown in Table 1.

Perceived usefulness

As shown in Table 1, the mean scores for all functionalities is greater than a neutral Likert scale rating of 3, which mean that all the functionalities are regarded as useful. However there were differences between two users group in terms of perceived functionality usefulness (Mann–Whitney test, $p < 0.05$).

Table. 1 Results of the robot acceptance questionnaire

Functionality	PU		PEOU	
	Mean		Mean	
	Elderly	Caregivers	Elderly	Caregivers
1. Navigation	3.16	3.2	3.0	3.2
2. Vital signs measurement	3.2	4.6	3.6	3.0
3. Manipulator function (fetch and carry small object)	3.06	3.6	3.33	3.2
4. Reminder	3.1	4.6	4.3	4.4
5. Calendar	3.2	4.2	4.13	4.6
6. Video conference application	4.06	3	4.4	4.8

The Mann–Whitney test, comparing the elderly and caregivers groups, in terms of perceived usefulness for vital signs measurement functionality was statistically significant, $z=-2.397$, $p=0.05$. The means for the two groups indicated that caregivers preferred this functionality ($M=4.6$, $SD=0.55$) over the elderly group ($M=3.2$, $SD=1.24$). Similar results were obtained for reminder functionality ($z=-2.616$, $p=0.05$), which is also preferred more by caregivers ($M=4.6$, $SD=0.55$), than elderly ($M=3.1$, $SD=1.18$). This is more or less expected because they usually have to care for many elderly during the working hours, so using the robot will lead to reduce their workload.

The results from Mann–Whitney test for video conference application, have also shown significant differences for both groups ($z=-2.272$, $p=0.05$). The video conference application was perceived as more useful by elderly group ($M=4.06$, $SD=0.98$), compared to the caregivers group ($M=3$, $SD=0.71$). From elderlies point of view, this application will reduce the loneliness, by bridging distances, and facilitating communications with friends and family.

Perceived ease of use

Similar to PU construct, the mean scores for all functionalities for PEOU was greater than a neutral Likert scale rating of 3, which mean that used functionalities are easy to use by both user groups.

However, there were no major differences between two user groups regarding functionality ranking in this case (Mann–Whitney test, $p=0.05$).

The results from Table 1 shows that both groups rang navigation functionality as most difficult to use, and a video conference application functionality as most easy to use. This is also expected because of the short period of usage of the robot system. Although the evaluation lasted for a month, the effective time that the participant were using the robot system was 2–3 h during the week (for some participants even less). We assumed that if the participants would have used the robot system more frequently and for a longer period they would improve their skills over time, and perceive navigation functionality as more easy to use.

Conclusion

The process of aging is often associated with various diseases and, consequently, with loss of independence. Telepresence robot systems can help to overcome these problems. In this paper we described a developed telepresence robot system that assist elderly in Activities of Daily Living (ADL), and support professional caregivers in their care to create less burden. The system also provides a two-way video contact with other people (doctors, nurses, family and friends), that lead to strengthen social interaction and relationships.

The evaluation study was conducted in order to measure user acceptance of developed telepresence robot system. We were also interested in how the potential user groups (elderly people and professional caregivers) would perceive such a system in general and what their opinions, needs and concerns are.

The results of the robot acceptance questionnaire demonstrated that the core functionalities provided by developed telepresence robot system are accepted by potential users. This finding corresponds with interview data, where users have expressed their positive opinions about the robot system. Also participants' identified significantly more benefits than concerns about using this system, and they stated that they are willing to use a developed telepresence system in both social and medical contexts.

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