A robotic system for home security enhancement

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ABSTRACT: Central to smart home security is the need for adequate surrounding awareness. Security systems have been designed for remote exploration and control, however, these still lack the simplicity needed by elderly and disabled. The majority of elderly people find the control of such systems laborious. This highlights the need for usable designs that take into consideration the cognitive limitations of this category of people. This paper contributes towards this problem through the introduction of a novel vehicular Remote Exploration Surveillance Robot (RESBot), capable of monitoring in real time the environment in response to events. The interaction with the system is achieved through natural language commands and hence, provides improved usability over traditional approaches. Results from the experimental usability evaluation of the RESBot system revealed considerable improvement over conventional home security systems.

Keywords: Human-robot interaction, Situation awareness, Home security, Teleoperation.

1 Introduction

The worldwide population of elderly people is growing rapidly and in the coming decades the proportion of old people will change significantly. This demographic shift will create a huge increase in demand for domestic home security technologies. Smart homes have been credited with saving the lives of many elderly, disabled and senior citizens [5]. The first generations of home security systems are mainly using CCTV cameras. However, these provide limited flexibility in maintaining sufficient situation awareness [7]. Plus, these systems are controlled using keyboard and joystick that hence pose cognitive strain on elderly users. According to [18] many CCTV is ineffective for day-to-day safety and security in general. Specifically, cameras could be badly placed, broken, dirty, or with insufficient lighting and this limits their effectiveness and efficiency. Moreover, when CCTV is used for command and control, safety operators performance is hampered due to the large number of disparate systems and information sources, and inefficient audio communication channels. This suggests that CCTV for crime prevention can only be effective as part of an overall set of measures and procedures designed to deal with specific problems. When it comes to elderly, the use of CCTV is inappropriate for all of the above reasons along with the fact that elderly are characterized by limited attentional resources that in effect constrain their capabilities with such systems. For elderly and disabled people to maintain adequate situation awareness it is important to provide them with only the salient cues from the environmental context. Too much or too little information may have the opposite effect with regards to situation awareness. Therefore, central to smart homes is the need for technologies that sufficiently address these requirements. Prerequisite for adequate situation assessment is effective interaction with the technology. Despite their success stories, smart homes have their limitations. It has been reported that smart home technology will be helpful only if it's tailored to meet individual needs [2]. This currently poses a problem as many of the interface control console designed do not take into consideration non-functional limitations associated with the elderly. In the same vein, there is a fundamental problem in making IT system user friendly for the elderly and disabled [19]. This work is motivated by the need to improve the safety living conditions of elderly/disabled by addressing two important factors that interest this category of people, namely, usability and cost. The former prerequisites usable interfaces designed that improve users' task performance through reduced cognitive effort. This requirement strive engineers in investigations for best fit between man and machine by considering the constraints and capabilities of elderly people. The later factor we address through a simple generic robotic platform.

Given that elderly and disabled are characterized by reduced memory and attention, the home security system proposed in this study uses an interaction metaphor that minimizes user effort and improves situation awareness. To that end, we adopted a human-centered approach for the human-robot interaction through simple natural language instructions. The underlying technology of the interaction metaphor is a mobile phone. The ubiquitous property and low weight of mobile phones overcomes fundamental problem during interaction. The proposed implementation utilizes a vehicular robotic surveillance system capable of indoor/outdoor remote observation in response to natural language commands. This constitutes an improvement over traditional approaches to home security management, characterized by dexterous manipulation of joy stick and keyboard interfaces that obstruct the users from the primary task. The research question that we address in this work is: "Does voice activated robotic surveillance system provides improved situation awareness for elderly/disabled compared to existing home security systems?"

The paper is organized as follows. Next section covers the literature on developments of human centered robotics especially in smart home security technologies. Following this is a detailed breakdown of the 'RESBot' architecture, design methodology and software implementation. Next, follows a usability evaluation of the proposed system and an interpretation of the results. The paper concludes with future directions.

2 Literature Review

The last 10 years witnessed robots becoming increasingly common in non-industrial applications, such as homes, hospitals, and service areas. These robots are often referred to as "human-centred" or "human-friendly" robotic systems due to the way the robot interfaces with the human users [15]. This close interaction can include contact-free sharing of a common workspace or direct physical human-machine contact. Contrasts to industrial robots where specific tasks are performed repetitively, human-centred robots are implemented on a totally different set of requirement [16]. These include: safety, flexibility, mechanical compliance, gentleness, and adaptability towards user, ease of use, communicative skills, and sometimes possession of humanoid appearance and behaviour. According to Heinzmann and Zelinsky [17] human centred robotics should have natural communication channels that involve not only language but also facial gestures and expressions along with providing high level of functionality and pleasure. Some successful human-centred robotic implementations include: Rhino the museum tour guide robot that was assigned tasks via internet teleoperation technique [20]. Among their other roles, robotic systems have been designed to aid home, industrial and business security. An example of robot security management system is the Mobile Detection

Assessment and Response System (MDARS) [21] deployed by the department of defense. MDARS simultaneously control multiple autonomous robots that provide automated intrusion detection and warehouse inventory assessment. Similarly, robots are becoming popular in home security and telecare [1-4]. Telecare is defined as the use of a combination of communications technology and sensing technologies to provide a means of manually or automatically signaling a local need to a remote service centre, which can then deliver or arrange an appropriate care response to the telecare service user. AVENUE is an example telecare robot [23]. However, current telecare and home security robots require dexterous manipulations [19] and hence, failed to take into consideration the human-requirements of elderly and disabled. Efforts have been reported that aim in easing the complexity of the interaction between elderly users and the robot. Phonebot, is an example that uses cell phone communication between user and robot [25]. Phonebot responds to calls via, a ring detector circuit, which establishes a connection between the user and the robot. The main limitation of Phonebot is the lack of a voice activated control mechanism and this creates a communication overload that obstructs the user from achieving his/her goals [25]. This one of the limitations we address in this research.

An additional issue that has emerged in the field of human-robot usability is the notion of enjoyment during interaction as reported by [26]. Specifically, [26] identified that there is high correlation between enjoyment and intention to use of a robotic system in a usability analysis conducted with elderly people. This indicates the need for enjoyment to be part of robot design. This constitutes another motivating factor of the research conducted and described in here.

3 The Remote Exploration Surveillance Robotic System (RESBot).

RESBot is a roving maneuverable vehicular surveillance system, which projects in real time contextual information of the environment for enhanced situation awareness of elderly and disabled people. The RESBot is a voice activated control mechanism that enables remote command and control for home security purposes. The main components of the system are described below:

- User navigation component
- Autonomous obstacle avoidance component
- Onboard pinhole surveillance camera.
- Robotic vehicle

User navigation is achieved through a voice recognition component. This can be trained in any language of choice and provides natural means for interacting with the system. This is of major importance to elderly and disabled people that are characterized by low cognitive and motor capabilities. Through this technology, we built a robotic system by incorporating existing technology into a unified robotic surveillance system**.**

The robot's on-board controlled camera provides 360 degrees visual coverage and thereby provides its users with the necessary contextual cues for improved situation awareness. For brevity, the user is capable of interacting with the robotic system using voice commands over GSM mobile phone. The visual feedback display enables the user to carry out real time surveillance of a remote environment. In order to limit the scope of our work, we concentrated on vehicle teleoperation that enable remote task execution.

The other main component of the system is the autonomous obstacle detection and avoidance system that provide effortless navigation of the robot. Finally, the automatic intrusion detection component provides real time recognition through a motion sensor. This component is responsible for the aromatic orientation of the camera and the notification of the user of an intrusion event. An overview of the system's architecture is presented in Figure 1.

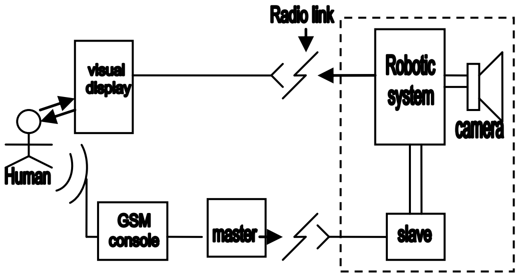

Figure 1: Outline of an operational RESBot system

Figure 2: The RESBot implementation.

4. Design and Implementation of RESBot

The RESBot is a novel implementation of a voice activated robotic system leveraging the use of modern GSM technology. The parallax Board of education (BOE) was used as the platform for its development. The robot is a small, skid-steered wheeled vehicle capable of limited outdoor/indoor work. The robot is equipped with a ring of infrared proximity sensors, power monitoring, and voice recognition decoder. An onboard pinhole camera provides forward video. Digital/Analogue transmitters are used for video and data communication. An on-board micro-controller processor performs navigation and obstacle avoidance.

The communication between the user and the robot is achieved through GSM digital transmission. GSM digital signals can pass through an arbitrary number of regenerators with no loss in signal and thus travel long distances with no information loss [8]. Users perceive situational cues from the environment through the onboard video feedback and accordingly respond to them by engage the robot in a voice command. The command and control mechanism is based on a user-centred interface design methodology in which visual displays provide information for decision-making and control [9]. Through this we achieve easy robot-user interaction for adequate contextual awareness [10]. A wireless video camera (Figure 2) is used to enhance motion planning. An onboard infra-red sensor provides situational cues that are analyses by the central system and subsequently inform the user through an automatic events generation.

The user can request status updated by invoking the robot at any time. The voice recognition decoder is responsible for recognizing the user input and accordingly converting this into an instruction for the robot's actuators. This component can be trained to recognize up to 40 instructions. After training, the user can instruct the robot using the specified language corpus. During training the user can validate the system's knowledge by repeating a trained word into the microphone. During the validation of this component, the index of the corresponding human instruction was displayed on a digital display. This helped to verify that the right instructions are associated with the right indexes. Output from the voice recognition circuit is fed into the robot's microcontroller for navigation. To achieve a more robust interaction between user and the robot, words with the same meaning were associated with the same action in the language corpus. Central to the robot is the microcontroller that processes human instructions for command and control. This component is responsible for the rotation of the on board camera during surveillance mode. Recognition of an event raises an alert to the user that accordingly navigates the robot and orients the camera. The robot is also equipped with an obstacle detection and avoidance algorithm that enables its autonomous navigation. To achieve this feature, three infrared sensors are used. Intrusion detection is achieved through an on board motion detector sensor. For the rotation of the camera and the wheeling of the robot sstandard and rotational servos are used.

5 Usability evaluation of the RESBot

Core to the success of the proposed home security system is adequate usability, given that the indented users have special needs and attentional constraints. Therefore, it was essential to primarily understand prospective users' relevant skills and mental models and accordingly develop evaluation criteria. However, robotics systems differ significantly from desktop user interfaces and hence, the use of empirically defined set of heuristics such as Nielsen are not suitable. To that end, it was decided to use an experimental usability evaluation approach in controlled settings. Typical HCI evaluations use efficiency, effectiveness, learnability and user satisfaction as evaluation metrics. Efficiency is a measure of performance time; effectiveness is a measure of task performance; learnability is a measure of how easy is to learn a system by a novice user and satisfaction a measure of pleasure. Learnability is considered as a key indicator for usability in human-robot interaction with elderly and disabled since it significantly affect system acceptance. Learnability incorporates several principles like familiarity, consistency, generalizability, predictability, and simplicity. These four measures were deemed appropriate for the experimental evaluation of the RESBot system and its comparison against the most popular home security system, namely CCTV.

To benchmark the proposed system against available low budget home security systems such as CCTV, we opted for a comparative study using two groups of participants. Each group was composed of 10 participants of age 60 and over. Throughout the study, CCTV and RESBot systems were referred to as System A and B respectively. Prior to the experiment each participant had to complete a consent form. Participants of each group were given instructions and demonstration on how to use each system through example scenarios. During training, participants were encouraged to ask questions. The evaluations involved two experiments using system A and B accordingly. The scenario of each experiment, involved participants independently investigating an alarm caused by a human intruder. The experiments took place in the participants' homes and a TV was used for video feedback. For system A, a static camera was mounted in the participant's garden. The CCTV camera was also equipped with a motion sensor that raised an alarm whenever it sensed motion within the covered area.

The first experiment was conducted with the use of the CCTV system and group A. The evaluation scenario required users to locate the hiding position of an intruder that was allowed to move around at will. In this experiment, it was assumed that intruder was not aware of the position of the CCTV camera. During the experiment, participants were asked to locate the intruder and specify his hiding position. The second experiment was conducted with the use of the RESBot system and group B. This group did not participate in the first experiment. Prior to the use of the RESBot system, participants were expected to train its instructions corpus. During this experiment, the RESBot was placed in the surroundings of each participant's home and the goal was to locate an intruder. Participants were informed of the intrusion through the system alarm. The manipulation of the RESBot was performed with the aid of a mobile console using voice commands. Visual feedback from the robot was projected on the TV. In both experiment the scenario was terminated with the recognition of the intruder's position.

Throughout the experiments, participants' actions and mistakes were recorded by the researchers along with their tasks and task's completion times. To assess users' situation awareness, we opted for the SAGAT approach described by Endsley[6]. Hense, during the scenarios, participants were asked to designate at different intervals, where they though the intruder was located. The actual and perceived location of the intruder enables the quantification of their situation awareness, that in turn guided their consequent actions/instructions with the system. With the completion of both experiments, each participant was asked to complete a questionnaire. This included constructs relating users' perceptions of: ease of use, usefulness, attitudes, and intention to use of the system. In addition, behavioral information regarding satisfaction and user experience with both systems, were also collected. Each participant's response was associated with a unique identification number to avoid bias during data analysis.

The evaluation of the two systems' was based on the level of user-acceptance, the assessment of which was based on the Technology Acceptance Model (TAM) [12]. TAM has been successfully used to study user's acceptance of IT systems using quantifications of users attitude that define the positive or negative feelings toward the IT system. In its most basic form it states that perceived usefulness and perceived ease of use determine the behavioral intention to use a system that can predict actual use. Specifically:

- *Perceived ease of use* (P1): defines as the degree to which an individual believes that learning to use a technology will require little effort. The participants' perceptions that system (A or B) was easy to use were captured with 12, five-point Likert-scale questions.
- *Perceived usefulness* (P2): examines individual believes that use of the technology will improve performance. The participants' perceptions of systems' usefulness were captured in 8, five-point Likert-scale questions
- *Attitude* (P3): feeling or emotion about using the technology. The participants' attitudes towards using the system (A or B) were assessed using 5, five-point Likert-type questions.
- *Intention to use* (P4): the likelihood that an individual will use the technology in the future. The participants' intention to use each system was assessed using 4 five-point Likert-type questions.

Questionnaires were used as the main instrument for measuring these influences. Each component of the TAM model was expressed in a number of questions. Items of the instrument that measured the same influence were grouped together to form generic constructs. In addition to the core TAM constructs, an extra set of questions regarding user satisfaction were also incorporated in the research instrument.

5.2 Analysis and Results

Data collected from the experiments was analyzed using the statistical package SPSS. Comparative analysis between the two systems was performed using a 2-tailed t-test for each of the constructs of TAM. Since we have no strong prior theory to suggest any relationship between the TAM components of system A and B, we opted for the 2-tailed t-test. The analysis performed a paired samples t-test to check the difference between the scores in each dimension. The difference between the two paired mean scores for TAM constructs ranged from P1-P4. P1 compared perceived usefulness of the two systems. P2 compared perceived ease of use, while P3 and P4 attitude towards use and intention to use respectively.

The collated results of table 1 highlight that for each of the TAM constructs, the mean scores between systems A and B differ significantly. In particular, perceived usefulness of system B is significantly higher than system A. Similarly, perceived ease of use, attitude and intention to use is significantly higher for system B. The 2-tailed test indicates that the difference between the two systems is significant and the results are not due to chance.

Table 1: Paired sample t-test

Pair	Mean	Std Dev	t	df	Sig
P1	-12.800	2.616	-15.472	9	.000
P2	-12.600	5.037	-7.909	9	.000
P3	-12.100	2.282	-16.762	9	.000
P4	-3.700	2.057	-5.687	9	.000

The results shows that the robotic system provides better usability and control over the CCTV system by better addressing the needs and capabilities of the elderly and disabled.

Additional data regarding the usability of the robotic system revealed that 90% of participants could use and interpret the feedback from the visual display with ease. Moreover, 90% of participants feel that the alarm produced by the system is suitable for attracting attention. Overall, the results yielded from the experiments demonstrated that:

- 80% of participants were able to navigate the robot with the voice recognition system.
- 70% of the participants spotted the intruders' changing position faster with the RESBot than the CCTV.
- Participants were not able to get the system to respond to the 'survey' and 'hold-on' commands using RESBot. Nevertheless, the other commands were sufficient for effective navigational surveillance.
- 90% of participants found customizing the commands with easy to remember words in their preferred language very satisfying
- Throughout the experiment 20% of participants complained about issuing a command more than once over the control console, for the robotic response.
- 100% of the participants were satisfied with the latency (reaction time) between a recognized command and robotic response.
- 90% of the participants agreed they had an enjoyable, engaging and satisfying experience using the RESBot.
- 80% of participants managed to locate the intruder in less time using the RESBot.
- 70% of participants had better situation awareness with the RESBot.

Conclusion/Future direction

As smart homes implementation gradually become widely adapted due to increasing aging population, the need for improving the safety living conditions of the elderly/disabled increases along with it. Similarly, there is a stressing need for usable human-robot interface designs that meet the needs and constraints of elderly and disabled [6]. In this research, we demonstrate the implementation of a vehicular robotic surveillance system (RESBot) capable of remote surveillance of the environment in response to natural language commands. This is an improvement over keyboard and joystick controls and hence, provides a more usable communication metaphor between elderly users and robotic systems. The study also highlighted an important issue in the literature by examining the effects of robotic systems operated by elderly people for enhanced home security through improved contextual awareness. The current research results provide key information to educators and commercial industries in providing a more robust security implementation of smart homes.

Future direction will be geared towards incorporating audio processing capabilities to address the needs of users with speech impediment. A possible implementation could also be the combination of visual and voice interface in a single control console such as PDAs.

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