

A Telementoring Robot for Home Care

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Abstract. Assistive technologies for telementoring in homes constitute a very promising avenue to decrease load on the health care system, reduce hospitalization period and improve quality of life. Teleoperated from a distant location, a mobile robot with some autonomous capabilities could become a beneficial tool in telehealth applications. However, design issues related to such systems are broad and mostly unexplored (e.g. locomotion and navigation in home settings, remote interaction and patient acceptability, evaluation of clinical needs and its integration into health care information systems). Mobile robots operating in home environments must deal with constrained space and a great variety of obstacles and situations to handle. This paper presents the interdisciplinary design methodology followed to develop Telerobot, a telepresence assistive mobile robot for home care assistance of elderly people. Using field trials with existing platforms, focus groups and interviews, initial requirements for the new mobile robot platform with its augmented video user interfaces are outlined.

Keywords. Mobile robot, Telementoring, Integration to health care information system.

Introduction

The demographic of an aging population and its impact on the reorganization of health care systems worldwide create unique opportunities to look at new approaches in delivering health care services. The concept of teleoperated assistive mobile robots to support the provision of home telehealth services is one solution that is worth investigating [3,4,8]. For instance, having sensors and actuators required in assistive tasks made mobile would decrease the costs and the complexity associated with instrumenting a home. With a team of robotics, clinical and geriatric experts, in 2003 we initiated the design of a new robotic platform for this type of application, intended for elderly people that have disabilities living at home.

The first challenge is to design a system that will be useful. Many different uses can be imagined for a home care assistive robot, such as manipulating and transporting objects, navigation assistance, cleaning, monitoring, etc. While these ideas can lead to interesting technological development, they may not address real needs. On the other hand, users do not necessarily know what new technology can do, so it may be difficult to outline needs, constraints and specifications for home care assistive robots. The second challenge is that homes are complex environments presenting a great variety of conditions (e.g., doorsteps, carpets, hard floor, stairs, objects of all sorts, constrained

spaces, etc.). With the current technology, it is unrealistic to believe that such machines can operate autonomously in homes right away; limits in structural, perceptual and processing capabilities are still too important for their efficient and secure uses. Therefore, a teleoperated system is more realistic, exploiting technological capabilities already available and relying on human interventions to compensate for the robot's limitations.

Telerobot, our mobile robotic platform provides mobility to sensors, actuators and communication devices for home telehealth services. This paper summarizes our iterative design methodology, starting with preliminary studies (field trials, focus groups, analysis of the health system architecture) that have enabled the design and validation of a new robotic telepresence system for home care assistance.

1. Preliminary Studies

Three types of preliminary studies were conducted in our project: telerobotic systems in home environments, focus groups with healthcare professionals and elderly people, and interviews with system users to model the health information architecture. The objective of these studies was to gather more information to come up with good initial specifications for the telerobotic system.

1.1. Telerobotic Systems in Homes

Even through teleoperation, ensuring the safety of the individual in the home where the robot is used and the safety of the robot itself are primary concerns [6]. The quality of the robotic teleoperation user interface and operator experience in teleoperating the robot are two factors that seem to have a direct impact on efficient and safe use of such systems. It has been shown that expert and novice operators have differing opinions regarding the utility and usability of different features in user interfaces [7].

Therefore, we conducted a pilot study to evaluate two conceptually different user interfaces for teleoperated mobile robotic systems, with both trained and untrained operators [5]. This study aimed at identifying locomotion and structural requirements for the new robotic platform, and user interface requirements for improved efficiency and security of novice operators of mobile robots. Field trials were conducted using two commercial robotic platforms: one specifically designed for telepresence application (the CoWorker, controlled by visual waypoint navigation directly using images coming from the robot's navigation camera); the other being a generic research platform (the Magellan, to validate laser-mapped position point navigation from a top-view, 2D map). A first set of trials (2 homes and 5 operators – 1 expert operator plus 4 novices – 2 roboticists and 2 clinical researchers) was conducted in 2004. Even though we had a small number of operators, we found the experience very insightful. For instance, In addition to characterizing physical constraints (measurements of different elements such as doorsteps, corridors, doorframes; carpets that are not fixed to the floor; instability of the platform when going over a doorstep and the effect on the video stream), we also faced the difficulty of evaluating complete teleoperation systems in natural settings (i.e., homes, instead of in controlled conditions such as the lab). Coming up with a good evaluation methodology and following a rigorous experimental protocol revealed to be a non-trivial task. We explored the use of a method comparing trained and untrained operator performances with respect to the performance of an

expert, thus eliminating potential bias from the robotic platform and the environment. We noted that untrained operators performed better using position point navigation, while trained operators had better performance with waypoint navigation. Overall, conducting preliminary trials revealed to be very useful in getting a holistic view of the issues to address in our project [5], and to refine the experimental methodology, as the project progresses, for the different studies to be conducted.

1.2. Focus Groups

Motivated by the practical but still abstract nature of the application, in addition to the novelty of its technical challenges, we put efforts into identifying and addressing the actual needs in telehome care interventions. The objectives of this study [2] were to explore with healthcare professionals involved in geriatric care and potential clients (the elderly) the concept of in-home mobile robotics in order to: 1) conduct a preliminary needs assessment, 2) identify potential target applications, and 3) identify check list items needed for the development of a prototype that could be used in pilot testing of these applications.

A trained moderator independent to the research team conducted focus groups interviews with two target groups consisting of 8 healthcare professionals (HP) and 6 community-living elderly (CLE). The concept of an in-home telepresence robot was illustrated using a photograph of a mobile robot, and participants were then asked to suggest potential health care applications. Interview data derived from the transcript of each group discussion were analyzed using qualitative induction based on content analysis.

The shift from a traditional hospital-centred model of care in geriatrics to a home-based model creates opportunities for using telepresence with mobile robotic systems in the context of telehome care. It was perceived by healthcare providers and community-living older adults with disabilities as a means of accomplishing specific tasks such as: (1) facilitating the provision of care for older adults living at home; (2) enhancing their safety; and (3) giving caregivers some respite and support. A robotic telepresence service would not replace healthcare professionals or family members, but could supplement them in providing care. Robotic telepresence was also seen as a way of reducing the travel time of healthcare professionals, especially for interventions that are of short durations (e.g. monitoring of injuries, verification and follow-up with the family). Furthermore, the results suggest that the perceived capabilities offered by teleoperated mobile robotic systems in the home could be used to assist multidisciplinary comprehensive patient care through improved communication between patients and healthcare professionals.

Potential applications for robotic telepresence include: monitoring the loss of autonomy and the patient's abilities by means of an analysis of tasks in the actual situation and in the natural environment; supervision or rapid access to a professional when patients return home from the hospital; remote tele-surveillance (i.e., guardian angel) of the older person so the family caregiver can leave the house; remote training (e-learning) of natural caregivers in the provision of medical care and the operation of specialized equipment.

Regarding usability issues, the principal concern was the use of cameras on the robot and the potential effect on their privacy. The size of the unit was also an issue as there were doubts about the operability of the mobile robot in small cluttered spaces. Community-living older adults with disabilities questioned the cost and financing of

the service and were doubtful about its usefulness in the context of institutionalized care. Health professionals voiced ethical concerns related to the eventual need to obtain clear consent from third parties interacting with the patient when the robotic telepresence solution was employed. They were also concerned that telepresence could replace human resources for senior citizens, limit social contacts and create dependency on it. A robotic telepresence service would not replace healthcare professionals or family members, but could supplement them in providing care.

User requirements were easier to elicit from the healthcare professionals than the community-living older adults with disabilities. Most of the user requirements mentioned were related to the operation and control of the mobile robot in the home. Specifically, the need to create a security perimeter around the robot to avoid increasing the risk of the patient falling and an efficient kill override of the unit for patients and/or third parties were identified. The quality of the audio/video communications, the physical appearance (size) of the system, its user-friendliness and its reliability were listed as key factors in the development of a prototype. Concerns were also raised about the noise generated by the unit when in operation.

1.3. Health Information Architecture

This study aims at identifying how a telepresence robotic system can be integrated to the health care information system. This difficult question requires addressing information management (flow and content for each user) in clinical care, to facilitate health care management, training and continuous improvement with technological progress. The roles of different users (e.g., health professionals, biomedical engineering, roboticists), the activities associated with these roles as for the sources and information content linked with these activities must be specified. We also have to establish how data coming from the robot should be integrated to the health information system.

The specific activities undertaken in any clinical settings revolve around three major themes: care, research and education. Through the implementation of an information system, these three themes must be employed and calibrated with, at the very least, the same precision found in the real clinical environment. The achievement of this calibration is an extremely challenging task as there are many different informational aspects to consider. For instance, embedded within each of the three themes are a number of major objectives depending on the particular clinical settings, which in turn must be precisely matched to each of their respective users. Therefore, the development of an informational architecture helps to ensure, facilitate and stabilize this integration.

To that end, experience has shown that without an integrated methodological approach, there is a high risk of a poorly functional health information system [1,10,11]. The system design process has, at the very least, two phases: the business process (the elicitation of user requirements) and the system analysis process. A general enterprise-based methodology is required, one in which its use results in the total integrative design, implementation and deployment of any type of health information system under any condition.

Our review of these methodologies indicates that it is difficult to assess the completeness of these methods because they are so inherently different with respect to one another. The main reason is that each particular methodology is context-specific so that their applicability does not reach beyond the particular situation that necessitated

the development and implementation of a particular health information system. A more general methodology is preferred, one in which its use results in the total integrative design, implementation and deployment of any type of health information system under any condition.

To address this issue, we adapted the Zachman framework [12], a framework utilized abundantly in non-health information domains, for health information purposes. Essentially, this framework originated from the need to develop an architectural approach to the design of any complex engineering product, including an information system. It conceptualizes all the information required as a two-dimensional table subdivided into six columns (specific informational perspective according to the following questions: WHAT – the material description; HOW – the functional description; WHERE – the location description; WHO – who is doing what; WHEN – when the events take place; WHY – why the choices are made) and five rows (representing the points of view of different actors in the system development process such as: Scope; Owner's view; Architect's view; Designer's view; Builder's view). Having such an analytical framework helps better visualize the arrangement of the necessary informational components required to achieve the system's purpose. It also encompasses the other methodologies into a simplified and consistent across clinical contexts.

For our project, as an initial study, we focused on the Owner's view, the Architect's view and the Designer's view. For the Owner's view, we conducted individual interviews with a representative set of users (i.e., five engineers, one kinanthropologist, two physiotherapists, one nurse, one doctor and one social worker). Three elements emerge from these interviews: information oriented toward the robot (teleoperation, autonomy, health-related sensors and actuators); information oriented toward the patient (medical evaluation, biological evaluation, functional evaluation); information oriented toward the robot with the patient (audio-video communication). The information gathered during these interviews was then modeled using UML (Unified Modeling Language) diagrams. This led to the design of an architecture illustrating how information gathered from the teleoperated robot and from communication with the patient would be exchanged toward a distant information system that would also be interconnected to the electronic health database. In addition to the teleoperating interface for the robot, two additional interfaces would be required, one for audio-video communication between the patient and the remote operator, and one for accessing the electronic health database (to be access only by medical personel, and not natural caregivers). We are currently in the process of analyzing the information architecture using a typical use-case scenario involving how a doctor, a nurse, a physiotherapist, a occupational therapist, analyzing if the flow of information is complete (even though it may be different from the various types of users) for the proposed architecture, in preparation of the next phase which is to build such information architecture.

2. System Design

Based on the knowledge acquired in these preliminary studies, we decided to design a mobile videophone robotic platform, thereby known as Telerobot. The first prototype is shown in Figure 1a. Navigating through obstacles and narrow spaces in homes while providing stable and appropriate video feed for teleoperating the platform led us to design a round-shaped robot with a rocker-boggie suspension. Locomotion is realized

using two motorized wheels and four omnidirectional wheels attached to rocker-bogie suspension. This suspension mechanism, shown in Figure 1b, acts as a mechanical filter to minimize disturbances caused by irregular grounds on the video streams (coming either from the bottom camera for teleoperation (placed underneath the laser range finder), or the two cameras fixed on the top shelf). It also allows the robot to go over large steps (up to 3 cm high).

A three-level hybrid deliberative-behavioral architecture, Telerobot is used to make the robot go to a specific location (e.g., going back to a charging station), be teleoperated while avoiding obstacles all around itself or holes in the floor, or stop moving. For teleoperation, video user interfaces are common in telerobotic systems, and intelligent interfaces are becoming increasingly important as users face increasing system complexity and information overload. An optimal teleoperation user interface must provide pertinent information about the system' states and conditions (objects, persons, free space, data, etc.) in conjunction with an efficient command system to the operator, with reasonable cognitive load for sustain and adequate uses. More specifically, we found that in home environments, the presence of small obstacles, corridors and doorways substantially increase the level of difficulty for both trained and untrained operators. Different teleoperated navigation strategies are possible with performance affected by the task to accomplish. In order to provide a minimum level of security for the operation of the teleoperated system, automation of the navigation strategy must keep the operator in sufficient vigilance without causing information overload. The system must offer different navigation strategies ranging from manual to semi and complete autonomy (e.g., when the robot must return to the charging station). Position-point navigation using a 2D map and sensor reading representations requires a certain level of cognition and complex mental models [9], while way-point navigation

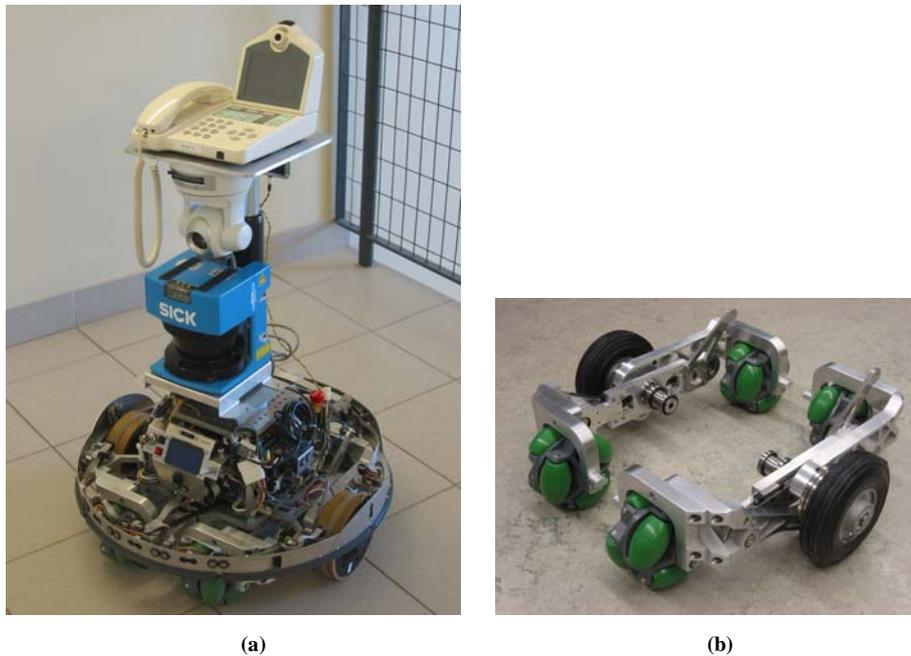


Figure 1. The (a) Telerobot and (b) suspension base shown with regular wheels

is limited to the field of view of the camera. We are investigating a new user interface combining the advantages of waypoint navigation and position point navigation to improve operator performances. A user interface combining the advantages of waypoint navigation and position point navigation could potentially improve operator performances. For enhanced safety and performance of inexperienced operators, one of our user interface prototypes combines the advantages of waypoint navigation (from a 2D map of the environment) and position point navigation (from images coming from the robot's navigation cameras). As shown in Figure 2, the central window shows a 3D model of the environment, on which the camera view is placed. This should facilitate understanding of the environment compared to just using video images with 2D map and sensor reading representations, which provide limited perspective and require a high level of cognition and complex mental models [9]. A 2D map and a robot sensor's representations are placed on the left side windows. Controls are on the bottom window.

Validation of Telerobot and the user interfaces in controlled laboratory conditions are currently being executed. Trials with a representative set of operators ($n=36$) were conducted to analyze the influences of the graphical interfaces on teleoperation tasks. Additional tests will be done to characterize Telerobot's locomotion and navigation (e.g., localization is required to match the 3D model with the video stream) capabilities. Once completed, we will be able to proceed with testing Telerobot in homes with no elderly people involved, conducting trials with a representative set of operators, focussing this time more on the control metaphors of the user interface and on illustrating concretely potential uses of the robot. The results will be used in focus groups for subsequent design iterations with clinicians and elderly people.

3. Conclusion

This paper presents the first iteration in our project of designing a telepresence robotic system for home care assistance. We believe that adopting an iterative elucidation

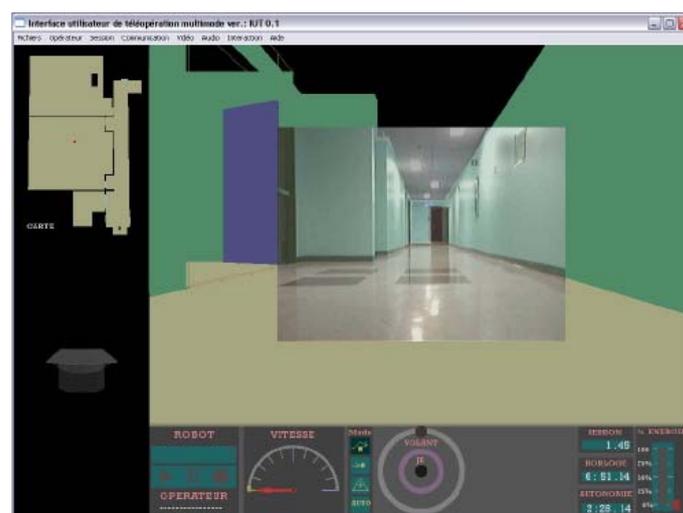


Figure 2. Graphical user interface with augmented video display

process inside a requirement engineering activity is the right solution for the work described in the paper. This project is influenced by the complex integration of rapidly evolving technological components (both hardware and software), in a novel application in which challenges are difficult to anticipate, involving a large number of participants (clinicians, natural caregivers, seniors, engineers, etc.), each with their own set of needs and constraints. Therefore, there are just too many factors (ranging from robotics, human and environmental) to take into consideration to start elaborating design specifications without conducting preliminary trials and assess their combined effects, or to initiate extensive testing in home environments to quantify the usability of the system in such settings.

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