Telepresence Robot for Home Care Assistance

F. Michaud†, P. Boissy‡, D. Labonté†, H. Corriveau‡, A. Grant§,
M. Lauria†, R. Cloutier†, M.-A. Roux†, D. Iannuzzi§, M.-P. Royer‡
† Department of Electrical Engineering and Computer Engineering, Faculty of Engineering
‡ Research Center on Aging, Sherbrooke Geriatric University Institute
§ Department of Bichemestry, Faculty of Medicine and Health Sciences
Université de Sherbrooke, Sherbrooke (Québec) CANADA J1K 2R1
{francois.michaud}@USherbrooke.ca

Abstract

Teleoperated from a distant location, a mobile robot with some autonomous capabilities can become a beneficial tool in telehealth applications. 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. However, design issues related to such systems are broad and mostly unexplored, but with very few systems currently available commercially. 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.

Introduction

The demographic imperative 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 (Katevas 2001; Pollack *et al.* 2002; Cesta *et al.* 2003). For instance, having sensors and actuators required in assistive tasks made mobile would decreasing the cost and the complexity associated with instrumenting a home. With a team of robotics, clinical and geriatric experts, we initiated in 2003 the design of a new robotic platform for this type of application, for elderly people that have disabilities living at home.

The first challenge is to design a system that would 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.

Another challenge is that homes are complex environments presenting a great variety of conditions (e.g., doorsteps, carpets, hard floor, stairs, objects of all sort, constrained space). With the current technology, it is unrealistic to believe that such machines can operate right away autonomously in homes; limits in structural, perceptual and processing capabilities are still too important for their efficient and secure uses. A teleoperated system is therefore more realistic, exploiting technological capabilities already available and relying on human interventions to compensate for the robot's limitations.

This paper presents our iterative design methodology addressing these issues for the development and validation of a robotic telepresence system for home care assistance.

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; 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.

Telerobotic Systems in Home Environments

Teleoperating a mobile robot in a home environment is an endeavor fraught with challenges. Robot's locomotion and perceptual modalities must be adapted to homes (e.g., stairs, door steps, obstacles of different types of material and size). Ensuring the safety of the individual in the home where the robot is used and the safety of the robot itself are primary concerns (Nokata & Tejima 2004). The quality of the robotic teleoperation user interface and the operator experience in teleoperating the robot are two factors that seem to have a direct impact on efficient and safe use of such systems.

Indeed, the teleoperation link (i.e., communication bandwidth) and the visual environment supporting the robotic teleoperation user interface generally restrict the amount of information available to the operator. Thus, an optimal robotic teleoperation user interface must provide pertinent information about the robot's states and environmental conditions (objects, persons, free space, etc.) in conjunction with an efficient command system to the operator. The expertise of the operator is also an influence. Expert and novice operators have been shown to have differing opinions regarding the utility and usability of different features in user interfaces (Olivares *et al.* 2003).

Therefore, we conducted a pilot study to evaluate two conceptually different user interfaces for teleoperated mobile robotic systems, with trained and untrained operators (Labonte *et al.* 2006). This study aimed at identifying locomotion and structural requirements for the new robotic platform, as for user interface requirements for improved efficiency and security of novice operators of mobile robots. The objective was to identify critical elements that must be considered in the design of such system, before considering conducting an in-depth study (e.g., statistical analysis with a probabilistic sample).

Field trials were conducted using two commercial robotic platforms: one specifically designed for telepresence application (the CoWorker, made by iRobot inc., which uses visual waypoint navigation); the other being a generic research platform (the Magellan, made by iRobot inc., to validate laser-mapped position point navigation). A first set of trials (2 homes and 5 operators – 1 expert, 2 roboticists and 2 clinical researchers) was conducted in 2004. Even though we had a small number of operators, we found the experience rich in information. 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 conducting an evaluation of complete teleopreation 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. This approach may provide a solution to the problem of extracting information for designing better user interfaces (Scholtz *et al.* 2004). We also noted that untrained operators performed better using position point navigation, while trained operators had better performance with waypoint navigation. Therefore, conducting preliminary trials revealed to be very useful in getting a holistic view of the issues to address in our project, and to prepare the methodology in the different studies as the project progresses.

Focus Groups

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.

Motivated by the practical nature but still abstract of the application, in addition to the novelty of its technical challenges, we put efforts on identifying and addressing the actual needs in telehome care interventions. The objectives of this study (Boissy *et al.* 2006) were to explore with healthcare professionals involved in geriatric care and potential client (the elderly) the concept of in-home mobile robotics in order to 1) conduct a preliminary needs assessment, 2) identify potential target applications, 3) identify check list items needed for the development of an prototype that could be used in pilot testing of these applications.

Focus group interviews are planned discussions facilitated by a moderator and designed to obtain attitudes and perceptions relating to concepts, products, services on a defined area of interest (Krueger 1994). 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). This study was approved by an ethical review board and participants gave their written informed consent prior to taking part in the focus group interviews. 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. Robotic telepresence was also seen as a way of reducing the travel time of healthcare professionals, especially for interventions that are of short duration (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 patients 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., gardian 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.

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 engineerings, 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 be integrated to the health information system.

The specific activities undertaken in any clinical setting 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 their are many different informational aspects to consider. For instance, embedded within each of the three themes are any 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 (Vassilacopoulos & Paraskevopoulu 1997; Staccini *et al.* 2005; Toussaint, Bakker, & Groenewegen 2001; Blobel 2006). 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 entreprise-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 (Zachman 1987), 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 modelized 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

Figure 1: Telerobot.

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 (eventhough is 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.

System Design

Using the information gathered with the preliminary studies, we decided to design a mobile videophone robotic platform, thereby known as Telerobot. The first prototype is shown in Figure 1. 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 with their attachment axis going through the center of the robot, allowing it to turn on the spot. Four omnidirectional wheels (two at the front and two at the back of the robot) are attached to the rocker-boggie suspension, in order to stabilize the frame. Figure 2 shows the suspension base, normally attached to the robot's body. This mechanism acts as a mechanical filter, preventing the robot to be influenced by punctual irregularities of the ground (compared to a robot with a rigid body, such influences is reduced by close to 50%). It minimizes disturbances of 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, and increase mobility on irregular ground. It also allows the robot to go over large steps (up to 3 cm high).

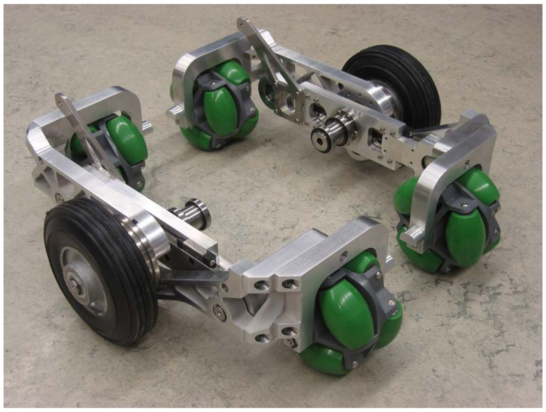

Figure 2: Suspension base (shown with regular wheels).

Figure 3 illustrates the decisional architecture used to control the robot. Using a three-level hybrid deliberative-behavioral architecture, Telerobot is programmed to 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. Different localization approaches are possible with the platform, such as odometry (using wheel encoders), beacons (using the Northstar system by Evolution Robotics) and map-based (using CARMEN, Carnegie Mellon Robot Navigation Toolkit (Montemerlo, Roy, & Thrun 2003)).

Video user interfaces are common in telerobotic systems (Goldberg 2000), and intelligent interfaces are becoming increasingly important as users face increasing system complexity and information overload. The quality of the teleoperation user interface and the operator experience in teleoperating the system are two factors that have a direct impact on the safety and performance of such systems (Olivares *et al.* 2003). 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.

Human-robot interaction studies have shown that operators rely heavily upon the video stream, to the exclusion of all other information on the interface (Bakey *et al.* 2004). To decrease the operators cognitive load, the goal is to integrate information on and around the video display(s) as much as possible (Bakey *et al.* 2004; Ricks, Nielsen, & Goodrich 2004). Graphical information (e.g., events, data) can be overlaid on the video streams or complement the camera view with additional information. The metaphor for the control interface (e.g., joystick control, waypoint positioning by clicking in the video stream) must also facilitate the opera-

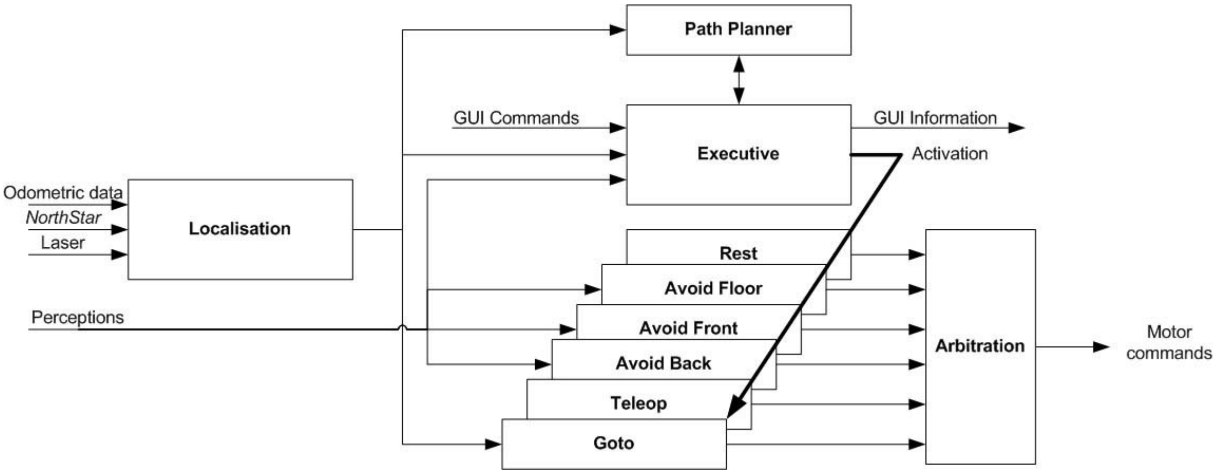

Figure 3: Telerobot's decisional architecture.

Figure 4: User interface with augmented video display.

tion of the remote devices. In our project, we have developed the basis of a generic framework to implement and evaluate a variety of augmented display configurations (e.g., multiple video streams and control modalities, semi-autonomous control modes with or without preset positions and modes).

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 keep 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 provide 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 [6], while way-point navigation is limited to the field of view of the camera. 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 robots navigation cameras). As shown in Figure 4, 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 (Ricks, Nielsen, & Goodrich 2004). A 2D map and a robot sensors representations are placed on the left side windows. Controls are on the bottom window.

Evaluation

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. A display coming from the videophone will be placed next to the robots interface, providing both the interaction (videophone) and the navigation views (for robot control). Evaluation metrics (Steinfeld *et al.* 2006) are going to be derived according to the applications needs. To measure the cognitive load, in addition to the primary task of the targeted application, operators will be ask to simultaneously conduct a secondary task (like answering a series of two-digit addition problems) appearing periodically. Videos will be taken to generate cases that will be used in focus groups, in a subsequent design iteration.

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 process inside a requirement engineering activity (Bray 2002) 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 difficulties 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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References

Bakey, M.; Casey, R.; Keyes, B.; and Yanco, H. 2004. Improved interfaces for human-robot interaction in urban search and rescue. In *Proceedings IEEE Systems, Man, and Cybernetics*.

Blobel, B. 2006. Advanced and secure architectural ehr approaches. *International Journal of Medical Informatics* 75(3-4):185–190.

Boissy, P.; Corriveau, H.; Michaud, F.; Labonte, D.; and Royer, M.-P. 2006. A qualitative study of in-home robotic telepresence for home care of community-living elderly subjects. *Journal of Telemedecine and Telecare*.

Bray, I. 2002. *An Introduction to Requirements Engineering*. Addison Wesley, Pearson Education.

Cesta, A.; Bahadori, S.; Cortellessa, G.; Grisetti, G.; Giuliani, M. V.; Locchi, L.; Leone, G. R.; Nardi, D.; Oddi, A.; Pecora, F.; Rasconi, R.; Saggese, A.; and Scopelliti, M. 2003. The RoboCare project cognitive systems for the care of the elderly. In *Proceedings International Conference on Aging, Disability and Independence*.

Goldberg, K. 2000. *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet*. The MIT Press.

Katevas, N. 2001. *Mobile Robotics in Health Care Services*, volume 7. Assistive Technology Research Series.

Krueger, A. 1994. *Focus Groups: A Practical Guide for Applied Research*. Sage.

Labonte, D.; Michaud, F.; Boissy, P.; Corriveau, H.; Cloutier, R.; and Roux, M.-A. 2006. A pilot study on teleoperated mobile robots in home environments. In *Proceedings IEEE/RSJ International Conference on Intelligent Robots and Systems*.

Montemerlo, M.; Roy, N.; and Thrun, S. 2003. Perspectives on standardization in mobile robot programming: The Carnegie Mellon navigation (CARMEN) toolkit. In *Proceedings IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2436–2441.

Nokata, M., and Tejima, N. 2004. A safety strategy for rehabilitation robots. In *Advances in Rehabilitation Robotics*, volume LNCIS 306. Springer-Verlag. 177–185.

Olivares, R.; Zhou, C.; Bodenheimer, B.; and Adams, J. 2003. Interface evaluation for mobile robot teleoperation. In *Proceedings ACSME*.

Pollack, M. E.; Brown, L.; Colbry, D.; Orosz, C.; Peintner, B.; Ramakrishnan, S.; Engberg, S.; Matthews, J. T.; Dubar-Jacob, J.; McCarthy, C. E.; Thrun, S.; Montemerlo, M.; Pineau, J.; and Roy, N. 2002. Pearl: A mobile robotic assistance for the elderly. In *Proceeedings AAAI Workshop on Automation as Caregiver*.

Ricks, B.; Nielsen, C.; and Goodrich, M. 2004. Ecological displays for robot interaction: A new perspective. In *Proceedings IEEE/RSJ International Conference on Intelligent Robotics and Systems*.

Scholtz, J.; Young, J.; Drury, J.; and Yanco, H. 2004. Evaluation of human-robot interaction awareness in search and rescue. In *Proceedings IEEE International Conference on Robotics and Automation*.

Staccini, P.; Jourbert, M.; Quaranta, J.; and Fieschi, M. 2005. Mapping care processes within a hospital: From theory to a web-based proposal merging entreprise modelling and iso normative principles. *International Journal of Medical Informatics* 74(3):35–44.

Steinfeld, A. M.; Fong, T.; kaber, D.; Lewis, M.; Scholtz, J.; Schultz, A.; and Goodrich, M. 2006. Common metrics for human-robot interaction. In *Proceedings Human-Robot Interaction Conference*.

Toussaint, P.; Bakker, A.; and Groenewegen, P. 2001. Integration of information systems: Assessing its quality. *Computer Methods and Programs in Biomedicine* 64:9–35.

Vassilacopoulos, G., and Paraskevopoulu, E. 1997. A process model basis for evolving hospital information systems. *Journal of Medical Systems* 21(3):141–153.

Zachman, J. 1987. A framework for information systems architecture. *IBM Systems Journal* 26(3).