Autonomous Robots 11, 87–95, 2001

Social Tele-Embodiment: Understanding Presence

ERIC PAULOS AND JOHN CANNY
Computer Science Department, University of California, Berkeley, CA 94720

Abstract. Humans live and interact within the real world but our current online world neglects this. This paper explores research into Personal Roving Presence (PRoP) devices that provide a physical mobile proxy, controllable over the Internet to provide tele-embodiment. Leveraging off of its physical presence in the remote space, PRoPs provide important human verbal and non-verbal communication cues. The ultimate goal is a computer mediated communication (CMC) tool for rich natural human interaction beyond currently available systems. This paper examines PRoP design choices, system architecture, social issues, and evaluations of several user studies.

Keywords: tele-embodiment, tele-presence, tele-robotics, tele-actor

1. Introduction

PRoPs are simple, inexpensive, internet-controlled, untethered, mobile tele-robots that strive to provide the sensation of tele-embodiment in a remote real space (see Fig. 1). The physical tele-robot provides video and audio links to the remote space as well as providing a visible, mobile entity with which other people can interact. PRoPs also enable their users to perform a wide gamut of human activities in the remote space, such as wandering around, conversing with people, hanging out, pointing, examining objects, reading, and making simple gestures. The focus of this work is to identify and distill a small yet sufficient number of traits that are vital to human communication and interaction and to physically implement them on PRoPs. This involves detailed study of verbal and non-verbal cues used in human communication.

We are also interesting in understanding how PRoPs can capture and employ what Daft and Lengel refer to as *Media Richness* (Draft and Lengel, 1984). This is essentially the ability for people to determine and use the appropriately rich communication media for the task at hand. Can PRoPs extend the richness beyond other CMC tools towards "face-to-face" (F2F)? Studies of online trust and persuasion prove the importance of F2F encounters (Rocco, 1998). One goal for PRoPs is as CMC tools that can be employed in situations requiring media rich human interactions: in situations where subtle communication cues that PRoPs allow manifest allow for online trust and persuasion to be successful.

1.1. Tele-Embodiment

Methods of achieving telepresence are not new with one of the first electrically controlled mechanical tele-operational systems being developed by Goertz (Goertz and Thompson, 1954) in 1954. Since then a variety of applications for tele-operated robotics have been explored (Sheridan, 1992). However, most of these systems are designed for a single specific task and are quite complex. They also typically require expensive special purpose dedicated hardware and a highly trained operator to control and interact with the mechanism in the remote environment. By design, PRoPs strive to constrain their development so that they will be accessible to a wide audience without additional, expensive, or extraordinary hardware. In essence, *telepresence for the masses*. More importantly, unlike typical telepresence systems employed in remote inspection or hazardous exploration tasks, the primary application of personal tele-embodiment systems is to facilitate human communication and interaction.

PRoPs allow humans to project their presence into a real remote space rather than a virtual space, using a robot instead of an avatar. This approach is sometimes referred to as "strong telepresence" or

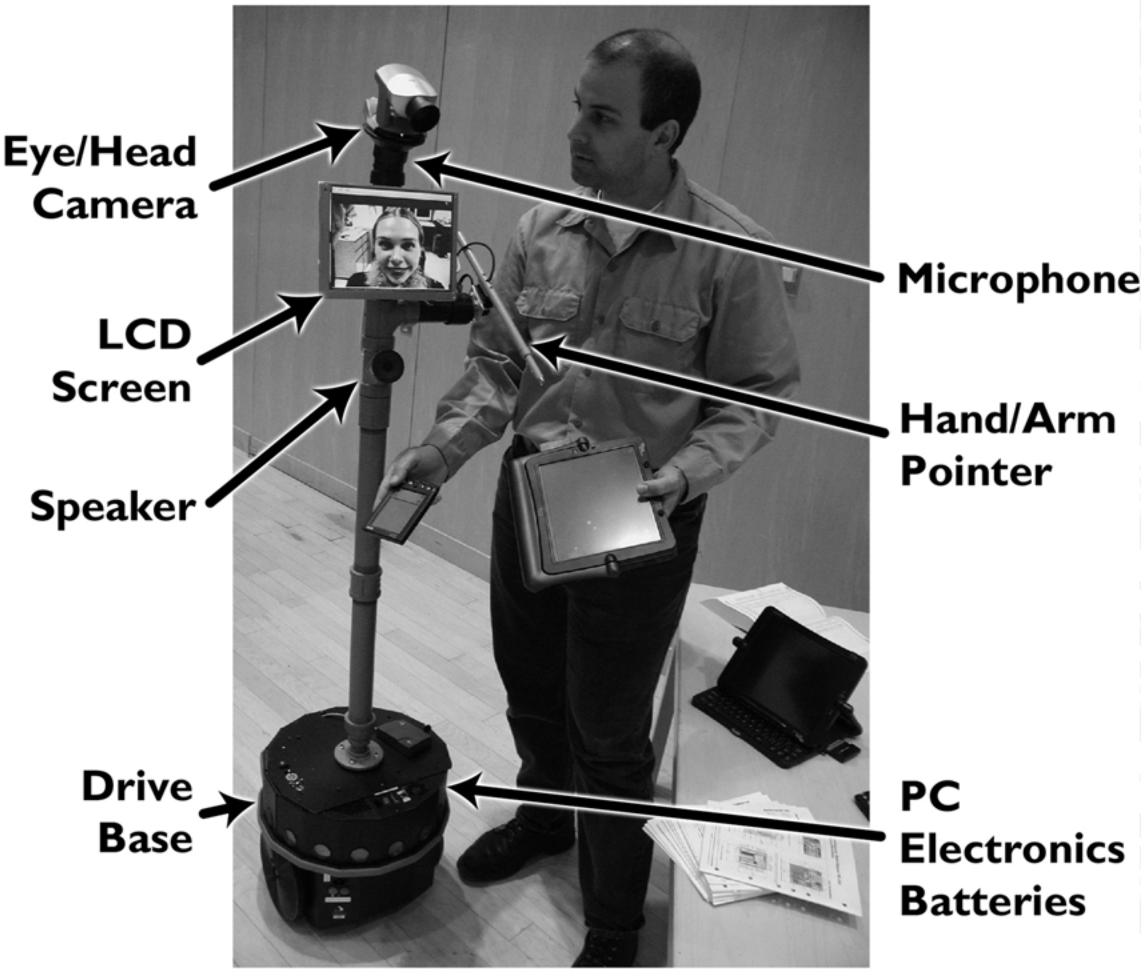

Figure 1. A PRoP and its various components as it interacts with another individual.

"tele-embodiment" since there is a mobile physical proxy for the human at the end of the connection. As a result the term *tele-embodiment* was coined to emphasize the importance of the physical mobile manifestation (Paulos and Canny, 1997). Tele-embodiment is telepresence with a personified perceptible body.

This approach differs fundamentally from more traditional versions of strong telepresence that involve an anthropomorphic proxy or android. Instead, PRoPs attempt to achieve certain fundamental human skills without a human-like form. More importantly, the research is driven by the study and understanding of the social and psychological aspects of extended human-human interactions rather than the rush to implement current technological advances and attempt to re-create *exact* face-to-face remote human experiences.

2. Previous and Related Work

PRoPs research is at the intersection of robotics, social psychology, communication, and human centered computing. As a result it draws on related work from a wide variety of fields.

Internet based tele-robotics works beginning in early 1995 (Goldberg et al., 1995) and later from several individuals has influenced our design (Siegwart et al., 1998; Grange et al., 2000). The PRoPs work is a direct descendent of earlier work with human sized small Internet tele-operated helium filled blimps (Paulos and Canny, 1998). In fact there are now companies such as *iRobot* exploring the field of Internet based telepresence.

Computer Mediated Communication (CMC) research has demonstrated important results towards understanding how humans interact with and communicate through technology. Ishii's ClearBoard (Ishii et al., 1993) is an early example of novel CMC tools. Projects such as Dourish's RAVE, Portholes, and Media Spaces (Dourish and Bellotti, 1994; Dourish et al., 1996; Dourish, 1998) investigate various video-presence tools and their accepted and applicable use by groups.

We have also drawn from various physical interaction systems such as Data Dentata (tele-handshaking) (Goldberg and Wallace, 1992), InTouch (tele-tactical interaction) (Brave and Dahley, 1997), and Gesture-Cam (tele-robotic gesturing) (Kuzuoka and Ishimoda, 1995). Even more closely related is work by the Ontario Telepresence Group using Video Surrogates, Hydra (Sellen et al., 1992), and Door Access Control to explore the use of physical proxies as portals for CMC.

3. System Architecture

PRoPs are designed from simple mobile robot bases with modifications to slow them to human walking pace and a 1.5-meter vertical pole to provide a realistic human vantage for the camera. On board the cart are a color video camera, microphone, speaker, color LCD screen, a few simple custom electronics, and various drive and servomotors (see Fig. 2).

3.1. Hardware

The current generation of PRoPs has undergone numerous major hardware changes during their evolution. These untethered systems are constructed from commercially available robot bases with onboard sonar, odometry, and an embedded single board computer. Various custom fabricated circuits provide the interface from the computer to remaining motors, sensors, and control hardware. Additional hardware supports full duplex audio, live video capture, and wireless 802.11 Ethernet.

The body is a low weight 1.5 meter ABS plastic pole that supports the attachment of various hardware and cabling. A speaker and microphone are located on the stalk of the body. Crowning the pole is a high quality pan/tilt camera that also supports software controlled 16x zoom, auto iris, and auto focus. Located directly below this camera is a 30 cm (12 inch) diagonal flat panel color display. Off to one side of this is the "arm/hand" hardware where a two-degree of freedom (2DOF) pointer is attached for simple gesturing. At the tip of this "limb" a small laser pointer is attached.

3.2. Software

A user connects to the PRoP using a standard web browser that invokes a Java applet. This applet reads the various input devices (keyboard, mouse, and joystick) and transmits the data to the PRoP. A Java based server runs onboard the PRoP, serving as the glue between the various PRoP hardware elements (i.e. camera, base, hand/arm, etc.) and the remote networked user. The user's Java applet also receives back various status information from the PRoP and displays it to the user. The two-way audio/video software is written to interface directly into H.323[1] video conferencing standards. H.323 supports a suite of protocols for low latency real time audio, video, and data transmission, ideal for use with PRoPs. The current solution uses

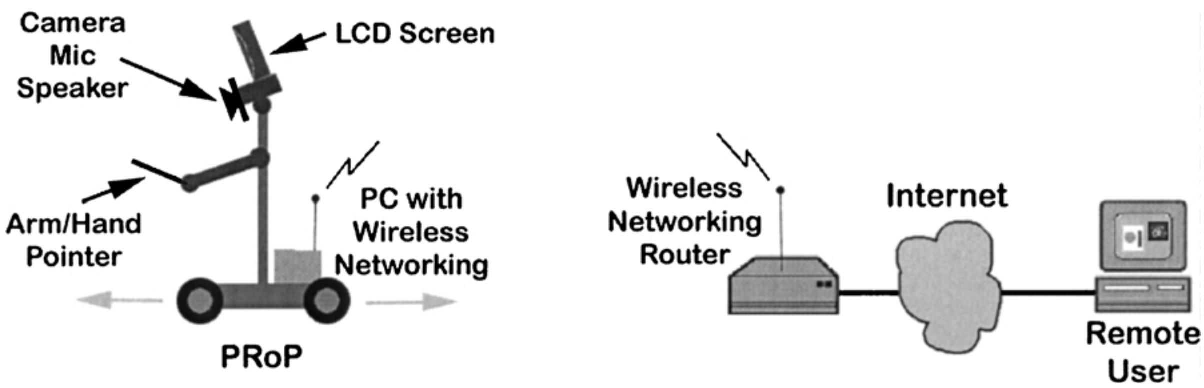

Figure 2. System overview of PRoP hardware.

NetMeeting, a freely available piece of software from Microsoft.

4. Control, Navigation, and Interface

A user drives the PRoP using the standard joystick left-right and forward-back controls. The "hat" or point-of-view (POV) switch found on more modern "gamers" joysticks directs the head pan-tilt motion. Zooming is controlled through the joystick's throttle or Z-axis controller. There are also several keyboard shortcuts for zooming and quickly setting the PRoP into frequently used positions.

4.1. Go There Now: Point and Click Interfaces

User observations reveal extreme control difficulty and tedium in two fairly common navigational tasks. The most common tasks are requests of the form "Hey I want to go over there" or "I want to get to the end of the hall" or "Look there's Jill, go over there so I can say hello" or "Move over to that door". Current work is exploring the use of a single, simple pointing gesture on an image to direct the PRoP (Crisman et al., 1998). The control mode will then run closed loop towards the goal without requiring any input from the user. Of course the user can interrupt the system at any time to steer the PRoP to a new location.

4.2. Smile: Creating a Tele-Visit Visual Scrapbook

A goal of this research is to allow people to be immersed into real remote spaces and allow them to explore and interact with the inhabitants there in much the same way as they would if they were truly present. However, there are some augmentations to PRoPs that can provide the remote individual with an experience beyond what is possible with an actual visit.

Rough position information from the PRoP's odometry data allows a simple map to be constructed. An individual captures images that are automatically embedded into the visualization of a simple map interface. This provides a visual history of a tele-visit (see Fig. 3 for an example of such a system). This data can be easily recalled from storage even when the PRoP is offline.

5. Tele-Experience

Two-way communication between humans with PRoPs creates a myriad of interesting remote experience possibilities as well as social dilemmas. We address several of these topics in this section.

Figure 3. Java visual scrapbook tool constructed during a PRoP visit.

5.1. Communication Channels

PRoPs strive to facilitate human communication and interaction at a distance by playing into a wide range of verbal and non-verbal cues. A brief description of various implemented cues follows.

Two-way audio: Primarily used for verbal communication as well as sensing subtle background sounds for determining spatial characteristics such as room size, activities, conversations, mood, etc.

Two-way video: The video screen allows for exchange of visual cues such as facial expressions while the camera serves and a general purpose tool for viewing a plethora of visual data about a remote space (i.e., Who's there?, What does it look like?, Is the person I'm talking to even looking at me?, etc.). Like the audio channel, the video signal undergoes a lossy compression. For a wide range of tasks, humans seem capable of transparently adjusting to this lower quality signal (Reeves and Nass, 1996).

Proxemics: Through the use of the mobile robotic base users are able to position themselves with respect to a group or individual. As well as providing browsing and exploring capabilities to the PRoP, this also permits first order proxemics to be expressed (Hall, 1966).

Directed Gaze: The movable pan/tilt head delivers a gaze direction non-verbal cue to remote individuals. The PRoP pilot can "turn and face" someone to see them, address them, or just give attention. This cue is also extremely important for back channeling during conversations.

Deictic Gesturing: A 2-DOF pointer attached near the location of an "arm/hand" portion of the PRoP facilitates simple pointing gestures. Users employ this tool to point out a person, object, or direction. Making simple motion patterns it can express interest in a conversation, agreement with a speaker, or gain attention for asking a question in a crowded room. To preserve meaning, nuance, and richness in these gestures continuous input devices are used.

Physical Appearance, Color, and Viewpoint: Employed as a communication tool in public settings, subtle physical design choices often hinder the effectiveness of PRoPs. Careful attention to its overall height, shape, and color are important. There has been much trial and error as well as anecdotal evidence for and against many of the elements in the current design. Height is one of these traits. A PRoP that was too high caused intimidation as it gazed down on others. When it was too low, users were required to awkwardly bend down or squat to communicate with others making the experience unnatural.

6. Experiments

PRoPs are novel technologies. The social conventions surrounding them are unknown and need to be studied (Kiesler, 1978). For example: How will they be used? When are they appropriate? Where do they fit into the social priority ordering (i.e. will a person interrupt phone call to speak with a PRoP enabled user)? Can a PRoP user be more persuasive than a user with videoconferencing alone? How does PRoP size, location, and positioning affect its influence and persuasion ability (Milgram, 1974)? How about compared to F2F? Many of these questions will remain open for some time, as PRoPs have only recently entered the CMC landscape. Several initial experiments have been performed to investigate two basic issues: (1) usability and acceptance and (2) network effects.

6.1. Experiment 1: Usability and Acceptance

In this experiment we attempt to assess the efficiency of the interface and control mechanisms for PRoPs as well as their appearance and acceptance. The experiment consists of a brief explanation of the PRoP controls and abilities. The user is then instructed to explore a building they are familiar with, locate a set of landmarks, and converse with another individual.

Users. The experiment involved seven individuals (4 female/3 male) ranging in age from 26 to 55. Computer familiarity varied from an experienced network administrator to a user who had spend almost no time on the Internet. Only one user had any familiarity with Internet based videoconferencing while two had significant experience with chat rooms and instant messaging systems. There was one avid gamer in the group. Although gathering data from hundreds of users would be nice, we found a wealth of useful feedback from even the small group we did examine. Restricted and limited access to the test facility was another hindrance to having a large test group.

Setup. The tests were held in a public building with no affiliation to a university, company, or research laboratory. In particular the building contained no "high-tech" facilities or technology related items that would distract the users. The PRoP was setup in a large 220 m^2 (2500 sq ft) room with hard floors. The room contained several large desks, chairs, a piano, and a blackboard. The PRoP stood turned on ready at one end of the room. A separate smaller room behind a closed door contained a standard computer (500 MHz Pentium-III with 512 MB running Windows 2000) with joystick, camera, microphone, and headphones. This computer was running on a private network with no other network traffic. A Proxim wireless bridge base station established a 2 Mb/s 802.11 link to the PRoP. The sonars and sonar feedback was disabled during this test leaving the users with only the most basic PRoP controls.

Tests. Individually, each user was brought into the room and shown the PRoP. They were advised that they would be using a new research project and be asked to evaluate it for a 30-minute period. They were also informed that they could pause or discontinue the experiment at any time and for any reason with no questions asked. The audio, video, pan-tilt-zoom camera, and mobility features were briefly explained. They were then escorted into the smaller room behind a closed door and shown the typical computer setup with A/V hardware. Video from the PRoP camera was already on the users screen. The experimenter explained and briefly demonstrated the joystick and keyboard controls for using the various features of the PRoP and then left the subject alone in the room.

The user was asked to perform two tasks. First, to maneuver the PRoP over to a table where some books were placed by another individual and to read the text on them. A confederate sat on the opposite side of the table with the books and interacted with the PRoP once it arrived at the table. The confederate communicated to the remote user via the PRoP. This task required basic navigation skills around several obstacles and use of the head pan-tilt-zoom controls. This test focused on getting the individual comfortable with the PRoP controls as well as assessing its use for reading documents and collaborating with others around a table or workspace.

During the second task, the user was instructed by the table confederate to find another location, typically near the blackboard or piano, and meet them there via the PRoP. When the individual arrived a brief discussion ensued for several minutes after which the experiment was ended and a post evaluation discussion occurred.

Evaluation. The experiment was designed to be casual. Questions focused initially on the initial basic reaction to the PRoP's appearance. More detailed discussions centered on the controls, UI, applications, missing elements, and specific "annoying" features.

Surprisingly, even with minimal instruction and unfamiliar hardware (i.e., the PRoP) all of the users were able to complete all of the tasks within the time allotted. Only one PRoP collision occurred during the course of the tests. The user easily recovered after they became aware they had backed into an object. Recall that presently there is no sensing or camera view from the rear of the PRoP making backing up in unfamiliar locations particularly precarious. Most users rotated the PRoP in place to turn as permitted by the kinematics of the robot base. The pace of the PRoP's motion, preset to a maximum of 50 cm/s, was "fine" for most users with only one individual noting it was "too slow". There was a general consensus that the joystick control was natural and easy to use. At least two individuals found the head pan-tilt control "too sensitive" and hence difficult to hone in on objects of interest while one user paid particular praise to the head control functionality. All of the users employed the keyboard controls and found them "natural" and "sensible". Interestingly, all of the individuals used the head to "look down" when navigating the PRoP in tight spaces, such as approaching the table or a person to converse with, even though no formal instruction was given about such control usability.

Every user was able to read the text on the book and used the zooming tools. Users repeatedly and easily positioned the PRoP from 3–20 cm from the edge of the table even though no instruction to do so was given. The time to complete the first task varied from 2–5 minutes.

Universally every user in the study ranked the audio and video network delay as the most annoying feature in the system. A video delay of 0.5 to 1 second was measured in this setup. Only one user listed the "picture quality" of the system as a problem. Two individuals explicitly mentioned their surprise at being able to discern various people's facial expressions with the PRoP's video. Although all the users were able to operate the system successfully, several users expressed difficulty navigating as a result of the video delays. The conversations during the second portion of the test also contained a 0.5 to 1 second delay.

The microphones used contained no echo cancellation; hence users would hear themselves slightly delayed on the PRoP. All of the users again commented on this but said that by the end of the test they found themselves adapting to the delay. They did this by allowing extra time between responses during dialog. At least one user found it extremely difficult to construct lengthy verbal responses due to the aural confusion resulting from hearing their own voice feeding back. Another found the PRoP motor sounds less than subtle.

Users were fairly split about missing elements. Extra navigational tools such as some range data to nearby objects and "a camera on the feet" were mentioned. One user was specific in needing a split screen, using one camera near the base to navigate while the other camera could be used to glance around from head height. Another specifically noted the difficulty in judging distance. The other missing element was a hand or hand-like tool. But again users were split when asked if such a hand would be frightening to individuals near the PRoP. Most people explained that if the hand were offering something, as in friendship or some form of greeting, as it approached the intimidation of the hand would be minimized or eliminated. That is, a PRoP initially carrying something in its hand would be acceptable. The hand addition came up most often for aiding in communication such as shaking hands. However, at least one individual noted that it was needed to perform remote work with the PRoP.

Several other PRoP appearance themes were discussed. Overall people found the PRoP friendly and non-threatening. One individual made particular praise of the shape and fact that there were no protrusions beyond the extent of the base. Two individuals, whose jobs involved interacting with children, independently pointed out that although they could imagine numerous applications for PRoPs in their work, its height was a major hindrance for interacting with children. For them, shifting their own height to be eye-to-eye with children was a necessary element of successful communication that the PRoP did not facilitate. Another physical feature was the "big bulky-shinny tires" that made the PRoP look intimidating to one individual.

Finally, most people could easily imagine using a PRoP for browsing places and visiting with people. However, there seems to be a universally agreed upon "acceptable use" policy. Users in general felt comfortable using it with people they already knew or those expecting the arrival of a PRoP—but not in other situations. In a more concrete example, one user was excited about a PRoP to go to a cousin's party saying "he would love it" but not to a store noting, "it may catch people off guard and frighten them."

6.2. *Experiment 2: Network Effects*

The majority of PRoP usage, including Experiment 1, operated within local networks. However, our claim has always been that PRoPs would be usable by "Anyone, Anywhere". Experiment 1 attempted to explore the "anyone" issue, but could people actually navigate around a crowded building from *anywhere* on the Internet? Experiment 2 explores this question.

Users. The experiment involved four individuals (3 male/1 female) ranging in age from 26 to 43. Computer usage varied from expert to intermediate levels of experience. While one of the users had viewed and used the PRoP previous to the experiment, the remaining 3 had no prior PRoP experience. In fact, two of the individuals had never even seen the PRoP nor been to our lab.

Setup. Each user was sent a brief email explaining the functionality of the PRoP (i.e., various joystick and keyboard controls). At a predetermined time, the individual connected to the PRoP using a Java applet and standard videoconferencing software. The software setup was typical of what a remote user would encounter. Individuals used their own computers and hardware as a remote user would. Remote connections were made from distances of over 9000 km (5600 miles) between the United States and Europe as well as locally within the San Francisco Bay Area. Diverse networking topologies such as T1, DSL, and cable modems were employed during these tests.

Tests. Once connected and basic communication established, the PRoP user was lead around a laboratory environment by a local guide. The guide pointed out projects and objects in the room with the PRoP user free to communicate regarding any of them. Next the PRoP user maneuvered through a rather cluttered lab and engaged other individuals and groups in conversation about their work. After several minutes the PRoP left through an open door and down a hallway as they walked with a confederate guide. After several spontaneous encounters within the hallway with people, the PRoP user maneuvered outside of the building. Finally, near the end of each hour-long session, the PRoP user re-entered the building and said goodbye before terminating the visit and logging off the PRoP.

Evaluation. This test was run near the extremes of expected PRoP operation, with users from Europe, over 9000 km away, attempting to visit a lab, meet people, and converse with them. Not surprisingly network delays were again listed as the major usability problem. Delays of up to 3 seconds were reported in this experiment. Since the interactions in this experiment were more spontaneous, users specifically noted that the delay made gaining people's attention difficult. Typically, a person would be walking down a hallway towards the PRoP. By the time the remote PRoP user saw the person and called out, "Hello, how are you doing?" the intended recipient had already walked passed the PRoP. Again we observed people adapting and compensating to this with earlier, shorter verbal callouts. This corresponds with what Clark refers to as the various "costs of grounding" in communication, particularly start-up costs (Clark and Brennan, 1991).

In every case the users were able to complete all of the operations within the time allotted. Again we found this separate set of users mentioning that they adapted to the delays for navigation. An exciting result is that the users from Europe were able to successfully use the PRoP. Although one of the users connecting from Europe had never seen the PRoP, used the system, or visited our lab, the test went off without even a single collision.

One user's occupation was as a journalist and described using the PRoP as a "thrilling experience" that "really felt like I was visiting Berkeley". This individual strongly felt that using the PRoP provided them with the important tools that they need for completing their job as a journalist. That is, to look around a lab or location, assess the current situation, approach particular individuals, and interview/interact with them appropriately. This user has subsequently used the PRoP to aid in gathering information for news stories at our university. Another user from Europe who had never been to the United States remarked at the end of the session, "Well I guess I've been there [to the United States] now."

7. Current and Future Work

We are exploring the design space of the arm/hand tools, experimenting with several video overlays for navigation aid, adapting several force-feedback joystick metaphors, and designing some posture cues in hardware.

Most importantly we are beginning user tests for "getting to know you" experiments. These tests are an extension of studies performed previously to measure trust and persuasion between people using F2F, chat, telephone, and videoconferencing. When results of these tests using PRoPs are completed we will have a better understanding of the usefulness and persuasiveness of PRoPs. Where do they fit into the existing social structure?

8. Conclusion

Our claim is that PRoPs provide an extremely useful, functional, powerful, new tool for supporting human communication and interaction at a distance. They enable a variety of important work and social tele-activities far beyond what we perform currently with our computers and networks. More importantly, our initial user tests have demonstrated important feedback as well as promising results concerning the usefulness and usability of PRoPs.

Acknowledgments

This research was supported by the National Science Foundation under grant number IIS-9978138. We would also like to thank Terry Fong and Chuck Thorpe for organizing the Vehicle Teleoperation Interfaces workshop where much of this paper's content was presented as well as the anonymous reviewers valuable comments.

Note

1. A standard approved by the International Telecommunication Union (ITU) that defines how audiovisual conferencing data is transmitted across networks that cannot guarantee quality of service (i.e., the Internet). By complying with H.323, multimedia products and applications from multiple vendors can interoperate, allowing users to communicate without concern for hardware compatibility.

References

http://www.dgp.toronto.edu/tp/other/tech.html). Ontario Telepresence Group.

Brave, S. and Dahley, A. 1997. in Touch: A Medium for Haptic Interpersonal Communication. ACM SIGCHI.

Clark, H.H. and Brennan, S.E. 1991. *Grounding in Communication. Perspectives on Socially Shared Cognition*, American Psychological Association: Washington, DC.
Crisman, J.D., Cleary, M.E., and Rojas. 1998. The dieictically controlled wheelchair. *Image and Vision Computing*, 16(4):235–249.
Daft, R.L. and Lengel, R.H. 1991. Organizational information requirements, media richness, and structural design. *In Management Science*, 32:554–571.
Dourish, P. 1998. Using metalevel techniques in a flexible toolkit for CSCW applications. *ACM Transactions on Computer-Human Interaction*, 5(2):109–155.
Dourish, P., Adler, A., Bellotti, V., and Henderson, A. 1996. Your place or mine? Learning from long-term use of audio-video communication. *Computer Supported Cooperative Work (CSCW)*, 5(1):33–62.
Dourish, P. and Bellotti, V. 1992. Awareness and coordination in shared workspaces. In *Proc. ACM Conference on Computer-Supported Cooperative Work CSCW'92* (Toronto, Ontario). New York: ACM.
Fischer, C.S. 1992. *America Calling: A Social History of the Telephone to 1940.* University of California Press: Berkeley.
Goertz, R. and Thompson, R. 1954. Electronically Controlled Manipulator. *Nucleonics.*
Goldberg, K., Mascha, M., Gentner, S., Rothenberg, N., Sutter, C., and Wiegley, J. 1995. Desktop teleoperation via the World Wide Web.
Goldberg, K. and Wallace, R. 1993. *Data Dentata.* ACM SIGGRAPH: Anaheim, CA.
Grange, S., Fong, T., et al. 2000. Effective vehicle teleoperation on the World Wide Web. *IEEE ICRA*, San Francisco, CA.
Hall, E.T. 1966. *The Hidden Dimension*, Doubleday: Garden City, NY.
Ishii, H., Kobayashi, M., et al. 1993. Integration of interpersonal space and shared workspace: ClearBoard design and experiments. *ACM Transactions on Information Systems*, 11:349.
Kiesler, S.B. 1978. *Interpersonal Processes in Groups and Organizations*, AHM Pub. Corp.: Arlington Heights, I1.
Kuzuoka, H. and Ishimoda, G. 1995. Supporting position expressions for spatial workspace collaboration. *Transactions of the Information Processing Society of Japan*, 36(6):1379–1386.
Marvin, C. 1988. *When old Technologies were new: Thinking About Electric Communication in the Late Nineteenth Century*, Oxford University Press: New York.
Milgram, S. 1974. *Obedience to Authority; an Experimental View*, Harper & Row: New York.
Murray, R.M., Li, Z., et al. 1994. *A Mathematical Introduction to Robotic Manipulation*, CRC Press: Boca Raton.
Paulos, E. and Canny, J. 1997. Ubiquitous tele-embodiment: Applications and implication. *International Journal of Human-Computer Studies*, 46(6):861–877.
Paulos, E. and Canny, J. 1998. *PRoP: Personal Roving Presence*, ACM SIGCHI: Los Angeles, CA.
Reeves, B. and Nass, C.I. 1996. *The Media Equation: How People Treat Computers, Television, and new Media like Real People and Places.* Cambridge University Press: Cambridge, MA.
Richardson, A.E., Montello, D.R., et al. 1999. Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition*, 27(4):741–750.
Rocco, E. 1998. Trust breaks down in electronic contexts but can be repaired by some initial face-to-face contact.
Sellen, A., Buxton, B., et al. 1992. Using spatial cues to improve videoconferencing.
Sheridan, T.B. 1992. *Telerobotics, Automation, and Human Supervisory Control*, MIT Press: Cambridge, MA.
Siegwart, R., Wannaz, C., et al. 1998. Guiding Mobile Robots through the Web. IEEE/RSJ Workshop, Victoria, Canada.

Eric Paulos is a PhD student in the Computer Science Department at the University of California, Berkeley. His research interests revolve around robotics and internet based personal telepresence, particularly the physical, aural, visual, and gestural interactions between humans and machines and various permutations of those interactions. He has developed several internet based tele-operated robots since 1995 when he implemented Mechanical Gaze. Since then he has designed several small human-sized Space Browsing helium filled tele-operated blimps, the first tele-operated laboratory, and ground based Personal Roving Presence (PRoP) devices.

John Canny is a Professor in the Computer Science Division at the University of California, Berkeley, which he joined in August 1987 after receiving his Ph.D. degree from the Massachusetts Institute of Technology. His research interests include Ubiquitous tele-presence. That is, studing sensing and actuation priorities for tele-embodiment along with the study and facilitation of computer-mediated group interaction and motion and gesture transmission. His other reseach interests include Impulse-based dynamic simulation, Human-Computer interaction through 3d direct manipulation, rapid prototyping of behaviors for simulated objects, many-body manipulation through vibration and friction or fluid flow, universal planar part feeders, geometric and algebraic algorithms applicable in robotics and graphics, development of fast motion planning and collision detection software, an algebra toolkit, hardware and software for flexible manufacturing, and three-dimensional sensors and displays.