Through-Walls Collaboration

Through-walls collaboration lets users in the field work in real time with users indoors who have access to reference materials, a global picture, and advanced technology. The concept leverages ubiquitous workspaces, augmented reality, and wearable computers.

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At the University of South Australia, we've been developing and evaluating technologies to support through-walls collaboration, in which users in an intelligent meeting room can work in real time with field operatives to view and manipulate data. The users in the field have first-hand knowledge of the current problem, whereas the indoor users have access to reference materials, a global picture, and more advanced technology—putting the two together in near real time should immensely improve collaboration between all parties. We use augmented reality (AR), the registration of projected computer-generated images over a user's view of the physical world, as a core technology to convey information (see Figure 1).

With this extra information, users can enhance or augment the physical world beyond their normal experience. Spatially located information relative to a user's context or situation can improve their understanding of the world at hand. The goal of this project is to bring collaboration tools into the hands of people working under very demanding conditions. These tools will provide a much better understanding of the complex circumstances that require people both in a control centre and in the field.

Disaster Relief Scenarios?

Imagine a cyclone inflicts extensive damage on Queensland's coast. Two immediate actions take place: first responders deploy to the affected areas and set up a command-and-control center, with people in the field providing information to the center. Control center personnel will use this data to direct resources to the appropriate places.

If the field operatives come equipped with AR wearable computer technology, they can more accurately provide their commanders a picture of the affected area's current state. AR wearable computer technology can provide digital images, videos, and voice information that are geospatially mapped to the recording point, which will give control center personnel better situational awareness. Using mobile AR systems, the field operatives can define annotated regions on the ground, denoting dangerous areas, completed searches, and areas that require immediate attention. The field operatives can also quickly edit 3D representations of buildings to show which portions have been damaged. Control center personnel can then direct field operatives to investigate particular areas by marking a digital 3D map that's reflected in the physical world viewed by the user in the field through AR technology.

As another example, suppose an expert needs to shut down a chemical plant and can't get there in time. To walk a field operative through the procedure, the video camera mounted on his helmet will let the control center-based expert see what the field operative sees. The expert can then speak and provide diagrams, images, and highlight regions of importance over the field operative's view. If he sees 12 levers, the expert merely circles the correct one. The expert can then
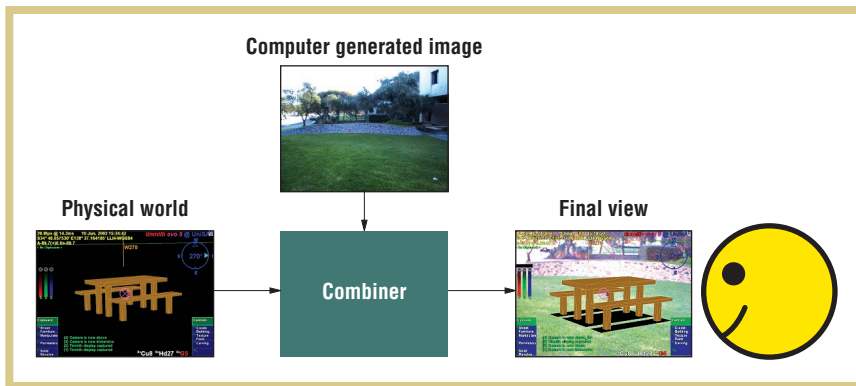
Figure 1. Overview of augmented reality. In augmented reality, the user views the physical world with graphical information overlaid and registered onto this view. This technology can geo-reference information and provide in-situ information for a user's location.

Figure 2. Tinmith wearable computer system. The motherboard of a high end notebook computer with additional electronics is contained in a belt-worn housing. The helmet forms a platform to support the head mounted display, orientation sensor, digital video camera, and GPS antenna. The single input device for the system is pair of wireless pinch gloves with computer vision tracked thumbs.

verify that the field operative pulled the correct lever on the video feed.

In a disaster recovery scenario, many groups of people must collaborate to save lives, but they're often located over a wide area and need to share information quickly. Current methods such as radio communication only allow limited types of information transfer, whereas using computers and shared databases allows maximum distribution to the people who need it. Improving collaboration is still a difficult problem that our research hopes to help solve.

Our goals include improving information access, supporting teamwork, facilitating communications, and allowing greater manipulation of information in the field. By linking advanced control rooms to mobile users, the centralized parts of the system can access on-site information to improve decision-making. The decision support component appears in artificial intelligence and expert systems literature and isn't a part of our investigation. Instead, our focus is on using AR to provide collaboration features that haven't previously been possible.

Supporting Through-Walls Collaboration

Our approach requires several different forms of technology (see sidebar "Bringing Together Existing Research).

We used the Tinmith backpack system developed at the University of South Australia and extended it as the mobile outdoor AR system (see Figure 2). It provides a suitable hardware and software platform, with existing interfaces to support connections to other systems. The LiveSpaces/HxI project at the University of South Australia supports the indoor command center with ubiquitous infrastructure, including tracking equipment, LCD projectors, tabletop display surfaces, and computers. Overall, the through-walls collaboration system has three major components: the indoor visualization control room, the outdoor wearable AR system, and collaboration between the two. We faced two fundamental research questions for supporting the collaboration:

- How is the visualization information presented to users in both the indoor and outdoor settings?
- How do users interact with the data?

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Indoor System

The indoor visualization control room leverages our current ubiquitous work-space investigations with LiveSpaces/HxI. The LiveSpaces HxI project includes several years of experience developing and investigating control room technologies for intense collaboration applications such as defense planning. Through-walls collaboration requires visualization of real-time information from one or more people in the field, directing people in the field, communicating with people in the field via AR information, and presenting data in a temporally coherent fashion.

The interaction techniques require an intuitive interface that allows group interaction in an ad hoc manner. We investigated tangible interfaces that naturally afford group interaction[1] and ubiquitous interaction techniques such as speech, gestures, and multimodal. A particularly powerful feature of the

Bringing Together Existing Research

Our project draws on three major areas of computer science research: computer-supported cooperative work (CSCW), wearable computing, and ubiquitous workspaces.

Computer-Supported Cooperative Work

CSCW collaboration technology facilitates multiple users accomplishing a large group task. Specifically, it helps combine or merge the work of multiple users; prevent or inform users when more than one person modifies data; and track the activities of multiple users. Collaborative technology—such as distributed whiteboards and remote videoconferencing systems—can also improve communication to attain a common goal.

Henrik Fagrell and his colleagues took CSCW into the field to investigate how handheld computing devices can communicate via a wireless network to facilitate collaboration.[1] They based their architecture FieldWise on two application domains: mobile and distributed service electricians and mobile news journalists. We're interested in wearable computing as an alternative to handheld computing because wearable computers leave the hands free when the user isn't interacting with the computer and still display data through a private head-mounted display (HMD).

Wearable Computing

Thanks to advances in wearable computing, users can operate many devices while freely moving about their environment. Traditional desktop input devices such as keyboards and mice can't be used when mobile, so they require new user interfaces for field workers. Currently available research and commercial devices include chord-based keyboards, forearm-mounted keyboards, track-ball and touch-pad mouse devices, gyroscopic and joystick-based mouse devices, gesture detection of hand motions, vision tracking of hands or other features, and voice recognition.

The first demonstration of AR operating in an outdoor environment is the Touring Machine at Columbia University. Steven Feiner and his colleagues[2] based the Touring Machine on a large backpack computer system, with all the equipment attached necessary to support AR. The Touring Machine provides users with labels that float over buildings, indicating the location of various buildings and features at the Columbia campus. Users interact with the system by using a GPS and head compass to control their view of the world. By gazing at objects of interest longer than a set dwell time, the system presents additional information. A tablet computer with a Web-based browser interface provides extra information and interaction with the system. Tobias Hollerer and his colleagues extended the Touring Machine for the placement of what they termed *situated documentaries*.[3] Their system shows 3D building models overlaying the physical world, letting users see buildings that no longer exist on the Columbia campus. Mark Billinghurst and his colleagues studied the use of wearable computers for mobile collaboration tasks.[4]

Ubiquitous Workspaces

Ubiquitous workspaces are computing environments restricted to a particular environment, such as an intelligent meeting room or planning facility. Research is well under way in various laboratories[5] to more fully understand the underlying infrastructure requirements for ubiquitous workspaces. In particular, researchers are interested in supporting intense collaboration activities such as time-critical contingency planning. Work by Gloria Mark[6] and others focus on project or "war" rooms for undertaking intensive design activities such as the design of NASA space missions or complicated software. The combination of electronic workplace support and new processes has significantly reduced the time required to undertake these activities.

REFERENCES

1. H. Fagrell, K. Forsberg, and J. Sanneblad, "Fieldwise: A Mobile Knowledge Management Architecture," *Proc. Conf. Computer Supported Cooperative Work*, ACM Press, 2000, **//page numbers?//**.

2. S. Feiner, B. MacIntyre, and T. Hollerer, "A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment," *Proc. 1st Int'l Symp. Wearable Computers* (ISWC 97), IEEE CS Press, 1997, pp. 74–81.

3. T. Hollerer, S. Feiner, and J. Pavlik, "Situated Documentaries: Embedding Multimedia Presentations in the Real World," *Proc. 3rd Int'l Symp. Wearable Computers* (ISWC 99), IEEE CS Press, 1999, **//page numbers?//**.

4. M. Billinghurst et al., "A Wearable Spatial Conferencing Space," *Proc. 2nd Int'l Symp. Wearable Computers* (ISWC 98), IEEE CS Press, 1998, pp. 79–86.**//page numbers?//**.

5. B. Johanson and A. Fox, "The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms," *IEEE Pervasive Computing*, vol. 1, no. 2, 2002, pp. 67–74.

6. G. Mark, "Extreme Collaboration," *Comm. ACM*, vol. 45, no. 6, 2002, pp. 89–93.

through-walls systems is that both indoor and outdoor users can provide an AR overlay with multimedia data such as images, text, video, and sound for highlighting information. Such annotations must be specified and displayed at physical scales such as building, car, and control panel sizes—for example, the indoor user must be able to specify
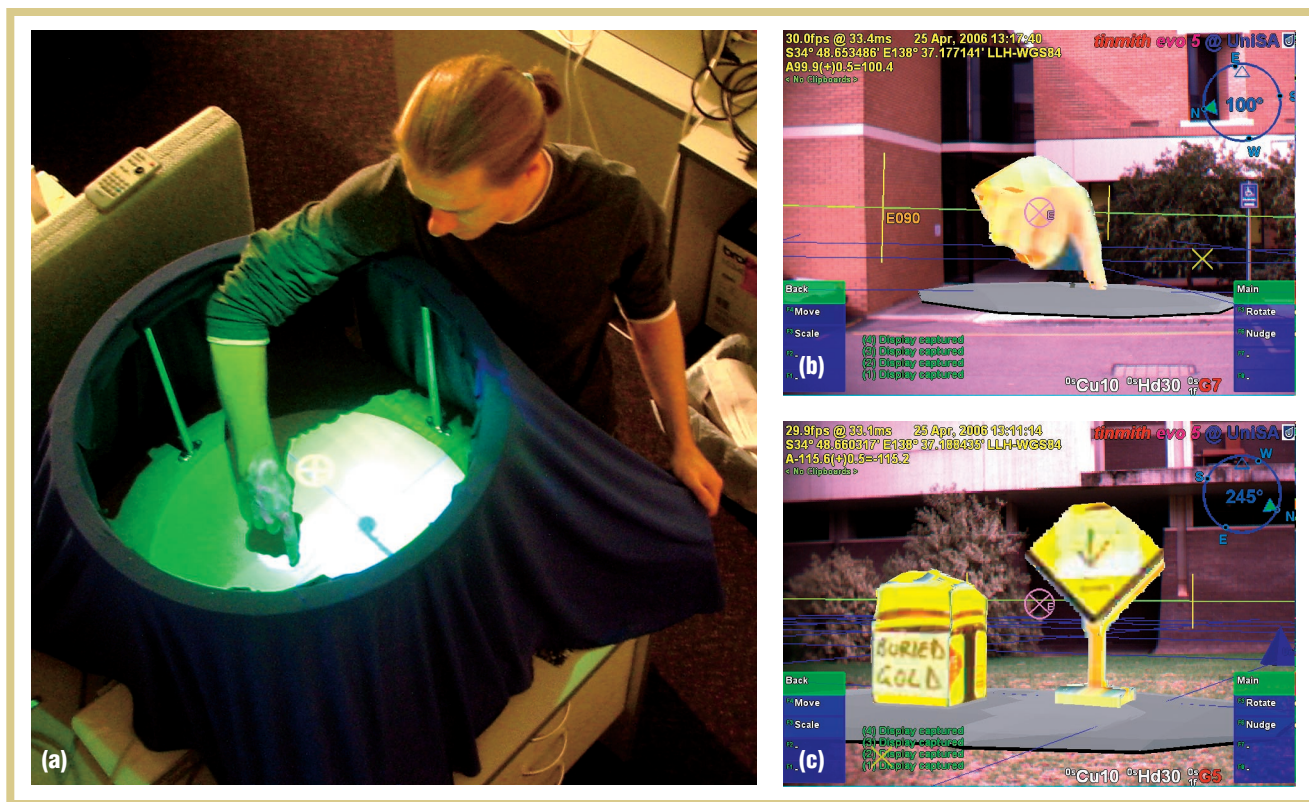
Figure 3. Hand of God (HOG) system. (a) An indoor expert employing the HOG interface. (b) Head-mounted display view as seen by the outdoor participant. (c) Physical props as signposts for the outdoor user.

these annotations relative to a map, a known location, or a user in the field.

The indoor system provides appropriate visualizations to support situational awareness for control room experts. As users annotate and change the virtual information landscape, indoor users see a temporally correct visualization of the alteration and adaptations.

Outdoor System

We built the outdoor wearable AR system around the Tinmith hardware and software platform and continue to investigate tools to support field operatives with through-walls collaboration. Clearly, presenting information to field operatives is the key to this investigation. Our previous work made the assumption that users in the field had full control of the information, which allowed for subtle presentation of the information.[2,3] But information that's pushed to outdoor users from a control room

requires a different cueing mechanism, and field operatives must be able to tune it. An important new direction is the inclusion of situated media, such as polygons, images, text, icons, video, movies, and sound.[4,5] In particular, field operatives can vary the level of detail of our situated media at their own discretion.

## Technologies to Support Through-Walls Collaboration

Support for a through-wall collaboration system requires several new technologies. The Wearable Computer Lab is investigating six to support this concept, including Hand of God, tabletop collaboration technologies, distributive VR/AR, remote active tangible interactions, mobile AR X-ray vision, and input devices for wearable computers.

Hand of God

Command-and-control centers require support for intense collaboration, so the

technology should be intuitive and simple to operate. Imagine a commander communicating to support people in the field and wanting to send a support person to a new position. The simplest method would be for the commander to physically point to a map that the field operative sees as a virtual representation. This technology supports through-walls collaboration with the commander providing meaningful information to the user in the field.

Aaron Stafford, Wayne Piekarski, and Bruce Thomas developed the Hand of God (HOG) system to present a wide path of communication among indoor experts and remote users.[2] Figure 3 depicts an indoor expert using it by pointing to locations on a map; both indoor and outdoor users have an additional audio channel. An outdoor field worker employing a Tinmith wearable computer visualizes a 3D reconstructed model of the indoor expert's hand,
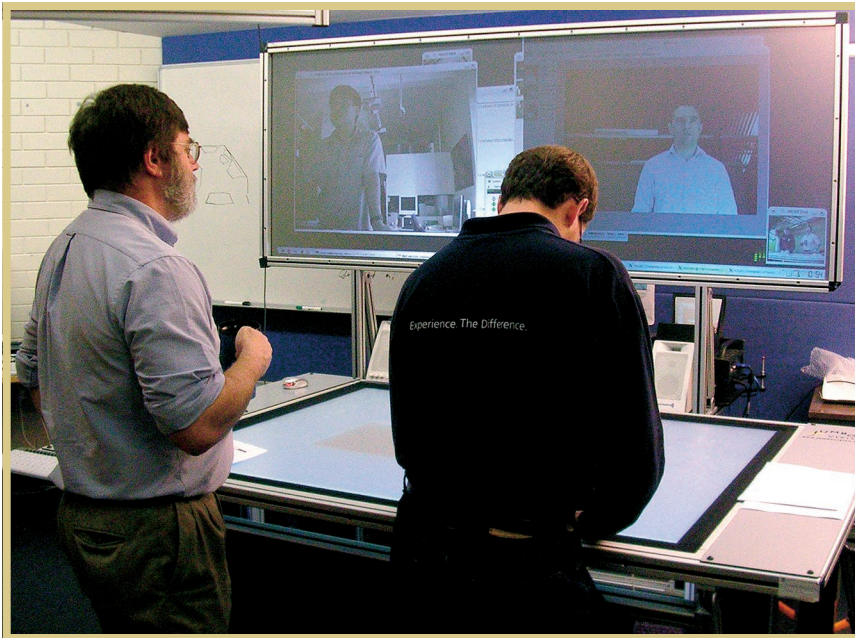
Figure 4. An HxI collaborative table. The vertical display surface provides for the display of video teleconferencing technology. The horizontal surface is a shared digital spaced where each of the users interact and visualize a common set of applications.

georeferenced at the indicated map point, as depicted in Figure 3a. The indoor expert can quickly and intuitively communicate to the outdoor field worker—in this example, by pointing to a precise location on a map and giving the outdoor user a visual waypoint to navigate to (see Figure 3b). The indoor command centre personnel can place physical props on the HOG table—for example, placing a signpost onto a georeferenced point, as shown in Figure 3c.

Tabletop Collaboration Technologies
Through-wall collaborations are inherently group activities, but many current CSCW technologies don't support collaborating groups well. Mixed presence groupware (MPG) is a new research domain within CSCW that transcends single display groupware (SDG) and one person per workstation distributive groupware (DG). Key to bridging the gap between SDG and DG are user interaction methodologies that let remote and collocated users of different groups feel like they're part of a single team. Each person must have equal abilities to interact with digital data and be on an equal

footing to prevent indoor teams from forming smaller groups and isolating remote teams. Each member of the total team must feel present in the total meeting. We've developed several tabletop user interaction technologies to support MPG, and we plan to employ these with the HOG technology in the future.

Our research group is part of the HxI Initiative, which was set up to support ICT-augmented human interactivity as a collaboration between the Commonwealth Scientific Research Organisation (CSIRO), Defence Science Technology Organisation (DSTO), National ICT Australia (NICTA), the University of South Australia's Wearable Computer Lab (WCL…this is introduced earlier, so use acronym earlier), and the University of Sydney's VisLab. The term HxI describes the trend toward ubiquity and human experience in information communications technology (ICT) environments. Specifically, the "x" in HxI represents research from several disciplines that collectively enhance "the factor of human interactivity" that MPG for teams to collaborate over tabletop display technologies (see Figure 4). MPG connects both collocated and distributed collaborators and their disparate

displays via a common shared virtual workspace.

Part of the HxI is the Braccetto project, which employs four tabletop displays with video teleconferencing nodes (AcessGrid or Conference XP) at four geographically different locations. Each table consists of a vertical display for teleconferencing and a horizontal display for the main working area. Removing the video and audio connection from the groupware application itself allows a wide range of applications to be shared on the horizontal display working area. Traditional VNC applications, Multipointer X Server (MPX), and TIDL allow users to share existing applications. //Who?// has developed several special-purpose MPG applications to explore explicit MPG behavior within the Braccetto project.

Distributive VR/AR
Traditional workstations might not always provide a powerful enough visualization capability for every task. Our research supports an indoor user employing virtual reality technology to perform through-walls collaboration with outdoor users employing AR. The indoor user, with the proper graphical representations of the outdoor environment, can gain a better situational awareness of the outdoor users' tasks and settings. In the future, we plan on employing VR technology to provide an additional commutation channel for through-walls collaboration.

So far, we've explored the interconnection of outdoor AR systems with an indoor VR system to achieve simultaneous collaboration in both domains. We developed the system to support mul-

tiple mobile users of wearable AR systems interacting with a fixed VR facility via a wireless network. It supports an application to simulate combat training, in which the AR users are soldiers with wearable computers, and the VR system is located at a command-and-control center. For soldiers, AR provides enhanced information about the battlefield environment, including the positions and attributes of simulated entities for low-cost outdoor training. Simultaneously, the system makes a complete picture of the battlefield available including real and simulated troops and vehicles via the commercial VR system MetaVR. As soldiers move, their GPS and digital orientation hardware provide the remote VR user and other AR users with the means to track positions in real time. The working system is based on our modular Tinmith wearable computer, which interacts with the ModSAF combat simulator to create a synthetic battle environment for safe training and monitoring. We used the DIS simulation protocol to communicate among the different systems.[3]

Remote Active Tangible Interactions

Physical objects, or props, provide a natural and intuitive interface for tabletop systems. If physical objects must be moved, an indoor user must physically alter their position to reflect a new position on the map. The physical objects can represent several data forms that require position and orientation updates: an simulation entity; a physical icon representing remote sensing data; or an artifact the outdoor user and indoor user are collaborating with. In the last case, the outdoor user can adjust the AR representation's graphical position and orientation, and the indoor physical prop should reflect these changes. In all three cases, it would be advantageous to have the physical props automatically update their position and orientation. We've developed several technologies we plan to integrate with HOG and other tabletop technologies.

To overcome the problem of synchronizing a distributive set of collaboration tabletop systems, we've been investigating Remote Active Tangible Interactions (RATI) systems,[6] which offer a fully featured distributed tangible user interface (TUI; see Figure 5). A TUI is a graspable physical interface built from physical objects such as Lego bricks, puppets, or coins. As a substitute for manipulating virtual GUI elements on the screen—such as widgets—with a mouse and keyboard, a TUI invites users to maneuver physical objects that represent virtual data or act as handles for virtual data. Such physical interactions are natural and intuitive, as they enable two-handed input and provide spatial and haptic feedback. We refer to the physical objects that make up a TUI as *tangibles*, and they can be either passive or active. Passive tangibles don't have any means of self-locomotion, whereas active tangibles can move themselves.

TUIs feature many benefits over traditional GUIs. George Fitzmaurice, Hiroshi Ishii, and William Buxton identified the following TUI advantages:[7]

- They allow for more parallel user input, thereby improving expressiveness or communication capacity with the computer.
- They leverage our well-developed, everyday skills of prehensile behavior for physical object manipulation.
- They externalize traditionally internal computer representations, facilitating interactions by making interface elements more "direct" and more "manipulable" by using physical artifacts.
- They exploit our keen spatial reasoning skills, offering a space multiplexing design with a one-to-one mapping between control and controller.
- They enable multiperson, collaborative use.

The ultimate goal of remote active

Figure 5. The latest version of the RATI. The current RATI is an advancement over our previous robots, in that the robots are smaller in size, have retractable wheels for better user manipulation, speakers for sound emission, and LED's for visual output.

tangible interactions is for users to experience remote collaboration with a TUI as if all participants were in the same place. Users should be able to ubiquitously project their actions to every other client's environment and feel like they're present at each remote site. Remote active tangible interactions are enabled by an active TUI, which is physically duplicated at each unique client. A computer can change an active TUI's state automatically, without the need for human intervention. This is the fundamental concept of remote active tangible interactions; a user can change the interface state of other clients by modifying their TUIs and see the changes automatically reflected in the other clients. So far, we've built two systems, one that supports two tables of two RATIs on each, and a second system that supports three tables with six RATIs on each.

The outdoor user can manipulate the virtual versions of the props they see in the field, translate the virtual objects along the ground plane, and then rotate them about an axis normal to the ground plane. With the use of RATI enhanced props on the HOG table, the physical props will reflect these manipulations.

Mobile AR X-Ray Vision

Outdoor users must physically move or walk to view different aspects of the physical world while performing their tasks. With through-walls collaboration, this could require them to investigate potentially hazardous locations. The use of robots for telepresence is a well-investigated area with several commercial products available. We extended this capability for in situ first-person perspective visualization to extend the ability for through-walls collaboration.

Several researchers in the WCL have explored the use of AR to provide users with X-ray vision capabilities.[8] Computer-created views of occluded items and locales appear in the user's vision of the situation. Our initial AR X-ray vision system employed wireframe models textured with video images captured from the outdoor environment. To overcome the issue of the rendered images appearing as though they were floating on top of occluding artifacts, we implemented edge overlay visualizations to provide depth cues for X-ray vision not available in our original system. This visualization process provides highlighted edges from the AR video stream to give cues that the X-ray video stream is behind the occluding object via a technique similar to that of Denis Kalkofen and his colleagues.[9] A second technique, tunnel cutout, provides highlighted sectioning to help outdoor users understand the number of occluded objects between them with X-ray vision. The work of Chris Coffin and Tobias Höllerer inspired this second technique.[10]

Input Devices

Controlling information in an unfriendly outdoor environment requires new user interfaces and input devices. Equally important are new input de-

Figure 6. AR x-ray vision through a brick wall. The image on the left shows the building that's occluding the user's view. The image on the right depicts the use of highlighted edges cues to provide the impression the x-ray vision is behind the wall.

vices for the command team to control the 2D and 3D information spaces in the control room. However, current technologies in both domains fall short of our requirements that these devices must be intuitive, nonintrusive, and robust; other input devices such as mice and keyboards aren't suitable for mobile work outdoors because they require a level flat surface.

The problem of registering virtual images with the user's view of the physical world is a main focus of current AR research, but there's little previous work in the area of user interfaces for controlling AR systems in an outdoor setting. Two major issues for developing these user interfaces are as follows: first, registration errors will make it difficult for a user to point at or select small details in the augmentation; and

second, pointing and selecting at a distance are known problems in VR and AR applications, compounded by the fact that the user is outdoors with less than optimal tracking for head and hands.

Our investigations into modeling 3D geometry outdoors have required complex user interfaces on par with what's currently available on desktop workstations. In addition, we've been investigating operations such as selecting small details in the augmentation, pointing and selecting at a distance, overlaying information, text-based messaging, and enhancing telepresence. We've also been performing empirical user studies of existing commercial pointing devices for wearable computers, including a handheld trackball, a wrist-mounted touchpad, a hand-held gyroscopic mouse, and the Twiddler2 mouse.[11]

We compared four pointing devices for performing drag-and-drop tasks of virtual data while stationary and walking. For the stationary experiment, the fastest device was the gyroscopic mouse, the trackball and touchpad ranked second fastest, and the slowest device was the Twiddler2. For the walking experiment, the trackball and touchpad performed the fastest, the Twiddler2 mouse was the next fastest, and the slowest device was the gyroscopic mouse. In the stationary experiment, the gyroscopic mouse and touchpad reported lower error rates per task, whereas the Twiddler2 and trackball reported higher error rates per task. In the walking experiment, the Twiddler2 and touchpad performed with lower error rates, the trackball ranked second, and the gyroscopic device performed with the highest error rate.

We've also performed studies on the usability issues of two tasks (selection
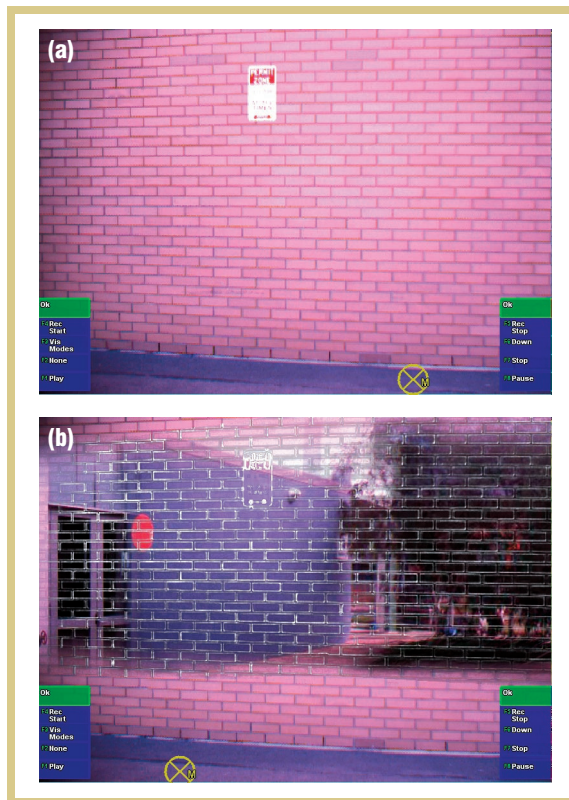
and annotation of a physical object) for users operating mobile AR systems.[12] The study compared a handheld gyroscopic mouse, a cursor controlled by the pose of the user's head (head cursor), and an image-plane vision-tracked device. We evaluated the selection task based on the number of mouse-button clicks, completion time, and a subjective survey; we evaluated the annotation task based on accuracy of the annotation, completion time, and a subjective survey. The devices performed each task with approximately the same accuracy (number of button clicks for the selection task and for the annotation task shape and position). The head cursor was statistically faster for the time taken to complete the selection task, and the vision-based image-plane device was statistically faster for the annotation task over the gyroscopic mouse. Subjectively, the gyroscopic mouse was the lowest ranked device. The image-plane and head cursor subjectively rated approximately the same for the selection task, and the image-plane was subjectively ranked better than both other devices for annotation. Based on this study, a combination of the head cursor for selection tasks and a better designed vision-based image-plane device would make the best overall device.

We are furthering our investigations in the individual technologies described in this article. As these technologies develop, we will better integrate them into a single unified system. As technology is miniaturized, we continue to build smaller and smaller wearable AR systems. Investigation into tabletop technologies is now a major research domain in its own right, and we plan to further our investigations and leverage the work of other researchers. The MPX system in the near future will be a supported technology within many Linux distributions via X.org, and this widespread dissemination will provide many future opportunities. One of our goals is a fully integrated evaluation with Australian Defence. ⊡

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REFERENCES

1. H. Ishii, "Tangible Bits: Coupling Physicality and Virtuality through Tangible User Interfaces," *Mixed Reality: Merging Real and Virtual Worlds*, Ohmsha Ltd., 1999, pp. 229–247.

2. A. Stafford, W. Piekarski, and B.H. Thomas, "Implementation of God-Like Interaction Techniques for Supporting Collaboration between Indoor and Outdoor Users," *Proc. //?// 5th IEEE and ACM Int'l Symp. Mixed and Augmented Reality* (ISMAR 06), IEEE CS Press, 2006, pp. 1–8.

3. W. Piekarski, B. Gunther, and B. Thomas, "Integrating Virtual and Augmented Realities in an Outdoor Application," *Proc. 2nd Int'l Workshop on Augmented Reality* (IWAR 09), IEEE CS Press, 1999, pp. 45–54.

4. S. Feiner, B. MacIntyre, and T. Hollerer, "A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment," *Proc. 1st Int'l Symp. Wearable Computers* (ISWC 97), IEEE CS Press, 1997, pp. 74–81.

5. T. Hollerer, S. Feiner, and J. Pavlik, "Situated Documentaries: Embedding Multimedia Presentations in the Real World," *Proc. 3rd Int'l Symp. Wearable Computers* (ISWC 99), IEEE CS Press, 1999, pp. 79–86.

6. J. Richter et al., "Remote Active Tangible Interactions," *Proc. 1st Int'l Conf. Tangible and Embedded Interaction* (TEI 07), ACM Press, 2007, pp. 69–73.

7. G.W. Fitzmaurice, H. Ishii, and W. Buxton, "Bricks: Laying the Foundations for Graspable User Interfaces," *Proc. Conf. Human Factors in Computing Systems* (CHI 95), ACM Press, 1995. pp. 442–449.

8. B. Avery, B.H. Thomas, and W. Piekarski, "User Evaluation of See-Through Vision for Mobile Outdoor Augmented Reality," *Proc. 7th IEEE/ACM Int'l Symp. Mixed and Augmented Reality* (ISMAR 08), IEEE CS Press, 2008, pp. 69–72.

9. D. Kalkofen, E. Mendez, and D. Schmalstieg, "Interactive Focus and Context Visualization for Augmented Reality," *Proc. 6th IEEE/ACM Int'l Symp. Mixed and Augmented Reality* (ISMAR 07), IEEE CS Press, 2007, pp. 191–201.

10. C. Coffin and T. Hollerer, "Interactive Perspective Cut-Away Views for General 3D Scenes," *Proc. IEEE Symp. 3D User Interfaces* (3DUI 06), IEEE CS Press, 2006, pp. 25–28.

11. J.E. Zucco, B.H. Thomas, and K. Grimmer, "Evaluation of Four Wearable Computer Pointing Devices for Drag and Drop Tasks when Stationary and Walking," *Proc. 10th Int'l Symp. Wearable Computers* (ISWC 06), IEEE CS Press, 2006, pp. 29–36.

12. B.H. Thomas, "Evaluation of Three Input Techniques for Selection and Annotation of Physical Objects through an Augmented Reality View," *Proc. //?// 5th IEEE/ACM Int'l Symp. Mixed and Augmented Reality* (ISMAR 06), IEEE CS Press, 2006, pp. 71–75.