# Ubiquitous Computing:
## Design, Implementation, and Usability

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Information Science REFERENCE

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Hershey · New York

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Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue, Suite 200
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

and in the United Kingdom by
Information Science Reference (an imprint of IGI Global)
3 Henrietta Street
Covent Garden
London WC2E 8LU
Tel: 44 20 7240 0856
Fax: 44 20 7379 0609
Web site: http://www.eurospanbookstore.com



Library of Congress Cataloging-in-Publication Data

Ubiquitous computing : design, implementation, and usability / Yin-Leng Theng and Henry Duh, editors.

p. cm.

Summary: "This book highlights usability theories, techniques, tools and best practices in these environments. It shows usable and useful systems are able to be achieved in ways that will improve usability to enhance user experiences. Research on the usability issues for young children, teenagers, adults, and the elderly is presented, with techniques for the mobile, ubiquitous, and virtual environments"--Provided by publisher.

ISBN-13: 978-1-59904-693-8 (hardcover)

ISBN-13: 978-1-59904-695-2 (e-book)

1. Ubiquitous computing. I. Theng, Yin-Leng, 1961- II. Duh, Henry.

QA76.5915.U259 2008

004--dc22

2007051616

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

# Chapter XI
# TeleTables and Window Seat:
## Bilocative Furniture Interfaces

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## ABSTRACT

*People can use computationally-enhanced furniture to interact with distant friends and places without cumbersome menus or widgets. We describe computing embedded in a pair of tables and a chair that enables people to experience remote events in two ways: The TeleTables are ambient tabletop displays that connect two places by projecting shadows cast on one surface to the other. The Window Seat rocking chair through its motion controls a remote camera tied to a live video feed. Both explore using the physical space of a room and its furniture to create "bilocative" interfaces.*

## INTRODUCTION

Over a decade ago, Weiser predicted a shift in the dominant human computer interaction paradigm from mouse and keyboard based graphical user interface (GUI) to ubiquitous tangible computational artifacts embedded in our environment (Weiser, 1991). Traditional GUIs require a high level of attention, while ubiquitous computing promises to provide the power of computation in everyday settings without the overhead of having to focus on operating a computer. Furniture presents a familiar and promising platform for such investigation. During the course of several years, we have explored a variety of furniture interface projects. Our goal for these projects has been to develop interaction techniques appropriate to traditional pieces of furniture that enable people to leverage additional computational resources.

"Bilocative" interfaces leverage the intimate connection between furniture and place to create an intuitive physical interface to facilitate the navigation and transmission of information between remote places. A bilocative furniture interface is a piece of furniture that is computationally enhanced so that it can usefully be understood to be in two places at once. Instead of providing a screen-based interface that must be navigated to find information about different remote places, each bilocative furniture piece in a room represents a connection to a particular distant place, and that information stream can be engaged just by approaching the piece of furniture and using it in the traditional manner. To explore this idea, we built two computationally enhanced furniture pieces, the TeleTables and Window Seat. These projects represent quite different approaches to connecting people with a distant place. The TeleTables attempt to generate an ambient interpersonal awareness between households by relaying information about cast shadows between the two tables. The Window Seat provides a much more direct connection, but through a familiar interaction. It projects a live video feed from a distant camera that is controlled by rocking the chair. Both projects allow a distant place to be engaged without a traditional interface such as a GUI or keypad.

The TeleTables project explores the potential of ambient interpersonal communication devices. TeleTables are composed of a pair of tables that enable people in two distant locations to see shadows cast on the opposite table. The surface of each TeleTable contains an array of photo sensors and display pixels and when someone sits down at one table, for example to have breakfast, areas of the table that are shaded by the breakfast activities light up in one color on both tables. If someone else sits down at the other table to have breakfast at the same time, the shaded areas of the table light up in a different color on both tables, so that both people having breakfast see that there are similar breakfast activities taking place in the other location. The interaction is different than a phone call or a chat, as it does not require the explicit intention to communicate with the other person; casting shadows on our kitchen tables is a side effect of various common activities. This mode of communication allows people to develop an ambient awareness of events at another location with a low fidelity data stream that intrudes only minimally, and symmetrically, on the privacy of both participants.

Through our Window Seat project, we have investigated how a rocking chair can be tied to a view into a particular distant place. Rather than requiring the navigation of a Web interface to find a particular Web cam and adjust where it is looking, we lower the barrier to entry for using Web cam technology: it is accessed just by sitting in the rocking chair tied to a particular place and rocking to adjust the view. This interface brings information navigation out of the computer screen and into the physical space of a room and its furniture. We posit that the conceptual mapping of a chair to a view of a particular place will be accessible to people at any level of technological literacy.

The remainder of this chapter first describes related work and then each project with a use scenario, system overview, and demonstration. We also discuss future research directions and reflect on the implications for furniture interface design.

## RELATED WORK

Many researchers have sought to leverage the familiarity of the interface afforded by furniture to create ubiquitous computational interfaces. We classify these computationally enhanced furniture projects into three groups by the functionality they afford: (1) providing a physical handle to control a virtual object, (2) retrieving useful information, and (3) supporting communication and awareness between distant places.

Tangible media projects have sought to provide direct control of virtual objects through physical handles. Much of the research involving furniture has focused on computationally enhanced tables, and there is even a conference devoted to "tabletop interaction" (Tabletop, 2006). Bricks (Fitzmaurice, Ishii, & Buxton, 1995), a graspable user interface, "metaDESK" (Ullmer & Ishii, 1997), and "DigitalDesk" (Newman & Wellner, 1992) all use the desk as an input device. Several projects have also sought to create computationally-enhanced furniture that can retrieve and present useful information. Samsung researchers (Park, Won, Lee, & Kim, 2003) built a computationally enhanced table, sofa, picture frame, and bed that attempt to provide useful information or services. For example, the picture frame provides local news, weather information, and stock market information and the bed gently wakes its occupant with a customized combination of smell, sound, light, and temperature. The Magic Wardrobe (Wan, 2000) is a computationally-enhanced wardrobe that identifies the clothes it contains using RFID tags and recommends new items for purchase from online stores. These projects are similar to ours in that they leverage the familiar interfaces presented by furniture. However, more relevant are computationally-enhanced furniture projects that attempt to support communication between places. Beckhaus, Blom, and Haringer (2005) built a stool to control a view of a virtual environment. The physical movement of the chair maps to movement in the virtual environment: (1) tilting the chair in any direction translates the current viewpoint; (2) rotating the seat rotates the virtual scene around the user's position. While the interaction for controlling the camera view is similar to our Window Seat, their stool does not attempt to bring information navigation out into physical space as does Window Seat, but merely serves as the joystick for a computer graphics workstation. The 6$^{th}$ Sense (Tollmar & Persson, 2002) is a lamp that encourages users to communicate with remote family members. With a family tree metaphor, each small light at the end of a branch represents a remote family member. A family member can turn on a small light to signal their presence to another member. The 6$^{th}$ Sense allows the users to feel "togetherness" with their loved ones without intruding on their lives. Similarly, our TeleTables project enables people to sense the presence of remote friends or family members. The 6$^{th}$ Sense interface introduces a novel interaction involving switches; our TeleTables leverage the traditional functions of a table, adding awareness feedback by illuminating patterns on the tabletop.

## FURNITURE MEDIATING AMBIENT COMMUNICATION (TELETABLES)

While communication technologies such as cellular phones, e-mail, and instant messaging have made direct spoken and written communication channels easily accessible, they all require focused attention and serve best to transmit explicit messages. Our TeleTables are a bilocative tabletop interface that exists in two places at once in that they simultaneously display shadows cast from two different locations. They explore the potential of using projected shadows from a remote place as a means of creating a nonverbal unfocused communication channel between distant places. A pair of kitchen tables equipped with light sensors and LED displays are tied together through the Internet so that a shadow cast on one table is displayed on both in colored light, with different colors used to distinguish local and remote shadows.

For example, Angela is a college freshman living in Pittsburgh. She sits down to eat breakfast and the surface of the table is washed with red light reflecting the shadow of her cereal bowl, coffee cup, and the movement of her arms over the frosted Plexiglas surface. Three states away, at her parent's house, the red lights on the surface of her parents' table echo those on Angela's. Her father notices the lights and is reassured that Angela is not skipping breakfast and is on time for her morning class. As Angela gets up from the table she notices a series of amber circles appear on the surface as her father sets out plates and cups for his and her mother's breakfast. The shadow of her father's activity reminds her that she needs to call her parents tonight and ask them to deposit money in her account to cover the lab fee for her robotics course next semester. The shadows displayed by the TeleTables give Angela and her parents the sensation of being close to each other, without overly intruding on their privacy or interrupting their busy lives.

## Design Schematic and Diagram

TeleTables are two tables where each functions as both an input and an output device. The surface of each table contains eight modules; each module is divided into a 2 by 4 grid; each grid cell contains a red LED, an amber LED, and a photocell. Therefore, the surface of each table is divided into an 8 by 8 grid with 128 LEDs and 64 photocells (Figure 1). A microcontroller uses row-column scanning to illuminate the LEDs and to read values from the photocells. In the current version of TeleTables, a pair of radio frequency transceivers establishes a wireless connection between the tables allowing the microcontrollers to directly exchange data. (In the next version, data will be transmitted over the Internet). Figure 1 also shows the information flow in the TeleTables. When a user casts shadows over one table, the microcontroller reads the photocell values, lights the corresponding local LED lights, and also sends data to the other microcontroller to light the corresponding LEDs on the other table.

Each table has four major components: the array modules (photocells, red LEDs, and amber LEDs), microcontroller, a 22" by 22" table, and

*Figure 1. Information flow in the TeleTables*

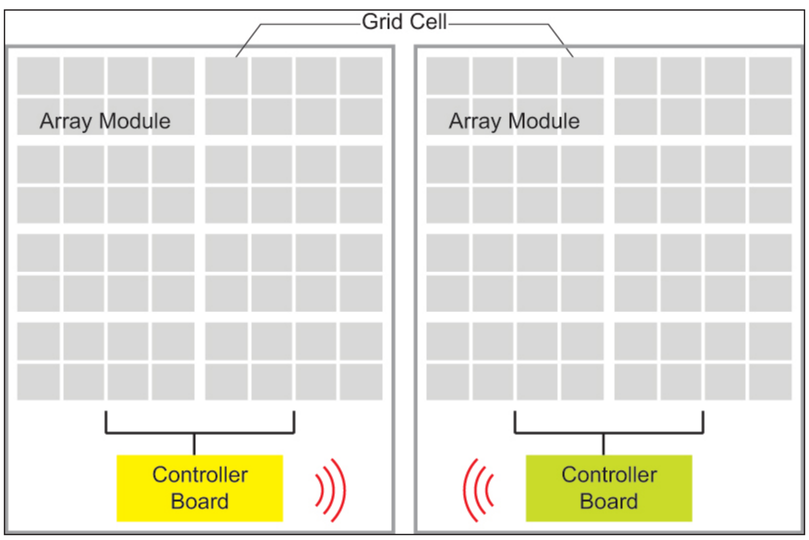
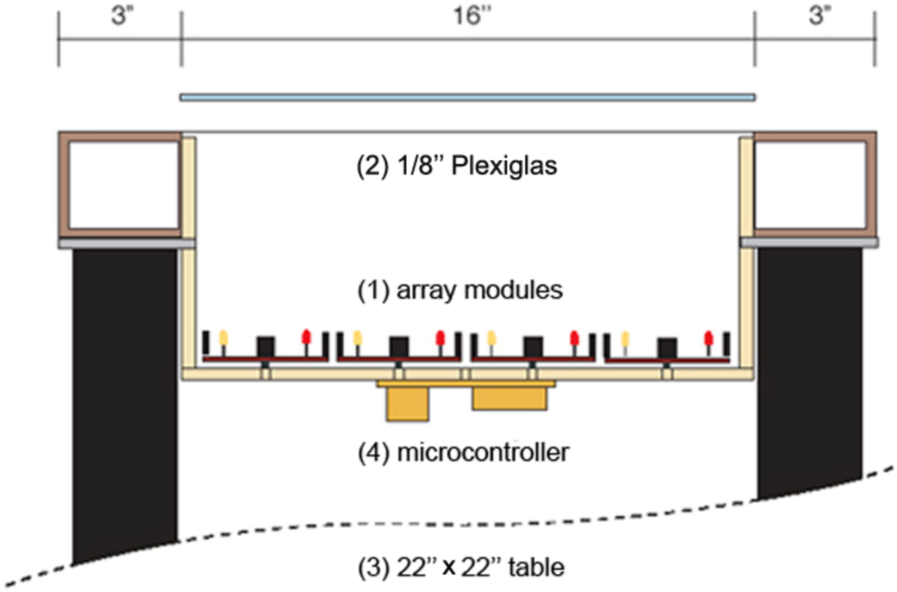


*Figure 2. Table components: (1) array modules (photocells, red and amber LEDs); (2) microcontroller; (3) 22” x 22” table; (4) 1/8” Plexiglas*




1/8” Plexiglas. We made a 3” deep compartment below the surface of an Ikea table to hold the printed circuit boards that constitute the eight array modules. A 1/8” translucent acrylic plastic forms the tabletop. We mounted a Basic Stamp 2 microcontroller with 16 digital I/O ports to the bottom surface of the table. Figure 2 illustrates the components of our table.

## Electronics

We divided each table into eight array modules, each a subarray of 2 by 4 cells. Each cell contains a red LED, an amber LED, and a photocell. Figure 3 shows the arrangement of array modules assembled into the table. We designed a circuit for an array module and engraved it on copper board using a computer-numerically controlled mill. Figure 4 illustrates the circuit diagram.

Each column of photocells is attached to a potentiometer for calibration, and to individual pins on the microcontroller to make a voltage divider circuit. As the shift register powers each row, the microcontroller reads threshold values of photocells in that row as 8 bits of a byte. If the voltage on the pin is below the microcontroller’s 1.5V internal threshold then the cell is considered “shaded” and the microcontroller lights the corresponding LED in that cell on both tables.

We showed the TeleTables as part of a public exhibit without introducing or explaining the project. We simply placed one TeleTable in one corner of a room and the other table in the opposite corner. We observed that most people quickly realized that placing their hands or an object above the surface of the table triggered red or amber lights in the shaded region. Many people also realized that they could control the light patterns on the other table as well as on the table they were interacting with directly, and through these shadows interact with someone sitting at the other table (Figure 5). However, the interactions

*Figure 3. Arrangement of array modules in a TeleTable*

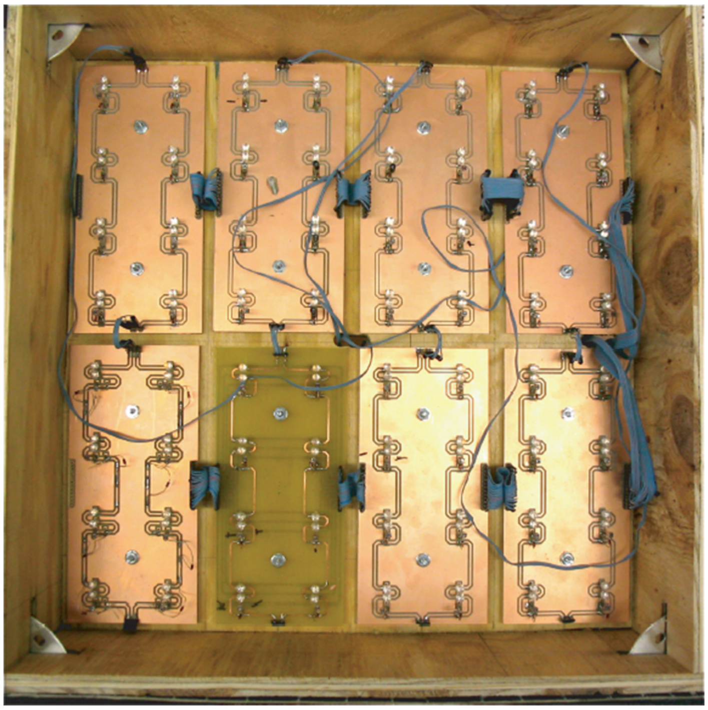


*Figure 4. Circuit diagram (a) array module schematic; (b) CAD drawing for copper board*

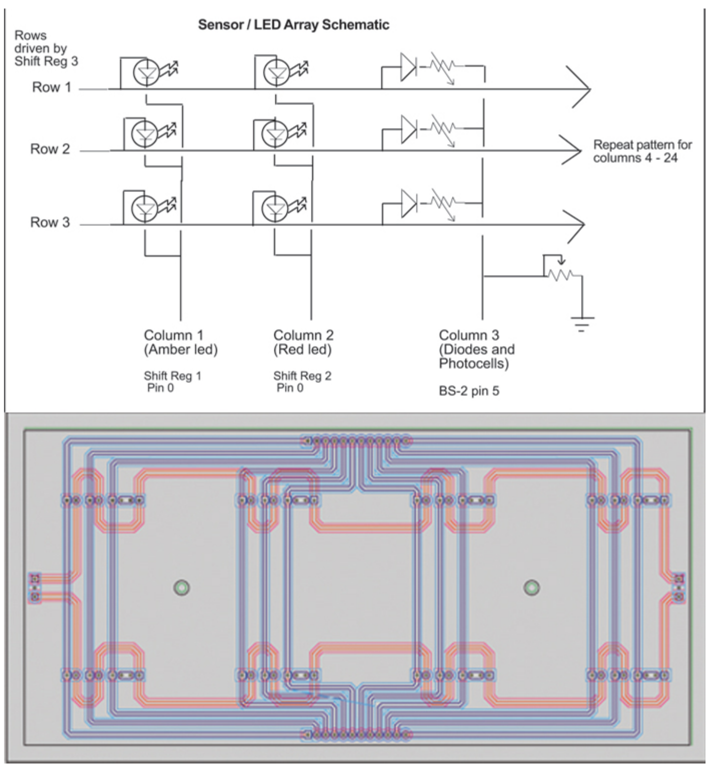


*Figure 5. Two friends interact using the TeleTables*

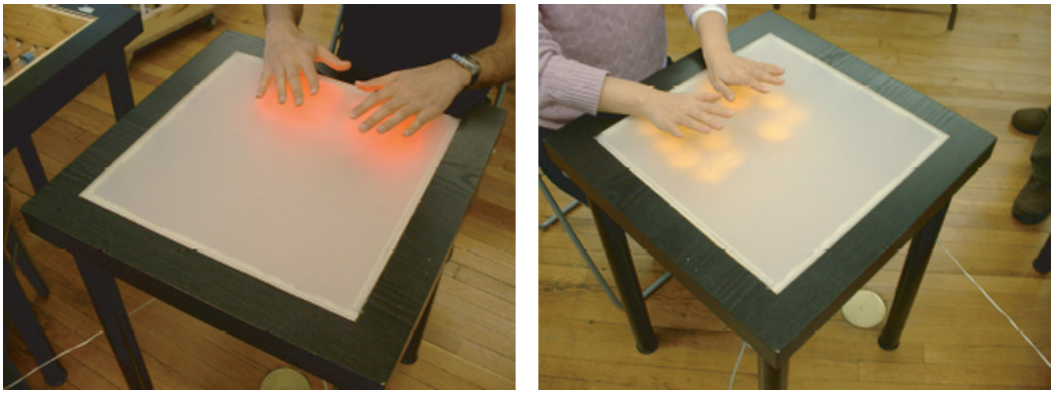


*Figure 6. Real and projected images of Steven Holl's Chapel of St. Ignatius. The second and fifth pictures are projected images from the scale model. The others are photos taken on site.*

we observed were more direct than we envision they would be when installed in a home, as the tables were not used as tables but as novel objects to be investigated by curious visitors.

## FURNITURE AS A LINK TO A REMOTE PLACE (WINDOW SEAT)

Window Seat is a remote camera interface that requires no computer literacy. A rocking chair in a room serves as a physical link to a live video feed of a remote location. The Window Seat is a bilocative interface because—conceptually—the chair exists in both locations. The representation is asymmetric: in one place there is a chair and a video screen showing the other place, while in the other there is only a camera to serve as avatar of the viewer and chair, which provides very little information about the other side. While sitting in Window Seat, a live view of a remote space is projected on a video screen in front of the chair. By rocking forward and back in the chair, the remote camera view pans up and down. When the armrests are pressed, the camera pans side to side.

The Window Seat can also be used to experience models rather than real places. In order to create the illusion of being immersed in a real space, the viewpoint of the camera must map to the relative human height in the scale model. In our installation, we placed an actuated Web camera inside a scale model of Steven Holl's St. Ignatius Chapel in Seattle. The scene the camera sees inside the model is projected on the wall in the viewing space. The chair controls the camera tilt and pan to look in different directions within the model. As shown in Figure 6, images from inside the model are similar to what visitors might experience in the real chapel.

## Design Schematic and Diagrams

The Window Seat has five major components. A physical chair serves as an input device; a Handyboard (Martin, 2001) microcontroller serves to orchestrate interaction; a camera captures remote images; and a projector displays them on a wall to provide a simulated immersive environment (Figure 7).

Figure 7 shows the flow of information in the Window Seat. As users rock the chair and press the armrests, the sensors transmit this information to the microcontroller. The microcontroller in turn drives two servomotors that control the camera angle. The remote view from the camera is then projected on the wall in front of the Window Seat rocking chair by a video projector housed inside the seat back (Figure 8).

The chair controls two axes of camera movement (up/down and left/right). When the user rocks the chair up and down, the camera tilts up and down. Control of panning is achieved by pressing on sensors attached to the armrests.

We used two kinds of sensors: an infrared sensor and two homemade pressure sensors. The infrared sensor is located beneath the seat (Figure 9) sensing the distance between the floor and the chair.

We made pressure sensors with conductive foam (easily obtained from standard electronics packing material) sandwiched between two washers (Figure 10). They act as variable resistors; when the foam is compressed the resistance is lower. When the user pushes the left pressure sensor, the camera pans left. As the user pushes harder, the microcontroller reads the lower resistance value and advances the servomotors further. If the user pushes both pressure sensors at the same time, the camera returns to a default position.

We considered several options to control camera panning. One option was to mount the chair on a swivel mount. However, if the chair swiveled, a wraparound screen would be needed. Another option was to mount pressure sensors on the seat cushion so that when the user shifts her center of gravity to the right, the camera pans to the right. However, preliminary user testing revealed this

*Figure 7. Information flow in the window seat*

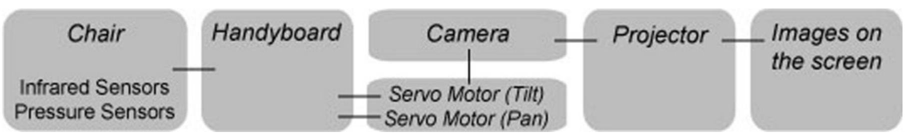



*Figure 8. Window Seat components: (1) physical chair; (2) handyboard microcontroller; (3) remote camera; (4) projector; (5) wall as display device*

*Figure 9. Camera movement and sensor placement*

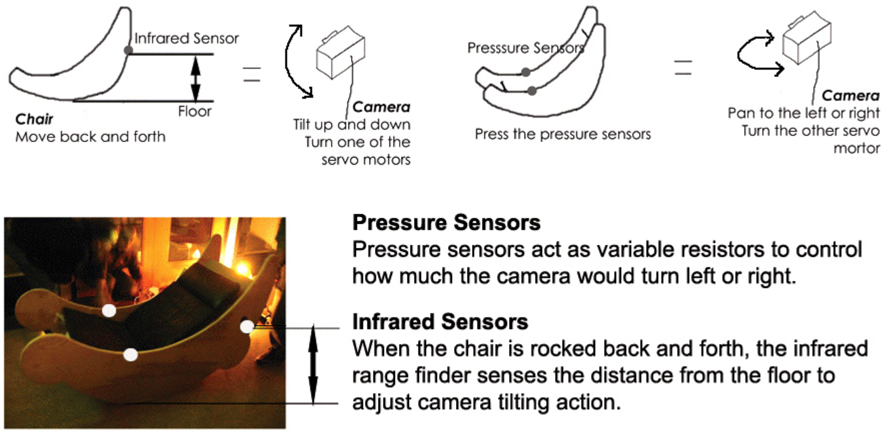



*Figure 10. Homemade pressure switch with washers and conductive foam*

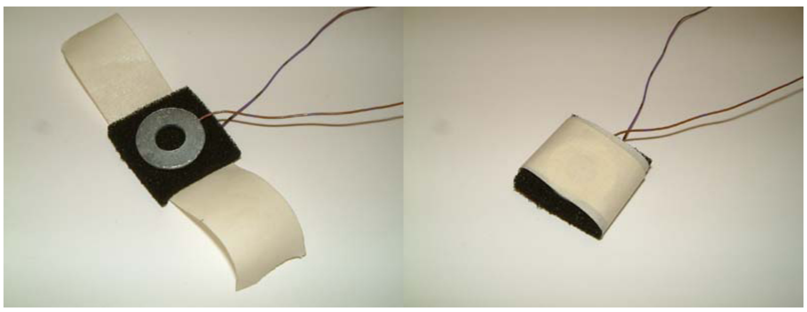
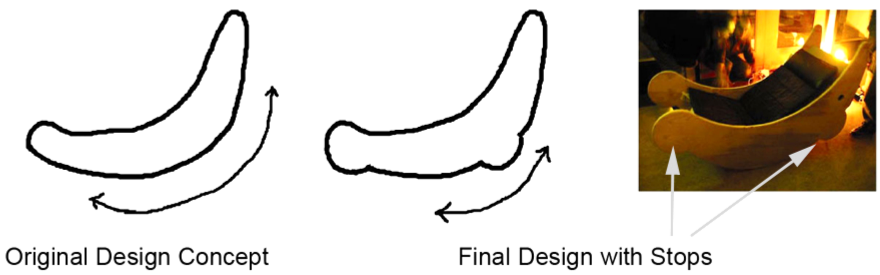


*Figure 11. Stops for chair balance*




interaction to be unnatural. It was also difficult to calibrate the camera movement with the values reported by the pressure sensors. Another idea was to install switches on the chair base, close to the user's legs, which would activate when the user sits up. However, we found that if the user leans back or lies down on the rocking chair, the switches would not always activate. Therefore, we decided to place the panning control sensors on the armrests. This makes it easy for the user to press them regardless of the user's position on the chair.

We also considered the ergonomic aspects of sitting comfort using chair design standards for

*Figure 12. Moving image on the screen*

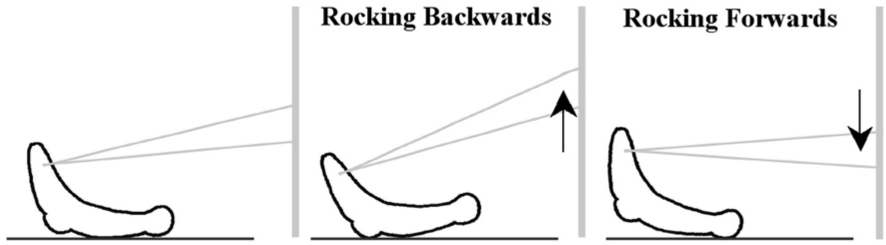
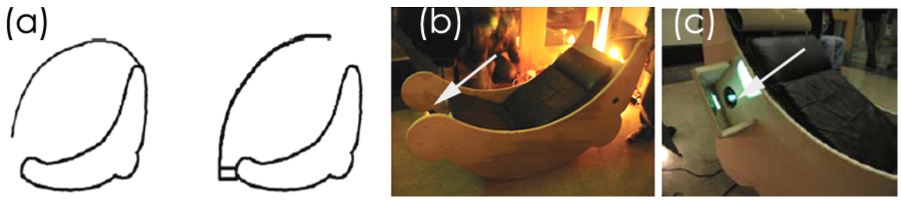



*Figure 13. (a) Screen design alternatives, (b) chair balance, (c) projector, and mirror placement*




length and width of the seat and back (Cranz, 1998). The basic shape of the chair is a crescent curve (Hennessey & Papanek, 1974) made of plywood. We designed the chair to balance easily with stops, which we placed in the middle and the end of the chair curve (Figure 11). Without these stops, the crescent shaped chair could fall backwards or forwards.

In our Window Seat design, we developed a mapping scheme for motion translation and configured the camera movement to correspond to the user's viewing height. The projected visual images move up and down as the user rocks back and forth because the video projector is mounted on the chair (Figure 12).

Our original design considered connecting a screen to the rocking chair from either the top or the bottom of the chair (Figure 13). These alternatives have the merit that the projected images move simultaneously with users because the screen attached to the chair moves with chair. That, in turn, would allow the user to control the camera pan by swiveling the chair. However, attaching the screen on the chair top makes the chair harder to rock, and mounting the screen on the bottom of the chair makes it hard to sit comfortably. Despite the merits of these design alternatives, we decided on the armrest control for a static screen that can make use of any vertical wall. In order to project the images onto the front wall, we mounted the projector inside the back of the chair. We mounted a weight on the bottom of chair as a counterbalance (Figure 13).

## Placement of Projector and Mirror Housing

We used a video projector to display interior space images onto the wall to create an immersive illusion for our users. We considered several alternatives for the projector position. We first tried to put the projector on the top of the chair, but learned that this placement of the projector is sensitive to the user's height and body shape. Instead we decided to put the projector inside the back of the chair (near its fulcrum) and used a mirror to reflect the image (Figure 13) out to the screen in front.

## DISCUSSION AND FUTURE WORK

### Future Work

To further evaluate bilocative furniture interfaces' utility for navigating information streams connecting remote locations, we would like to install several of these pieces in people's homes and observe their use. By observing bilocative interfaces in use in homes, we hope to be able to evaluate whether having a straightforward physical interface to information streams would encourage people to make use of them more often and provide a more satisfying experience than screen-based navigation of an interaction with remote information streams.

### Discussion

We have explored the idea of using pieces of furniture as spatial links to information streams tied to remote locations. We call these bilocative furniture interfaces as they can be understood as being in two places at once, which provides a useful and intuitive conceptual map for the information stream provided. We believe that it is important to maintain the original interaction model afforded by a piece of furniture (to sit, to place objects) while extending its functionality to provide additional value such as remote presence awareness and immersive viewing.

## ACKNOWLEDGMENT

We thank our TeleTables and Window Seat team members: Bridget Lewis, and Kursat Ozenc, who worked on the TeleTables, and Doo Young Kwon, Babak Ziraknejad, and Jennifer Lewis, who worked on the Window Seat. This work was supported by the U.S. National Science Foundation grant under Grant ITR-0326054.

## REFERENCES

Beckhaus, S., Blom, K. J., & Haringer, M. (2005). Intuitive, hands-free travel interface for virtual environments. In *Proceedings of IEEE Virtual Reality Conference, Workshop on New Directions in 3D User Interfaces 2005,* Bonn, Germany (pp. 57-60). Shaker Verlag.

Cranz, G. (1998). *The chair: Rethinking culture, body, and design*. New York: Norton.

Fitzmaurice, G. W., Ishii, H., & Buxton, W. (1995). Bricks: Laying the foundations for graspable user interfaces. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI),* Denver, Colorado (pp. 442-449). ACM Press.

Hennessey, J., & Papanek, V. J. (1974). *Nomadic furniture: How to build and where to buy lightweight furniture that folds, collapses, stacks, knocks-down, inflates or can be thrown away and re-cycled*. New York: Pantheon Books.

Martin, F. G. (2001). *Robotic explorations: A hands-on introduction to engineering.* Prentice Hall.

Newman, W., & Wellner, P. (1992). A desk supporting computer-based interaction with paper documents. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, Monterey, California (pp. 587-592). ACM Press.

Park, S. H., Won, S. H., Lee, J. B., & Kim, S. W. (2003). Smart home - digitally engineered domestic life. *Personal and Ubiquitous Computing, 7*(3-4), 189-196.

Tabletop. (2006). *Proceedings of the First IEEE International Workshop on Horizontal Interactive Human-Computer Systems,* Adelaide, Australia. IEEE Press.

Tollmar, K., & Persson, J. (2002). Understanding remote presence. In *Proceedings of the Second*

*ACM Nordic Conference on Human-Computer Interaction (NORDCHI),* Aarhus, Denmark (pp. 41-50). ACM Press.

Ullmer, B., & Ishii, H. (1997). The metaDESK: Models and prototypes for tangible user interfaces. In *Proceedings of ACM Symposium on User Interface Software and Technology (UIST)* (pp. 223-232). ACM Press.

Wan, D. (2000). Magic wardrobe: Situated shopping from your own bedroom. *Personal and Ubiquitous Computing, 4*(4), 234-237.

Weiser, M. (1991). The computer for the 21st century. *Scientific American, 265*(3), 66-75.