Ubiquitous Media Spaces

A Multimodal Interaction Approach

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Keywords: Ubiquitous Media, Pervasive Computing, Human Computer Interaction

Abstract: This paper outlines new facilities within a ubiquitous media space supporting multimodal interaction. We believe that the current approach to developing electronic based design environments is fundamentally defective with regard to support for multimodal interaction. In this paper, we present an alternative ubiquitous computing environment, based on an integrated design of real and virtual worlds. We implement a research prototype environment called *iCube*. The functional capabilities implemented in *iCube* include spatially-aware 3D navigation, laser pointer interaction, and tangible media. Some of its details, benefits, user experiences, and issues regarding human-computer interaction are discussed.

1 INTRODUCTION

Ubiquitous computing is a new paradigm that outlines the vision of the next generation of computation (Weiser, 1991). Industry and research efforts in human-computer interaction are quickly moving to integrate the computation world with the physical world, connecting designers with a pervasive web of interactive computers and physical devices. A major requirement of such integration has been the development of *ubiquitous media*, allowing computational services pervasive throughout our entire environment. A parallel trend is to support all aspects of *multimodal interaction* with a growing number of information appliances over a pervasive network.

An often used strategy is to integrate information appliances into architectural spaces, allowing users to interact with our surroundings in an intuitive and social manner. In light of this strategy, architectural space can be considered as an interface between people and digital information. An extensive literature on architectural use in human-computer interaction addresses such special issues as "media spaces" (Bly, Harrison, and Irwin, 1993), and "cooperative buildings" (Streitz, eißler, and Holmer, 1998), "augmented reality" (Buxton, 1997), "tangible bits" (Ishii and Ullmer, 1997), among others. Similar issues of ambient media have motivated the development of "interactive workspaces" (Johanson, Fox, and Winograd, 2002) and "intelligent room" (Coen, 1998).

This paper describes work in progress for developing a ubiquitous media space supporting multimodal interaction. We believe that the current approach to developing electronic based environments is fundamentally defective with regard to support for multi-person multimodal interactions in an integrated space. While computer technology has advanced to support digital design, the principle of interface design is not sufficient for transferring the considerable skills designers have acquired in working with traditional media. In this paper, we present an alternative ubiquitous computing environment, based on an integrated design of real and virtual worlds. There are many types of ubiquitous computing environments. Our interest is in the development of the media-rich smart studios of the future.

This paper is organized as follows. First, we review the current approach to interactive design of ubiquitous media. In section 2, we outline new facilities within an *iCube* research prototype environment. The functional capabilities of *iCube* and issues regarding explicit support for multimodal interaction are presented. Some of its details, benefits, user experiences, and issues regarding human-computer interaction are discussed in section 3. Finally, we perform an empirical study to investigate how to map a spatial setting to an underlying ubiquitous computing infrastructure and a corresponding model of interaction.

1.1 Ubiquitous Media

The term *ubiquitous media* is used to design a computing environment where media is *pervasive*, yet computation is *invisible*. Industry and research efforts are quickly moving to integrate designers with ubiquitous media in a place which will be sensitive, adaptive, and responsive to various physical and social settings. We are encountered a physical situation where computational devices become increasingly embedded and deployed in a variety of spatial settings, such as buildings, rooms, and everyday objects. As computers pervade the fabric of our environments and everyday activities, our design environments and processes need to be redesigned to accommodatea new way of manifesting computation in the physical world.

We are convinced that ubiquitous media have enormous potential to influence the way we operate and interact with design. Here we review some characteristics of ubiquitous media with respect to three perspectives: *places*, *artifacts*, and *activities*.

The architectural components of a place may be *external* or *internal*. The external components include touch-sensitive walls, floors, ceilings, furniture, and other computer-augmented spatial elements. The internal components are computational units in the architecture of a system infrastructure, carrying out background computation such as information processing and data sharing over a network. An important perspective is associating information with a particular locale and perceiving the information as if it is really there.

Computer-augmented artifacts may be *environmental* or *mobile*. The environmental artifacts refer to fixed physical devices such as interactive whiteboards, electronic drafting tables, CAVEs, and other specialized large displays. The other physical devices are perceptual devices, as sensors and actuators, proactively monitoring and reacting to the real world. The mobile devices refer to personal devices such as laser pointers, cell phones, PDAs, tablet PCs, electronic tags, and other wearable devices. There is inevitable growth in the range of smart devices available in augmenting our everyday activities. User will move from device to device to get their work done. The smart devices not only convey information to mobile users, but support an awareness of the surroundings and change behaviour depending on the situation that they are encountered.

Activities may be performed *formally* or *informally*. Design critiques and reviews often take place in such a formal setting as in weekly coordination meeting. Non-desktop interface modalities such as pen, touch, vision, and speech are largely used in a formal meeting. Alternatively, designers interact informally within the workspace, so as to be aware of "who is working on what" and receive design feedback from their coworkers. The workspace setting should support collaborative design activities and adapt interaction modalities appropriate to the task.

Together, the different kinds of perspectives define a human-centered design space of ubiquitous media, illustrated in Figure 1. Human-centered ubiquitous media will integrate places, artefacts, and activities in an integrated space, which involve more than one devices and computational services. Our response to this combinatorial problem attempts to build a modular interactive system that deals with all the possible combination. The proposed solution is to define modular domains of ubiquitous media, and to provide the means to integrate combinations of these modules into custom configurations of work spaces. This solution may be applicable to any single interactive workspace project.

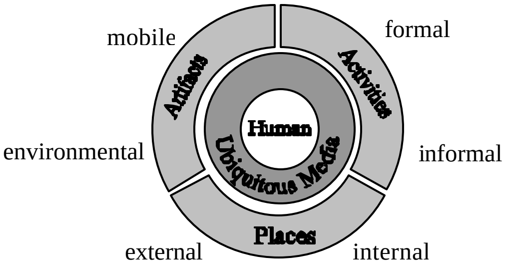

Figure 1 A human-centered design space of ubiquitous media

1.2 A Design Scenario

For the purpose of illustration in this paper, we will consider a set of desired capabilities, in a scenario of designers in a digital design studio, carrying out design reviews and critiques. A variety of devices includes interactive whiteboards, touch-sensitive tables, computer-augmented devices, laser pointers, video projectors, and web cameras for object tracking and recognition. There may be a variety of collaborative design activities in the studio but we will focus on the design reviews and critiques activities for purposes of discussion.

1. Jacky sets up a touch-sensitive interactive table, allowing people to use multiple modalities such as pen, touch, and speech to make annotations on the projected digital drawing over the table.
2. Jacky designs a display tablet to "cut" the virtual model over the digital drawing. With its touch-sensitive setup display, a building section view appears on the tablet display immediately after the tablet is well placed on the table. Moving the display tablet consequently creates a continuous sequence of image snapshots, resulting in a "live" walk-through animation.
3. Jacky uses a laser pointer to control the viewpoint of the digital model projected on a wall-sized display. He uses hand gestures to move digital contents across multiple displays.

Advances in ubiquitous computing technology have made the scenario feasible today. The desired functionality demonstrated in the scenario has been implemented in the *iCube* project, which will be elaborated in the next section.

2 THE *iCube* PROJECT

Our research group in Information Architecture Lab in National Cheng Kung University in Taiwan is developing an *iCube* project, a long-term project to develop the needed ubiquitous computing technologies supporting the media-rich smart studios of the future. The work presented is part of the *iCube* project, including *spatially-aware 3D navigation*, *laser pointer interaction*, and *tangible media*. An initial focus of this project has been the development of interactive design technology supporting multimodal interaction, and more recently, for supporting media-space integration.

2.1 Spatially-Aware 3D Navigation

In order to get this research work in practice, we begin with the development of *spatially-aware navigator*, a display tablet coupled with an interactive table for interactive 3D navigation in design. We begin to set up an interactive table by installing an overhead projector on the ceiling with a mirror, which refracts projection light onto a table surface. We mount an interactive whiteboard device (e.g. Mimio) on the table, which can quickly transform an office table into a touch-sensitive interactive table. The interactive table allows people to draw sketches, make annotations, and capture notes for later retrieval. The interactive table, with its horizontal setup display, provides flexibility in dealing with different requirements in a design space, a presentation area, and a crit room.

After setting an interactive table, we choose a mid-sized acrylic fiber tablet coupled with a touch-sensitive screen to install spatially-aware navigator. We mount a light-emitting diode (LED) on the display tablet to track its position. The position of the display tablet is sensed based on recognition of LED infrared light, illustrated in

Figure 2.

The overhead projector mounted on the ceiling projects building plan geometry on the table. A “section” snapshot of the 3D model is superimposed on the tablet display immediately after the display tablet is well placed and activated. The section view is displayed corresponding to the position of the tablet with reference to building plan geometry. People can move the spatially-aware navigator forward and backward over the interactive table to view different building sections. The section view reacts immediately in response to changes in the position of the spatially-aware navigator.

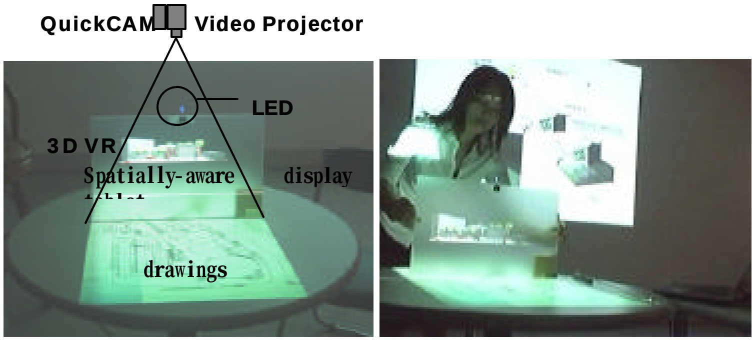

Figure 2. The setup of spatially-aware navgator (on the left); The user obtains a “live ” walk-through animation through the continuous movement of the tablet (on the right).

We use “cutting plane in hand” metaphor to design the spatially-aware navigator. From the user’s perspective, the display tablet is served as “a cutting plane” to obtain a snapshot of building section views. Users can perceive a virtual 3D model in the real world through the movement of the display tablet forward and backward. More importantly, moving the display tablet consequently creates a continuous sequence of image displays, resulting in a “live” walk-through animation, as shown in Figure 2

2.2 Laser Pointer Interaction

In addition to spatially-aware navigator, we develop a camera-tracked laser pointer to interact with a projection screen. A basic interaction technique is to detect the laser spot position. We use a web-camera to capture real-time images in 30 frames per second. Since laser spot is highly focusing light, we choose the color recognition technique to detect the laser spot position. After detection, the system sends a message to the application, carrying the coordinate of the laser spot to trigger an event for computational services.

A fundamental capability of later pointer interaction is using the laser to control viewpoint of the 3D model, as shown in Figure 3 Design reviews and critiques require that people be able to interact at a distance from a large display surface. Laser pointers become a general tool being used to remotely point out an information object for design communication. Our work is to transform a laser pointer into an information remote manipulation tool, allowing people to intutively interact with information on a large projected display. We consider laser pointer interaction is an important functional component of the *iCube* project to direct group's attention in design presentation.

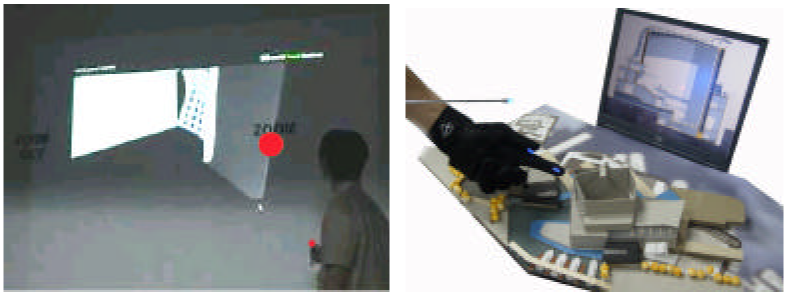

Figure 3. The presenter uses a laser pointer to control the viewpoint of the 3D model (on the left); Moving or pointing the physical model changes the perspective geometry display (on the right).

2.3 Tangible Media

We apply the same interaction technique to the development of tangible media. There are two kinds of tangible media in the iCube project. One is coupling digital design media with physical models, allowing users to integrate multiple forms of digital and physical representations. Moving or rotating the physical model correspondingly changed the perspective geometry of the digital model, as shown in Figure 3.

The other kind of tangible media is based on hand gesture recognition techniques, allowing users to directly grasp and manipulate digital information. We design a half-finger glove mounted with three LEDs for hand gesture method of input, whereby specific hand movements would represent different commands. The development of gesture recognition is based on an arm-waving video-processing technique that uses cameras to track an arm position, and respond to specific hand movements. This gesture recognition system requires a web camera to detect the number and position of LED light spots. An actuator switch is mounted on one side of the glove. When the LED-mounted half-finger glove is acted on, the camera detects the number and position of LED light spots, and triggers a corresponding event to perform an operation.

In the *iCube* setting, the presenter can use hand gestures to zoom in/out a digital model, and control its viewpoint for design reviews, as shown in Figure 4. Users are allowed to use hand gestures to point, grasp, and manipulate digital information without additional cost. This is in contrast with the current approach to augmented reality by overlaying digital information onto real-world images through head-mounted display devices. An important consideration of our work is that people can see each other's hand gestures relative to the virtual model without head-mounted display.

Figure 4. The presenter puts on LED-mounted half-finger gloves and uses hand gestures to point, grasp, and move digital contents (on the left); Specific hand gestures control the viewpoint of a digital model (on the right).

In the current implementation, we use a combination of an RF-based wireless network and the local area network already installed in the building. All ubiquitous media and physical devices are connected to the wireless network. The fixed components in physical space include interactive whiteboards (e.g. mimio), touch-sensitive tabletops, web cameras, and other environmental sensors. The mobile components include PDAs, tablet PCs, and notebook computers that come along with network-cards.

3 EMPERICAL STUDIES

In order to test the usability of our innovative spatial systems, we conducted an empirical study investigating how to map a physical space to an underlying ubiquitous computing infrastructure and a corresponding model of interaction. We first select a senior design studio from our department of architecture. The senior design studio was chosen because the senior students used both paper-based and computer-based design media together in their design processes. They presented their work in a so-called "hybrid" presentation. We designed the project and design studios, interviewed the students, and recorded the design critique activities. Here we report some results of the empirical studies regarding the current work practice of design teams and their requirements for the media-rich smart studios of the future.

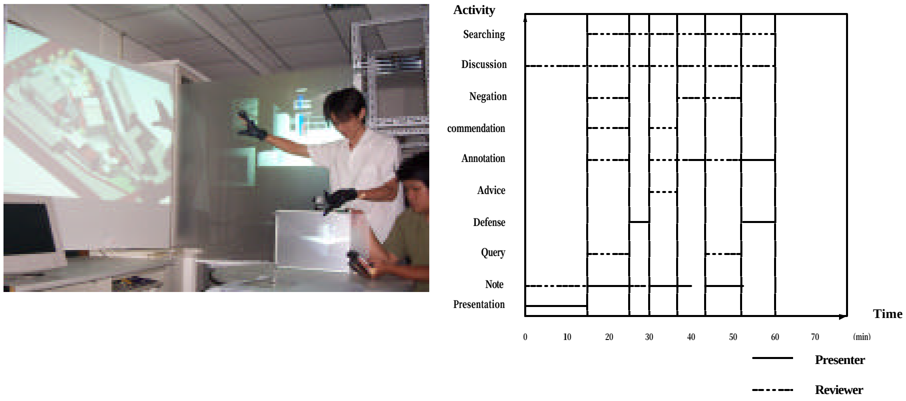

Figure 5. The setup of *iCube* for emperical studies (on the left); Visualization of users' activities over time in the design critique session (on the right).

The results showed that the *iCube* prototype environment provides several enhancements in design communication and interaction, and preserves many of the affordances of traditional design media. Our quick response to the use of ubiquitous media in the *iCube* setting is "*design presentation is no more than conducting an orchestra*" [Laurel, 1993]. *iCube* has provided new intuitive forms of communication and interaction for design reviews and critiques. The setup of *iCube* and visualization of users' activities for our empirical studies are shown in Figure 5.

Our experience in the *iCube* setting has shown that ubiquitous media spaces seem to have advantageous capabilities not found in the standard approach to design studio settings. The capabilities include:

1. Using "cutting plane in hand" metaphor, anyone was easily to move around the spatially-aware 3D navigator over the drawings to create building section views, as shown in Figure 2. It has encouraged designers to communicate directly through engaged interaction with computer-augmented artifacts. By coupling a sequence of section views with building plan geometry, the user perceived a virtual 3D model both in the physical space and in the mental construct. It is extremely useful for naive designers to learn and create a sense of spatial cognition in architectural design.

2. By coupling digital representations with physical representations, traditional media have gained new electronic properties without losing their physical properties. As shown in Figure 3, moving or pointing the physical model correspondingly changed the perspective geometry display of the virtual model. The mixed use of physical and digital forms in design reviews and critiques helped designers to transfer the considerable skills they have acquired in working with traditional media.

3. Using "orchestral conducting" metaphor in the *iCube* setting, interaction with digital models has been largely an *environmental* experience, rather than a desk experience. People remotely controlled the viewpoint of the digital model

on a large projected display for discussion and sharing ideas. The user could easily manipulate digital information while carrying on a face-to-face conversation with reviewers, as shown in Figure 5. This is in contrast with the desktop setting where a group of people look over the user's shoulder to view the image display on a small-sized computer monitor. The reviewers feel frustrated because they cannot directly control the computer. The desktop setting could not afford, quite literally, social interaction.

An important issue emerging from this work is coordinating the interactions of people and media in an integrated space. In the course of our empirical studies, we have integrated design activities that are interleaved and involve more than one physical device, e.g. the display tablet, pointers, and large displays. We have encountered three different aspects of interaction: *people-to-people, people-to-media,* and *media-to-media*. Each of these raises a different set of requirements for interactive system design. In most cases, the users focused on people-to-media interaction, with less concern for people-to-people interaction or formal underpinnings underlying media-to-media interaction.

While most of the users were given some quick training for hand-gestured method of input, they were not aware of "the sphere of control" corresponding to the sensor-activated territory within the space. As a result, the users attempted to move the spatially-aware navigator to cut an arbitrary section that was beyond the scope of sensor detection. Arm-waving vision-processing techniques were also limited in a certain area. In the meanwhile, the combinatorial use of the facilities cuts across the device boundaries. The simultaneous use of multiple later pointers on a wall-sized display would possibly cause a conflict.

Based on our observations, each of the facilities presented in *iCube* is a well-understood well-controlled medium. The combinatorial use of the facilities in an integrated space, however, is complex and dynamic. Some of the results on the current state were somehow beyond our expectations. More centrally, there is no design principle or method that mediates the interplay between ubiquitous media in the integrated space as it is acted on.

4 DISCUSSION AND CONCLUSION

We have outlined new facilities within a ubiquitous media space supporting multimodal interaction. These include spatially-aware 3D navigation, laser pointer interaction, and tangible media. Our experience in using these facilities in the *iCube* setting has shown that it successfully integrated the computation world with the physical world for supporting design reviews and critiques. We have also highlighted some issues that arise in our empirical studies. Our overall goals are to develop the needed interaction capabilities for the media-rich smart design studio of the future, and also for enhancing the support for embodied interaction responding to much higher levels of complexity.

Our work suggests that a new generation of ubiquitous CAD environments is possible, based on an integrated design of real and virtual worlds. Such an environment is transparent and intuitive, allowing users to engage in normal design activities and interact with our surroundings in an intuitive and social manner. Ubiquitous media can be defined to support various interaction modalities. These media can be combined in different combinations to support customized configuration of the architecture of a design space, a presentation area, and a crit room. A major underlying premise of this work is the need for physical programming of ubiquitous CAD environments, requiring reorganization of multi-user multimodal interactions with multiple devices in an integrated space.

As the style of interaction is moving beyond the desktop to the real world where we live and act, more emphasis is required on the underlying system infrastructure that is able to coordinate the interactions of applications executing on a variety of devices. We are currently considering several extensions of this work, including design principle for supporting mediated interaction, seamless integration of media-space modules, and a system infrastructure to coordinate the interactions of ubiquitous computing applications.

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