iCube: Ubiquitous Media Spaces for Embodied Interaction

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Abstract: This paper outlines new facilities within ubiquitous media spaces supporting embodied interaction between humans and computation. We believe that the current approach to developing electronic based design environments is fundamentally defective with regard to support for multi-person multimodal design interactions. 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 design support 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 to be pervasive throughout our work environments. A parallel trend is to support all aspects of interaction spaces with a growing number of smart devices embedded in rooms, walls, and furniture (Carroll 2001).

Given inevitable growth in the range of computer-augmented architectural elements, architectural space will become an interaction interface between people and digital information. We refer to this interaction space as *ubiquitous media space*. An extensive literature on ubiquitous media spaces addresses such special issues as “cooperative buildings” (Streitz et al. 1998), “media spaces” (Bly et al. 1993), “augmented reality” (Buxton 1997), “tangible interfaces” (Ullmer and Ishii 2001), among others. Similar issues of embodied interaction have motivated the development of the workspaces of the future (Dourish 2001, Johanson, et al. 2002, Coen 1998).

This paper describes work in progress for developing ubiquitous media spaces supporting embodied interaction between humans and computation. We believe that the current approach to developing electronic based environments is fundamentally defective with regard to support for multi-person multimodal interactions. In this paper, we present an alternative ubiquitous computing environment based on an integrated design of real and virtual worlds. In such an environment, architectural space can be used for expression of digital information, allowing users to interact with computation in an intuitive manner. There are many application types of ubiquitous computing environments. Our interest is in the media-rich smart studios of the future.

This paper is organised as follows. First, we describe the functional requirements for ubiquitous media. In section 2, we outline new facilities within a research prototype environment called *iCube*. The functional capabilities of *iCube* and issues regarding explicit support for embodied interaction are presented. Finally, we perform an empirical study to assess the usability of the *iCube* prototype. Some of its details, benefits, user experiences, and issues regarding design support are discussed.

1.1 Ubiquitous Media

The term *ubiquitous media* is used to denote a new paradigm for human-centred computing: the information is *ubiquitous*, yet the computation is *invisible*. Here we identify different kinds of functional requirements for developing ubiquitous media spaces, which can be classified in a three-dimensional design space, illustrated in Figure 1.

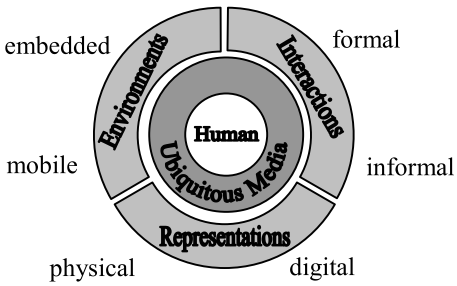


Figure 1 A Human-Centred Design Space of Ubiquitous Media

The first dimension is the seamless integration of *digital* and *physical* representations. Architecture has relied upon multiple representations to depict design ideas. Today we rely on a range of drawing representations, various digital and physical models, various forms of analysis and so forth. Designers must articulate different forms of digital and physical representations by themselves without computer augmentation. Without coupling digital representations with physical representations, it has added additional cognitive load upon designers in design communication and interaction.

The second dimension involves interaction interfaces that reflect the social nature of the collaborative design process. Buildings are inherently collaborative endeavours. Architects need to interact with various professionals to share ideas and receive feedback in the design process. The interaction may be formal such as design reviews and critiques. Alternatively, the interaction can happen informally when people meet occasionally in the shared workspace. It has been recognized that traditional design media such as drafting tables or pin-up whiteboards afford large-format interaction interfaces for social interaction. They create a sense of shared awareness by virtue of visibility. In contrast to the affordances of traditional design media, the conventional desktop workstation seems to preclude informal and spontaneous use, and discourages social interaction.

Collaboration support is required that respects the social factors and which goes beyond simply giving a larger display surface in the design studio. To some degree now and increasingly the future, there is inevitable growth in the range of smart devices in augmenting collaborative design activities. We will encounter a physical situation where computational devices become increasingly embedded and deployed in our work environments and everyday lives. This has a profound effect on future design environments, enabling new classes of computational services in the collaborative design process. Today much of our design work is carried out at desktop computer workstations. In these settings, interaction with computation has been largely a desktop experience. Very soon, we will carry *mobile* devices from place to place to support collaborative design work, and associate information with the *embedded* environmental devices in a particular locale. Under such conditions, interaction with computation will soon become an *environmental* experience rather than a desktop one.

Representations, *interactions*, and *environments* are three major criteria that constitute the design space of ubiquitous media. We assume that there will be an expanding set of system capabilities provided in future design environments supporting ubiquitous media, and also for enhancing the support for embodied interaction in the design studio. In general these capabilities significantly go beyond the services addresses within the current design environment.

1.2 Interaction Modalities

We begin by developing the capabilities needed to fully support ubiquitous media spaces, with special consideration of interaction modalities. The term *interaction modalities* refer to a combination of multiple modes of interaction. To make interactions in a ubiquitous media space truly natural, it is first necessary to extend the current interface modality for human-computer interaction. Here we distinguish between four types of interfaces that are often used in presenting a design: *gesture, pens, laser pointers,* and *batons*. In addition, we identify a set of interaction events that capture meaningful semantics in design communication, including *pointing, annotations, manipulation,* and *navigation*. Combining varied interaction interfaces and events results in sixteen modes of interaction, as shown in Figure 2. Under this matrix, we can instantiate non-desktop interaction modalities for specific design tasks, given a set of interfaces and events available in any particular situation.

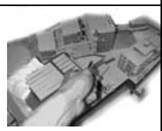
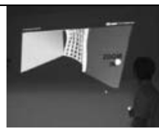
interfaces / events	gesture	pens	laser pointer	baton
pointing				
annotations				
directing				
navigation				

Figure 2 A Matrix of Interaction Modalities for Mapping between Interfaces and Events in Design Presentation

Our response to this combinatorial modalities attempts to build modular interactive systems that deal with all the possible combinations in the matrix. Major questions about the practical use of such systems include: How can we integrate combinations of these modules into custom configurations of interaction spaces? How can we map a design space to the corresponding interaction modalities? How many interaction modalities are possibly used in presenting a design? How can we adapt non-desktop interface modalities appropriate to the design task? These questions are fundamental to the design of ubiquitous media space and will be addressed in later sections.

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 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 technology supporting embodied interaction, and more recently, for supporting modular integration of ubiquitous media spaces.

2.1 Spatially-Aware 3D Navigation

We are motivated to develop a ubiquitous media space to bridge the physical-virtual gaps. In order to get this idea in practice, we begin with the development of a spatially-aware 3D navigation tool by which designers can manipulate the VR model through engaged interaction of artefacts in the physical space. We refer to it as *spatially-aware navigator*. A spatially-aware navigator consists of a set of physical devices, including a vertical tablet device and a horizontal table surface. The former is for displaying a dynamic building section view, whereas the latter displays the corresponding building plan geometry, illustrated in Figure 3.

Figure 3 The Set-up (left) and Operation (right) of the Spatially-aware Navigator

We use "cutting plane in hand" metaphor to design the spatially-aware navigator. Underlying the spatially-aware navigator is a virtual reality model that reacts immediately in response to changes in the position of the tablet device. A "section" snapshot of the 3D model is superimposed on the tablet display immediately after the tablet is activated and well placed on the table surface. The user can relocate the tablet device to a new position, which automatically resets the 3D model's section view related to its corresponding coordinates of the building plan geometry. From the user's perspective, the display tablet is served as "a cutting plane" to obtain a snapshot of building section views in the physical space. By acting through the interactive system with its spatial set-up, the spatially-aware navigator allows the user to perceive a 3D model in his/her mental construct as if it is really there in the physical space.

In the implementation, we set up an interactive table by installing an overhead projector on the ceiling with a mirror refracting projection light onto a table surface. An interactive whiteboard device (e.g. Mimio) is installed on the table, which can quickly transform an office table into a touch-sensitive interactive table. After setting an interactive table, we design a vertical display surface by choosing a mid-sized acrylic fibber tablet. We embed a light-emitting diode (LED) on the display tablet to track its position. The position of the display tablet is sensed based on camera-based colour recognition of LED infrared light. The tablet device, with its vertical set-up, displays a section view immediately after the user move it to a new position. In contrast to the physical model, the users can move the tablet device over the interactive table to inspect different building sections of the digital model in detail. In the meanwhile, moving the display tablet creates a sequence of image displays, resulting in a "live" walk-through animation.

2.2 Laser Pointer Interaction

Laser pointer is a general tool being widely used in design presentation to point out an object remotely for design reviews and critiques. From a sociological perspective, laser pointer is an important tool to direct group's attention in group discussions. We consider laser pointer interaction is an important functional component of the *iCube* project to interact with digital information. An important functionality is to control the viewpoint of a digital 3D model in design reviews and critiques. Our work is to transform a laser pointer into an information remote manipulation tool, allowing people to intuitively interact with information at a distance from a large display surface.

The immediate technical challenge for laser pointer interaction is to detect the laser spot position. In the *iCube* implementation, 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 colour recognition technique to detect the laser spot position. After detection, the system sends an event to the CAD application. The event carries the coordinate of the laser spot to trigger an operation for computational services. Using laser pointer interaction, the user can control the viewpoint of the 3D VR model at a distance, as shown in Figure 4.

Figure 4 Laser Pointer Interaction (left) and Hand Gesture Recognition (right)

We apply the same computer vision technique to the development of hand gesture recognition for design presentation (Figure 4). We design a half-finger glove mounted with three LEDs for hand gesture method of input, whereby specific hand movements would represent different control commands. Our gesture recognition system requires a web camera to detect the number and position of LED light spots mounted on the half-finger glove. The development of gesture recognition is based on an arm-waving image-processing technique that uses cameras to track an arm position and specific hand movements. When the LED-mounted half-finger glove is acted on in gesturing, the camera detects the number and position of LED light spots, and triggers a corresponding event to perform an operation. In contrast with laser pointer interaction, the users can use hand gestures to zoom in/out a digital model, and control the wall-sized display at a distance.

2.3 Tangible Media

In our initial prototype environment, we develop an *iCube* space equipped with the interaction facilities, including spatially-aware navigator, laser pointers, and tangible media. Here we exploit two primary capabilities of tangible media in support of design communication and interaction. First, digital representations are coupled with physical representations in a new form supporting embodied interaction. Secondly, the system allows users to grasp and move digital contents across physical devices. Our goal is to develop a media-rich proactive design environment with a certain degree of ubiquity and tangibility.

Figure 5 shows the implementation of tangible media in our initial prototype environment. In the Figure 5 on the left, the viewpoint of the digital model is bound to the orientation of the physical model. Moving or rotating the physical model correspondingly changes the perspective geometry of the digital model projected on the side wall. In the Figure 5 on the right, we provide an interactive table and a touch-sensitive wall display, which serve as a platform for direct manipulation of underlying digital information. The users use hand gestures to point, grasp, and manipulate a set of digital images. When the users "throw" it at the side wall, the digital image is conveyed from the table surface to the side wall display. An important consideration of our work is that people can see each other's hand gestures relative to the movement of 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.

Figure 5 Coupling Physical and Digital Models (left) and Moving Digital Contents Using Hand Gestures (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, electronic tags, 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 initial prototype, we conducted an empirical study on the practical use of the *iCube* facilities. We first chose a digital design team to test the *iCube* facilities, and then recorded the design critique activities. Here we report some results of the empirical study regarding the current work practice of design teams and their requirements for the media-rich smart studios of the future.

Based on our observations, we found that some of the results on the current state were somehow beyond our expectations. *iCube* seems to have advantageous capabilities not found in the standard approach to design studio settings. The capabilities include:

1) The spatially-aware navigator used "cutting plane in hand" metaphor to interact with a 3D virtual model. The user created a sense of spatial cognition in design by embodying interaction- cutting the section of the model- in the physical space. The novice designers learned the meaning of "sections" directly by acting though the "cutting plane". People were easily able to set up the spatially-aware 3D navigator anywhere in the studio supporting shared awareness.

2) Laser pointer interaction used "orchestral conducting" metaphor to direct the display of digital information. People could point out an information object at a distance and control the viewpoint of the digital model on a large projected display. An important perspective is the affordance of social interaction. The user could manipulate digital information while carrying on a face-to-face conversation with the reviewers. This was in contrast with the desktop setting where a group of people looked over the user's shoulder to view the image display on a small-sized computer monitor, which discouraged social interaction.

3) Tangible media were extremely useful in bridging the physical-virtual gaps. The design technology allowed traditional tools to gain new electronic properties without losing their physical properties. It also helped designers to transfer the considerable skills they have acquired in working with traditional media. People felt better in the use of tangible media because they could directly control and manipulate the digital information without using complex computer commands. It encouraged traditional designers to accept new design technology through engaged interaction with computer-augmented artefacts.

Each of the facilities presented in the *iCube* project has a well-understood wellcontrolled domain. The combinatorial use of the facilities in an integrated space, however, is complex and dynamic. In the course of our empirical studies, the users attempted to move the spatially-aware navigator to cut an arbitrary section that was beyond the scope of sensor detection. The same problem occurred in the practical use of tangible media because arm-waving image-processing techniques were limited in a certain area. While most of the users were given some quick training for hand-gestured method of input, they were not aware of the sensor-activated territory corresponding to the sphere of control within the space. This implies the need for spatial interface design in physical locations, capable of detecting the sphere of control. Another problem is the simultaneous use of multiple later pointers on a wall-sized display, resulting in a conflict. It requires management methods to coordinate the interaction between ubiquitous media in multi-person multimodal interactions in an integrated space.

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 design of ubiquitous media. In the course of our empirical studies, the user's focus was episodic because he/she was engaged in a conversation with people in an integrated space (i.e. people-to-people interaction). To some degree the user did not have additional cognitive capacity to fully focus on media-to-media interaction while carrying on people-to-people interaction. In certain occasions, the user had to mediate the interplay between ubiquitous media while he spoke to other people, which was socially unacceptable.

4 CONCLUSION

Our overall goals are to develop the needed capabilities for enhancing the support for embodied interaction between humans and computation, and also exploit the potential level of interactivity for the media-rich design studio of the future. A major underlying premise of this work is the need for a new generation of ubiquitous CAD environments based on an integrated design of real and virtual worlds. If we think deeply, from a sociological perspective, many valuable affordances of the traditional techniques were lost during the first generation desktop-based CAD revolution. Our work suggests a new way of manifesting computation in the physical space, yet preserving the affordances of traditional design techniques.

In this paper, we have demonstrated a prototype implementation of a ubiquitous media space that is attempted to bridge the gap between physical space, virtual space, and logical space. Physical space is where we work and act in the real world. Virtual space exists in computers and networks. Logical space captures the way we reason about design. Our experience in the initial *iCube* setting has shown that ubiquitous media spaces have enormous potential to influence the way we operate and interact with design computation, and in particular unify the models of physical space, virtual space, and logical space.

The impact of ubiquitous computing on human-computer interaction within an integrated space appears to us to be the basis for the development of the media-rich design studios of the future. As the style of interaction is moving beyond the desktop into the real world we act, more emphasis is required on a solid understanding of human designers' capabilities and needs. There are still some gaps to fill and technical challenge to meet. The new challenge is to develop formal methods for coordinating the interactions between ubiquitous media in an *iCube* space. We are currently considering several extensions of this work, including the means for the seamless integration of *iCube* modules in different scales, and design principle for dynamically mapping a physical space to an underlying coordination infrastructure and a corresponding model of embodied interaction.

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