Advanced Ubiquitous Media for Interactive Space

A Framework

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Abstract: Developing ubiquitous media for interactive space requires interdisciplinary collaboration in studying ubiquitous computing. This work generalizes the criteria in the many disciplines of ubiquitous computing into a conceptual framework, including interaction interfaces, sensing technologies, application control, and human adaptation. This work presents a novel system architecture based on such a framework, and a research prototype recently developed called *IP*$^{++}$. Additionally, the design principles and the potential of *IP*$^{++}$ are discussed.

1 INTRODUCTION

The next revolutionary human-computer interaction technology concerns interactions between people, computers and information by developing technologies that naturally reflect human behaviour and support the subtleties of everyday life. Ubiquitous media technologies for off-the-desktop interaction applications have been extensively studied for many years (Abowd and Mynatt 2000). Recent works have proposed integrating physical and digital interactions in the emerging field of interactive space (Winograd 2001, Streitz et al. 2003). This approach requires interdisciplinary collaboration, involving fields such as computing, architecture, industrial design, engineering and cognitive psychology. However, due to the lack of a conceptual framework, the research scope and interactive space design principles have been hard to define. More effort is needed in developing an interdisciplinary framework that articulates various viewpoints on ubiquitous media, while emphasizing the potential application of interactive space to transform our built environments.

To integrate ubiquitous media into interactive space, this work has developed a conceptual framework that addresses general criteria regarding the multiple disciplines of ubiquitous media. These general criteria include *physical-digital interaction interfaces, sensing and perceptual technologies, application and service control,* and *human and environmental adaptations.* Each criterion denotes a distinct functional requirement for developing advanced ubiquitous media for interactive space. After articulating these requirements, the overall system architecture and design principles can be easily realized for different interactive space application domains.

The research prototype presented in this work is part of the *IP*++ project most recently developed by our Information Architecture Laboratory. This project focused initially on developing advanced ubiquitous media, and more recently on developing the theory of mapping toward smart environments (Jeng 2004).

2 UBIQUITOUS MEDIA

This work builds on previous studies in structuring the design space of ubiquitous media over several dimensions. One dimension depicts a wide spectrum of *environments*, ranging from real, augmented, augmented virtual, to virtual reality. Another dimension augments *objects* by incorporating sensing and communication capabilities. The computer-augmented objects may be mobile, portable, wearable, tangible, embedded or ambient, such that information and services are provided when and where desired. The third dimension denotes *human activities* involving different situations at home, at school, at work, in the shops or on the move. This design space matrix makes the application domain of ubiquitous media and the different roles of ubiquitous computing technology in interactive space easy to understand. The design space matrix of ubiquitous media is depicted in Figure 1.

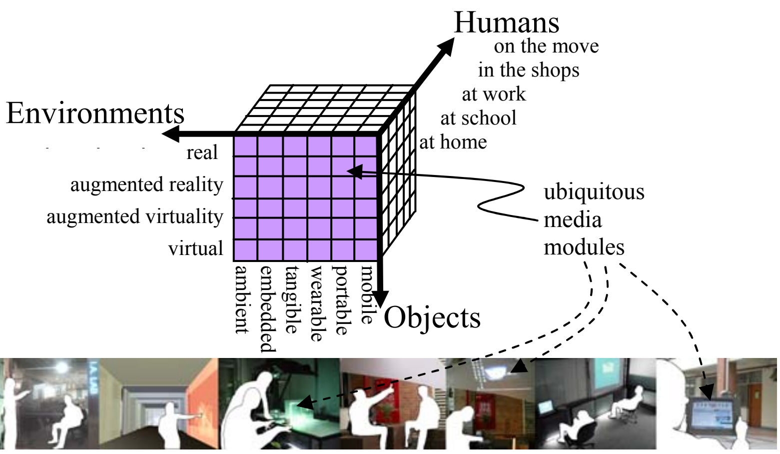

Figure 1 The design space matrix of ubiquitous media

Different research and development have progressed rapidly by augmenting *environments, objects* and *humans* with sensing, computing and communication capabilities. These approaches in different fields converge on the boundary between physical and digital worlds (O'Sullivan and Lgoe 2004). This work proposes a human-centred framework that articulates the various perspectives and major investigation aspects of ubiquitous media for interactive space. The next section elaborates the core of the proposed conceptual framework.

3 A FRAMEWORK

Figure 2 shows an overview of the conceptual framework. The framework describes four key elements of the kernel- a matrix of the design space. Four key elements of the conceptual framework are: (1) *physical-digital interaction interfaces;* (2) *sensing and perceptual technologies;* (3) *application and service control, and* (4) *human and environmental adaptations*. These elements are described in detail in the following sections.

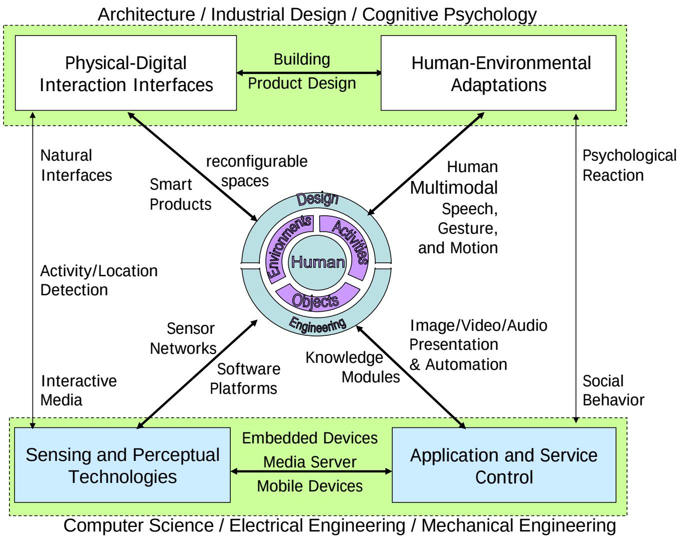

Figure 2 A conceptual framework

3.1 Physical-Digital Interaction Interfaces

When bringing ubiquitous media to interactive space, interaction interfaces include a new set of problems, since interaction interfaces must be constantly present in the real world and support embodied interaction for everyday practices. Several research issues for designing physical-digital interaction interfaces have emerged.

From explicit interaction to implicit interaction: Human-computer interaction is moving from command-based devices (e.g. keyboards and pointing devices) to support natural interaction using gestures, handwriting and speech. The move toward natural interaction poses multiple novel technical, design, and social challenges. For example, stepping on the floor of a room is sufficient to detect a person's presence there. Therefore, a new interaction model is needed to support several distinct features of *implicit human interaction*, as follows (1). Implicit human input cannot be easily defined in terms of a finite set of modes. (2) The input has no clear boundary (e.g. starting and end points) (3) Implicit human input may be nested and long-lasting. (4) Multiple input activities may operate concurrently. (5) Output can be multi-scaled with ambient displays. (6) Output may be dynamic physical operations distributed in different locations.

From foreground computation to background computation: As computers vanish into the background, human-computer interaction becomes similar to the way humans interact with the physical environment. Researchers increasingly believe that building space should be transformed into a set of interaction interfaces between humans and computers. Buildings would largely integrate computational devices for physical interaction.

From single-user systems to multi-user interaction with mixed reality: People live in a world of mixed reality with two distinct environments: the physical environment where people reside and interact face-to-face and the digital environment where virtual agents interact. Much work is needed to support multi-user interaction in an interactive space, and to articulate and connect events in the physical and digital worlds.

3.2 Sensing and Perceptual Technologies

Sensing technologies are increasingly being used to provide implicit input for natural interaction interfaces. The trend toward sensing-based interactions has imposed a basic requirement on any ubiquitous media to support implicit multimodal inputs in interactive space. Sensing technologies can be briefly classified into three categories: (1) location sensors, (2) mobile sensors, and (3) environmental sensors.

Location sensors: Location sensors are embedded in a room or place to detect human presence. Examples of location sensors are web cameras that use computer vision and recognition technologies that identify behaviour patterns and interpret the signals of human activities. Other commonly used sensing technologies are optical, magnetic and capacitance sensors coupled with radio frequency devices to receive sensed signals. In these experiments, capacitance sensors are used to create smart floors. The aim of a smart floor is to identify a user's presence and provide location-aware information when a person walks into a space. A matrix of capacitance sensors underlying the smart floor triggers the wall-sized display of audio-video projectors in interactive space. Figure 3 shows an example of a smart floor.

Mobile sensors: Mobile sensors are worn in human bodies to detect human motion, gesture and social settings. Examples include sensors that equip handheld devices with perceptual capabilities. Mobile sensors can detect how a device is held and determine how to respond. Radio frequency identity (RFID) is another example of electronic tagging associated with the wide variety of objects tracked by barcodes. Coupling with wireless network connections together, RFID technologies enable digital annotations of physical objects and locations, which potentially change how people interact with the physical environment.

Environmental sensors: Environmental sensors are conventionally installed in our built environments to measure temperature, humidity, pollution or nerve gas levels to ensure safety and quality. Examples of environmental sensors include the thermostat of a heating system, which switch the heating on when the temperature drops below a certain level, and automatic light switches, which use sensors to detect the presence of humans in public places (e.g. stairways and restrooms) to save energy.

This work identifies two significant facets of sensor-based interactions that are relevant to interactive space design. The first aspect is a sensor network combined with an adaptive software platform to develop ubiquitous media applications. The other aspect refers to creating user experiences in the cognitive process of sensor-based interactions. Creating user experiences stipulates natural cognitive mapping between human actions and sensing effects. Together, sensor-based interactions require a ubiquitous computing infrastructure that maps to the physical space and its corresponding interaction model.

Sensing and perceptual technologies have been increasingly recognized as useful in developing context-aware smart environments. Often, a mixture of location, mobile and environmental sensors can be applied to command control, replacing existing user interfaces and physical switches in the real world. The nature of sensor-based interactions is implicit, continuous and human-centered. Using sensors for implicit input-output interactions has potential to alter the nature of our built environments.

Figure 3 From left to right: the making process of computer-augmented architectural elements with sensor networks

3.3 Application and Service Control

This attempt to support interactive space requires not only linking many sensors and media to locations. Some fundamental conceptual shifts occur in the backend system architecture for application and service control.

Transforming low-level sensor data to high-level application context The first problematic question is, "How is sensor data transformed to application context? How is it interpreted?" In all cases, sensor data derives from low-level device output represented by bits. The low-level sensor data (e.g. "0" or "1" denoting the state of the sensor) has to be translated to high-level application information (e.g. "walking into a space.”). When the sensor detects a person in a given context, a particular interpretation of the context can be formalized in a triple <*user_ID, location, event*>: a user identifier, the user’s location and the user event. A triple of the context can be extended to environmental features (e.g. temperature and humidity) and the human state (e.g. emotion and psychological reactions).

Triggering context-aware responsive actions: The next question following sensor data context is, “What action is suitable for ubiquitous media in reply to a specified context?” In the example of interactive space, the spatial components such as walls and floor may respond such that an action is triggered in terms of a specific spatial and social context identified by the sensor networks. The responsive action can be multimedia access control (e.g. automatically display of a pre-programmed video), environmental control (e.g. switch lighting on or off), or surveillance monitoring (e.g. start recording, send alert emails).

Application execution and service control: Responsive actions are generally executed in two main stages, service execution and application control. Applications specify and execute services, which include from multimedia access control, environmental control, and surveillance monitoring. In a complicated example such as interactive space, however, services may involve complicated process coordination, stipulating effective management of applications and their corresponding internal events dispatched from sensor networks.

Coordination infrastructure: User activity tracking may involve integrating inputs from many heterogeneous devices and sensors. For example, capacitance sensors are embedded in the floor to provide location information. Other sensors such as cameras are used by programs that identify a user’s gesture. Each sensor has its own driver, requiring integration of heterogeneous sensor data. Data integration necessitates a separate layer of system components in the backend to generate an integrated high-level application context related to the interaction.

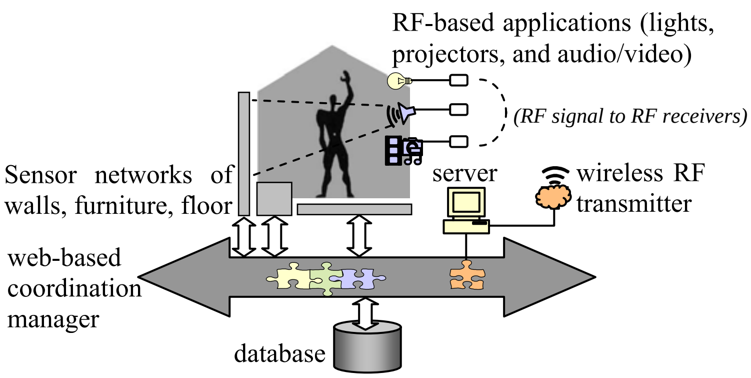

Figure 4 The system architecture

To handle these problems, a system architecture was developed for building ubiquitous media applications. First, the system architecture must decouple sensor networks from application programs and services. Second, a separate coordination manager layer is required to coordinate activities across system components in the backend. The coordination manager schedules events and monitors the validity state so that the applications and services can be executed in the correct order. The system architecture is depicted in Figure 4.

3.4 Human and Environmental Adaptations

Interactive space is uniquely human-centred design. Ubiquitous media are designed to reduce the cognitive load of human users. Paradoxically, ubiquitous media might turn around and place a considerable demand on humans because they have become part of the physical environment to which people strive to adapt. Even with the most human-centered methodology, ubiquitous media might not be a natural part of the human system. Therefore, researchers need to study how ubiquitous media affect human cognition, and how humans adapt to technological and environmental changes.

Identifying human activities and cognitive processes: Many domains of cognition are relevant to the above aims. One domain focuses on human factors test and evaluation of ubiquitous media to be designed and created for an interactive space, including identifying the human cognitive processes and capturing the reactive and adaptive bahaviors of the human users when they try to interact with ubiquitous media. Activities take two forms. *Efficiency-driven activities* must tightly couple cause and effect, and avoid making mistakes in the interaction. *Exploration-based activities* have more room for ambiguity, enabling users to learn through engaged interactions.

Exploiting natural mapping between actions and perception: The need for adaptation occurs when actions and perception do not match. Observations from this work show that creating new forms of sensor-based interactions often leads to confusion and annoying user experience, but this problem is not due to technology. Rather, the effects of the responsive actions do not match with the desired outcome. People feel comfortable if they can expect what is happening in their environment. Therefore, natural mapping between actions and perception needs to be incorporated into a design, resulting in immediate understanding and compelling user experience.

Creating spatial metaphors to guide user behaviors: What metaphors can be used for ubiquitous media in interactive space? In other words, what is the next "desktop" metaphor? Current experiments are aimed at creating spatial metaphors to guide user behaviors in an interactive space. People like to understand every aspect of their surrounding environments. Users may wander around if they do not know where and how to activate a device, and hesitate to proceed with an action if they cannot predict its effects. In designing interactive space, the set of possible actions and movements needs to be visible to users, and the peripheral information should be moved into the foreground of the user's attention.

4 PUT IT ALL TOGETHER: THE *IP*$^{++}$ PROJECT

To demonstrate how the framework can be applied to the design of ubiquitous media for interactive space, this work describes a recently developed application called *IP*$^{++}$. The *IP*$^{++}$ project consists of four major components: *smart floor, interactive walls, smart cubes, and information canvas for ambient displays*. The smart floor consists of a set of elevated floor boards, each of which is embedded with capacitance sensors to identify human presence. When the sensor-embedded floor identifies the presence of people, an event (e.g. ambient displays) is triggered over the floor and information canvas. An interactive wall comprises a set of small-sized wall modules, each of which is embedded with an optical sensor to detect when a person passes by. Smart cubes are computer-augmented furniture equipped with capacitance sensors. Parts of the smart cubes are installed with all-in-one computers and monitors. The information canvas is composed of stretchable material for situated ambient displays. Together, smart floor, interactive walls, smart cubes, and information canvas form an interactive space from traditional architectural space.

The *IP*$^{++}$ project reflects the inherent feature of multi-disciplinary framework. First, a set of composition rules is investigated to design the *IP*$^{++}$ modules coupling with architectural design. The architectural space comprises physical-digital interaction interfaces. For the purpose of modularization and mobility, all the parts of smart floor, interactive walls, and smart cubes can be reconfigured into varied building modules. Second, the *IP*$^{++}$ modules are augmented by computer hardware and sensor networks with sensing, computing and communication capabilities. Third, sensor networks are developed in combination with software application execution and web service provision. Finally, cognitive technologies are being developed to examine how humans adapt to ubiquitous media in interactive space.

The *IP*$^{++}$ project aims to extend the notion of the *Information Portal* (IP) in the physical world, as an analogy to *Internet Protocol* (IP) in the digital world. The *IP*$^{++}$ project is intended as a dynamic, reconfigurable, and interactive spatial system that provides mixed reality, natural interaction interfaces, and programmable automatic service control. The aims of *IP*$^{++}$ are to build an interactive space that can link ubiquitous media to physical locations, connect events in the physical and virtual worlds, and create new user experiences through enabling sensing technologies. As the time of writing, the *IP*$^{++}$ project is under development in conjunction with an interactive media exhibition in digital museum.

5 THE APPLICATION: INTERACTIVE MEDIA EXHIBITION

While the research prototype was being undertaken, the author was invited to demonstrate the *IP*$^{++}$ research prototype at the Taiwan New Landscape Movement Exhibition 2004. We take this opportunity to demonstrate our ubiquity work in public. The exhibition adapted the original configuration for the *IP*$^{++}$ project and designed two L shapes to build an interactive exhibition space. Figure 5 shows a view of the IP^{++} research prototype at the Taiwan New Landscape Exhibition. The IP^{++} prototype has three kinds of sensing-based interactions. First, visitors to the exhibition were invited to walk through the IP^{++} exhibit space, which has three sensor-embedded smart floor boards denoting the *past, present*, and *future* development of Taiwan's landscape. As the visitor moved on to one of the smart floor boards, the floor sensor triggered the display of animations corresponding to the past, present, or future Taiwan landscape. The projected information was determined by the backend IP^{++} system according to the visitor's location on the smart floor boards. A sequence of snapshots of interactive activities is shown in Figure 5.

Secondly, a set of physical icons was designed to be attached to the interactive wall, enabling visitors to interact directly with a computer-generated three-dimensional model, using gestures without wearing any devices. The physical icons were embedded with optical sensors for issuing "rotate", "zoom in" and "zoom out" commands. As the visitor moved one or both hands over the optical sensors, the system issued an implicit command to rotate, zoom in, or zoom out the computer model correspondingly. Therefore, this exhibit was device-free and allowed complex gestures to be performed with a composite command.

The final experiment in this exhibition is a lounge area installed with three computer-augmented cubes. One cube acted as a computer display while the other two sensor-embedded cubes serve as smart seats to sit down. As the visitor sat himself on the cubic box, the sensor inside the box detected the presence and triggered the display of information relevant to the exhibition on the surface of the other cubic box.

Figure 5 A sequence of snapshots of the IP^{++} interactive media exhibition

6 CONCLUSION

This work developed a framework for ubiquitous media systems and their functional requirements, while simultaneously presenting a research prototype of interactive space most recent developed called the IP^{++} project. The IP^{++} project starts from technical integrations with advanced ubiquitous media and incrementally moves to interactive space design.

This work gives a brief example from the research prototype to help create new ideas of human-computer interaction, and poses some research ideas for the future. In accordance with this perspective, a large-scale collaborative research consortium spanning multiple disciplines, research institutes, and industries will be formed to develop interactive space. The proposed framework is a basis for the integration of computing across disciplinary boundaries.

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