

Classroom in The Era of Ubiquitous Computing ——Smart Classroom

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Abstract: This paper first presents four essential characteristics: natural user interface, automatic capture of class events and experience, context-awareness and proactive service, collaborative work support, of futuristic classroom in the upcoming era of ubiquitous computing. Then it elaborates the details in the design and implementation of the ongoing Smart Classroom project. It concludes by some self-evaluation of the project's present accomplishment and description of its future research directions.

Keywords: Intelligent environment, ubiquitous computing, multimodal human-computer interaction, smart classroom

1. Introduction: From UBICOMP to Smart Classroom

Desktop and laptop have been the center of human-computer interaction since the late of last century. As is a typical situation of human's dialogue with computer that a single user sits in front of a screen with keyboard and pointing device, interacting with a collection of applications. In this model, people often feel that the cumbersome lifeless box is only approachable through complex jargon that has nothing to do with the tasks for which they actually use computers. Too much of their attention is distracted from the real job to the box. Deeper contemplation on valuable matured technologies tells us: the most profound technologies are those that disappear, which means they weave themselves into the fabric of everyday life until they are indistinguishable from it [Weiser 1991]. We use them everyday, everywhere even without notice of them. Based on this point of view, computer is far from becoming part of our life.

Mark Weiser first initiated the notion of Ubiquitous Computing (UBICOMP) at Xerox PARC [Weiser 1993], which envisioned, in the upcoming future, ubiquitous interconnected computing devices could be accessed everywhere and used effortlessly, unobtrusively even without people's notice of them, just as electricity or telephones of today. This inspiring view of prospect has been accepted and spread so fast and widely that in a short time of a few years, many ambitious projects have been proposed and carried

on to welcome the advent of UBICOMP. There are a bunch of branch research fields under the banner of UBICOMP, such as Mobile Computing, Wearable Computing and also Intelligent Environment, etc. The focus of this paper, Smart Classroom, belongs to the field of Intelligent Environment. But what is Intelligent Environment? In our point of view, we define it as an augmented spacious environment populated with many sensors, actuators and computing devices. These components are interwoven and integrated into a distributed computing system which is able to sense its context through sensors, to execute intelligent logic on computing devices and serve its occupants by actuators. (In some research studies, Intelligent Environment is also referred as Interactive Space, Smart Space etc.)

In researches of Intelligent Environment, there are several relevant and challenging problems need to be solved, such as the interconnection of computing devices on many different scales, the handling of various mobility problems caused by user's movement, and network protocol, software infrastructure, application substrates, user interfaces issues etc. Although many projects have been conducted in the name of Intelligent Environment, they have different emphases. Some focus on the integration of different sensing modalities [Coen 1999, HAL 2000], some aim at the adaptability of Intelligent Environment to user's preference [Mozer 1999], some are interested in automatic capture of events and rich interactions that occurs in a Intelligent Environment [eClass 2000, Adowd 2000], and some target at facilitating the collaboration of

multi-user multi-device within a technology-rich environment [Interactive Workspace 2000, Fox 2000]. We can easily enumerate several other ongoing Intelligent Environment project with different specializations, such as Georgia Tech's Aware Home [Aware Home 1999, Kidd 1999], IBM Research's DreamSpace [DreamSpace], Microsoft Research's EasyLiving [EasyLiving] etc. Because our institute has been committing itself to the research and application of human-computer interaction, media integration, CSCW, distance learning, etc., we developed special interest in exploring the impact of ubiquitous computing to education. This leads to the project of Smart Classroom.

In the later rest of this paper, we're going to first present our views of futuristic classroom in UBICOMP. And then toward the ideal model of classroom, which sounds a little Utopian, we'll explain the idea and focus of our exploration. Later some details in the design and implementation of our present work will be illustrated. We'll conclude by a short description of our future goals.

2. What Should Classroom in The Era of UBICOMP Be Like?

Michael H. Coen from MIT Artificial Intelligence Lab said, "Predicting the future is notoriously difficult". [Coen 1999] Yes, we're not able to prescribe what future would be, but we're able to create toward what we think it would be. In our point of view, the following features are essential to a smart classroom in the era of UBICOMP, and will serve as the guidelines in our ongoing Smart Classroom project.

We have generalized four characteristics of futuristic classroom, which are: natural user interface, automatic capture of class events and experience, context-awareness and proactive service, collaborative work support. Most of these features are directly inherited from Intelligent Environment except for the last one, which is prominently important for a smart classroom while not a requisite of a general Intelligent Environment.

Natural user interface

As Mark Weiser has observed, "Applications are of course the whole point of ubiquitous computing". In accordance with this essence of UBICOMP, it is necessary for a smart classroom to free its occupant's attention to computer. To rescue people's energy from irrelevant interaction with computer to the intentioned goal, allowing user's interaction with computer in as natural a manner as possible is vital. In such a new

paradigm of human-computer interaction, people convey information to computer through their most familiar and accustomed ways like voice, gesture, eye-gaze, expressions etc. Auxiliary input devices like keyboard, mouse, are not necessary. In the reverse side, computer tends to serve people like an intelligent assistant. It utilizes technologies like projector display, voice synthesis, talking head, etc to be as animate as a human being. This is what we call natural user interface.

To get clearer image, suppose a lecturer in the Smart Classroom commanding through voice. "Let's go to chapter two". Computer recognizes the command through voice analysis and projects the wanted courseware of chapter two on display. Lecturer also uses hand gesture as a virtual mouse to annotate on the projected electronic board. Through combination of eye gaze (or finger pointing) and voice command, lecturer can zoomed in the image of an area in the projector to give emphasized explanation on a specific topic.

Automatic capture of class events and experience

This is what eClass project of Gatech called "automated capture, integration and access" problem []. We use computer in classroom not only to enhance the quality of education activity, but also to augment its capability, which was impracticable traditionally. The automatic capture of class event and experience belongs to such capabilities. It's not just record of video and audio in the environment, which is common in traditional distance learning-television broadcasting program. It includes the record of group collaboration, multimedia events, multiple channels of human computer interaction, etc, all the events and experience that happened in the environment. The captured events and experience should be assembled into a kind of multimedia compound document. People can recreate the class experience by play the recorded multimedia compound document, and also can search a specific event or query knowledge within the compound document. This technology provides lecture content to students who are unable to attend the class in person, as well as to those who wish to review the material at a later time.

For example, suppose a lecturer giving a class on Artificial Intelligence in a Smart Classroom. All the audio, video information, lecturer's annotation events, student's question events, Smart Classroom's controlling of lights, slides, etc, are recorded into a multimedia compound document. When a student wants to review the knowledge of Alpha-Beta Pruning problem, he can just query about it through his hand-held computer, and rewind to the previous

talk on it for a quick review and then comes back. After the class, students can also replay the document to recreate the class experience.

Context-awareness and proactive service

What is context-awareness? According to Dey & Abowd (from Gatech 1999), "context is any information that can be used to characterize the situation of an entity, where an entity can be a person, place, physical or computational object", "context-awareness is the use of context to provide task-relevant information and/or services to a user, wherever they may be". Which means the Intelligent Environment can understand user's intention not only based on audio-visual inputs, but also based on its situational information. Proactive service means to serve the user without his request. Proactive service is based on the Intelligent Environment's capability of Context-awareness. This model of service is disparate from traditional human-computer interaction paradigm, in which computer respond to human's explicit command. In the Intelligent Environment, the computer remembers the past, recognize the present, and predicate the future. It reasons human's intention through analysis of all the information collected based on its accumulated knowledge base. Then it tries to serve its occupant proactively with the reasoned intention of its user.

For example, the lecturer is explaining a formula displayed on the electronic board. When the lecturer points at it and starts to talk about it, the computer understands that the lecturer is going to attract students' attention to the specific area of display. Then it zooms in the area in the display of that formula without the lecturer having to command "Zoom in this region". Another example, when the lecturer wants to have a student named Jack to give his opinion on a topic, he points at the student and says, "Jack, would you please say something about what you think of this problem?". The computer then automatically focuses the video camera and microphone array on Jack and filters the noise emitted from spaces other than Jack's place.

Collaborative work support

Class is essentially a procedure consisting of multiple persons' participation. In the environment of ubiquitous computing, the introduction of many interconnected computing devices and wide area network support enables us to extend beyond the space boundaries imposed by traditional classrooms. With this technological advance, collaborations of multi-user and multi-device can be possible. And the support for collaboration is becoming a requisite of a smart classroom. The collaborative work support of a Smart Classroom

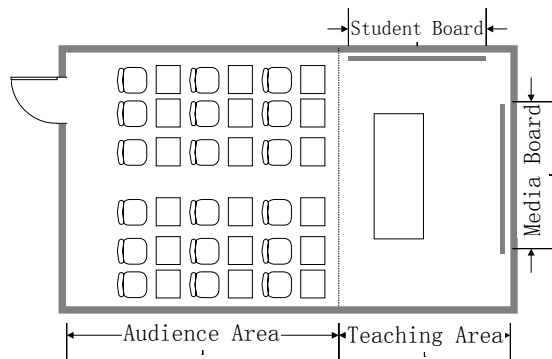
can be categorized into two classes. One is the collaboration of multiple attendants within the Smart Classroom holding various computing devices like, pen-based devices, hand-held devices and wearable computer etc. The other is the collaboration of remote participants and local attendants. The demand for collaboration support is so obvious that many commonly observed tasks in a classroom, like group discussion, need the collaboration of multiple persons. There are some projects specialized in enabling and exploiting smart classroom's collaboration support, such as collaborative note-taking in both Gatech's eClass [eClass 2000] and Stanford's Interactive Workspaces [Interactive Workspaces 2000].

3. The Focus of Smart Classroom

Smart Classroom is a big project, every above-mentioned aspect of it is challenging and a long-term effort. Our institute has been committing itself to the research on multimodal human computer interfaces, CSCW in wide area network, and also multimedia integration. We have accumulated some techniques and experience in exploring Smart Classroom's following features: natural user interface, automatic capture of classroom events and experience, and collaborative work support. So in initial phase of our project, we focus on applying our previous research achievements to realize an experimental environment. We have set up the physical experimental environment to demonstrate our idea and focus. In this Smart Classroom, we mainly aim at enabling lecturer's natural use of Smart Classroom to give lessons through gesture and voice command, enabling Smart Classroom's capture of class events and experience such as operations on courseware, video-audio streams of class, etc for later review and search, enabling remote students' joining of the class with all kinds of mobile computing devices. In order to give clearer image of our research, an elaboration of the physical experimental environment layout and its user-experience scenario are given as following.

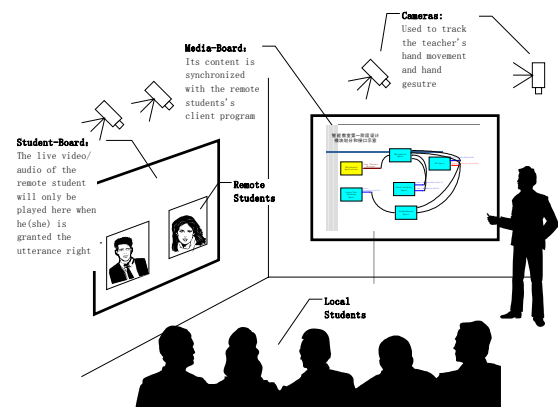
Like MIT AI lab's Intelligent Room, our Smart Classroom is physically built in a separate room of our lab. Several video cameras, microphones are installed in it to sense human's gesture, motion and utterance. According to UBICOMP's characteristic of invisibility, we deliberately removed all the computers out of sight. Two wall-sized projector displays are mounted on two vertically crossed walls. According to their purposes, they are called "Media Board" and "Student Board" separately. The Media Board is used for lecturer's use as a

blackboard, on which prepared electronic courseware and lecturers' annotation are displayed. The Student Board is used for displaying the status and information of remote students, who are part of the class via Internet. The classroom is divided into two areas, complying with the real world classroom's model. One is the teaching area, where is close to the two boards and usually dominated by lecturer. The other is the audience area, where is the place for local students. Why are both remote students and local students supported in this room? The answer is simple, that we're complying with the philosophy of Natural and Augmented. Natural means we'll obey real-world model of classroom as much as possible to provide lecturer and students the feeling of reality and familiarity, which leads to the existence of local students. Augmented means we'll try to extend beyond the limitation imposed by the incapability of traditional technology, which is the reason for remote student.



In Smart Classroom, users' rights to use the room are mapped to their identification. There is an audio-visual identification module identifying the identity of users in this room and authorize control right to lecturer. With the help of visual motion-tracking module, Smart Classroom can be aware of its occupants' places in the room. Once a user identified as lecturer entering the teaching area, he is supposed to control the Smart Classroom by voice and gesture command. Lecturer can use hand-gesture as a virtual mouse on the Media Board to annotate, or add/move objects on the electronic board. He can also command linking in courseware, execute operations like scrolling pages, removing objects, granting speech right, etc by voice. All the lecturer's operation on the courseware and audio-video information captured in the Smart Classroom are automatically recorded and integrated to a multimedia compound document. The recorded information is also lively broadcasted to remote Students via Internet synchronously. Through software's application layer trans-coding and adaptive reliable multicast transport, remote students are promised to join the

class with devices varied in computational power and display resolution through heterogeneous network varied in quality of service.



The following is a typical user-experience scenario happened within the Smart Classroom. Multiple persons enter the room through the door. At the door, there is an audio-visual identification module identifying the entering person's identity through facial and voice identification. If the person is identified as lecturer, he is granted the control right of the Smart Classroom. The visual motion-track module tracks the lecturer's motion in the room. Once he steps into the teaching area, he is supposed to be able to use gesture and voice command to exploit the Smart Classroom to give lessons. Persons in the Smart Classroom other than lecturer are deemed as local students. When the lecturer is in the teaching area, he can start the class by just saying, "Now let's start our class." The Smart Classroom then launches necessary modules as Virtual Mouse agent, Same View agent (which will be talked about later). Lecturer loads prepared electronic courseware by utterance like, "Go to Chapter 1 of Multimedia course". The HTML-based courseware is then projected on the wall display. Lecturer can use hand-motion to stimulate the Virtual Mouse agent to annotate on the electronic board. Different hand gestures have been assigned different semantic meanings, which cause several operations like highlighting, annotating, adding pictures, remove object, executing links, scrolling pages etc, on the electronic board. Lecturer can also grant speech right to remote students by finger pointing or voice command, like "Alan, please give us your opinion". On the Student Board, remote students' photos and some information as name, role, speech right etc are displayed. When a remote student pleads for speech right, his icon on the Student board twinkles. Once the lecturer grants speech right to a specific remote student, his video and audio streams are synchronously played both in the Smart Classroom and on other remote students'

computers.

4. Details of Smart Classroom's Design and Implementation

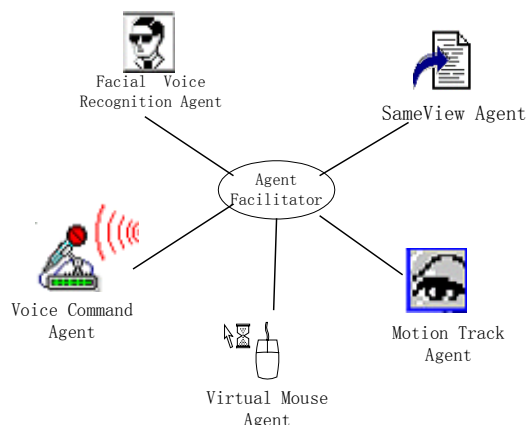
The Smart Classroom is essentially a distributed parallel computing environment, in which many distributed software/hardware modules collaborate to accomplish specific jobs. Software infrastructure is the enabling technology to provide facilities for software components' collaboration. There are some candidate solutions to software infrastructure, such as Distributed Component-Oriented Model, like EJB, CORBA, DCOM, etc, and Multi-Agent Systems (MAS). In the context of Intelligent Environment, Multi-Agent System is more competent than Distributed Component-Oriented Model due to the following reasons: higher encapsulation level, faster evolution from design to implementation, easier development and debugging, and most importantly, more accordant to the need of dynamic reconfiguration and loose-coupling.

In current stage, instead of developing our own Multi-Agent System, we choose to use SRI's famous open source MAS product, Open Agent Architecture. There're already many successful multimodal human-computer interaction projects built on OAA. Its delegating computing model also fits well in our need of software infrastructure. In OAA's delegating computing model, the network of distributed software modules is conceptualized as a dynamic community of agents, where multiple agents contribute services to the community. When external services or information are required by a given agent, instead of calling a known subroutine or asking a specific agent to perform a task, the agent submits a high-level expression describing the needs and attributes of the request to a specialized *Facilitator agent*. The Facilitator agent will make decisions about which agents are available and capable of handling sub-parts of the request, and will manage all agent interactions required to handle the complex query. Such a distributed agent architecture allows the construction of systems that are more flexible and adaptable than distributed object frameworks. Individual agents can be dynamically added to the community, extending the functionality that the agent community can provide as a whole. The agent system is also able to adapt to available resources in a way that hard-coded distributed objects systems can't.

In the schematic figure of our Smart Classroom there're five dedicated agents (except for the Facilitator agent of OAA). The Facial-voice identification agent is in charge of the Smart

Classroom's login identification and authentication. When a person entering the room, he is required to place his face into a specific zone of a video camera's capture range, and say a login word. The vision-part of the agent identifies the person by searching in a pre-trained user library, and the voice-part authenticates the identified person by voice-based speaker recognition.

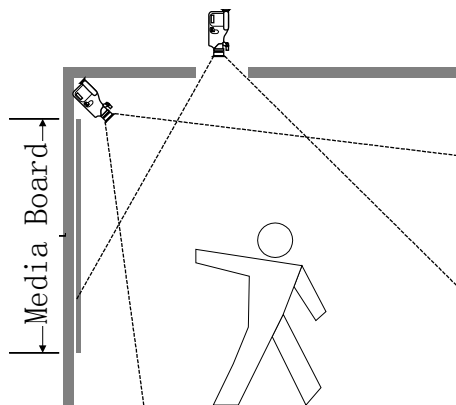
The motion-tracking agent is a computer vision based agent. There's a pan-tilt video camera mounted on the upper side of the front wall, monitoring the whole range of the room. The motion-tracking agent receives video stream input from the camera and tracks the lecturer's position and movements in the room. When lecturer enters /leaves the teaching area, motion-tracking agent will signal the corresponding events to the agent society.



The Smart Classroom's voice command support is realized by a speaker independent continuous speech recognition agent. We use IBM's simplified Chinese version of ViaVoice SDK to wrap the voice recognition agent. The agent receives digitized signals sampled and transmitted from a wireless microphone, which is carried by the lecturer. And then recognizes its command within a dynamically loaded vocabulary set. Once a recognizable command is reached, the voice recognition agent dispatches that command to the agent society. Other corresponding agent is responsible for the execution of that command.

The Virtual Mouse agent is used for hand-gesture's stimulation of mouse events and shortcut command to activate operations on the electronic multimedia courseware, which is displayed on the projector. It's also a vision-based agent. There are two video cameras specialized for the sake of virtual mouse event recognition. One is installed on the top of the projection display, the other is mounted on the ceiling of the room. Through the analysis of the two camera's video stream, the track and recognition of hand's 3D movements and gestures can be accomplished

based on some computer-vision algorithm. The virtual mouse agent then dispatches the recognized mouse event or shortcut command to the agent society.



SameView agent plays a core role in our Smart Classroom's pedagogical scenario. It is based on a legacy desktop application, namely SameView, which is developed by media group of our institute. The purpose of SameView is to provide multimedia group discussion software for sparsely distributed users via heterogeneous networks. SameView has the following features: a shared MediaBoard (multimedia extensions to traditional electronic whiteboard), adaptive multimedia contents trans-coding according to terminal's network Qos and computing power, adaptive reliable multicast in wide range of heterogeneous networks, live capture of video/audio streams and multimedia events into self-defined multimedia compound document, post-edit and playback of the captured multimedia compound document, self-equipped authoring tools for courseware-editing.

In our Smart Classroom, we leverage the SameView's desktop version code as much as possible. We only revised some of its input/output user interface, such as adding a separate Student Board for display by exploiting dual display adapter card support of Microsoft Windows 98/2000, projecting the Media Board in full-screen mode to remove the vestiges of desktop software with the Windows-style menu, toolbar, title bar, etc. The most crucial reformation to SameView is the wrapping of it as an autonomous agent in Smart Classroom's agent community, which enables it to receive user's natural input from other dedicated agents like voice command recognition agent and virtual mouse etc. and then behave interactively.

5. Conclusion: Future goals for Smart Classroom

Our current stage Smart Classroom is a primitive prototype of futuristic classrooms, which attempts to embody some of its distinguishing features like natural use of computer, capture of class events and collaborative support. It is still far from a real Smart Classroom. Its resolutions to some key problems in Intelligent Environment are simple, intuitive and somewhat application-specific. Although many research issues need to be addressed in order to realize genuine Smart Classroom, we stride forward the first step toward the ambitious goal. In the near future, we'll make efforts in enhancing the Smart Classroom in some of the following aspects.

Add more modalities and applications.

We'll try to equip some more modalities of human inputs like vision-based tracker, embedded microphone array and various distributed sensors to sense human's context. And progress in the sensing technologies needs to be matched by progress in applications that use sensed information. Application is one of the key driving forces of technical advance. We'll conceive more realistic and useful scenarios in the Smart Classroom and also cooperate with different research groups whose application projects have high potential to take advantage of the capability of Smart Classroom. We believe the rise in the amount and sort of applications will enable generalization of Smart Classroom's design and implementation.

Add a brain.

The current design implementation of the Smart Classroom focus on the human's natural input to the computing environment, the next step is to move a higher level and to give it the ability to understand. It is not just to utilize multimodal interface, but also to add-on context-aware intelligence. The classroom should be able to reason human's intention through analysis of all the gathered inputs and proactively serve its occupants. There is some research studies in reasoning human's intention based on predefined grammars or probabilistic statistical model. Each of them has innate weakness. We'll try to explore the combination of them.

Add multi-user interaction.

In the current stage Smart Classroom, there is only one user (lecturer) naturally interacting with the Intelligent Environment Other attendants are just watchers or listeners and are not able to exploit the fascinating features of natural interaction. Because a class is bound to have multiple participants, to make a qualified Smart Classroom, we need to enhance the classroom's support for multi-user interaction. In our next step, we'll empower the classroom

with capability to track and identify more than one user dynamically, and enable Smart Classroom's in-place service to every user in the room.

6. Acknowledgement

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