Collaborative Augmented Reality: A Prototype for Industrial Training

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Abstract

In this paper, we describe a prototype of a collaborative industrial teletraining system, based on distributed augmented reality. Augmented reality typically interfaced by a wearable computer is a natural method to present computer-based tools by merging graphics with a view of the real world. Distribution enables users on remote sites to collaborate on the training tasks by sharing the view of the local user equipped with a wearable computer. In this prototype, the users can interactively manipulate virtual objects that substitute for real objects, try out and discuss the training tasks.

Keyword: Augmented Reality, Wearable Computing, Computer Supported Collaborative Work, Industrial Training

1. Introduction

1.1 Background

Augmented Reality (AR) is a powerful user interface paradigm enhancing a user's perception by incorporating the computer-generated information into the real world. It is a variation of virtual reality. With AR, the user interacts with the real world in a natural way, simultaneously use the computer to explore related information and to interact with computer-generated virtual objects. In contrast, the user of virtual reality completely immerses into a synthetic environment.

The combination of the virtual and real world in AR is accomplished by a Head-mounted Device (HMD) and tracking devices, i.e. a head-mounted camera or magnetic tracker. In a typical vision-based AR system a user is wearing a HMD equipped with one or two cameras. When he looks around, certain features in the video images captured by the camera are detected to track the camera's position and orientation relative to the objects in the real world. Then the graphic images generated with this information are rendered on the HMD.

Wearable computers are the next generation of mobile computing devices. In general, a wearable computer may be defined as a computer that is subsumed into the personal space of the user [9]. A typical wearable computer may be composed of a computer processor and a battery mounted on a belt or backpack, a head mounted display (HMD), wireless communications hardware and an input device such as a touchpad or chording keyboard or voice input capabilities. A wearable computer enables mobility and promises exciting applications with augmented reality. Some of them have already been demonstrated. A prominent example is Columbia's "Touring Machine"[1], which assists a user in locating places and allowing a user to query information about items of interest, like campus buildings, library, etc.

1.2 Collaborative Augmented Reality

Computer supported collaborative work (CSCW) allows the computer to be used as a medium for human communication. Several attempts have been made to construct more informative and natural collaborative workspaces with a wearable computer. The NETMAN[2] proposes a collaborative wearable computer system that supports computer technicians in their task of maintaining a campus network with the help of remote experts, but this system doesn't support augmented reality.

There is a number of researchers that have already developed table-top AR systems for supporting face-to-face collaboration. The AR2 Hockey system of Ohshima [3] allows two users to play virtual air hockey against each other. A game of Augmented Reality Chess demonstrates collaboration of the stationary user with the mobile user in Reitmayr's system [4]. However, the users in these systems have to be present in the same physical space and share it. The remote users can not join the shared space and do the collaboration work.

Training costs are a considerable part of expenses for many industries, especially when the customers or employees need to learn to use equipment or devices that are expensive and costly to repair. The problem is compounded when the trainers are far from the would-be trainees. A Collaborative Virtual Environment (CVE) is one of the solutions for industrial training and a prototype CVE was developed at the Multimedia Communications Research Lab, University of Ottawa [5]. However, with this system the trainees are completely immersed in the computer-generated virtual environment and separated from the real world. With the training experience in a virtual environment, the trainees may be still confused as to when they are doing the real world task. Collaborative Augmented Reality (CAR) is an attractive solution to this problem. CAR embeds computer-based tools in the users' real environment and enables users experience a real training exercise with a shared space that is filled with both real and virtual objects.

1.3 Contribution

In this paper we explore the possibility of a shared mobile 3D workspace for collaborative augmented reality. We present a collaborative augmented reality prototype for industrial training with the following characteristics.

- Virtual information, such as annotation and 3D virtual objects, is superimposed on the real world environment of the wearable computer users.
- A personal workspace surrounding the wearable computer user allows him/her to organize the 3D models spatially and directly interact with them in a natural way.
- Remote users can share the augmented reality workspace of one wearable computer user, see what he/she sees and watch his/her action as if the remote users are present in the physical world.
- Instead of working with the physical objects, the remote users manipulate and interact with the virtual objects placed in the augmented reality workspace as in the physical space gaining some valuable experience.
- The users can engage real-time audio conversation such as discussing the real world task and give some advice or instruction to the wearable user.

Several challenges need to be addressed to realize the described characteristics. Distributed applications need real time synchronization of shared data to present the same state to all users. A good control mechanism and flexible support for interaction and collaboration tasks in distributed AR applications need to be provided. In this paper, we propose an architectural solution for our distributed AR prototype, and investigate the main issues that arise from distributing an AR application between multiple users. Some mechanisms for supporting interaction and collaboration tasks are provided and discussed.

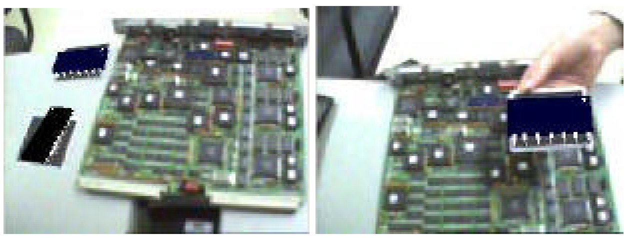
Our prototype is created for an industrial training application. However, it can be applied to other applications. In the following section we will describe our prototype for industrial training, and in section 3, we will explain the system design issues, including the design considerations, system architecture and some software models. In section 4, the experimental results are discussed. And a conclusion is given in section 5.

2. Prototype

Figure 1. A trainee works with a wearable computer

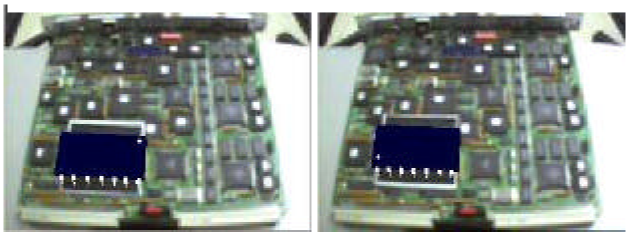
Imagine a trainer and some trainees are in different locations. The trainees are trained to install a chip on a switch board. As shown in figure 1, a trainee wearing a wearable computer is going to work with a physical switch board on the table. Let's refer to him/her as the local trainee A. A trainer T and a remote trainee B who are in different locations are working on the remote workstations, watching A's action through the shared view of the local trainee. All of them are equipped with a microphone and are able to talk through live audio.

Figure 2 shows the screenshots of a collaborative training exercise running with our system. When local trainee A is looking at the table, he can see two different virtual chips around a physical switch board, as shown in figure 2(a). One virtual chip has nine pairs of pins while another chip has seven pairs of pins. As shown in figure 2(b), trainee A picks up the chip with seven pairs of pins and move it to be close to the switch board. As shown in figure 2(c), the chip is laid on the socket with all of the pins lined up and the pin 1 marked with white dot on the chip surface is on the top right of the figure. Remote trainee B would try to install the chip in another way and he shows the trainer T and the trainee A his idea by orientating the virtual object with the keyboard or mouse. As shown in figure 2(d), the virtual chip is rotated by trainee B with the small white dot on the bottom left of the picture. Trainer T point out that both of the pin1 and the socket should be matched up for correct installation else it will produce serious damage to the chip. Through this interactive "real" training exercise the trainees can gain valuable experience.



(a) A physical board with virtual chips around

(b) Local trainee A is moving a virtual chip



(c) A virtual chip is laid on the board

(d) The virtual chip is rotated by remote trainee B

Figure 2. Installing a chip

3. System Design

3.1 Design Considerations

In this system, the visualization end points that allow the users to participate in the collaborative augmented reality workspace include:

- Wearable computers worn by trainees in the real-world task;
- Desk-bound workstations used by the trainer and other trainees in the remote location.

All of these visualization end points are connected with a network. Since the system consists of multiple users, and they have to share some information such as video and interaction data, so we designed this system in distributed client/server architecture. The clients refer to the above visualization end points. With this architecture the system has more extension capability. Our system can support 64 clients at maximum at the same time.

To decide where and which virtual objects should be superimposed on the real world. Certain features have to be in the view to calculate the camera viewpoint relative to the real world and to recognize the virtual object identification. Currently we use the technique proposed by kato-billinghurst-Weghorst-Furness[6] for this target. In their proposal, a marker with a square region and some pattern inside of the square region is used to track the camera viewpoint relative to the marker and recognize the marker's identification which identifies the virtual object to be superimposed.

The computational tasks that operate on the pose tracking, virtual object recognition and rendering tasks that generate graphic images to be visualized could be time consuming and computationally intensive, especially if the data being explored are complex and huge. This invariably leads to very low frame rates. According to a research by Durlach [7], delays greater than 60ms between head motion and visual feedback impair adaptation and the illusion of presence. A collaborative augmented reality system needs to provide the minimum frame rate (10 frame/sec), while collaborating with other users in parallel.

We allocate the tracking process to the server for the following advantages:

- Reduce the workload of the wearable computer that has lower battery and CPU speed compared with PC workstation;
- Centralize the media database. The update to the media database in the server will be propagated to the clients in the initiate procedure.

3.2 Architecture

The system is a distributed system that consists of two kinds of major components: the server; and one or more clients including wearable computers and workstations. Figure 3 shows the flow diagram of the system. To simplify the diagram and clearly present the flow of the system, we show three components: a server, a wearable computer and a workstation. The implementation for both system components, i.e. wearable computer and workstation, is the same.

As shown in Figure 3, the camera in the wearable computer captures the video images. The video image is rendered in the display screen of HMD. The encoded video image and other status information are packed and sent to the server. The server receives and unpacks the data. The encoded image is decoded and analyzed by the tracking routine to calculate the camera pose and marker's

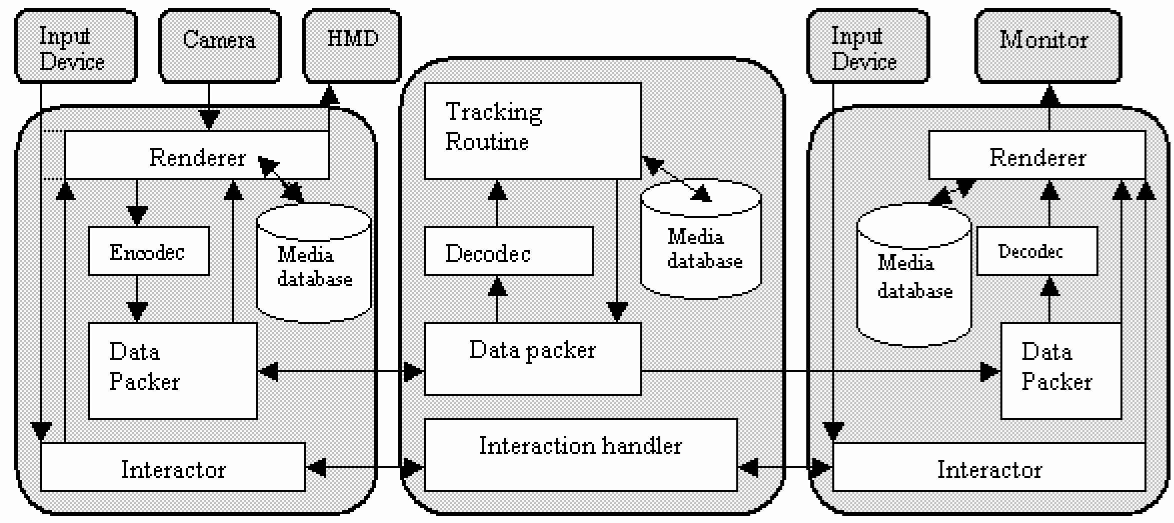


Figure 3. System Diagram

identification in the server. Then the marker's identification and camera transformation matrix are sent back to the wearable computer. The wearable computer extracts the 3D model from media database according to the marker's identification, and generates the graphic image and renders it.

The server also sends the encoded video image, marker's identification and camera transformation matrix to the workstation. The workstation unpacks the data and decodes the video image. The 3D model is extracted from media database according to the marker's identification. The workstation generates the graphic image and renders it with the video image onto the monitor.

3.3 Communication

The communication layer is responsible for all the exchange of information amongst users. In our system, the communication is comprised of two primary components: video handling and a database component called interaction handling.

3.3.1 Video Handling

In our system, the JPEG compression/decompression technique is used to encode/decode the video images. We also use the data packer to pack and unpack the data before they are transmitted. The data packet of the encoded video image, the camera transformation matrix and the marker's identification are transmitted with reliable TCP.

3.3.2 Interaction Handling

We use a distributed shared memory technique via a database class to disperse the interaction events between participants. When a participant manipulates a virtual object with the keyboard or mouse, this event will update the database and it will be propagated to all the subscribers of the database via the server. The subscribers will be notified via a callback function. The updates are sent to the server with UDP as the data package is small and the loss of it won't affect the synchronization between the clients. The server will then forward the data to all of the clients with reliable TCP as any loss of this information could lead to misunderstandings in the communication between participants. The database server can arbitrate any conflicts and maintain a uniformity to ensure consistency in the shared environment.

To enforce greater consistency requirements, a locking mechanism to lock data on a shared memory is provided so that only a single client may update the shared memory at any one time. Attempts by other clients to update the memory will be ignored.

3.3.3 Latecomer Support

In collaboration applications, some participants may join the application at a later time. In our application, the server will check for new clients regularly and add them to the client list when found. As long as the new comer subscribes to the shared memory of the specific data, it will be sent the data in the shared memory and keep the same state with the other subscribers.

3.3 Audio Conference

The audio capturing module allows participants to enter into an audio-conferencing session. The module is based on the Microsoft NetMeeting SDK.

The system is implemented in C and C++. The clients run on Windows98 and the server runs on Windows2000. We use CAVERNsoft [8], a C++ toolkit for building tele-immersive applications, for communication between the clients and the server.

4. Experimental Results & Discussion

We tested our prototype with three Pentium III workstations equipped with GetForce2Go video chip on MS Windows 2000. One workstation works as a server and the other two work as clients, while one of them is equipped with a video camera. The workstations are connected via a 10M Ethernet. With this testbed our prototype maintains 15 frame/seconds update rate. Currently, our research lab is equipped with a Xybernaut MA IV wearable computer with a 233 MHz Pentium MMX. We also run the prototype in the wearable computer, but the frame rate is limited to 3 frames/second since the wearable computer doesn't have OpenGL capacity. So a powerful wearable computer with a good 3D accelerator is recommended. A possible alternative could be a powerful laptop carried by the user in a backpack and equipped with a GetForce2Go video chip and an I-glass see-through stereoscopic color Head Mounted Display mounted with a camera.

During the manipulation of the virtual objects, the local user can pick up a virtual object with a marker and manipulate it very flexibly. To manipulate the virtual objects in the remote site, we try both of the methods of manipulation through mouse and keyboard. It is difficult to manipulate models with any precision in the 3D space with a 2D mouse. When more than one virtual objects are in the scene, the problem arises of how to choose one of the virtual objects to manipulate. As a special element of the augmented reality application, the view update is at least 10 frames per second when the user moves around. It is difficult to pick one of the virtual objects in the scene with the mouse. With the keyboard, we choose the virtual object with the known identification number and operate with a specified key to manipulate the virtual objects. This avoids the drawback of a 2D mouse and is very flexible to operate.

5. Conclusion and Future Work

In this paper, we described a prototype developed for industrial teletraining which features augmented reality and collaboration. The different components of the prototype were introduced and data communication issues in the system were explained. The different ways of remote manipulation of the virtual models in the shared augmented reality workspace were discussed.

In the near future, we intend to improve the prototype in various ways. The user interface and interaction methods need enhancement to make manipulation of graphical objects easier, and to convey more awareness of the collaboration.

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