Simple Collaborative Indoor-Outdoor Modelling Using Mobile Augmented Reality

Wayne Piekarski[1]

[1]Wearable Computer Lab
University of South Australia
Mawson Lakes Bvd, Mawson Lakes
Adelaide, SA, 5095, Australia
Tel. +61 8 8302 5070 Fax +61 8 8302 3381
wayne@cs.unisa.edu.au, http://www.tinmith.net/wayne

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1. Introduction

This paper presents some preliminary results from research we have been performing in the area of collaborative 3D modelling with augmented reality (AR). While there has been a wide range of research work investigating problems such as displays and registration (Rolland and Fuchs 2000), tracking (Welch and Foxlin 2002), and user interfaces (Azuma *et al.* 2001), these systems are primarily focussed on improving the experience for a single, stand-alone user. Previously, we have presented a number of prototypes that allow users to perform real-time 3D modelling using a mobile AR system (Piekarski and Thomas 2003a) (Piekarski and Thomas 2004), but these were standalone applications for single users to operate. In previous papers describing our software architecture (Piekarski and Thomas 2003b), we have described how the ability to support multi-user collaborative systems is possible. In this paper we describe in more detail collaboration applications that we have developed and how they are implemented.

While the 3D modelling systems we have presented previously solved a number of interesting research questions, these systems were not embedded into commercial quality applications. Applications need to still be designed to solve problems in particular domains, and attempting to build these applications exposes limitations in current user interfaces and technology. We are currently exploring the use of AR to support search and rescue scenarios in outdoor environments. A scenario we envisage is where a disaster has caused buildings to collapse with people trapped in the rubble. By giving some rescue workers AR systems, they will be able to see the geometry of existing buildings to know where people will likely be trapped, and then coordinate other traditional rescue workers. While this is an interesting application, much of this functionality could be achieved using traditional paper maps. However, in this scenario there are a number of other problems that also need addressing. Teams of workers need to be coordinated by a control centre managing the effort. The control centre knows about the overall picture but not specifics from each local area. The local rescue workers know what they are doing locally but not what is happening elsewhere. If rescue teams are not coordinated effectively then their efficiency is reduced and less people will be rescued in time. Communications is currently performed using simple radios and verbal instructions, with potential confusion resulting in errors that could be life threatening. Therefore it is critical that systems be developed to support these scenarios to improve the effectiveness of both the coordinators and the people out in the field.

We propose the use of mobile AR systems to support more direct communication between indoor coordinators and remote field workers. Indoor coordinators can easily send updates to information over a network, and provide graphical cues to mobile users to tell them where to go and perform their task. The outdoor user's wearable computer is fully aware of its position and viewpoint, and so this information can be sent back to the command centre. The command centre then knows where all their workers are, making management more effective. The outdoor users are able to see graphical information overlaid over their current view, with models of previous buildings shown but also other data such as overlays of instructions and commands for them to follow. These outdoor users can also make graphical annotations to the existing models, and this is communicated back to the command centre and then distributed to other users.

In this paper, we will describe some of the work we are performing to realise the goal described here. The first section of this paper describes related work in the field. We then describe application scenarios that we have tested, followed by implementation details of our system.

2. Related work

Collaborative work using augmented reality has been possible for a number of years in various forms. For example, the Coterie (MacIntyre and Feiner 1996) toolkit was developed to provide language level primitives to support a distributed shared memory. By integrating an in-built interpreted language, tracker abstractions, animation, and a scene graph Repo-3D (MacIntyre and Feiner 1998), applications were developed that were distributed across multiple machines. This software was also used to develop the first mobile outdoor AR system, the single user Touring Machine (Feiner *et al.* 1997).

The Studierstube system (Schmalstieg *et al.* 2000) (Reitmayr and Schmalstieg 2001) is designed to support collaborative augmented reality applications such as shared design tasks. Users can work together in an indoor environment, performing painting and manipulation of 3D objects with the results immediately available for others to see. Studierstube is based on an extended version of OpenInventor, where the scene graph is modified to support distribution transparently (Hesina *et al.* 1999). By embedding all application state into the scene graph, applications can be easily distributed and migrated between machines.

There are a wide range of systems that also support the distribution of scene graphs. Some example systems are DIVE (Frecon and Stenius 1998) and Avocado (Tramberend 1999). By using multicast, DIVE is able to improve scalability and reduce bandwidth usage. Avocado provides similar features as VRML fields and routes, with objects attached to each other and processed using a scripting language.

Based on the designs of these various systems, the Tinmith-evo5 software architecture was developed to support distributed applications for augmented reality (Piekarski and Thomas 2003b). Tinmith has been optimised for the most common cases where all the software runs on a single machine, but supports the ability to distribute information over a network if needed. Internally, Tinmith maintains an object store containing all data in the system within a file system-style structure. It is possible to listen to changes and receive serialised modifications over the network. All objects within Tinmith have been designed from the ground up to be part of this file system model, and so any data (such as user input, trackers, or scene graphs) can be easily sent over the network. In most typical cases, Tinmith sends data only in a single direction and is optimised for this case.

Using the Tinmith-evo5 software architecture, we have developed 3D modelling applications that allow users to work outdoors and construct the geometry of large outdoor shapes such as buildings, grassy areas, trees, and automobiles in real-time. When working in outdoor environments, objects are typically quite large and far away compared to indoor environments, and therefore harder for the user to judge the distance and scale of accurately (Cutting and Vishton 1995). As a result, special modelling techniques known as *augmented reality working planes* were developed to provide surfaces for users to draw against (Piekarski and Thomas 2004). We developed a series of high-level techniques known as *construction at a distance* (CAAD) that allow users to perform constructive solid geometry modelling to create complex shapes out of simple input primitives (Piekarski and Thomas 2003a). The user interface for the modelling application is controlled using a set of custom developed pinch gloves with fiducial marker based tracking. The user can reach out and point at objects to make selections and to make changes, and finger presses are used to select from the presented menu options.

3. Indoor-outdoor collaboration

We have performed some initial investigations into the support for performing collaborative tasks between mobile outdoor users and other indoor users. In our scenarios, a single user wearing a mobile AR system goes outdoors to perform a 3D modelling task. Indoor users sit around a table and view information rendered on displays and projected onto the walls. Each of the displays runs a copy of the Tinmith software, which is able to monitor the mobile system and render the display from any desired viewpoint. Figure 1 shows the immersive AR view experienced by the outdoor user, with their hands being used to carve out the shape of a building in real-time. Figure 2 shows an external VR view of the world, which can also be viewed by the outdoor user if they desire. In this view, the camera is outside of the user's body and shows a virtual sky box around the avatar. Since the Tinmith software supports the distribution of most internal values in the software, a similar view is also accessible from a remote machine. This view can be displayed on an indoor monitor or wall projector, and the indoor user can use a mouse to select a different viewpoint. An example control room we have constructed is shown in Figure 3, containing both LCD projectors and plasma displays. While it is possible to get an immersive view just like the outdoor user, currently the live video stream is not sent over the network.

Figure 1 shows a user constructing a building shape, and these changes are reflected in real-time back to the indoor users located in the control room of Figure 3, viewing images such as in Figure 2 to monitor the progress of the operation. The indoor and outdoor users are connected via an audio stream sent over a wireless network, so that they can discuss the operation in progress. The indoor user is able to guide the outdoor user with the task they need performed, and the indoor user is able to respond by performing the operation or asking for further information to clarify the operation.

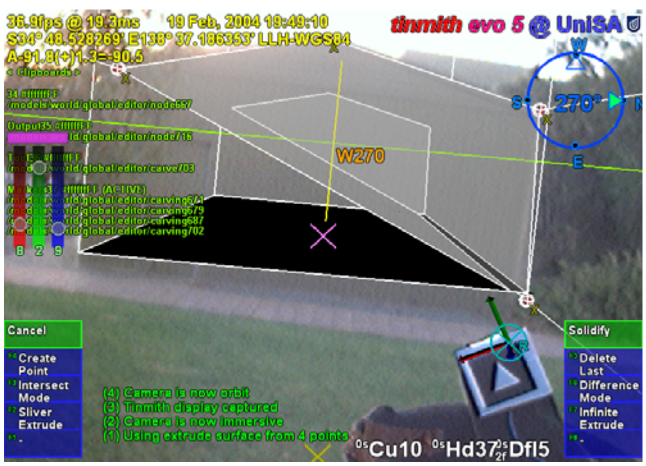

Figure 1 – Building under construction using the laser carving technique. Captured from the immersive view of the outdoor AR user.

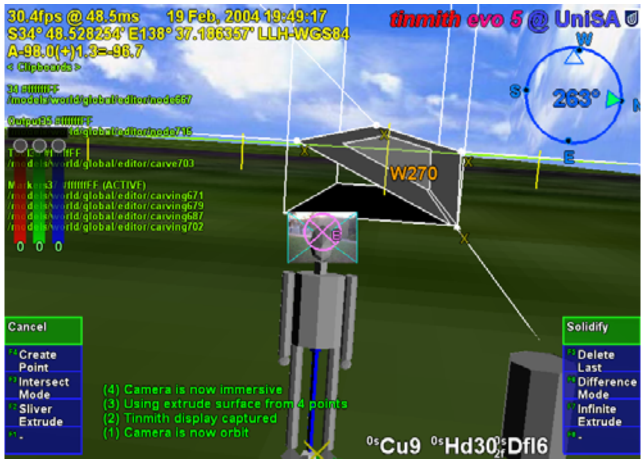

Figure 2 – External view for Figure 1, showing the view that indoor users experience while monitoring the progress of the building task outdoors.

Figure 3 – A view of our indoor command centre, which is configured with multiple displays and projectors showing views such as from Figure 2.

4. Implementation

We are currently using an 802.11 wireless connection to connect the mobile AR systems to the indoor control room. The hardware is configured for 11 Mbps operation but this can drop to 1 Mbps as the distance to the base station increases. Any available internal Tinmith data is available for transport across the wireless network, depending on what the indoor clients request. Tinmith uses a custom XML format for sending only the differences in serialised objects over the network, since most values within an object remain constant. Tinmith also supports a compact binary protocol for devices such as trackers where updates are frequent and can be lost without penalty. The audio is compressed using a GSM-style codec and is bi-directional between indoors and outdoors. Currently we do not implement wireless video, but we are working on suitable compression methods and more capable wireless antennas to support higher bandwidth requirements.

While indoors we employ standard desktop machines with 3D graphics hardware to display to the projectors, we have developed our own custom mobile augmented reality system for use outdoors, as shown in Figure 4. Our system has a single integrated case containing all the components, with a Pentium-M 2.0 GHz processor, 1 Gb RAM, Nvidia GeForce Go 6200, Bluetooth, 802.11 wireless, necessary integration electronics, and two 8 Ah batteries. The helmet uses an IO-Glasses display, InertiaCube3 orientation sensor, Trimble Ag132 GPS, and PointGrey DragonFly camera.

Figure 4 – User wearing the Tinmith 2005 mobile outdoor augmented reality system

5. Conclusion and future work

This paper has presented some of the initial work we have performed to support collaboration between outdoor AR users and indoor control centre users. We have demonstrated the capability of being able to perform simple 3D modelling tasks outdoors, and allowing these results to be monitored indoors in real-time. Indoor users have the ability to communicate with outdoor users, assisting with the process and giving guidance based on higher-level situational awareness than is available to the local outdoor user.

We are currently exploring how multiple outdoor AR users can work with multiple indoor users in a variety of different combinations. Rather than a single user performing a modelling task outdoors, multiple users could work together to perform the modelling techniques from many viewpoints simultaneously, reducing the amount of time and movement needed. One outdoor user could make annotations against an object that has been selected by another outdoor or indoor user. Using more conventional desktop user interfaces, an indoor user could make changes to 3D models that can be seen by outdoor AR users. There are many possible combinations and we are currently in the process of developing frameworks and performing evaluations to understand how powerful collaborative AR applications can be better supported in the future.

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Biography

Dr Wayne Piekarski is the Assistant Director of the Wearable Computer Lab at the University of South Australia. His previous PhD and current research interests are focussed in the areas of 3D user interfaces, input devices, computer graphics, and mobile outdoor augmented reality systems such as Tinmith. Wayne's home page is at http://www.tinmith.net/wayne