COLLABORATION WITH TANGIBLE AUGMENTED REALITY INTERFACES

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ABSTRACT

We describe a design approach, Tangible Augmented Reality, for developing interfaces for supporting face-to-face collaboration. By combining Augmented Reality techniques with Tangible User Interface elements, we can create interfaces in which users can interact with spatial data as easy as real objects. Tangible AR interfaces remove the separation between the real and virtual worlds and so enhance natural face-to-face communication. We describe several prototype applications showing how this design approach can be applied in practice.

1 INTRODUCTION

Computers are increasing being used to support communication and collaboration. However, although many researchers have explored how computers can be used to enhance remote collaboration there has been less work in providing support for face-to-face collaboration. This is particularly true for viewing and manipulating spatial data.

Early attempts at supporting face-to-face collaboration were based around computer conference rooms. For example, the Colab room at Xerox (Stefik 1987) used a network of workstations running distributed software applications designed to support brainstorming, document preparation, and other tasks for small group face-to-face meetings. However user's collaborating on separate workstations, even if they are side by side, do not perform as well as if they were huddled around a single machine (Inkpen 1997). This is because the computer introduces an artificial separation between the task space and communication space, preventing people from being aware of the normal communication cues that are used in a face-to-face setting.

One way of removing this artificial seam is by using Augmented Reality (AR) technology to overlaying virtual imagery directly onto the real world. In this way the display space and communication space can become one. In the Studierstube project co-located users can view and manipulate virtual models while seeing each other in the real world, facilitating very natural face to face communication (Schmalsteig 1996). In earlier work we found that users prefer collaboration in an AR setting than an immersive virtual environment and can perform better on some tasks because they can see each other's non-verbal cues (Billinghurst 1997). However, although AR interfaces provide a natural environment for viewing spatial data it is often challenging to interact with and change the virtual content.

Another approach is through Tangible User Interfaces (TUI) (Ishii 1997). In this case physical objects and ambient spaces are used to interact with digital information. Collaborative Tangible User Interface projects have been developed that use digitally enhanced real objects to support face-to-face collaboration or provide a tangible representation of remote collaborators. For example in the Triangles project (Gorbet 1998) several users can gather around a table and play with electronic triangular objects to compose poetry or interactive stories.

Tangible interfaces are powerful because the physical objects used in them have properties and physical constraints that restrict how they can be manipulated and so are easy to use. Physical objects are also integral to the face-to-face communication process. Brereton finds that design thinking is influenced by the objects in the environment, and that designers actively seek out physical props to aid in face-to-face collaboration (Brereton 2000). Gav finds that people commonly use the resources of the physical world to establish a socially shared meaning (Gav 1997). Physical objects support collaboration both by their appearance, the physical affordances they have, their use as semantic representations, their spatial relationships, and their ability to help focus attention. Thus TUI combine these properties with an intuitive interface for manipulating digital data.

Although intuitive to use, with TUI interfaces information display can be a challenge. It is difficult to dynamically change an object's physical properties, so most information display is confined to image projection on objects or augmented surfaces. In those Tangible interfaces that use three-dimensional graphics there is also often a disconnect between the task space and display space. For example, in the Triangles work, visual representations of the stories are shown on a separate monitor distinct from the physical interface (Gorbet 98). Presentation and manipulation of 3D virtual objects on projection surfaces is difficult, particularly when trying to support multiple users each with independent viewpoints. Most importantly, because the information display is limited to a projection surface, users are not able to pick virtual images off the surface and manipulate them in 3D space as they would a real object.

To overcome the limitations of the AR and TUI approaches and retain the benefits of physical objects in face-to-face collaboration we have been exploring an interface metaphor we call Tangible Augmented Reality (Tangible AR). In the next section we describe this in more detail and in the remainder of the paper present some Tangible AR interfaces for intuitive face-to-face collaboration.

2 TANGIBLE AUGMENTED REALITY

Tangible Augmented Reality interfaces are those in which each virtual object is registered to a physical object and the user interacts with virtual objects by manipulating the corresponding tangible objects. Thus Tangible AR combines the intuitiveness of Tangible User Interfaces with the enhanced display possibilities afforded by Augmented Reality. In the Tangible AR approach the physical objects and interactions are equally as important as the virtual imagery and provide a very intuitive way to interact with the AR interface. The intimate relationship between the real and virtual also naturally supports face-to-face collaboration.

This approach solves a number of problems. Tangible User Interfaces provide seamless interaction with objects, but may introduce a separation between the interaction space and display space. In contrast most AR interfaces overlay graphics on the real world interaction space and so provide a spatially seamless display. However they often force the user to learn different techniques for manipulating virtual content than from normal physical object manipulation or use a different set of tools for interacting with real and virtual objects.

A Tangible AR interface provides true spatial registration and presentation of 3D virtual objects anywhere in the physical environment, while at the same time allowing users to interact with this virtual content using the same techniques as they would with a real physical object. So an ideal Tangible AR interface facilitates seamless display and interaction. This is achieved by using the design principles learned from TUI interfaces, including:

- The use of physical controllers for manipulating virtual content.
- Support for spatial 3D interaction techniques (such as using object proximity).
- Support for both time-multiplexed and space-multiplexed interaction.
- Support for multi-handed interaction.
- Support for Matching the physical constraints of the object to the requirements of the interaction task.
- The ability to support parallel activity where multiple objects are being manipulated.
- Collaboration between multiple participants

Our central hypothesis is that AR interfaces that follow these design principles will naturally support enhaned face-to-face collaboration. In the next section we describe some interfaces we have developed to explore this.

3 SAMPLE INTERFACES

We have tested the Tangible AR approach in a variety of prototype interfaces, including; Shared Space: A collaborative game designed to be used by complete novices, AR PRISM: An interface for geospatial visualisation, and Tiles: A virtual prototyping application.

All of these projects were built on top of ARToolKit, a software library we have developed for computer-vision based AR applications (Kato 99). ARToolKit tracks camera position and orientation relative to a marked card and so can be used to exactly overlay virtual images on real world objects, making it ideal for developing Tangible AR interfaces.

3.1 Shared Space

The Shared Space interface was a game developed for the Siggraph 99 conference to explore how Tangible AR principles could be applied in an application that could be usable by complete novices. In this experience multiple users stood across a table from one another (fig. 1). On the table were marked cards that could be freely moved and picked up. Each of the users wore a lightweight head mounted display (HMD) with a video camera attached in which they can see a view of the real world. When users look at the cards they see three-dimensional virtual objects exactly overlaid on them. The goal of the game is to collaboratively match up the virtual models, by placing related models side by side. When users get a correct match the pair of models is replaced by an animation of the two objects (fig 2).

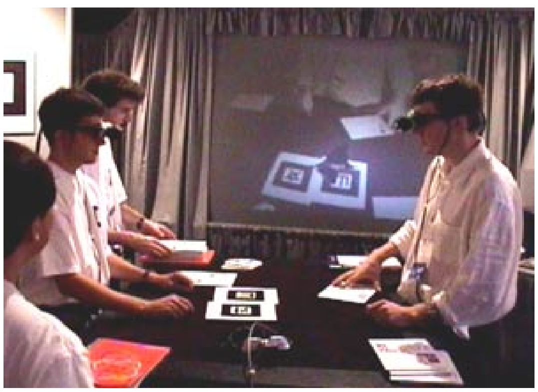

Figure 1: The Shared Space Siggraph 99 Application

Figure 2: Proximity-based Virtual Object Interaction. Placing two related objects side by side plays an animation of the objects interacting.

Over 3,500 people have tried the Shared Space game and given us feedback. Users had no difficulty with the interface. They found it natural to pick up and manipulate the physical cards to view the virtual objects from every angle. Since the matches were not obvious some users needed help from others at the table and players would often spontaneously collaborate with strangers who had the matching card they needed. They would pass cards between each other, and collaboratively view virtual objects and completed animations. By combining a tangible object with virtual image we found that even young children could play and enjoy the game. In surveys conducted users felt that they could easily collaborate with the other players and interact with the virtual objects.

3.2 AR PRISM

The AR PRISM interface explored how Tangible AR techniques could be used to support face to face collaboration and object-based interaction with the users environment. The application domain was geographic data visualization and the underlying idea was that multiple users gathered around a real map should be able to see and manipulate three-dimensional virtual geographic information superimposed on the map while seeing each other in the real world. This manipulation should be based on physical markers and tangible interaction techniques. To achieve this the interface combined the ARToolKit tracking technology with an overhead camera that could track object positions and hand gestures relative to a real map. Users stood around the real map looking at it through HMDs with small cameras attached. As the user moved their hand across the surface of the map in their HMD they saw a graphic overlay of longitude and latitude information for the location their hand was pointing at and icons representing data available at that point. If the user wanted to view some of the geological dataset they placed a terrain marker on the map (figure

3) and they would see a virtual terrain model of that location (figure 4). Users could then pick up the models, look at them from any angle, and pass them to each other.

Figure 3: Using AR PRISM

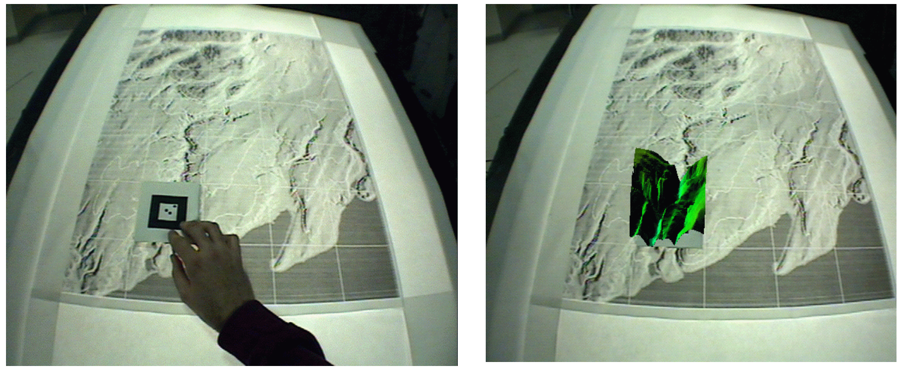

Figure 4: The view inside the Head Mounted Display. As a user places a tile over the real map, a virtual 3D terrain model is shown at that location.

If the user wanted to see a new portion of the virtual terrain they simply moved the marker to a new map location, the system recognized the new location and swaped terrain models. The AR scene and real map were aligned so that features seen on the map could be seen in the three-dimensional virtual model overlaying the same map location. In addition to showing virtual terrain models we also implemented a "Sensor-Data" metapor where other markers could be placed beside the virtual terrain marker to load additional data. For every grid location in the real map there was three-dimensional topographic information available, and for some locations there was also soil, hydrology and well information. So placing a soil tile beside the terrain model would cause the texture on the terrain model to change to show soil type information. Similarly, placing the well marker beside the terrain model would show sub-surface wells.

We are in the process of conducting formal user studies with the AR PRISM interface, although almost one hundred people have tried the software informally. These users generally found the software very easy to use and felt that being able to lift pieces of virtual terrain off the real map was a very compelling experience. Associating a virtual dataset with a physical object meant that this data was as easy to manipulate as the real object. They also liked the ability to see other users in the real world at the same time as seeing the AR model, and felt that this supported natural face-to-face collaboration. However they felt that the HMDs were encumbering and did not provide high enough resolution to clearly read the real map.

3.3 Tiles

Tiles is an AR authoring interface that explored how more complicated functionality could be supported using tangible 3D widgets. The application domain was rapid prototyping for aircraft instrument panels and the interface consisted of a metal whiteboard, a book, and two stacks of magnetic tiles. Using Tiles, one or more users would sit in front of the whiteboard and collaboratively lay out a virtual aircraft instrument panel (Figure 5).

The various tangible elements of the interface served a different purpose. The whiteboard was the working space where users could layout virtual aircraft instruments. The book served as a *menu object*, and users saw a different virtual instrument model on each page. One stack of tiles served as *data tiles* and showed no virtual content until virtual objects were copied onto them. The remaining tiles were *operator tiles* and were used to perform basic operations such as *deletion, copying* and a *help* function. Each of the operations tiles had a different three-dimensional virtual icon to show what their function was (fig 6).

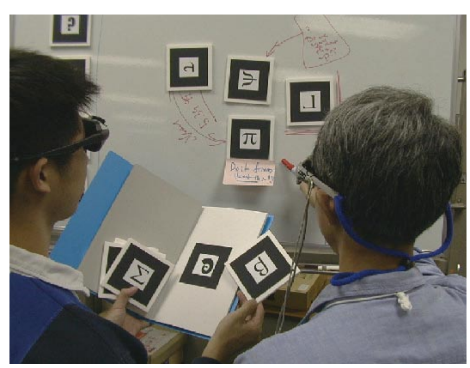

Figure 5: Using the Tiles Interface

Virtual images appeared attached to the physical objects and could be picked up and looked at from any viewpoint. Interaction between objects was based on physical proximity, however the operation that was invoked by bringing objects next to each other depended on their semantic. For example, touching a data tile that contained a virtual instrument with the trashcan delete tile, removed the virtual instrument. Once virtual instruments have been placed on the data tiles, these can be attached to the whiteboard to layout a prototype virtual instrument panel .

The Tiles interface supported collaboration on a number of different levels. Users could both be wearing HMDs and could see the shared virtual content. If one user didn't have an HMD on he would still be able to reference the virtual models by the physical cards/placeholders there were attached to. There was also an external monitor giving them a view of that the HMD user could see. Finally, the whiteboard can be drawn on so annotations can serve as another tool to help the face-to-face collaboration. This may be especially important for collaboration between users with and without HMDs so people who cannot see the virtual content can still understand what types of models are on the markers.

Trashcan delete widget　　Talking head help widget

Figure 6: Widget Representations

4 CONCLUSIONS

In this paper we have advocated a new approach for face-to-face collaboration based on a Tangible Augmented Reality metaphor. As our prototype systems have shown, by combining TUI and AR design principles we can develop interfaces that naturally support face-to-face collaboration and spatial data manipulation. However there is still a large amount of work that needs to be done to compare how collaboration with these types of interfaces is different from more traditional computer supported tools. In addition to running more rigorous user studies, in the future we intend to explore how Tangible AR interfaces can be combined with projective technology, and what other tangible manipulation techniques can be used.

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