Augmenting Reality with Projected Interactive Displays

Claudio Pinhanez
IBM T.J. Watson Research Center, P.O. Box 218
Yorktown Heights, N.Y. 10598, USA

Abstract. This paper examines a steerable projection system, the *everywhere displays projector (ED-projector),* which transforms surfaces into interactive displays. In an ED-projector, the display image is directed onto a surface by a rotating mirror. Oblique projection distortion is removed by a computer-graphics reverse-distortion process and user interaction (pointing and clicking) is achieved by detecting hand movements with a video camera. The ED-projector is a generic input/output device to be used to provide computer access from different locations of an environment or to overlay interactive graphics on any surface of a space, providing a simpler, more comfortable, and more social solution for augmented reality than goggles. We are investigating applications of ED-projectors that provide computer access in public spaces, facilitate navigation in buildings, localize resources in a physical space, bring computational resources to different areas of an environment, and facilitate the reconfiguration of the workplace.

1 Introduction

Most augmented reality systems are based on the use of goggles that create graphics on a transparent display positioned between the real world and the eyes of the user. If the graphics need to be aligned to some aspect of the physical reality, the position of the goggles has to be constantly determined in relation to the environment, to assure the necessary alignment.

This paper describes a projection system that overcomes this problem by directly projecting the graphics on the surfaces of the physical environment. To provide flexibility in the projection we have developed a prototype that deflects the image projected by an LCD projector using a rotating mirror (see Fig. 1). Moreover, the system uses a video camera to detect user interaction (such as pointing and clicking) on the projected image, allowing device-free interaction with a computer system. With this apparatus, we allow not only access to computer displays from any surface of a space but also enable the computer to directly label and “act” upon objects and people in the real world through the projection of images and light patterns.

Our approach of projecting information has clear advantages over the goggles normally used in augmented reality systems. First, projection allows the augmentation of real environments with information and graphics without requiring the users to wear goggles and without installing multiple displays or wiring sensors to surfaces. Also, it is not necessary to track the user’s head position

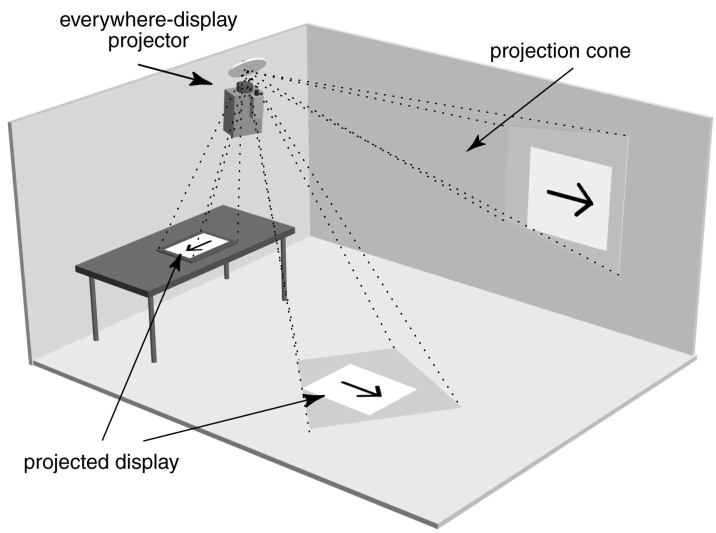

Fig. 1. Using the everywhere displays projector to create displays on different surfaces in a room.

and attitude since the graphics are overlaid directly on the surfaces in the real world. And finally, multiple users can easily share the information being projected, making projection-based augmented reality systems much more adequate for collaborative or social situations.

2 The Everywhere Displays Projector

The basic *everywhere displays projector*, or simply *ED-projector*, is composed of an LCD projector and a computer-controlled pan/tilt mirror. The projector is connected to the display output of a computer, which also controls the mirror. Fig. 2 shows a prototype of an ED-projector built with an off-the-shelf rotating mirror used in theatrical/disco lighting. In the configuration shown in Fig. 2, the projector's light can be directed in any direction within the range of approximately 70 degrees in the vertical and 120 degrees in the horizontal. When positioned in the upper corner of a room, this prototype is able to project in most part of the four walls, and almost all the floor.

2.1 Brightness and Contrast

Our prototype currently employs a 1200 lumens LCD projector that has proved to have enough brightness and contrast to project images on the surfaces of a normal office room with the lights on. Although we have not conducted experiments to determine the perceived brightness and contrast, in typical home and office conditions a white pattern projected by our prototype is approximately 10 times

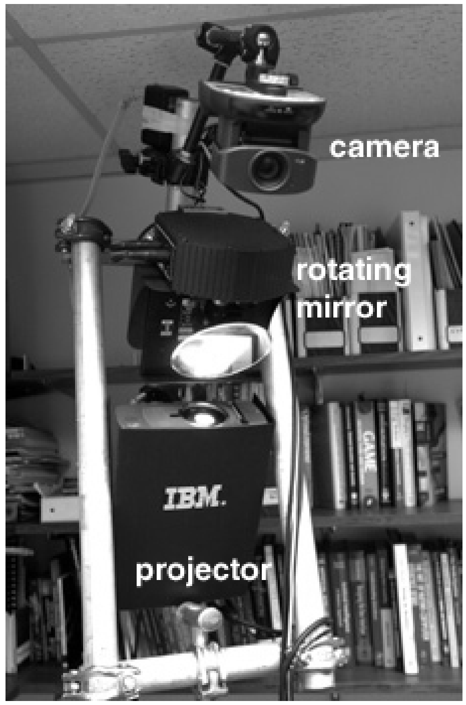

Fig. 2. Prototype of the everywhere displays projector.

brighter than its surroundings. With such a difference in brightness, viewers perceive the white projected pattern as “white” and any neighboring area receiving only the ambient light as “black.”

2.2 Correcting for Oblique Projection Distortion

As illustrated in Fig. 1, when the projection is not orthogonal to the surface, the projected image can appear distorted. To correct the distortions caused by oblique projection and by the shape of the projected surface, the image to be projected must be inversely distorted prior to projection. In general, this distortion is non-linear and is computationally expensive. However, we have developed a simple scheme that uses standard computer graphics hardware (present now in most computers) to speed up this process.

Our scheme relies on the fact that, geometrically speaking, cameras and projectors with the same focal length are identical. Therefore, to project an image obliquely without distortions it is sufficient to simulate the inverse process (i.e., viewing with a camera) in a virtual 3D computer graphics world. As show in Fig. 3, we texture-map the image to be displayed onto a virtual computer graphics 3D surface identical (minus a scale factor) to the real surface. If the position and attitude of this surface in the 3D virtual space in relation to the 3D virtual camera

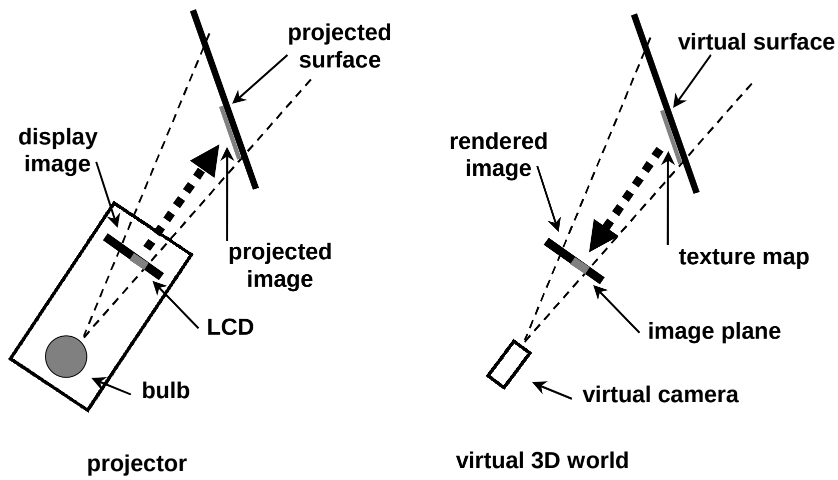

Fig. 3. Using a virtual computer graphics 3D world to correct the distortion caused by oblique projection by simulating the relationship between the projector and the projected surface.

is identical (minus a scale factor) to the relation between the real surface and the projector, and if the virtual camera has identical focal length to the projector, then the view from the 3D virtual camera corresponds exactly to the "view" of the projector (if the projector was camera).

In practice, we use a standard computer graphics board to render the virtual camera's view of the virtual surface and send the computed view to the projector. It is easy to see that if the position and attitude of the virtual surface are correct, the projection of this view compensates the distortion caused by oblique projection or by the shape of the surface. Of course, an appropriate virtual 3D surface must be uniquely used, and calibrated, for each surface where images are projected.

So far we have experimented only with projecting on planar surfaces. The calibration parameters of the virtual 3D surface are determined manually by simply projecting a special pattern and interactively adjusting the scale, rotation, and position of the virtual surface in the 3D world, and the "lens angle" of the 3D virtual camera.

2.3 Focus

A problem with oblique projection is that it is not possible to put all areas of the projected image simultaneously in focus. Fortunately, current commercial projectors have a reasonable depth of focus range, enough to maintain decent focus conditions in most cases. We have succeeded in projecting on surfaces with more than 60 degrees of inclination in relation to the projection axis without significant degradation of focus. However, the problem becomes more severe as the distance between the projected surface and the projector decreases.

Fig. 4. Interacting with projected display by hand.

3 Making the ED-Projector Interactive

Although a device that simply projects images on multiple surfaces has many applications, we are particularly interested in making the projected surface interactive like a touch screen. We are currently investigating the use of a pan/tilt video camera that is controlled by the computer so it has a complete view of the projected surface (see Fig. 2). The goal is to have the user interact by moving her hand over the projected surface, as if the hand was a computer mouse; and by moving the hand rapidly towards the surface, to generate a “click” event (see Fig. 4). Techniques similar to the ones described in [1] can be used to detect the hand’s position and the interaction gestures. It is important to notice that using vision-based interaction with the projected display allows user interaction without any contact with physical devices, making the ED-projector a system easily usable in public spaces or in hazardous environments.

4 Examples of Applications

The ED-projector is a generic input/output device that has been designed for use in multiple applications. We are just beginning to explore such applications as illustrated in the examples below. These applications can be basically classified in two types. The first class of applications deals with typical augmented reality applications: the ED-projector can be used to point to physical objects, show connections among them, attach information to objects, and to project dynamic patterns to indicate movement or change in the real world. The second class of

Fig. 5. Augmented reality application: overlaying the database of the contents of a file cabinet on the top of the cabinet.

applications corresponds to the creation of computer desktop-like interactive displays that provide computer access from surfaces of objects, furniture, walls, floor, etc.

4.1 Bringing Information to a Physical Location

Most applications of augmented reality are concerned with the virtual attachment of information to places and objects in the real world. Among such applications, we have been using the ED-projector to bring information to a physical location where the information is used or needed. Fig. 5 shows a situation where a database application accessing a list of files is projected on the top of the file cabinet that contains those files. In this situation, the user can search the computer database using any kind of complex query, obtain and refine answers, and use the results to find the corresponding files in the cabinet.

4.2 Navigation

ED-projectors are ideal devices to support user navigation through an environment. For instance, by installing an ED-projector in a corridor it is possible to project information on any wall, door, or area in the floor. Moreover, if the intent is to provide directions for visitors, an ED-projector-based system has the advantage that no device needs to be given or worn by the visitor. Plate 7, Fig. 1 shows an example application where the projector is used to signal the direction of

Fig. 6. Resource localization application: finding and checking-out a digital camera.

an emergency exit on the floor. Notice that the rotating mirror allows one single ED-projector to switch among different areas and directions as needed.

4.3 Tagging and Localization of Resources

In a physical environment where the position of objects or components is known to the computer, it is possible to use an ED-projector system to visually point to an object's position or to tag it with relevant information, without requiring the user to wear or carry any kind of device. Fig. 6 shows an example where the ED-projector responds a verbal request for the position of an object (a digital camera) by directly pointing to the location of the object in the room. The system follows by displaying a checkout list near the object that allows the user to update the information about the item just by touching the projected checklist. Similarly, information about the digital camera or instructions for its use could have been displayed on the same area.

Unlike systems based on goggles, it is possible to have a similar application in a public space. For example, a ED-projector can be used in a store to provide information about specific items, help customers to find products, and point to special promotions. All that is required is a set of white or light-colored surfaces where the information is to be projected such as walls, floors, or pieces of cardboard.

4.4 Dynamic Configuration of Workplaces

Workplaces are increasingly becoming more versatile. As an example, a personal office many times is also used for small meetings, and for collaborative work. The ED-projector can be used as a tool to help the reconfiguration of a workplace for different functions. Plate 7, Fig. 2 shows an example where a desktop application is projected on a desk and then moved onto a whiteboard. Unlike the interactive whiteboard described in [1], the ED-projector can move the application around the room as needed; for instance, to the top of a desk for detailed reading or writing, to a whiteboard for group discussion, and to a blank wall if the area of the whiteboard is temporarily needed for writing or scribbling.

4.5 Computer Access in Public Spaces and for Disabled People

The ED-projector can also be used to provide computer and information access in spaces where traditional displays can be broken or stolen, or create hazardous conditions, such as in public spaces and areas subject to harsh environmental conditions. The device also permits an interactive display to be brought to the proximity of a user without requiring the user to move. In particular, the ED-projector can facilitate the access and use of computers by people with locomotive disabilities. For instance, it can project an interactive display on the sheet of a hospital bed without creating the risk of patient contact with any device. The patient, in this case, can interact with the display by simply using his hand and use it to search for information, call doctors and nurses, or to obtain access to entertainment.

5 Discussion

Although there has been a substantial amount of research on interactive projected surfaces [1, 2, 3], the concept of the everywhere displays projector is unique in its combination of steerable projection and interactive display and interface. In particular, unlike tangible object-based interfaces [4], it does not require the construction or use of special, electronically enhanced objects. Instead, the ED-projector is a way to transform any surface or object, without modifications, into a generic data I/O device by simply projecting and sensing light.

A major advantage of the ED-projector over computer graphics goggles is that no user contact with any physical device is required. Moreover, since information is projected directly over the physical objects, it is not necessary to track the user's head position in the environment, or to design mechanisms to cope with the inevitable delays.

Although we have just started examining and prototyping specific applications, we believe that this device can not only simplify the use of augmented reality but also significantly expand its range of applications. We are currently working on improving the performance of the ED-projector and on the deployment of applications.

References

1. Crowley JL, Coutaz J, Berard F. Things that See, Communications of the ACM 2000; 43(3): 54-64.
2. Raskar R, Welch G, Cutts M et al. The Office of the Future: A Unified Approach to Image-Based Modeling and Spatially Immersive Displays. In Proc. of SIGGRAPH'98, Orlando, Florida, 1998, pp 179-188.
3. Underkoffler J, Ullmer B, Ishii H. Emancipated Pixels: Real-World Graphics in the Luminous Room. In Proc. of SIGGRAPH'99, Los Angeles, California. 1999, pp 385-392.
4. Ishii H, Ullmer B. Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms. In Proc. of CHI'97, Atlanta, Georgia. 1997, pp 234-241.

Plate 7 Fig. 1. Navigation application of an everywhere displays projector: pointing to the emergency exit**.**

Plate 7 Fig. 2. An everywhere displays projector moving a desktop application front the top of a table to a whiteboard.