Introduction to augmented reality

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ABSTRACT

This paper presents an overview of basic aspects of Augmented Reality (AR) and the main concepts of this technology. It describes the main fields in which AR is applied nowadays and important AR devices. Some characteristics of Augmented Reality systems will be discussed and this paper will provide an overview of them. Future directions are discussed.

Keywords: Augmented Reality, Virtual Reality, Scientific Visualization

1 INTRODUCTION

Augmented Reality (AR) is a new technology that involves the overlay of computer graphics on the real world (Figure 1). One of the best overviews of the technology is [4], that defined the field, described many problems, and summarized the developments up to that point. That paper provides a starting point for anyone interested in researching or using Augmented Reality.

AR is within a more general context termed Mixed Reality (MR) [20], which refers to a multi-axis spectrum of areas that cover Virtual Reality (VR), AR, telepresence, and other related technologies.

Virtual Reality is a term used for computer-generated 3D environments that allow the user to enter and interact with synthetic environments [9][27][28]. The users are able to "immerse" themselves to varying degrees in the computers artificial world which may either be a simulation of some form of reality [10] or the simulation of a complex phenomenon [33][9].

Figure 1: AR example with virtual chairs and a virtual lamp.

In telepresence, the fundamental purpose is to extend operator's sensory-motor facilities and problem solving abilities to a remote environment. In this sense, telepresence can be defined as a human/machine system in which the human operator receives sufficient information about the teleoperator and the task environment, displayed in a sufficiently natural way, that the operator feels physically present at the remote site [26]. Very similar to virtual reality, in which we aim to achieve the illusion of presence within a computer simulation, telepresence aims to achieve the illusion of presence at a remote location.

AR can be considered a tecnology between

VR and telepresence. While in VR the environment is completely synthetic and in telepresence it is completely real, in AR the user sees the real world *augmented* with virtual objects.

When designing an AR system, three aspects must be in mind: (1) Combination of real and virtual worlds; (2) Interactivity in real time; (3) Registration in $3D$.

Wearable devices, like Head-Mounted-Displays (HMD) [28], could be used to show the augmented scene, but other technologies are also available [4].

Besides the mentioned three aspects, another one could be incorporated: Portability. In almost all virtual environment systems, the user is not allowed to go around much due to devices limitations. However, some AR applications will need that the user really walks through a large environment. Thus, portability becomes an important issue.

For such applications, the $3D$ registration becomes even more complex. Wearable computing applications generally provide unregistered, text/graphics information using a monocular HMD. These systems are more of a "see-around" setup and not an Augmented Reality system by the narrow definition. Henceforth, computing platforms and wearable display devices used in AR must be often developed for more general applications (see section 3).

The field of Augmented Reality has existed for just over one decade, but the growth and progress in the past few years has been remarkable [12]. Since [4], the field has grown rapidly. Several conferences specialized in this area were started, including the International Workshop and Symposium on Augmented Reality, the International Symposium on Mixed Reality, and the Designing Augmented Reality Environments workshop.

2 AR Components

2.1 Scene Generator

The scene generator is the device or software responsible for rendering the scene. Rendering is not currently one of the major problems in AR, because a few virtual objects need to be drawn, and they often do not necessarily have to be realistically rendered in order to serve the purposes of the application [4].

2.2 Tracking System

The tracking system is one of the most important problems on AR systems mostly because of the registration problem [3]. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised. For the industry, many applications demand accurate registration, specially on medical systems [16][4].

2.3 Display

The tecnology for AR is still in development and solutions depend on design decisions. Most of the Displays devices for AR are HMD (Head Mounted Display), but other solutions can be found (see section 3).

When combining the real and virtual world two basic choices are available: optical and video technology. Each of them has some tradeoffs depending on factors like resolution, flexibility, field-of-view, registration strategies, among others [4].

Display technology continues to be a limiting factor in the development of AR systems. There are still no see-through displays that have sufficient brightness, resolution, field of view, and contrast to seamlessly blend a wide range of real and virtual imagery. Furthermore, many technologies that begin to approach these goals are not yet sufficiently small, lightweight, and low-cost. Nevertheless, the past few years have seen a number of advances in see-through display technology, as we shall see next.

3 AR Devices

Four major classes of AR can be distinguished by their display type: Optical See-Through, Virtual Retinal Systems, Video See-Through, Monitor Based AR and Projector Based AR.

The following sections show the corresponding devices and present their main features.

3.1 Optical See-Through HMD

Optical See-Through AR uses a transparent Head Mounted Display to show the virtual environment directly over the real world (Figures 2 and 3). It works by placing optical combiners in front of the user's eyes. These combiners are partially transmissive, so that the user can look directly through them to see the real world. The combiners are also partially reflective, so that the user sees virtual images bounced off the combiners from head-mounted monitors.

Prime examples of an Optical See-through AR system are the various augmented medical systems. The MIT Image Guided Surgery has concentrated on brain surgery [15]. UNC has been working with an AR enhanced ultrasound system and other ways to superimpose radiographic images on a patient [23]. There are many other Optical See-through systems, as it seems to be the main direction for AR.

Despite of these specific examples, there is still a lack of general purpose see-through HMDs. One issue for Optical See-through AR is the alignment of the HMD optics with the real world. A good HMD allows adjustments to fit the eye position and comfort of individual users. It should also be easy to move it out of the way when not needed. However, these movements will alter the registration of the VE over the real world and require re-calibration of the system. An expensive solution would be to instrument the adjustments, so the system could *automagically* compensate for the motion. Such devices are not reported in the literature.

Figure 2: Optical See-Through HMD.

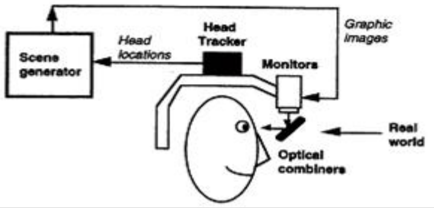

Figure 3: Optical See-Through Scheme.

Recent Optical See-Through HMD's are being built for well-known companies like Sony and Olympus and have support for occlusion, varying accommodation (process of focusing the eyes on objects at a particular distance). There are very small prototypes that can be attached to conventional eyeglasses (Figure 4).

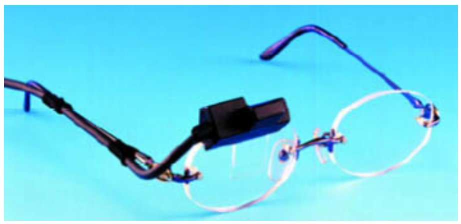

Figure 4: Eyeglass display with holographic element.

3.2 Virtual Retinal Systems

The VRD (Virtual Retinal Display) was invented at the University of Washington in the Human Interface Technology Lab (HIT) in 1991. The aim was to produce a full color, wide field-of-view, high resolution, high brightness, low cost virtual display. Microvision Inc. has the exclusive license to commercialize the VRD technology (Figure 5).

This technology has many potential applications, from head-mounted displays (HMDs) for military/aerospace applications to medical purposes.

The VRD projects a modulated beam of light (from an electronic source) directly onto the retina of the eye producing a rasterized image (Figure 6). The viewer has the illusion of seeing the source image as if he/she stands two feet away in front of a 14-inch monitor. In reality, the image is on the retina of its eye and not on a screen. The quality of the image he/she sees is excellent with stereo view, full color, wide field of view and no flickering characteristics [13][24].

Figure 5: Virtual Retinal System HMD.

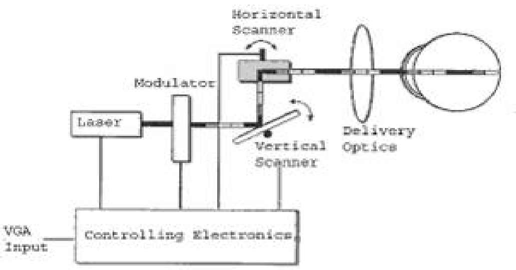

Figure 6: Virtual Retinal System Scheme.

3.3 Video See-Through HMD

Video See-Through AR uses an opaque HMD to display merged video of the VE and view from cameras on the HMD (Figure 7).

This approach is a bit more complex than optical see-through AR, requiring proper location of the cameras (Figure 8). However, video composition of the real and virtual worlds is much easier. There are a variety of solutions available including chroma-key and depth mapping. Mixed Reality Systems Lab (MRSL) of Japan presented a stereo video see-through HMD at ISAR 2000. This device addresses some of the parallax related to location of the cameras vs eyes.

Figure 7: Video See-Through HMD.

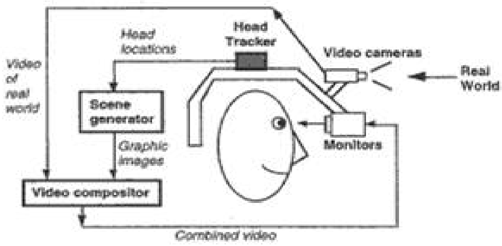

Figure 8: Video See-Through Scheme.

3.4 Monitor Based

Monitor Based AR also uses merged video streams but the display is a more conventional desktop monitor or a hand held display. It is perhaps the least difficult AR setup, as it eliminates HMD issues. Princeton Video Image, Inc. has developed a technique for merging graphics into real time video streams. Their work is regularly seen as the first down line in American football games. It is also used for placing advertising logos into various broadcasts.

3.5 Projection Displays

Projector Based AR uses real world objects as the projection surface for the virtual envi-

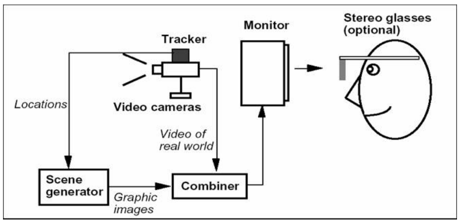

Figure 9: Monitor Based Scheme.

Figure 10: Monitor Based Example.

ronment (Figures 11,12).

It has applications in industrial assembly, product visualization, etc. Projector based AR is also well suited to multiple user situations. Alignment of projectors and the projection surfaces is critical for successful applications.

Figure 11: Projector Based AR.

4 Applications

The Augmented Reality technology has many possible applications in a wide range of fields, including entertainment, education, medicine, engineering and manufacturing.

It is expected that other potential areas of applications will appear with the dissemination of this technology.

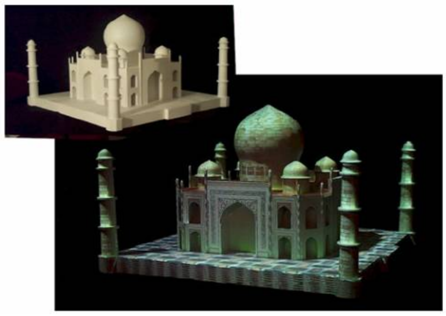

Figure 12: Projector Based AR.

4.1 Medical

Because imaging technology is so pervasive throughout the medical field, it is not surprising that this domain is viewed as one of the more important for augmented reality systems. Most of the medical applications deal with image guided surgery (Figure 13) [15].

Figure 13: Image Guided surgery.

Pre-operative imaging studies of the patient, such as CT (Computed Tomography) or MRI (Magnetic Resonance Imaging) scans, provide the surgeon with the necessary view of the internal anatomy. From these images the surgery is planned.

Visualization of the path through the anatomy of the affected area (where a tumor must be removed, for example) is done by first creating a 3D model from the multiple views and slices in the pre-operative study. The model is then projected over the target surface to help the surgical procedure.

Augmented reality can be applied so that the surgical team can see the CT or MRI data correctly registered on the patient in the operating theater while the procedure is progressing. Being able to accurately register the images at this point will enhance the performance of the surgical team and eliminate the need for the painful and cumbersome stereotactic frames that are currently used for registration [15].

Another application for augmented reality in the medical domain is in ultrasound imaging [2]. Using an optical see-through display the ultrasound technician can view a volumetric rendered image of the fetus overlaid on the abdomen of the pregnant woman. The image appears as if it were inside of the abdomen and is correctly rendered as the user moves [25] (Figure 14).

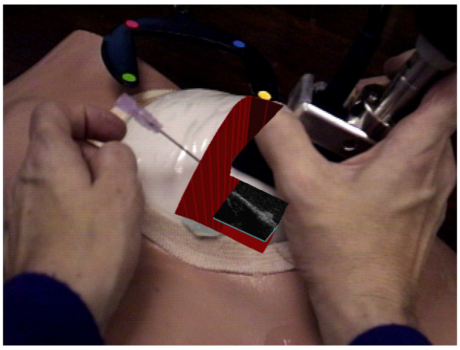

Figure 14: Ultrasound Imaging.

4.2 Entertainment

A simple form of augmented reality has been in use in the entertainment and news business for quite some time. Whenever you are watching the evening weather report, the speaker remains standing in front of changing weather maps. In the studio the reporter is actually standing in front of a blue screen. This real image is augmented with computer generated maps using a technique called chroma-keying. Another entertainment area where AR is being applied is on game development [31] (Figure 15 and 16).

Princeton Electronic Billboard has developed an augmented reality system that allows broadcasters to insert advertisements into specific areas of the broadcast image (Figure 17). For example, while broadcasting a baseball game this system would be able to place an advertisement in the image so that it appears on the outfield wall of the stadium.

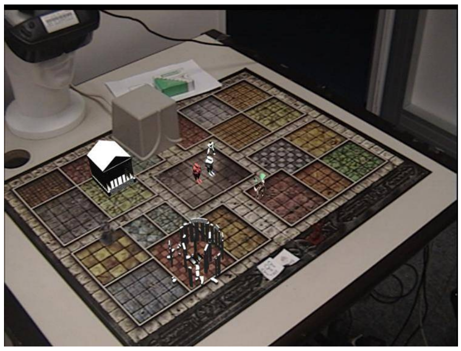

Figure 15: Games using a virtual table and synthetic objects.

Figure 16: VR-Border Guards, an AR game

The electronic billboard requires calibration to the stadium by taking images from typical camera angles and zoom settings in order to build a map of the stadium including the locations in the images where advertisements will be inserted. By using pre-specified reference points in the stadium, the system automatically determines the camera angle being used and referring to the pre-defined stadium map inserts the advertisement into the correct place.

Figure 17: Advertisement on a Football game.

4.3 Military Training

The military has been using displays in cockpits that present information to the pilot on the windshield of the cockpit or the visor of the flight helmet (Figure 18). This is a form of augmented reality display.

By equipping military personnel with helmet mounted visor displays or a special purpose rangefinder the activities of other units participating in the exercise can be imaged. While looking at the horizon, during a training section for example, the display equipped soldier could see a virtual helicopter rising above the tree line. This helicopter could be being flown in simulation by another participant. In wartime, the display of the real battlefield scene could be augmented with annotation information or highlighting to emphasize hidden enemy units [32].

Figure 18: Military Training.

4.4 Engineering Design

Imagine that a group of designers are working on the model of a complex device for their clients.

The designers and clients want to do a joint design review even though they are physically separated. If each of them had a conference room that was equipped with an augmented reality display this could be accomplished.

The physical prototype that the designers have mocked up is imaged and displayed in the client's conference room in 3D. The clients can walk around the display looking at different aspects of it. To hold discussions the client can point at the prototype to highlight sections and this will be reflected on the real model in the augmented display that the designers are using. Or perhaps in an earlier stage of the design, before a prototype is built, the view in each conference room is augmented with a computer generated image of the current design built from the CAD files describing it [1] (Figure 19).

Figure 19: AR applied to Engineering Design. This figure shows a real object augmented with virtual tubes.

4.5 Robotics and Telerobotics

In the domain of robotics and telerobotics an augmented display can assist the user of the system [17][21].

A telerobotic operator uses a visual image of the remote workspace to guide the robot. Annotation of the view would be useful as it is when the scene is in front of the operator. Besides, augmentation with wireframe drawings of structures in the view can facilitate visualization of the remote 3D geometry.

If the operator is attempting a motion it could be practiced on a virtual robot that is visualized as an augmentation to the real scene. The operator can decide to proceed with the motion after seeing the results. The robot motion could then be executed directly which in a telerobotics application would eliminate any oscillations caused by long delays to the remote site. Another use of robotics and AR is on remote medical operation (Figures 20 and 21).

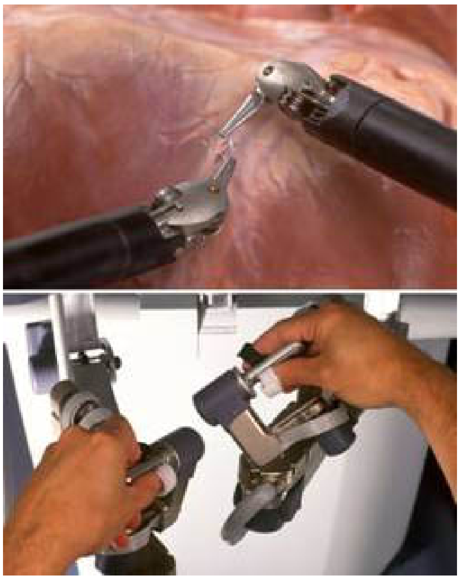

Figure 20: Virtual surgery using robot arms.

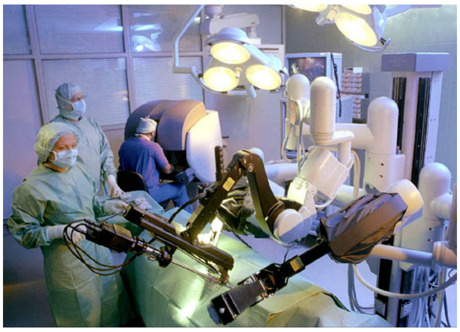

Figure 21: Robotics using AR for remote medical operation.

4.6 Manufacturing, Maintenance and Repair

When the maintenance technician approaches a new or unfamiliar piece of equipment instead of opening several repair manuals they could put on an augmented reality display. In this display the image of the equipment would be augmented with annotations and information pertinent to the repair. For example, the location of fasteners and attachment hardware that must be removed would be highlighted (Figure 22).

Boing made an experimental system, where the technicians are guided by the augmented display that shows the routing of the cables on a generic frame used for all harnesses (Figure 23). The augmented display allows a single fixture to be used for making the multiple

Figure 22: AR used to aid mechanical work.

harnesses [29].

Figure 23: AR applied to maintenance work.

4.7 Collaborative AR

AR addresses two major issues with collaboration: seamless integration with existing tools and practices, and enhancing practice by supporting remote and co-located activities that would otherwise be impossible.

Collaborative AR systems have been built using projectors, hand-held and head-worn displays. By using projectors to augment the surfaces in a collaborative environment, users are unencumbered, can see each others eyes, and are guaranteed to see the same augmentations [6].

Examples of collaborative AR systems using see-through displays include both those that use see-through handheld displays and see-through head-worn displays [14] (Figure 24).

5 Visualization Issues

Researchers have begun to address problems in displaying information in AR, caused by

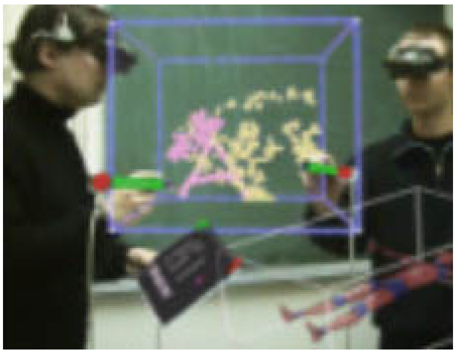

Figure 24: The Studierstube collaborative AR system.

the nature of AR technology or displays. Work has been done in the correction of registration errors and avoiding hiding critical data due to density problems.

5.1 Visualization Errors

In some AR systems, registration errors are significant and unavoidable. For example, the measured location of an object in the environment may not be known accurately enough to avoid visible registration error. Under such conditions, one approach for rendering an object is to visually display the area in screen space where the object could reside, based upon expected tracking and measurement errors [19]. This guarantees that the virtual representation always contains the real counterpart.

Another approach when rendering virtual objects that should be occluded by real objects is to use a probabilistic function that gradually fades out the hidden virtual object along the edges of the occluded region, making registration errors less objectionable [11].

5.2 Removing real objects from the environment

The problem of removing real objects is more than simply extracting depth information from a scene. The system must also be able to segment individual objects in that environment. A semi-automatic method for identifying objects and their locations in the scene through silhouettes is found in [18]. This enables the insertion of virtual objects and deletion of real objects without an explicit 3D reconstruction of the environment (Figure 25).

Figure 25: Virtual/Real occlusions. The brown cow and tree are virtual (the rest is real)

5.3 Photorealistic Rendering

A key requirement for improving the rendering quality of virtual objects in AR applications is the ability to automatically capture the environmental illumination information [7][22][30].

For example, in [8] it is presented a method that, using only an uncalibrated camera, allows the capture of object geometry and appearance, and then, at a later stage, rendering and AR overlay into a new scene.

6 Conclusions and Future Work

Despite of the many recent advances in AR, much work remains to be done. Application developments can be helped by using the available libraries. One of them is ARToolkit [5], that provides computer vision techniques to calculate a camera's position and orientation relative to marked cards so that virtual 3D objects can be overlaid precisely on the markers.

Here are some areas requiring further research if AR is to become commonly deployed.

Ubiquitous tracking and system portability: Several impressive AR demonstrations have generated compelling environments with nearly pixel-accurate registration. However, such demonstrations work only inside restricted, carefully prepared environments. The ultimate goal is a tracking system that supports accurate registration in any arbitrary unprepared environment, indoors or outdoors. Allowing AR systems to go anywhere also requires portable and wearable systems that are comfortable and unobtrusive.

Ease of setup and use: Most existing AR systems require expert users (generally the system designers) to calibrate and operate them. If AR applications are to become commonplace, then the systems must be deployable and operable by non-expert users. This requires more robust systems that avoid or minimize calibration and setup requirements.

Photorealistic and advanced rendering: Although many AR applications only need simple graphics such as wireframe outlines and text labels, the ultimate goal is to render the virtual objects to be indistinguishable from the real ones. This must be done in real time, without the manual intervention of artists or programmers. New techniques in image based rendering must be considered in order to accomplish this task [7].

AR in all senses: Researchers have focused primarily on augmenting the visual sense. Eventually, compelling AR environments may require engaging other senses as well (touch, hearing, etc.).

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