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AUGMENTED REALITY

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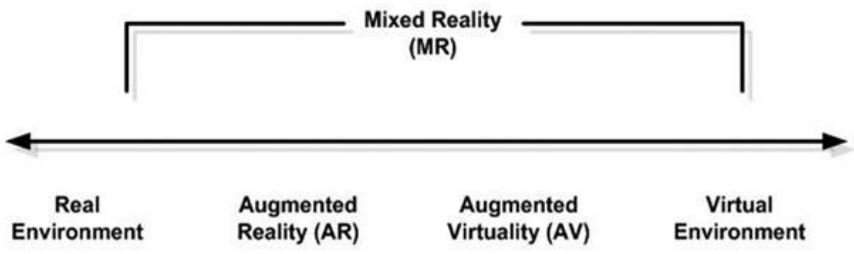
ABSTRACT: A revolution in computer interface design is changing the way we think about computers. Rather than typing on a keyboard and watching a television monitor, Augmented Reality lets people use familiar, everyday objects in ordinary ways. A revolution in computer interface design is changing the way we think about computers. Rather than typing on a keyboard and watching a television monitor, Augmented Reality lets people use familiar, everyday objects in ordinary ways. This paper surveys the field of Augmented Reality, in which 3-D virtual objects are integrated into a 3-D real environment in real time. It describes the medical, manufacturing, visualization, path planning, entertainment and military applications that have been explored. This paper describes the characteristics of Augmented Reality systems. Registration and sensing errors are two of the biggest problems in building effective Augmented Reality systems, so this paper throws light on problems. Future directions and areas requiring further research are discussed. This survey provides a starting point for anyone interested in researching or using Augmented Reality.

I. INTRODUCTION

The "paper-less" office has proven to be a myth: not only are office workers still inundated with paper, but they must now handle increasing quantities of electronic information. Worse, they are poorly equipped to bridge the gap between these two overlapping, but separate, worlds. Perhaps it is not surprising that computers have had little or no impact on white collar productivity [1, 2]. The problem is not restricted to office work. Medicine has enjoyed major advances in imaging technology and interactive diagnostic tools. Yet most hospitals still rely on paper and pencil for medical charts next to the patient's bed. A recent study of terminally-ill patients in the U.S. concluded that, despite detailed information in their electronic medical charts, doctors were mostly unaware of their patients' wishes. Despite its importance, the electronic information all too often remains disconnected from the physical world. [3]

Augmented Reality addresses such problems by reintegrating electronic information back into the real world. Augmented Reality (AR) is a variation of Virtual Environments (VE), or Virtual Reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, ARsupplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space AR can be thought of as the "middle ground"between VE (completely synthetic) and telepresence (completely real) [4] [5]. Milgram defined a continuum of Real to Virtual environments, where Augmented Reality is one part of the general area of Mixed Reality. In both Augmented Virtuality and Virtual Environments (Virtual Reality), the surrounding environment is virtual, while in AR the surrounding environment is real.

FIGURE 1



Virtuality Continuum (Milgram and Kishino, 1994, as cited by Christian, 2006, p. 2)

What is Augmented Reality?

The basic goal of an AR system is to enhance the users perception of andinteraction with the real world through supplementing the real world with 3D virtual objects that appear to coexist in the same space as the real world. Many recent papers broaden the definition of AR beyond this vision, but in the spirit of the original survey we define AR systems to share the following properties:

1. Blends real and virtual, in a real environment
2. Real-time interactive
3. Registered in 3D

Registration refers to the accurate alignment of real and virtual objects. Without accurate registration, the illusion that the virtual objects exist in the real environment is severely compromised. Registration is a difficult problem and a topic of continuing research.

Certain AR applications also require removing real objects from the environment, in addition to adding virtual objects. For example, an AR visualization of a building that used to stand at a certain location would first have to remove the current building that exists there today. Some researchers call the task of removing real objects Mediated or Diminished Reality, but this survey considers it a subset of Augmented Reality.

How does augmented reality work?

The webcam connected to your computer is capturing video in the traditional manner (by taking lots of photos in quick succession). When you hold the “marker” in front of the webcam it sees the marker, captures the information / pattern encoded in it and sends this information to the computer. The computer recognises the information and overlays the marker with an image. To the viewer it appears as though the image has materialised by magic. The computer can track the size and movement of the image. This means if you move the marker closer to the webcam the image will get bigger. If you tilt the marker to the left, the image will tilt to the left. This process is similar to sports telecasts seen on television, such as swimming events, where a line is dynamically added across the lanes to indicate the virtual position of the current record holder as a race proceeds.

A key measure of AR systems is how realistically they integrate augmentations with the real world. The software must derive real world coordinates, independent from the camera, from camera images. That process is called image registration which uses different methods of computer vision, mostly related to video tracking.[12] Many computer vision methods of augmented reality are inherited from visual odometry. Usually those methods consist of two parts.

First detect interest points, or fiduciary markers, or optical flow in the camera images. First stage can use feature detection methods like corner detection, blob detection, edge detection or thresholding and/or other image processing methods. The second stage restores a real world coordinate system from the data obtained in the first stage. Some methods assume objects with known geometry (or fiduciary markers) present in the scene. In some of those cases the scene 3D structure should be pre calculated beforehand. If part of the scene is unknown simultaneous localization and mapping (SLAM) can map relative positions. If no information about scene geometry is available, structure from motion methods like bundle adjustment are used. Mathematical methods used in the second stage include projective (epipolar) geometry, geometric algebra, rotation representation with exponential map, kalman and particle filters, nonlinear optimization, robust statistics.

Marker detection procedure

The first goal of a marker detection process is to find the outlines of potentialmarkers, and then to deduce locations of marker's corners in the image. In addition, detection system needs to confirm that it really is a marker and decipher its identity. Finally, the system calculates the pose using the information from thedetected marker location.

The basic marker detection procedure consists of the following steps:

1. Image acquisition
    - acquisition of an intensity image.
2. Preprocessing
    - low level image processing
    - undistortion
    - line detection/line fitting
    - detection of the corners of the marker.
3. Detection of potential markers and discard of obvious non-markers
    - fast rejection of obvious non-markers
    - fast acceptance test for potential markers.
    - Marker-based tracking
4. Identification and decoding of markers
    - template matching (template markers)
    - decoding (data markers).
5. Calculation of the marker pose
    - estimation of marker pose
    - Iterative pose calculation for accurate pose.

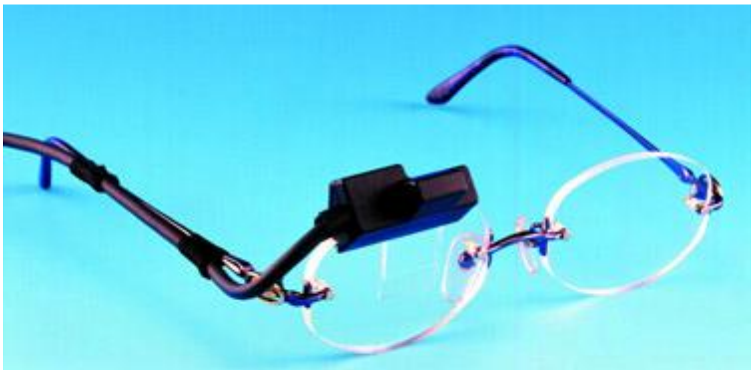
The image acquisition step is actually a separate process; it just provides theimage for the marker detection process. Marker detection pipelines may differ fromthis template. The execution order of the steps may differ or the system may merge steps into the same algorithm. In particular, many implementations combineacceptance/rejection tests with other tasks; the system may reject a markercandidate at any stage of the detection process when it notices that the candidate cannot be a marker. However, the main concept is usually the same.In the following, we discuss each step of the marker detection procedure in a more detail, except for identifying and decoding markers, which depends on the marker type.

II. Enabling Technologies

A. See-Through Displays

Display technology continues to be a limiting factor in the development of AR systems. There are still no seethrough displays that have sufficient brightness, resolution, field of view, and contrast to seamlessly blenda 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. Presence of well-known companies: Established electronics and optical companies, such as Sony and Olympus, now produce opaque, color, LCD-based consumer head-worn displays intended for watching videos and playing video games. While these systems have relatively low resolution (180K.240K pixels), small fields of view, and do not support stereo, they are relatively lightweight (under 120 grams) and offer an inexpensive option for video see-through research. Sony introduced true SVGA resolution optical see-through displays, including stereo models (later discontinued), which have been used extensively in AR research.

FIGURE 2: Minolta eyeglass display with holographic element. (Courtesy of Hiroaki Ueda, Minolta Co, Ltd.)



B. Projection Displays

An alternate approach to AR is to project the desired virtual information directly on those objects in the physical world that are to be augmented. In the simplest case, the augmentations are intended to be coplanar with the surface on which they are projected and can be projected monoscopically from a room-mounted projector, with no need for special eyewear. Examples include a projection of optical paths taken through simulated elements on a virtual optical bench [6], and an application where a remote user controls a laser pointer worn by another user to point out objects of interest [7]. Generalizing on the concept of a multi-walled CAVE environment, Raskar and colleagues [8] show how large irregular Surfaces can be covered by multiple overlapping projectors, using an automated calibration procedure that takes into account surface geometry and image overlap. They use stereo projection and liquid crystal shuttereyewear to visualize 3D objects. This process can also beapplied to true 3D objects as the target, by surroundingthem with projectors [9].Another approach for projective AR relies on head-wornprojectors, whose images are projected along the viewer. sline of sight at objects in the world. The target objectsare coated with a retroreflective material that reflects lightback along the angle of incidence. Multiple users can seedifferent images on the same target projected by their ownhead-worn systems, since the projected images cannot beseen except along the line of projection. By usingrelatively low output projectors, non-retroreflective realobjects can obscure virtual objects.While these are strong advantages, the use of projectorsposes a challenge for the design of lightweight systemsand optics. Figure 4 shows a new prototype that weighsunder 700 grams [10]. One interesting application ofprojection systems is in Mediated Reality. Coating ahaptic input device with retroreflective material and projecting a model of the scene without the devicecamouflages the device by making it appear semitransparent. [11]

FIGURE 3: Experimental head-worn projective display using lightweight optics. (Courtesy of Jannick Rolland, Computers & Graphics, November 20014 **Univ. of Central Florida, and Frank Biocca, Michigan State Univ.)**

III. APPLICATIONS

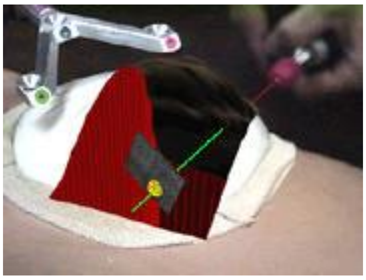
A. Medical

Doctors could use Augmented Reality as a visualization and training aid for surgery. It may be possible to collect 3-D datasets of a patient in real time, using non-invasive sensors like Magnetic Resonance Imaging (MRI), Computed Tomography scans (CT), or ultrasound imaging. These datasets could then be rendered and combined in real time with a view of the real patient. In effect, this would give a doctor "X-ray vision" inside a patient. This would be very useful duringminimally-invasive surgery, which reduces the trauma of an operation by using small incisions or no incisions at all. A problem with minimally-invasive techniques is that they reduce the doctor's ability to see inside the patient, making surgery more difficult. AR technology could provide an internal view without the need for larger incisions.

AR might also be helpful for general medical visualization tasks in the surgical room. Surgeons can detect some features with the naked eye that they cannot see in MRI or CT scans, and vice-versa. AR would give surgeons access to both types of data simultaneously. This might also guide precision tasks, such as displaying where to drill a hole into the skull for brain surgery or where to perform needle biopsy of a tiny tumour. The information from the non-invasive sensors would be directly displayed on the patient, showing exactly where to perform the operation.

FIGURE 4: Virtual fetus inside womb of pregnant patient. (Courtesy UNC Chapel Hill Dept. of Computer Science.)

FIGURE 5: Mockup of breast tumor biopsy. 3-D graphics guide needle insertion. (Courtesy UNC Chapel Hill Dept. of Computer Science.)



B. Manufacturing and repair

Another category of Augmented Reality applications is the assembly,maintenance, and repair of complex machinery. Instructions might be easier tounderstand if they were available, not as manuals with text and pictures, but rather as3-D drawings superimposed upon the actual equipment, showing step-by-step thetasks that need to be done and how to do them. These superimposed 3-D drawings can be animated, making the directions even more explicit.

Several research projects have demonstrated prototypes in this area. SteveFeiner's group at Columbia built a laser printer maintenance application,shown in Figures 4 and 5. Figure 4 shows an external view, and Figure 5 shows theuser's view, where the computer-generated wireframe is telling the user to remove thepaper tray. A group at Boeing is developing AR technology to guide a technician inbuilding a wiring harness that forms part of an airplane's electrical system. Storingthese instructions in electronic form will save space and reduce costs. Currently,technicians use large physical layout boards to construct such harnesses, and Boeingrequires several warehouses to store all these boards. Such space might be emptiedfor other use if this application proves successful [12] [13] [14].

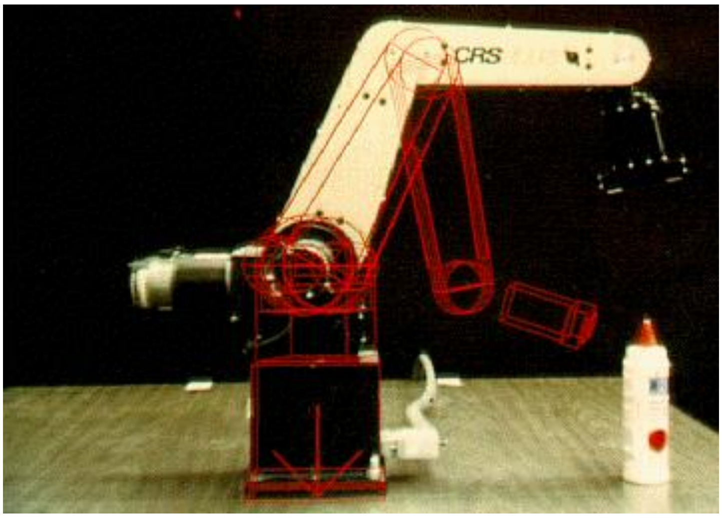
FIGURE 6: Prototype laser printer maintenance application, displaying how to remove the paper tray. (Courtesy Steve Feiner, Blair MacIntyre, and Dorée Seligmann, Columbia University.)

FIGURE 7: Adam Janin demonstrates Boeing's prototype wire bundle assembly application. (Courtesy David Mizell, Boeing)

C. Robot path planning

Teleoperation of a robot is often a difficult problem, especially when the robotis far away, with long delays in the communication link. Under this circumstance,instead of controlling the robot directly, it may be preferable to instead control avirtual version of the robot. The user plans and specifies the robot's actions bymanipulating the local virtual version, in real time. The results are directly displayedon the real world. Once the plan is tested and determined, then user tells the realrobot to execute the specified plan. This avoids pilot-induced oscillations caused bythe lengthy delays. The virtual versions can also predict the effects of manipulatingthe environment, thus serving as a planning and previewing tool to aid the user inperforming the desired task. The ARGOS system has demonstrated that stereoscopicAR is an easier and more accurate way of doing robot path planning than traditionalmonoscopic interfaces [15]. Others have also used registeredoverlays with telepresence systems. Figure 10 shows how a virtual outline can represent a future location of a robot arm.

FIGURE 8: Virtual lines show a planned motion of a robot arm (Courtesy David Drascic and Paul Milgram, U. Toronto.)



D. Entertainment

At SIGGRAPH '95, several exhibitors showed "Virtual Sets" that merge realactors with virtual backgrounds, in real time and in 3-D. The actors stand in front ofa large blue screen, while a computer-controlled motion camera records the scene.Since the camera's location is tracked, and the actor's motions are scripted, it ispossible to digitally composite the actor into a 3-D virtual background. For example,the actor might appear to stand inside a larFge virtual spinning ring, where the frontpart of the ring covers the actor while the rear part of the ring is covered by the actor.

The entertainment industry sees this as a way to reduce production costs: creating andstoring sets virtually is potentially cheaper than constantly building new physical setsfrom scratch. The ALIVE project from the MIT Media Lab goes one step further by populating the environment with intelligent virtual creatures that respond to user actions [16].

E. Military aircraft

For many years, military aircraft and helicopters have used Head-Up Displays(HUDs) and Helmet-Mounted Sights (HMS) to superimpose vector graphics upon thepilot's view of the real world. Besides providing basic navigation and flightinformation, these graphics are sometimes registered with targets in the environment,providing a way to aim the aircraft's weapons. For example, the chin turret in ahelicopter gunship can be slaved to the pilot's HMS, so the pilot can aim the chinturret simply by looking at the target. Future generations of combat aircraft will bedeveloped with an HMD built into the pilot's helmet [17].

IV. Future directions

This section identifies areas and approaches that require further research toproduce improved AR systems.

Hybrid approaches: Future tracking systems may be hybrids, becausecombining approaches can cover weaknesses. The same may be true for otherproblems in AR. For example, current registration strategies generally focus on asingle strategy. Future systems may be more robust if several techniques arecombined. An example is combining vision-based techniques with prediction. If the
fiducials are not available, the system switches to open-loop prediction to reduce theregistration errors, rather than breaking down completely. The predicted viewpointsin turn produce a more accurate initial location estimate for the vision-basedtechniques.

Real-time systems and time-critical computing: Many VE systems are nottruly run in real time. Instead, it is common to build the system, often on UNIX, andthen see how fast it runs. This may be sufficient for some VE applications. Sinceeverything is virtual, all the objects are automatically synchronized with each other.AR is a different story. Now the virtual and real must be synchronized, and the realworld "runs" in real time. Therefore, effective AR systems must be built with realtimeperformance in mind. Accurate timestamps must be available. Operatingsystems must not arbitrarily swap out the AR software process at any time, forarbitrary durations. Systems must be built to guarantee completion within specifiedtime budgets, rather than just "running as quickly as possible." These arecharacteristics of flight simulators and a few VE systems. Constructingand debugging real-time systems is often painful and difficult, but the requirementsfor AR demand real-time performance.

Perceptual and psychophysical studies: Augmented Reality is an area ripe forpsychophysical studies. How much lag can a user detect? How much registrationerror is detectable when the head is moving? Besides questions on perception,psychological experiments that explore performance issues are also needed. Howmuch does head-motion prediction improve user performance on a specific task?How much registration error is tolerable for a specific application before performanceon that task degrades substantially? Is the allowable error larger while the user movesher head versus when she stands still? Furthermore, not much is known aboutpotential optical illusions caused by errors or conflicts in the simultaneous display ofreal and virtual objects.Few experiments in this area have been performed. Jannick Rolland, FrankBiocca and their students conducted a study of the effect caused by eye displacementsin video see-through HMDs. They found that users partially adapted tothe eye displacement, but they also had negative aftereffects after removing theHMD. Steve Ellis' group at NASA Ames has conducted work on perceived depth ina see-through HMD. ATR has also conducted a study.

Portability: As explained why some potential AR applicationsrequire giving the user the ability to walk around large environments, even outdoors.This requires making the equipment self-contained and portable. Existing trackingtechnology is not capable of tracking a user outdoors at the required accuracy.

Multimodal displays: Almost all work in AR has focused on the visual sense:virtual graphic objects and overlays. But explained that augmentationmight apply to all other senses as well. In particular, adding and removing 3-D soundis a capability that could be useful in some AR applications.

Social and political issues: Technological issues are not the only ones thatneed to be considered when building a real application. There are also social andpolitical dimensions when getting new technologies into the hands of real users.Sometimes, perception is what counts, even if the technological reality is different.For example, if workers perceive lasers to be a health risk, they may refuse to use asystem with lasers in the display or in the trackers, even if those lasers are eye safe.Ergonomics and ease of use are paramount considerations. Whether AR is truly acost-effective solution in its proposed applications has yet to be determined. Anotherimportant factor is whether or not the technology is perceived as a threat to jobs, as areplacement for workers, especially with many corporations undergoing recentlayoffs. AR may do well in this regard, because it is intended as a tool to make theuser's job easier, rather than something that completely replaces the human worker.Although technology transfer is not normally a subject of academic papers, it is a realproblem. Social and political concerns should not be ignored during attempts tomove AR out of the research lab and into the hands of real users.

V. Conclusion

Augmented Reality is far behind Virtual Environments in maturity. Severalcommercial vendors sell complete, turnkey Virtual Environment systems. However, no commercial vendor currently sells an HMD-based Augmented Reality system. Afew monitor-based "virtual set" systems are available, but today AR systems areprimarily found in academic and industrial research laboratories.After the basic problems with AR are solved, the ultimate goal will be togenerate virtual objects that are so realistic that they are virtually indistinguishablefrom the real environment Photorealism has been demonstrated infeature films, but accomplishing this in an interactive application will be muchharder. Lighting conditions, surface reflections, and other properties must bemeasured automatically, in real time. More sophisticated lighting, texturing, andshading capabilities must run at interactive rates in future scene generators.Registration must be nearly perfect, without manual intervention or adjustments.While these are difficult problems, they are probably not insurmountable. It tookabout 25 years to progress from drawing stick figures on a screen to the photorealisticdinosaurs in "Jurassic Park." Within another 25 years, we should be able to wear apair of AR glasses outdoors to see and interact with photorealistic dinosaurs eating atree in our backyard.

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