

AVIS-MS: Advanced Visual and Instruction Systems for Maintenance Support

Progress Report

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Complexity, customization, and packaging of military platforms and systems increase maintenance difficulty at the same time as the available pool of skilled technical personnel may be shrinking. In this environment maintenance training, technical order presentation, and flight-line operational practice may need to adopt “just-in-time” procedural aids. Moreover, the realities of real-world maintenance may not permit the hardware indulgences and rigid controls of laboratory settings for visualization and training systems, and at the same time the actual activities of maintainers will challenge requirements for portable or wearable devices. This project has investigated technologies that maybe used in the maintenance of Air Force equipment.

There are several modalities available for the conveyance of maintenance information, including, text, diagrams, images, speech, video, and 3 dimensional models and environments as well as live demonstrations. Currently most stored maintenance information is conveyed through text and diagrams. During this project we investigated the feasibility of using more advanced technology such as head mounted displays (HMD), fusion trackers, wearable computers, unique input devices, and AR software. We experimented with merging many of the available modalities while concentrating on the feasibility of using state of the art AR hardware. On other recent related projects we have experimented with voice recognition and text-to-speech software. At the onset of this project we deemed these to be inappropriate software devices for the flight-line maintenance application due to the high noise level in the environment and the relatively poor performance of such software. Our main focus was therefore on AR and the related devices.

Augmented Reality

An *Augmented Reality* (AR) system generates for the user a composite view by superimposing virtual information onto a real scene with the goal of helping the viewer to better understand the environment. The superimposed information can be text, such as instructions, or a virtual scene. Regardless of the information type, it needs to be displayed correctly, at the right time and in the right place, to present the user with a unified, single real visual scene.

There are two main methods for displaying the AR scene for a user:

(1) Video based see-through Augmented Reality

In this method, the real scene is captured by video cameras, and then merged with the virtual scene generated by a computer. The real and virtual scenes are integrated before the user sees them. This means that the user will be viewing the real scene indirectly through the video camera recording. A diagram of a video see-through system is shown in Figure 1.

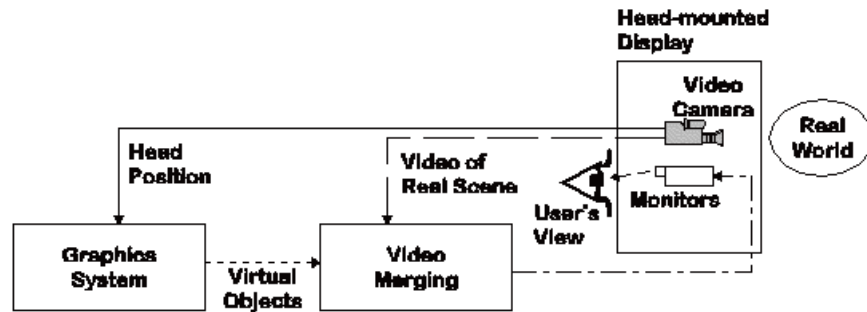


Figure 1 Video See-through AR [1].

(2) Optical based see-through Augmented Reality

In an optical based see-through AR system, the user views the real scene directly, and the virtual scene is optically merged directly in the user's view, as shown in Figure 2. This optical merging can be done through the use of head-mounted displays or other projection devices.

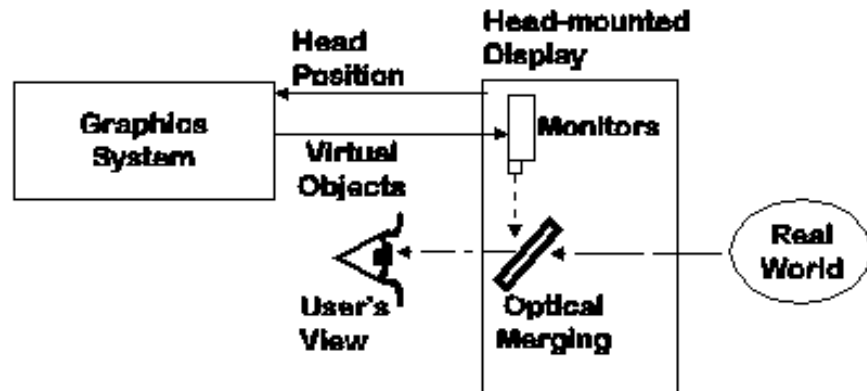


Figure 2 Optical see-through AR [1].

Augmented Reality vs. Virtual Reality:

The greatest difference between AR and Virtual Reality (VR) is that the user in an AR system can simultaneously observe a superimposed virtual and real scene. The user in VR only views a virtual scene. VR strives for a totally immersive environment, while

AR tries to merge the real world scene with a virtual scene while maintaining the user's sense of presence in the real world.

Main Challenges

The first challenge to building a successful AR system is to find a mechanism to display the real and virtual scenes at the same time, so that the virtual scene and real scene are seamlessly blended together. Video-based see-through and optical-based see-through methods are two basic solutions to solve this problem, shown as in Figure 11 and Figure 2, but there are still many open issues: *e.g.*, how to let them have the same perceptual brightness, and how to manage relative depth issues (display real objects over virtual ones and virtual objects over real objects).

The second challenge is registration (tracking). In fact, the registration problem also exists in VR and film special effects, so it is not unique to AR systems, but the requirements of accuracy and real-time performance of AR make it more difficult.

For an immersive VR system, registration is also required so that changes in the rendered scene match with the perceptions of the user, but any errors here will only cause conflicts between the visual system and the kinesthetic or proprioceptive (orientation) systems. Because visual perception always dominates our other perceptions a user in a VR can accept or adjust to a visual stimulus that overrides the discrepancies with input from sensory systems. In fact, the lack of coordination between the visual and vestibular system can be exploited to make people in VR feel they are exploring a large space when in fact they are making continuous walking turns in a small area [2]. In contrast, errors of mis-registration in an AR system are between two visual stimuli that we are trying to fuse to be seen as one scene. AR systems are thus more sensitive to these errors.

Another challenge comes from the real time performance requirement of AR. Because the real environment is a true real-time environment, any delay or lagtime in computing and displaying virtual objects will be more visible in AR when they are presented with the real scene at the same time. So a successful AR system should run as fast as the real environment, and have some mechanism to make these two scenes run synchronously.

The main challenges for AR are summarized below:

(1) Displays

- a. **See through:** AR needs see-through displays to show the real and virtual scene at the same time. But current see-through displays do not have sufficient brightness, resolution, field of view, and can not seamlessly blend a wide range of real and virtual imagery.
- b. **Delay:** Some display delay in VR may be tolerable, but any mismatch between a virtual and real scene and will make an AR system fail.
- c. **Occlusion**[105]: Augmenting a scene need not only *add* objects to a real environment but also has the potential to *remove* them[2]. To maintain the correct visual relationship between virtual and real objects, some real objects may be blocked.

- d. **Parallax error:** Most video see-through displays have a parallax error, caused by the cameras being mounted away from the true eye optical axis.
- e. **Fixed eye accommodation:** Most displays have fixed eye accommodation (focusing the eyes at a particular distance).
- f. **Multimodal display:** Sometimes AR requires mixed real and virtual modalities other than just the visual modality, such as sound or haptics. There has been little work in this area.

(2) Tracking

Tracking and sensing are used to report the locations of the user and the surrounding objects in the environment, which is also the basis of registration. AR places stringent real-time demands on trackers and sensors in three areas:

- a. Greater input variety and bandwidth;
- b. Higher accuracy;
- c. Longer range.

(3) Registration

One of the most basic problems for AR systems is the registration problem. An AR system should align its virtual and real scenes correctly, to make them appear to be in the same space. AR again presents stringent real-time and positional accuracy requirements.

(4) Interaction modality

In an AR system, objects are either real or virtual, but virtual objects cannot present haptic (physical solidity and weight) cues. This discrepancy is a challenge for interactive AR systems.

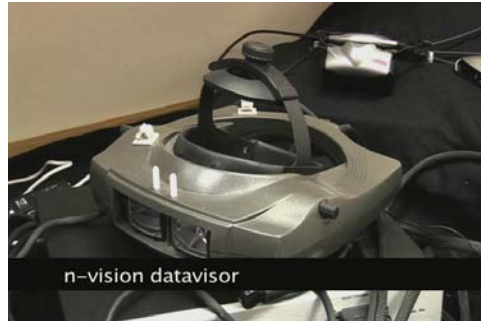
(5) Authoring and tools

Creating the content for AR environment including 3D models, text, overlays, and interactions is also a challenge. Creating and storing semantic information with the geometric models would ease this task.

During the course of this project we examined both optical see-through AR and VR.

Head Mounted Displays

For this project we worked with three different types of head mounted displays, a true AR display (nVision Datavisor), an opaque display (eMagin Z800 3DVisor), and a sliver display (MicroOptical SV-9 PC Viewer).



nVision Datavisor

We were able to borrow the datavisor from another laboratory here at Penn, but normally this HMD can be purchased for approximately \$25K (including the see-through option). With the see-through option, this device is capable of true AR. It allows the viewer to see virtual imagery on top of a real scene.

We were using an older version of this device, but the state-of-the-art version allows 1280 x 1024 resolution with 80° monocular field of view (FOV) and 120° maximum horizontal FOV at 180Hz and 24 bit color. The major drawback of this device is its size and weight. We feel that it would be much too cumbersome for the flight-line maintenance application. The version of the hardware that we used for testing was also not wireless. In addition to the cumbersome HMD, it required a very large control box.



eMagin Z800 3DVisor

We purchased this display for approximately \$900. It is a much less cumbersome device and therefore more wearable than the nVision Datavisor. It also includes a control box, but it is considerably smaller and much more portable.

This eMagin display does not afford AR. It is a completely opaque display that does support VR applications. This device would be feasible for VR training applications, but for operational environments, it does not seem feasible. The maintainer would be required to remove and replace the device throughout the maintenance task. This comfortable device has 360° horizontal FOV (with tracking device), 24 bit color at a resolution of 800 x 600, and includes stereovision. It also weighs less than 8 oz. and is USB-powered.



MicroOptical SV-9 PC Viewer

This display was purchased for approximately \$990. This sliver display can be mounted on most glasses including safety glasses, as shown here. Unlike the eMagin visor, it obstructs only a small portion of the wearer's FOV and can be easily flipped out of the way when not in use.

Like the eMagin display, it does not afford true AR. It does, however, permit simultaneous viewing of both real and virtual scenes, though they are not superimposed. It also does not support stereovision, but out of all of the display devices this is the most wearable and practical for the flight-line maintenance application. It displays 24 bit color at a resolution of 640 x 480 and 60 Hz. It can be configured for the left or right eye and has 14° horizontal FOV. It is battery powered with a fully charged battery lasting approximately 3 hours.

Wearable Computer



We looked at a few different wearable computers, but settled on the **Sony Viao U50**, because it was recommended by colleagues, was lightweight, has good battery life, is affordable, is relatively powerful, and runs a standard operating system.

We purchased the Viao for approximately \$2800. The basic specifications include Intel Celeron M 900MHz processor, 512MB RAM, 20GB hard-drive, 64MB VRAM, 5" display, 800 x 600 on screen resolution, and enhanced battery life of 5.5 hours (2.5 standard). It weighs 1.21 lbs. and runs Windows XP. Though we have not yet made use of it for this project, it also includes a touch screen. One notably missing feature of the

U50 is a microphone port. This missing feature would make voice activated applications more difficult. It is possible to connect microphones through the USB ports.

Input Devices

When considering how a maintainer might interact with an instruction delivery tool, we considered traditional input mechanisms (*i.e.*, keyboards and mice). We feel that these tools are not optimal in the maintenance environment. Focusing on a computer screen and mouse and keyboard distracts from the maintenance task. Additionally, the grimy nature of maintenance is not conducive to these devices. Hence, we decided to experiment with the use of CyberGloves and hand gestures. They may be worn under traditional work gloves that would help to protect them.

The other input device that we tested is the Intersense Fusion Tracker. An important interaction with a virtual environment is synchronized movement of the eye and the virtual camera. For a maintenance task this includes positioning the camera in the virtual environment to the same point of view as the maintainer has in the real world. For this purpose, we included the fusion tracker in our experimental demonstration.



Immersion Wireless CyberGlove

This new wireless CyberGlove II system provides 22 high-accuracy joint-angle measurements. It uses resistive bend-sensing technology to transform hand and finger motions into real-time digital joint-angle data. Each sensor is extremely thin and flexible being virtually undetectable in the lightweight elastic glove. The basic CyberGlove II system includes one data glove, two batteries, a battery charger, and a USB/Bluetooth technology adapter with drivers. The CyberGlove has 0.5° resolution and repeatability to 1° . The typical data rate is 100 records per second. Its operating range is within a 30 foot radius of the USB Bluetooth adapter.



Intersense Fusion Tracker IS-1200

This is a wide-area, wearable, 6-DOF hybrid tracking and navigation system designed for AR and mobile computing applications. It uses an inertial tracker for orientation and an optical sensor for position. Its accuracy is 0.1° in orientation and 3.0 mm. in position. Circular data matrix fiducials provide up to 32,000 unique position references. The update rate is 180 Hz and it can be interfaced via Ethernet, shared memory, USB, or RS-232.

Demonstration Application

We designed a demonstration to test the individual devices as well as their interactions and applications to instruction delivery. We chose to center our demonstration on a piece of hardware that was readily available to us and has some degree of complexity, our (old) video editing rack.



The demonstration involves a user wearing a display device, CyberGlove, Sony Viao, and Fusion Tracker. Instructions are displayed on wearable viewer and hand signals from the CyberGlove allow the user to cycle through the instructions and activate and deactivate the devices. The Viao is the central controller for the system, running all of the necessary software and permitting the user to be entirely untethered. The Fusion Tracker can be used to track the position and orientation of the user and thereby customize the view of the virtual rack being displayed. The accompanying video shows a user wearing the MicroOptical display and CyberGlove and using them to properly setup the video rack to copy a tape.

While the overall application was straightforward, the knowledge gained about the devices and issues present in instruction delivery applications were invaluable. Our first consideration was the display devices and their feasibility in this application. For the most part, all three of the display devices were easy to get working. All that was required was to properly set the display resolution and refresh rate. The DataVisor and 3DVisor had additional possible settings. The DataVisor is capable of true AR allowing the virtual and real world to merge. This would be ideal for this application facilitating the highlighting of real objects with virtual designations and information. However, it quickly became apparent that the DataVisor was not well suited for practical application. The device is rather heavy and awkward; performing maintenance instructions while wearing it would be quite difficult. The 3DVisor is much less cumbersome, but it is not a see-through display, completely blocking the user's view while it is being worn. This means that the user would have to remove it before doing the maintenance instruction and replace it again to get more information about the task.

The compact design of the MicroOptical display makes it the most feasible display for this application. In addition to its unobtrusive design that can be mounted on many different types of glasses, this display can easily be flipped out of view entirely. As with all such display devices, the resolution is small (640 x 480) and font, font sizes, and color need to be carefully chosen to ensure that the user can easily read the information being

displayed. Certain things that are taken for granted when designing large size (workstation display screen) interfaces become a challenge. Font choice is important, because text needs to be legible at a small resolution. Fonts “sans serifs” are easier to read when they are smaller and bold-facing them is helpful. Color is also an important thing to consider. On small displays, light color text on a dark background is easier to read than dark text on light backgrounds.

For our demo application we constructed a simple GUI (graphical user interface) in FLTK [3] that displayed an image of the video rack and allowed the user to cycle through an instruction set.

When considering controllers for our application, we were looking for another unobtrusive device that is also easy to use. We purchased a wireless CyberGlove which is thin enough to be worn under work gloves. Being wireless allows unencumbered movement. We wrote a hand shape recognizer in C++ using the provided SDK. The code recognizes three hand shapes/gestures; an open hand to toggle activation of the recognition system, ensuring that interaction with the system is intentional, a fist gesture to move to the next instruction, and a pointing gesture to move to the previous gesture. All hand shapes must be held for a second for recognition. The software system is actually set up such that any gestures can be used. A GUI was written, again in FLTK, to allow the user to record individualized gestures for each interactive command. This allows the user to customize the interface to any comfortable and memorable gesture set.

At this stage we can visualize instructions and images on a sliver display interacting with the application through gestures recognized from CyberGlove input. A true AR system can additionally take into account the user’s point of view of the scene. This enables the system to aid the user in identifying parts and states. We used the Fusion Tracker to track the position and orientation of the user’s head. A mockup of the scene was then displayed in an OpenGL window. The Fusion Tracker is small and lightweight. It is easily mounted on a helmet or cap.

Development Issues

During the implementation of our demonstration application we encountered a few issues that needed to be addressed. The viability of the displays is stated above. In the end we feel that the MicroOptical display is a quite viable choice for maintenance instruction delivery.

Overall the CyberGlove is a well-designed and reliable device. The licensing of the SDK, however, caused a few problems. When installing the SDK a code is generated. This code is then emailed to Immersion who returns another code to be entered in the authorization software to permanently unlock or authorize the software. In itself, this is not a bad procedure; however, this procedure only authorizes the software for one user on the computer where it is installed. Installing the software on another computer or reinstalling the software on the same computer or allowing another user on the computer to use the software, requires sending and receiving a new code from Immersion. While Immersion was very prompt in sending the codes, in our lab setting and particularly on a team project this authorization procedure was less than ideal.

The SDK for the CyberGlove seems well-developed, at least for this application. We extended a few of the methods easily. Our hand shape recognition code for this demonstration was not sophisticated or robust. The code includes a tolerance in the hand shape comparisons (between the stored sample and the real-time hand shapes). This tolerance is specified in degrees for each joint angle. Some preliminary experimentation has shown that, optimally, different tolerances are needed for different people. A more robust technique, perhaps a machine learning algorithm, would correct this small problem.

The Fusion Tracker was much more difficult to get working. It is a relatively new product that was not well document. Getting the tracker fully working required several lengthy calls to technical support and returning the tracker for repair after a firmware update. The next challenge was to get the device working through a USB port instead of a serial port. Using the USB port provides the necessary power to the tracker, whereas using a serial port requires an AC power source which would restrict movement. The tracker also requires a fair amount of set up for an environment, including calculating the size and positions of the visual fiducials and attaching them. Once this setup is done for an environment it is not required again. The hardest part of dealing with the tracker was figuring out how the data that the tracker was giving us corresponded to our coordinate system. The easy part was dealing with the API. Although not every aspect has been documented yet, it was mostly intuitive. Once the server code is running on a computer, there are only a few function calls needed to receive the streaming data.

When we started this project, the initial idea was to use the tracker to identify where the user was looking at and overlay images corresponding to certain instructions onto what the user was seeing. However, the see-through display that we had was far too bulky for that idea to be practical. An alternative to overlaying images would be to use the tracker to find out where the user is looking, and use a static image appropriate for that viewpoint. For example, if the user is supposed to press a button on the video rack, but standing farther away from the device, then put an image of the entire device on the screen while highlighting the general area that the user should be focusing on. As the user steps closer to the device, display a closer view of the video rack.

One of the major constraints of the tracker is the need for the fiducial targets. In order to get correct translation and orientation information, there must be at least four fiducials in the field of view of the tracker's camera, and the tracker must be within some distance of the targets. If this is not the case, this tracker will most likely start to drift, meaning that data being returned from the tracker states that the tracker is slowly moving or rotating in some random direction. The size of the targets dictates how far away the tracker can be located while still returning reliable data. Our setup consisted of a grid of targets four inches wide spaced roughly two feet apart. This enabled us to get consistent readings up to seven feet away. In the case of an aircraft hangar this might not be a viable solution. The targets would most likely have to be situated on the device being operated on. However, this may give rise to problems while trying to maintain a view of at least four fiducials.

The Sony Viao that we used was adequate for our demonstration application. Because it is a small, wearable device it is not very powerful. We question its feasibility as the program size and complexity increase. Since our purchase of this Viao, they have

discontinued this model, but they are producing newer and slightly more powerful models.

Summary and Recommendations

Throughout this project we have been concerned with testing the ease of use of these devices, their reliability, and their feasibility in the maintenance domain. We are concerned that the devices maybe too inhibiting for the maintainers, even though they are relatively compact. Ultimately, it must be determined if the benefit is worth the cost. In reviewing the benefits of using VR/AR equipment, we must consider the ease of use and type and amount of information that can be conveyed when compared to existing methods (computer screens and paper). This information must originate somewhere and somehow during the instruction authoring process.

We are interested in and would recommend investigating novel instruction authoring systems that would provide additional data to be advantaged in a VR/AR instruction delivery system. We propose expert authoring of instructions by demonstration. An expert can be captured through audio, video, and motion capture performance of a maintenance task. These modalities can then be used both in the authoring of instructions and as additional data during the delivery of the instructions. Over the past several years we have been developing a Parameterized Action Representation (PAR) [4]. We believe that PARs can be used to both recognize actions from motion capture data [5] and fill in necessary semantics that may not be found directly in any of the audio, video, or motion capture streams. This expert authoring application is our next challenge.

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