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AN AUGMENTED REALITY SYSTEM FOR MILITARY OPERATIONS IN URBAN TERRAIN

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ABSTRACT

Many future military operations are expected to occur in urban environments. These complex, 3D battlefields introduce many challenges to the dismounted warfighter. Better situational awareness is required for effective operation in urban environments. However, delivering this information to the dismounted warfighter is extremely difficult. For example, maps draw a user's attention away from the environment and cannot directly represent the three-dimensional nature of the terrain.

To overcome these difficulties, we are developing the Battlefield Augmented Reality System (BARS). The system consists of a wearable computer, a wireless network system, and a tracked see-through head-mounted display (HMD). The computer generates graphics that, from the user's perspective, appear to be aligned with the actual environment. For example, a building could be augmented to show its name, a plan of its interior, icons to represent reported sniper locations, and the names of adjacent streets.

This paper surveys the current state of development of BARS and describes ongoing research efforts. We describe four major research areas. The first is the development of an effective, efficient user interface for displaying data and processing user inputs. The second is the capability for collaboration between multiple BARS users and other systems. Third, we describe the current hardware for both a mobile and indoor prototype system. Finally, we describe initial efforts to formally evaluate the capabilities of the system from a user’s perspective through scenario analysis. We also will discuss the use of the BARS system in STRICOM's Embedded Training initiative.

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Many future military operations will occur in urban environments [CFMOUT-97]. Military operations in urban terrain (MOUT) present many unique and challenging conditions for the warfighter. The environment is extremely complex and inherently three-dimensional. Above street level, buildings serve varying purposes (such as hospitals or communication stations). They can harbor many risks, such as snipers or mines, which can be located on different floors. Below street level, there can be an elaborate network of sewers and tunnels. The environment can be cluttered and dynamic. Narrow streets restrict line of sight and make it difficult to plan and coordinate group activities. Threats, such as snipers, can continuously move and the structure of the environment itself can change. For example, a damaged building can fill a street with rubble, making a once-safe route impassable. Such difficulties are compounded by the need to minimize the number of civilian casualties and the amount of damage to civilian targets.

In principle, many of these difficulties can be overcome through better situational awareness. The Concepts Division of the Marine Corps Combat Development Command (MCCDC) concludes [CMOUT-97]:

> "Units moving in or between zones must be able to navigate effectively, and to coordinate their activities with units in other zones, as well as with units moving outside the city. This navigation and coordination capability must be resident at the very-small-unit level, perhaps even with the individual Marine."

These conclusions were strengthened in the document "Future Military Operations on Urbanized Terrain" where the MCCDC notes:

> "...we must explore new technologies that will facilitate the conduct of maneuver warfare in future MOUT. Advanced sensing, locating, and data display systems can help the Marines to leverage information in ways which will reduce some of the masking effects of built-up terrain."

Finally, in 2001 the DUSD (S&T) identified five critical hard topics, one of which was MOUT. Under MOUT, the use of augmented reality technology to enhance situational awareness was a noted technology improvement.

A number of research programs have explored the means by which navigation and coordination of information can be delivered to the dismounted soldier. Many of these approaches are based on handheld maps (e.g., an Apple Newton), or opaque head-mounted displays (HMDs). For example, the Land Warrior program introduced a head-mounted display that combined a map and a "rolling compass" [Gumm-98]. Unfortunately, these methods have a number of limitations. They obscure the user's field of view and do not truly represent the three-dimensional nature of the environment. Moreover they require the user to integrate the graphical display within the environment to make sense of it. This work is sometime difficult and distracting from the current task. To overcome these problems, we propose the use of a mobile augmented reality system.

A *mobile augmented reality* system consists of a computer, a tracking system, and a see-through HMD. The system tracks the position and orientation of the user's head and superimposes graphics and annotations that are aligned with real objects in the user's field of view. With this approach, complicated spatial information can be directly aligned with the environment. For example, the name of a building could appear as a "virtual sign post" attached directly to the side of the building. To explore the feasibility of such a system, the Naval Research Laboratory (NRL) is developing a prototype augmented reality (AR) system known as BARS, the Battlefield Augmented Reality System. This system will network multiple outdoor, mobile users together with a command center.

To achieve this goal many challenges must be overcome [Julier-99]. This paper surveys the current state of development of BARS and describes ongoing research efforts. We describe four major research areas. The first is the development of an effective, efficient user interface for displaying data and processing user inputs (such as the creation of new reports). The second is the capability for collaboration between multiple BARS users and other systems (CAVEs or Workbenches). Third, we describe the current hardware to provide both mobile and indoor prototype systems. Finally, we describe initial efforts to formally evaluate the capabilities of the system from a user's perspective. We discuss the scenario analysis we have performed for the system and conclusions drawn to date. We also will discuss the use of the BARS system in STRICOM's Embedded Training initiative.

BARS USER INTERFACE

The mobile outdoor system is designed with usability engineering methods to support efficient user task performance. BARS must provide information to the user, and the user must be able to enter data into the system. Neither flow of information can be allowed to distract the user from the primary task. An important feature of the user interface is that BARS must be able to monitor many sources of data about the user and use intelligent heuristics to combine those data with information about the environment and tasks. For example, it might be possible to monitor the level of stress of the user in order to tailor the amount of information needed and reduce it to a minimum during high-stress situations.

The Shared Information Database

The system contains a detailed 3D model of objects in the real environment that is used to generate the registered graphical overlay. This model is stored in a shared database that also contains information about the objects such as a general description, threat classification, etc. Using knowledge representation and reasoning techniques, we can also store in this database information about the objects' relevance to each other and to the user's task.

The Information Filter

The shared database contains much information about the local environment. Showing all of this information can lead to a cluttered and confusing display. We use an information filter to add objects to, or remove objects from, the user's display. We use a spatial filter to show only those objects that lie in a certain zone around the user. This zone can be visualized as a cylinder whose main axis is parallel to the user's "up" vector, where objects that fall within the cylinder's walls are shown, and the user can vary the inner and outer diameters of the cylinder walls. We also use semantic filters based on the user's task or orders from a commander—for example, a route associated with a task will be shown regardless of the user's spatial filter settings, and threats will be shown at all times.

Selecting Objects

Early uses of BARS will mainly consist of users observing and selecting objects in the environment, either to find out more about them ("Where is the electrical cut off switch?") or to add information about them ("I saw a sniper on the third floor of that building."). Thus, the system should include a mechanism to allow the user to easily select items in the environment.

Our research on interaction paradigms is guided by two facts. First, many of the objects a user interacts with are distant (greater than 5m away) and are large (e.g., a building). Second, the position and orientation of the user's head is accurately tracked. Therefore, most interactions are via gestures that require a user to point at distant objects. To date, we have utilized a handheld wireless mouse. The gestural input requires two steps. First, the user faces the possible object of interest (adjusting head orientation). Then, using the mouse, the user maneuvers a cursor over the object. When the user presses the mouse button, a "gaze ray" is constructed from the user's head position and the cursor position; this is intersected with the shared information database to determine what objects have been selected. Although current tracking methods do not always achieve the accuracy necessary, we find them sufficient and are working to improve the performance of the tracking system.

Speech and Gesture Input

The mouse-based interface described in the previous subsection has two important limitations. First, it is difficult to perform complicated interactions with a handheld mouse; a user must resort to various types of drop-down menus. Second, one of the user's hands is occupied with the need to hold and manipulate a mouse. To overcome these problems, we are researching speech and gesture input techniques. These techniques will support more sophisticated interactions and minimize errors. We are implementing speech and gesture techniques with the Adaptive Agent Architecture, which is part of the QuickSet application suite [Cohen97]. We have already performed a preliminary integration of a 2D handheld gesture display with BARS and we are investigating how novel 3D tracking technologies can be used to implement 3D gesture recognition..

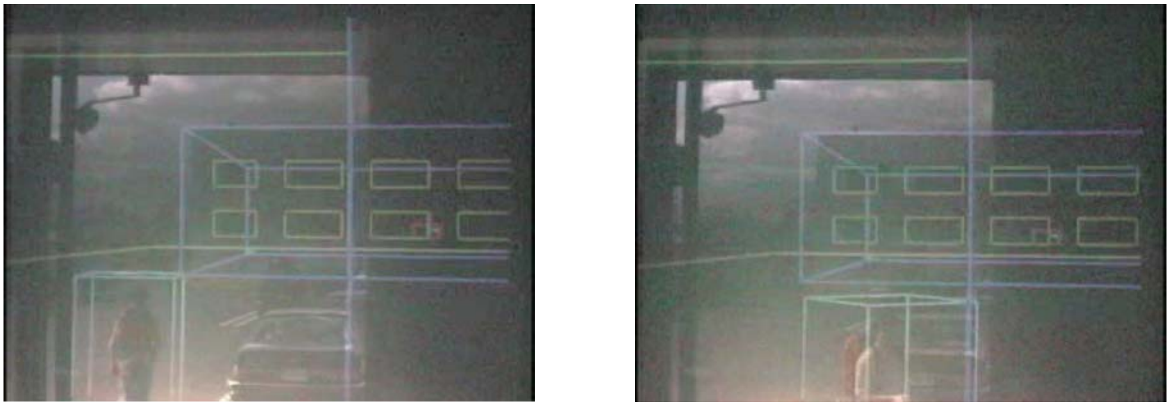

Figure 1: A remote BARS user is highlighted with a box shape. In this example, the user is also physically visible, but the position information is transmitted for all mobile users and can show the location of an occluded user.

COLLABORATION BETWEEN USERS

Through its ability to automatically distribute information, BARS can be used to facilitate collaboration between multiple users. Collaboration can occur horizontally (between mobile users) and vertically (between mobile users and a command center).

Collaboration Mechanism

The BARS collaboration system ensures that the relevant parts of the shared database are replicated on every user's machine. Information is deemed relevant to a particular user based on the information filter described previously. Users join distribution channels that work like IP multicast groups; however, the actual implementation does not depend on IP multicast. Based on the importance of the data, the channels use reliable and unreliable transport mechanisms in order to keep network traffic low. For example, under optimal conditions, user positions are updated in real time (at least 30 Hz) using unreliable transport, but with a frequency of around 5 Hz, user positions are sent reliably so that those with overloaded connections will at least get positions at a usable rate (Figure 1).

A channel contains a class of objects and distributes information about those objects to members of the channel. Some channels are based on physical areas, and as the user moves through the environment or modifies the spatial filter, the system automatically joins or leaves those channels. Other channels are based on semantic information, such as route information only applicable to one set of users, or phase lines only applicable to another set of users. In this case, the user voluntarily joins the channel containing that information, or a commander can join that user to the channel.

Figure 2: An annotated view of the hardware configuration of the current BARS prototype.

BARS PROTOTYPE

Built from commercial, off-the-shelf (COTS) products, the mobile prototype for BARS is composed of (Figure 2):

- Ashtech GG24-Surveyor (real-time differential kinematic GPS receiver for position tracking)
- InterSense InertiaCube2 (for orientation tracking)
- Sony Glasstron LDI-D100B see-through HMD (when color and stereo rendering are important) or
- MicroVision laser retinal scanning see-through head-worn display (when legibility in very bright or very dim conditions is important)
- Dell Inspiron 7000 Notebook computer (main CPU and 3D graphics engine)

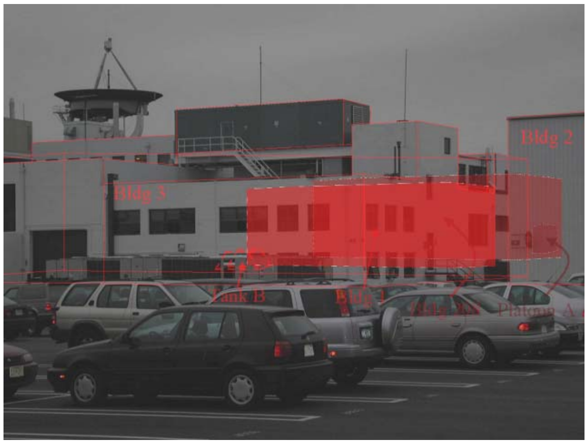

Figure 3: A sample protocol to show the location of occluded objects. The first three layers are shown with outlines of varying styles. The last three layers are shown with filled shapes of varying styles.

- Wavelan 802.11 11Mbps Wireless network card and FreeWave Radio Modem 115Kbps (currently used just to broadcast GPS differential corrections)
- Interaction devices (currently a wrist-mounted keyboard and wireless hand-held gyroscope-equipped mouse)

The indoor prototype system uses the same displays, although the laser retinal scanning display is rarely needed under controlled lighting. Indoors, we must substitute the InterSense IS900 tracking system for the combination of the GPS and inertial units. This system is similar in that it includes its own inertial components, and it uses ultrasonic blips in from microphones mounted in rails hanging from the ceiling in place of GPS. The tracking algorithm internal to the device is quite similar to the combined GPS and inertial method on the mobile prototype. We use a Dell PC equipped with Dual Xeon 1.7GHz processors, an ATI FireGL II graphics processor, a standard Ethernet network connection, standard keyboard, and wireless hand-held gyroscope-equipped mouse.

The software is implemented using Java JDK 1.3 for high-level object management and C for high performance graphics rendering. The combination of software and hardware yields a system able to register a 3D model in stereo at more then 30 frames per second on the mobile prototype and 85 frames per second on the indoor prototype.

PRELIMINARY BARS EVALUATION

User interaction occurs in user-based and task-based contexts that are defined by the application domain. *Domain analysis* plays a critical role in laying the groundwork for developing a user-centered system. We performed domain analysis in close collaboration with several subject matter experts (i.e. military personnel who would be candidate BARS users) [Gabbard-02]. Domain analysis helps define specific user interface requirements as well as user performance requirements, or quantifiable *usability metrics*, that ensure that subsequent design and development efforts respect the interests of users. *User information requirements*, also identified during domain analysis (and focused through the development of use cases and scenarios), ensure that the resulting system provides useful and often time-critical insight to a user's current task. The most intuitive and usable interface in the world will not make a system useful, unless the core content of the system provides value to the end user. Finally, domain analysis may also shape system requirements, typically with respect to system components that affect user performance.

Domain analysis often includes activities such as use case development, user profiles, and user needs analysis. *Use cases* describe in detail specific usage contexts within which the system will be used, and for which the system should be designed. *User profiles* characterize an interactive system's intended operators and their actions while using the system. The process of defining representative users in turn yields information that is useful in making design decisions. A *user needs analysis* further refines high-level user goals identified by user profiles by decomposing these goals within the context of the developed use cases. Moreover, the user needs analysis provides an assessment of what capabilities are required of the system to assist users in achieving these goals. The capabilities can then be further analyzed to identify specific user interaction requirements as well as information requirements.

The BARS use case gives a platoon the mission to infiltrate an enemy facility and destroy two tanks of suspicious chemical agents. Analysis of this scenario gave a set of requirements, including the information requirements for different BARS users and the generic set of tasks that each user needs to accomplish. This analysis revealed a set of features that cannot be easily delivered by any current AR system. For example, one user-centered requirement says that the system must be capable of conveying the location of hidden and occluded objects to the user. For example, a warfighter on a mission might want to know the location of friendly forces hidden behind a wall. This requirement spurred research on display of hidden objects. We have, through expert evaluation, designed three potential protocols (Figure 3 gives one example.) through which such information can be displayed. We take advantage of classic methods of technical illustration and use combinations of the following parameters.

- solid, dashed, or dotted lines or polygons
- intensity or color
- outlined or filled polygonal representation
- line thickness

Until user-based usability evaluations are conducted, however, all such designs are speculative. We have identified a number of principles, such as using multiple parameters to differentiate different distances or number of occluding objects, limiting the number of objects in a given direction, and that parameters can be confounded or masked by the characteristics of the display. For example, intensity of the graphics can sometimes be confounded with background intensity, or with stippling (dashed or dotted) effects. We are conducting user-based evaluations in the summer and fall of 2002 to determine how various parameters interact and how the user performs under a variety of designs and tasks. The evaluation will employ representative domain users, performing tasks derived from the BARS use case. To our knowledge, this is one of the first user-based, mobile, outdoor AR usability evaluations. BARS and other non-traditional computer systems are much more difficult to evaluate than their 2D graphical user interface counterparts [Bowman-02] and as such, will likely require the invention of new evaluation techniques.

In addition, the user-centered requirements identified important performance bounds on known system requirements. For example, by identifying the likely set of objects of interest to BARS users, we discovered that registration (and thus tracking) has to be good enough to accurately position graphical indicators on buildings and streets, but it does not have to be any more accurate than this. This bound is important, because highly accurate tracking is extremely difficult.

EMBEDDED TRAINING AND BARS

So far, this paper has concentrated on the possible uses of BARS as a situational awareness tool. However, BARS and augmented reality have the potential to significantly impact training. As dismounted warrior systems become more sophisticated, the need for detailed, precise, and advanced training and simulation has become paramount. The US Army Simulation, Training, and Instrumentation Command (STRICOM) has initiated an embedded training program [Dumanoir-02] to study how revolutionary techniques can be applied to this domain. STRICOM, in conjunction with NRL is studying how BARS can impact training at three-levels: as a means to blend synthetic and live forces; as a means to provide “training wheels” to show trainees critical information; and as a tool to assist trainers in constructing and operating a training scenario.

The first aspect utilizes BARS to “enrich” an existing scenario. Many MOUT facilities consist of a small group of fairly bare buildings that occupy a self-contained area, typically no more than a few city blocks. However, if a user’s position and orientation were accurately tracked, synthetic forces and building features can be inserted into the user’s environment. If a user were connected through a wireless network to a simulation system such as OneSAF, users could be presented with reactive entities such as air forces (simulate call for fire) or even with individual combatants. Furthermore, BARS could be used to mix live forces at physically different sites (such as multiple MOUT facilities) into the same environment. However, it should be noted that this application is extremely technically challenging. Registration must be accurate to the nearest pixel to ensure that occlusion by the real world is correct. As noted in the previous section, usability evaluation will help determine what level of accuracy a warfighter requires to complete a (simulated) mission.

The second aspect is to use BARS to provide trainees with a set of “training wheels”. For example, BARS could be used to visualize Fatal Funnels or other structural risks in urban environments. Furthermore, it could be combined with recording or playback systems to assist in post mortem analysis of a training exercise.

The final aspect is to provide the trainer with a BARS system. Through its ability to convey situational awareness information such as the location of trainees who might not be visible from the trainer’s vantage point, BARS could enable synthesis of more compelling and difficult training scenarios.

Current research plans are considering the first of these training aspects and, in particular, we are beginning to study how to interface BARS with a simulation system.

SUMMARY

We have presented the Battlefield Augmented Reality System in its current research state. The basic goal of BARS is to aid situational awareness for MOUT. To provide a useful and usable system, we are conducting research on the user interface and collaboration methods. We are beginning to use the current prototype to formally evaluate the usefulness and usability of the system, and expect to conduct our first user studies on basic information display research in the coming months. As we continue to refine the BARS domain analysis and subsequent usability engineering activities, we will iteratively improve the current prototype to a field-deployable prototype in the coming years.

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