BARS: Battlefield Augmented Reality System

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Abstract

Many future military operations are expected to occur in urban environments. These complex, 3D battlefields are extremely demanding and introduce many challenges to the dismounted warfighter. These include limited visibility, lack of familiarity with the environment, sniper threats, concealment of enemy forces, ineffective communications, and a general problem of locating and identifying enemy and friendly forces. Better situational awareness is required for effective operation in the urban environment.

We believe that situational awareness needs cannot be met using traditional approaches such as radios, maps and handheld displays and more powerful display paradigms are needed. We are researching mobile augmented reality (AR) through the development of the Battlefield Augmented Reality System (BARS) in collaboration with Columbia University. The system consists of a wearable computer, a wireless network system and a tracked see-through Head Mounted Display (HMD). The user's perception of the environment is enhanced by superimposing graphics onto the user's field of view. The graphics are registered (aligned) with the actual environment. For example, an augmented view of a building could include a wireframe plan of its interior, icons to represent reported locations of snipers and the names of adjacent streets.

This paper describes the major challenges and the current implementation of BARS. In particular, we stress the need for high value graphical displays which provide the relevant, critical information for a user's current context. These displays should be precisely registered with the environment. There are three major research areas. First, an information distribution system is being developed which distributes to a mobile user only a relevant subset of the common tactical picture. Second, to prevent information overload, we have developed an intelligent filter which selects and prioritizes the type of augmented information which is needed by a user's mission profile. Finally, high performance tracking and calibration systems are required to achieve accurate registration. We describe a general calibration framework that allows precision registration to be carried out in the field.

Introduction

Many future military operations are expected to occur in urban environments [CFMOUT-97]. These complex, 3D battlefields are very demanding and introduce many challenges to the dismounted warfighter. First, the environment is extremely complicated and inherently three-dimensional. Above street level, buildings serve many purposes (such as hospitals or communication stations) and can harbor many risks (such as snipers or mines) which can be located on many floors. Below street level, there can be a complex network of sewers and tunnels. Second, the cluttered environment makes it difficult to plan and coordinate group activities. In narrow, crowded streets it is virtually impossible for all members of a team to be in direct line of sight of one another. Third, the urban environment is highly dynamic and constantly changing. Dangers, such as the positions of snipers can change continuously. Furthermore, the structure of the environment itself can evolve. For example, damaged buildings can fill a street with rubble, making a once safe route impassable. These difficulties are compounded by the need to minimize the number of

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civilian casualties and the amount of damage to civilian targets.

In principle, many of these difficulties can be greatly reduced by providing greater situational awareness to the individual combatants. For example, if a user were shown the location of other members of his team, planning and coordination could be greatly simplified. A number of research programs exist which are testing digital maps or "rolling compass" displays [Gumm-98]. The United States Marine Corps, for example, tested a system called SUITE in the 1998 Urban Warrior Advanced Warfighting Experiment. SUITE was composed of a small laptop computer, a GPS receiver and a radio modem. The system provided users with a continuously updated map display. Although these types of displays have many advantages, including detailed information about the environment (through maps) which provide automatic and continuous updates of the location of entities in the environments, there are a number of important limitations. First, a map is an inherently two-dimensional display whereas the urban environment is inherently three-dimensional. Second, a user must switch attention between the environment and the handheld display. To overcome these difficulties, we propose the use of Augmented Reality (AR).

Figure 1: Image captured from a see-through augmented reality system. Various computer-generated annotations are overlaid directly on objects in the user's environment.

AR is, in effect, a "heads up display". The position and orientation of the user's head is tracked. The user wears a see-through head mounted display. Computer graphics are drawn into the display and these graphics align with objects in the user's environment. An example of the output from the prototype BARS is shown in Figure 1. Computer graphics are overlaid on a real building to annotate various structural features (such as windows) from a previously established database.

The first successful mobile augmented reality system was the Touring Machine [Feiner-97]. The system provided a user with labels and information about the Columbia University Campus. BARS, which builds directly upon this work and is being developed in collaboration with Columbia University [Höllerer-99], seeks to greatly extend this functionality to provide the user with high value graphical displays which provide the relevant, critical information for a user's current context. In [Julier-99], we argued that three major research thrusts had to be addressed: tracking (estimating where the user is located), user interface design (what the user sees) and user interaction (how does the user make requests, reports and queries from the system). In this paper, we describe the current implementation of BARS which partially addresses the first and second research challenges. The next section describes the information management system. We discuss the environment model and describe both the environment and the data distribution mechanism which propagates reports between multiple users. To prevent information overload, an information filter has been developed. This mechanism selects and prioritizes the type of augmented information which is needed by a user's mission profile, ensuring that only the most relevant information is presented to the user. The tracking and calibration framework is described next. Finally, we outline the current BARS prototype.

Information Management System

The information management system is responsible for describing the environment and disseminating this information to the remote user. It is built designed with the following assumptions:

1. Any object of any type can, at any time become sufficiently "important" that it must be highlighted by the system.
2. Certain types of objects (such as the location of enemy forces) are extremely important and should be known by all users all the time.
3. Some objects (such as way points or objectives) are only critical to the mission profile of a particular individual.
4. If an object has no "special properties", it should exhibit the following default behavior. The environment surrounding the user is known in the highest detail possible. As distance increases, the user might want to know progressively less and less information. At a significant distance, might

only have the critical landmarks as well as the locations of known friendly and enemy forces.

Database Structure

All objects in the environment are considered to be "first class" entities which have a separate, identifiable name, location and size. Examples of entities include physical objects (such as building, tree, tank, road, warfighter), spatial objects (such as areas or regions) and logical objects (such as waypoints and routes). The objects are organized hierarchically using the concept of containment. The top-level is a *City* entity which contains all other objects in the environment. The city entity contains buildings, streets, sewer systems and force units. In turn, each of these entities contains other sub-entities. A building, for example, can contain walls, floors, windows and doors.

Data Distribution

The design of the data distribution mechanism is guided by two important properties: the bandwidth is finite and the scheme should be robustness to network failures[2].

The basic approach is illustrated in Figure 2 and is an extension of the distribution concept initially described in [Brown-98]. The network is viewed as a collection of software objects which are non-fully replicated. When a particular object (such as a mobile user or a report of a sniper) is to be created, a single "master" copy is created on one computer which forms part of the information network. Although any computer can serve as the "master", we expect to only create these at a remote computing site. When another system wants to know about that object, it creates a "ghost" (or non-fully replicated) version of the master entity. The ghost version can be a highly simplified version of the master object. For example, the master might contain detailed track history information whereas the ghost could simply be a report of current location and an uncertainty ellipse. The ghost copies are used to perform tasks such as updating the graphics display. When the master entity changes, it automatically sends updates to all of its ghost copies. When a remote system wants to change the master, it sends a request to the master entity which processes the state change request and broadcasts the result.

This system meets the two requirements described above. First, the required bandwidth is reduced because a system only receives data about its ghost entities. Second, because each remote system maintains its own "ghost" entities, only the changes to these entities need to be distributed, greatly simplifying the type and kind of information which will be transmitted. Furthermore, these updates are automatically pushed and there is no need to use a data polling mechanism. Finally, if a network connection fails, the remote system does not receive further updates of its ghost entities. However, these entities still exist in the remote system and can be used, for example, for display purposes.

An important feature of this system is that it must decide *what* objects will be distributed and *how* a system, when it enters the network, discovers what objects are available. This is achieved through the use of the Connection and Database Manager (ConMan). The ConMan knows on which machine each master entity and its ghosts are maintained, and the spatial position of each entity in the environment. Based on aura interactions [Greenhalgh-95] and arbitrary rules we can add to the ConMan, it directs objects to initiate or cease communications between themselves. Thus, communications are only set up between entities that need to know about each other, eliminating unnecessary network traffic.

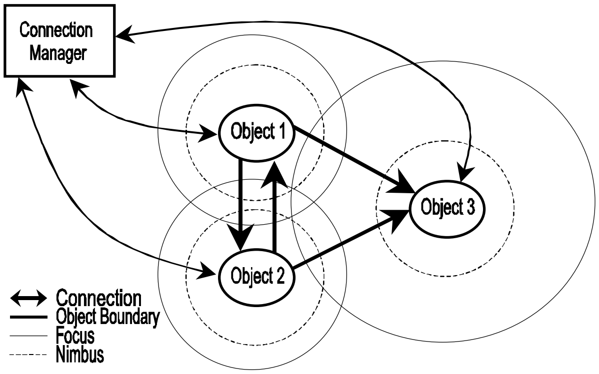

Figure 2: The Data Distribution Mechanism. The environment consists of three entities (Objects 1, 2, and 3). The focus of each entity is shown by a solid circle, and its nimbus by the dashed circle. Connections between each entity are brokered by the Connection Manager (as indicated by the lightweight connection arrows). Because the focus of Object 1 overlaps the nimbus of Object 2 and vice-versa, each entity contains a ghost copy of the other. The arrows show connections that are used to update the copies. Object 3 is a "stealth" viewer – its focus intersects

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[2] This research work does not focus on the design of robust data transport layers because a number of such layers (for example that used in SRI's InCON system[Seaton-98]) have already been developed. Our work focuses on what data will be transmitted over these layers.

the nimbuses of Objects 1 and 2 and so it receives copies of these objects. However, neither Object 1 nor Object 2 creates or receives updates of Object 3.

Entities may also join the simulation simply by existing in a relational database which is linked to the ConMan. The ConMan analyzes the entities stored in the database and calculates their nimbuses. When the ConMan determines that an entity in the simulation needs to interact with an entity in the database, the ConMan instantiates the object based on the information in its database record. For example, in a simulation of a city, information about all buildings is stored in the database. The ConMan determines that the new mobile user needs to be aware of some buildings nearby, instantiates new objects for those buildings, and connects the user object with the building objects. As the user moves through the environment, he may encounter more buildings that will be instantiated by the ConMan. The instantiations of objects can be considered a collective write-through cache for the database. When an entity (that has a record in the database) is changed, the change is written to the database.

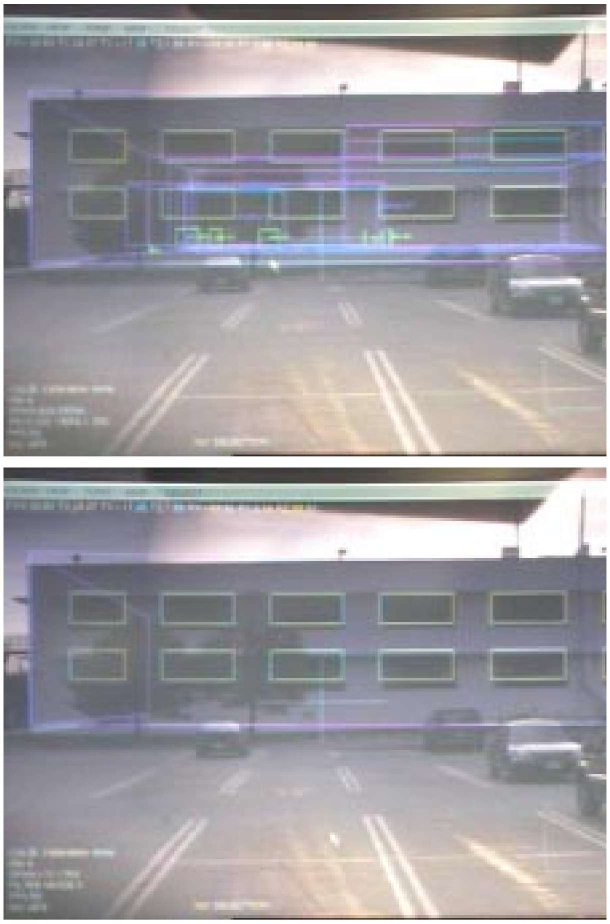

Figure 3: The effect of clutter. The top picture shows the view of a building. Several other buildings are visible behind, making the display extremely cluttered and confusing. The bottom picture shows the same dataset when the information filter is enabled.

Information Filter

Once the information has been distributed to a mobile user, the system must still plan and coordinate what information must be shown. The reason is illustrated in Figure 3. If the system simply shows the user all information which is known about the environment, the result can be a highly cluttered display which is difficult to interpret. To overcome this problem, BARS utilizes an intelligent information management filter to decide which entities have the highest priority and must be shown to the user [Sestito-00]. The filtering is a logical extension and refinement of the aura used with the object distribution.

To help the decision process and to take into account the variety of situations that can be encountered, the user can select a filtering mode according to his current mission. Current mission modes are: **stealth**, **reconnaissance**, **route**, and **attack**. So, for example, the route mode will show the user the position of enemy and friendly forces, his destination point, hazardous materials found in the way, zones for potential enemy ambushes. In addition to these basic modes an individual user is able to decide to increase or decrease the importance of certain objects.

Once the filtering mode has been selected, the filtering process is done in three stages:

1. In the first stage, all the objects that are of critical importance to the user are shown at all times. Objects in this category include enemy forces and hazardous zones such as mine fields. All the objects that are selected by this filtering stage are sent straight to the graphics system to be displayed to the user.
2. In the second stage, objects that are important to the mission are selected. For example in a route or reconnaissance mission the names of important streets and buildings are selected. The importance of each object is described in the database. A heuristic system based on the current Army field manuals for operations in urban terrain is used to designate importance values to each object. Due to the complexity of the missions being carried out, the complexity associated is a multi-dimensional vector. So, one component has the tactical importance for an offensive operation of the

object, another component has the importance a civil target, and so on. While this filtering reduces the number of objects that are of potential interest to the user, a large number of objects are still selected. Thus, a third filtering stage is necessary.

3. In the third stage, the objects selected by the second stage are filtered again, but now according to their “region of influence” (RI). The RI specifies the volume in space where an object is of relevance for the mission, or the region where the object has any kind of influence in the development of the mission at hand. The region of influence is calculated by a heuristic formula in the BARS filter. It is a dynamical entity which value depends on the mission mode, the importance of the object and other factors. If the object has been selected by the stage 2 of the filtering process, and its region of interest intersects the user's one, the object is displayed, otherwise, it is being held until the user steps into the object's RI.

The objects that have been selected at the end of the process are send to the graphic management system that displays the information to the user. The graphical management system is being designed to also determine in what part of the user's field of view the information will be displayed. This way, information will not be clustered in the center of attention of the user and it will be less distracting.

Calibration system

Once the set of objects have been determined, they must be drawn in such a way that they correctly align with the real world. The user viewing direction in the virtual world is determined at each frame using the position and orientation measured by the corresponding position and orientation sensors. Because of the characteristics of the display (such as field of view), the properties of the trackers (such as biases) and due to the fact that each user wears the display slightly differently, a precise calibration system which can be applied, while the user is in the field, must be used. Traditional approaches have used specially designed indoor environments. These are not appropriate, and a new framework has been developed. The framework solves two calibration parameters simultaneously. The first is the transformation from the world referential to the base referential and is equivalent to calculating the mapping the report from a sensing device to the true position and orientation of the sensor. To a first approximation, these parameters tend to be constant for a device and can be usually extrapolated from the tracker manual. For example, our inertial sensor measures orientation with respect to a referential having an axis aligned to the earth magnetic field and another axis pointing up. In this case the referential depends upon one’s location on the earth. The second transformation maps the sensing unit referential to the viewpoint referential attached to one of the user’ eyes. It depends on the way the sensing unit is attached to the HMD and the way the HMD is worn. To solve this unknown, each user must calibrate the system prior to using. This calibration is achieved by displaying in the user’s head mounted display a wireframe representation of certain features in the environment. The user turns their head until the virtual representation aligns with the real-world. At this point, the transformation can be determined and accurate registration is achieved.

Experimental System

A fully functioning prototype of the outdoors part BARS system has been implemented. The hardware system, is portable, wearable, and can operate both indoors and outdoors. The software system lets the user see information about the environment (e.g. building names and locations) superimposed upon the real world.

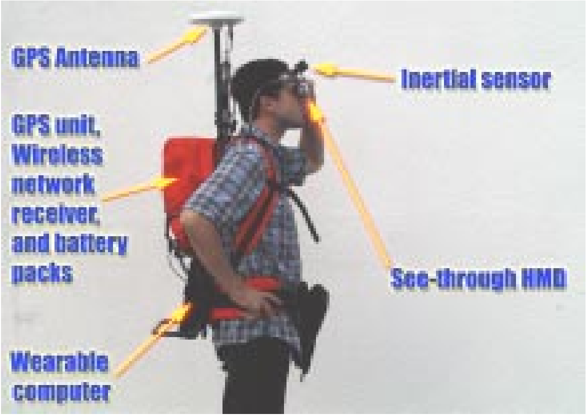

Figure 4: The hardware for the prototype BARS system.

Hardware Description

The system is composed of several interconnected off-the-shelf components which are shown in Figure 4. These components are:

- **A Dell Inspiron 7000 laptop.** This is a 366MHz Pentium II-based laptop computer which carries out the major tasks (data distribution, filtering, scene generation). Our initial trials suggest that, with a dedicated graphics card, a system with considerable less computational resources is sufficient.

- **Ashtech GG24-Surveyor GPS receiver**. This is a dual constellation (uses both the US NavStar and Russion GLONASS satellites) kinematic differential GPS receiver. With a base station, it is capable of providing (in clear areas), position measurements with centimeter level accuracy.
- **An InterSense IS300Pro inertial tracker**. This device uses gyroscopes and compasses to precisely determine the orientation of a body with respect to a reference referential oriented along the earth magnetic field. The compasses are used to correct for the drift occurring with gyroscopes over time
- **A FreeWave Radio Modem**. This is capable of transmitting 115kbits/s over long ranges (greater than 20 miles). In an urban environment (NRL), we have demonstrated its capability to transmit from the interior of one building through two other buildings to a remote site over 50 m away. The data are fed to and read from the units using a serial connection at speeds up to 115 Kbps. A TCP/IP connection is opened between each radio pairs to allow for multiple channels of data through the same link using multiple socket connections. Currently the only information driven by the link is the correction messages emitted by the fixed GPS receiver. Later, the base station will transmit local versions of the database to the mobile units as needed. The mobile units will emit location information and will, in turn, receive the database part required. Additionally, changes to the global database will be possible allowing update messages from a remote station to the base station.
- **A Sony Glasstron Head-Mounted Display (HMD).** This provides a lightweight high-resolution solution to display graphics superimposed upon the real world for the BARS prototype. The display has its own battery and can display screens of resolution SVGA. The display is connected to computer via the SVGA port replicating the screen.

Portable batteries power all components. This enables the whole system to be wireless and to be transported by an individual. The processing unit (a laptop computer) is communicating with the GPS receiver, the radio unit, and the inertial tracker using a serial link. The BARS is composed of a stationary unit called base station and remote units transported by users in the field called mobile user.

The architecture of the system is shown in Figure 5. A typical output from the prototype BARS is shown in Figure 6.

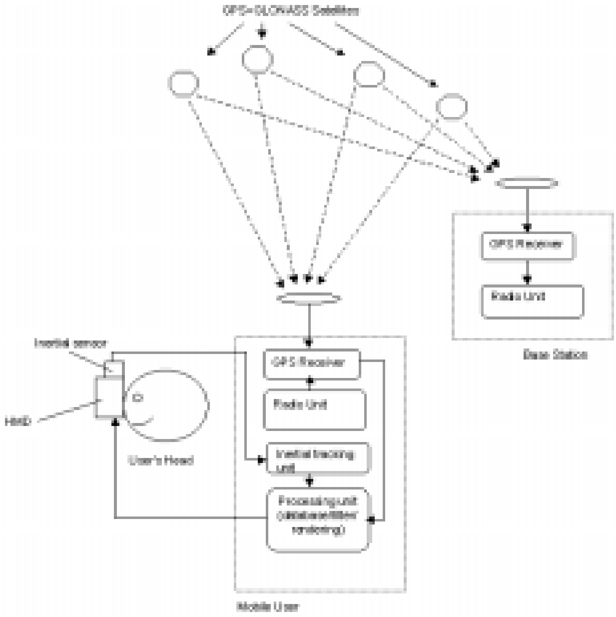

Figure 5: Architecture of the prototype BARS.

Summary

Augmented Reality has the capability to significantly change the way in which information can be delivered to the individual warfighter. Through registering high value graphical displays which provide the relevant, critical information for a user's current context, we believe that situation awareness can be greatly improved, leading to faster and more informed decisions. This paper has described some of the research issues and the current progress of the BARS.

Acknowledgements

This work was sponsored by the Office of Naval Research, Virginia.

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Figure 6: Output from the prototype BARS. The top picture shows an output from the system, the bottom shows an overview map display.