so that viewers in the presentation building, the ECOC, and throughout the battlespace could watch the video simultaneously.

NRL's Communication Systems Branch continues to develop advanced mobile networking techniques to meet the demands of tomorrow's mobile warfighters.

Acknowledgments: The development of the OBS mobility architecture and the success of the field exercise was a joint effort between several government agencies and private contractors. Sponsorship was provided by the Defense Advanced Research Projects Agency (DARPA), AFRL/RSS, NRL, and the Army Communications and Electronics Command (CECOM). MCWL and the Extended Littoral Battlefield (ELB) Program Office were participating activities in the field exercise. TRW, BBN Technologies, L-3 Communications, and Hughes Research Laboratories were the contractors responsible for the OBS development.

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Augmenting the Urban Battlefield

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The urban environment is perhaps the most difficult environment that the warfighter faces. First, it is extremely complicated and inherently three-dimensional. Above street level, buildings can harbor many risks (such as snipers or mines) that can be on many floors. Below street level, there can be networks of sewers and tunnels. Second, coordination between team members can be difficult. In narrow, crowded streets it is unlikely that all members of a team will be in direct line of sight of one another.

Third, the urban environment is highly dynamic. Not only do the locations of threats change (e.g., a sniper repositions) but also the infrastructure itself can change (e.g., damaged buildings can fill a street with rubble, making a once-safe route impassable). All of these difficulties are compounded by the need to minimize civilian casualties and damage to civilian targets. The effects of these problems have been illustrated in many examples, from Berlin in World War II to Mogadishu and even to Grozny. In principle, many of these difficulties can be overcome through better situational awareness. To meet these needs, NRL is developing the Battlefield Augmented Reality System (BARS).

Background: BARS uses a display paradigm known as *augmented reality* (AR). The user's position and head orientation is tracked, so that the system knows where the user is located and the direction of the user's gaze. The user wears a see-through, head-mounted display and computer-generated imagery is aligned (from the user's point of view) with the real world. The advantages of AR can best be appreciated by considering the (far easier) problem of providing jet pilots with a heads-up display. A pilot must be aware of the full 3D environment and, in particular, the location of aircraft. A 2D display (such as a map or a personal digital assistant (PDA)) would divert the pilot's attention away from the environment, leading to a possibly critical loss of situational awareness. AR allows a mobile user to maintain continual awareness of the environment. At the same time, 3D information can be provided in a hands-free and intuitive manner.

The BARS System: BARS pushes the state of AR research in several directions.[1] First, the application domain—delivering situational awareness to a mobile user in the urban environment—is complex and a great deal of attention must be paid to what is to be displayed, how it is to be aligned, and how it is to be represented. Second, the outdoor system must be wearable and self-contained. Third, the system must be multi-user and must allow multiple mobile users to collaborate directly with one another and with a fixed base station.

Figure 6 shows the current development system; Fig. 7 is a typical output from the system. This mobile system is capable of showing buildings, windows, doors, routes, maps, and situation awareness information such as the location of other mobile users.

BARS Research: AR research is complicated by its intrinsically multidisciplinary nature. Topics covered include computer graphics, human-computer interface, system design and engineering, robotics and machine vision, and evaluation. Our major research thrusts are:

- *Tracking*. To accurately register the graphics against features in the environment, the system must accurately measure the position and orientation of the user's head. "Open loop" tracking systems (such as GPS and inertial systems) are not sufficiently accurate, and we are currently in-

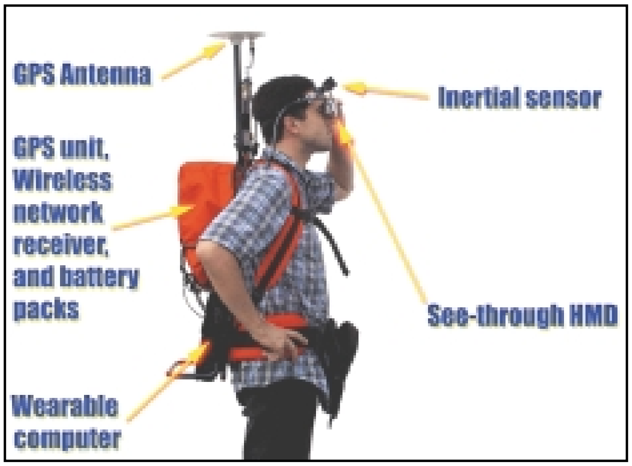

FIGURE 6
Current BARS development system. This system is developed using COTS products, hence its size. (This system might be a familiar sight to regular users of the Building 28 cafeteria.)

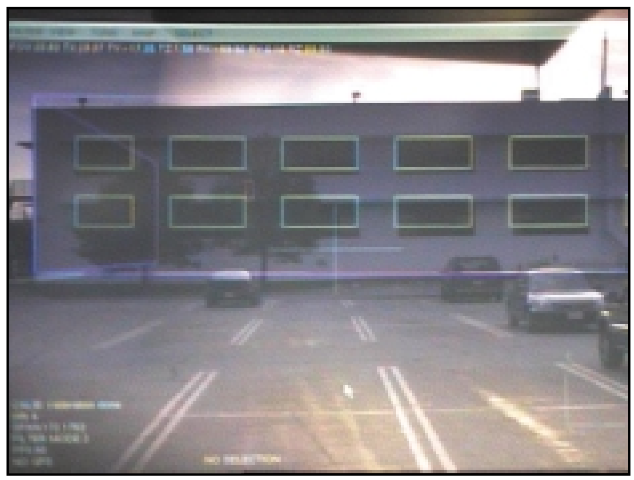

FIGURE 7
Output from AR system, captured by camera aligned with the head-mounted display.

vestigating vision-based tracking systems developed at the University of Southern California and MIT.

- *Calibration*. Different users wear the system differently, and subtle differences in the placement of the display can lead to significant registration errors. Therefore, we have developed tools and techniques for interactively calibrating the display.

- *User interface design*. Many different types and kinds of data can be shown to a user, and we explore the use of various types of representations and their effectiveness.

- *User interaction*. Users will have the capability to query and enter data into the system. To date, most systems have focused on the use of handheld displays and wrist-mounted keyboards. We are exploring the use of multimodal interactions (integrated speech and gesture recognition).

- *Information filtering*. Due to its complexity, the urban environment contains reports of many objects in a small space. We are developing tools that automatically determine what information should be shown to a user at any given time.[2] Metrics include the type of mission, the types of objects, and training manuals.

- *Software architecture and data distribution*. We are developing flexible software architectures and data distribution systems for delivering the appropriate subset of information to a particular user at the right time and the right place.

- *Virtual Reality "Command Center."* To explore the interaction between a command center and several outdoor, mobile BARS users, we are modeling a portion of NRL and displaying it in our virtual reality CAVE facility (a full-sized, fully immersive room). While good techniques exist to model urban areas for fly-throughs, new methods are required to model urban areas with geophysical accuracy.

Conclusions and Future Developments: We have built one of a handful of systems that is capable of outdoor, mobile AR. The system contains many advanced features such as the information filtering discussed above. We expect to shortly perform a seminal demonstration of multiple outdoor users working together using BARS. Within the next year, we will be demonstrating the interplay between the outdoor users and the VR Command Center. Longer-term issues we are starting to address include user evaluation to optimize the effectiveness of the system and the use of automated tools to construct accurate and detailed models of an urban environment.

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[Sponsored by ONR]

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End User Terminal and Wearable Ground Control Station

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Under Office of Naval Research and United States Marine Corps (USMC) sponsorship, the Tactical Electronic Warfare Division (TEWD) has developed a unique capability for the USMC. The End User Terminal (EUT+) is a lightweight, ruggedized, wearable computer. This capability was developed to provide a wearable computer for Marine Corps Warfighting Laboratory (MCWL) experimentation. MCWL has been developing a suite of hardware, software, and communications infrastructure to determine the efficacy of enhanced situational awareness at the battalion level and below. The EUT+ is seen as meeting the needs at the individual rifleman, fireteam, squad, and platoon levels. More recently, TEWD was asked to develop a squad-level unmanned air vehicle (UAV). Because of the likely forward deployment of this asset, a wearable ground control station (GCS) was seen as being advantageous. The development of the EUT+ and the wearable GCS are explored, as are the salient specifications and expected future deployments.

Development: Crucial in the development of an advanced wearable computer is the recognition that it must be rugged, lightweight, easy to use, and easily maintained by the Marine in the field. The system developed by NRL meets these criteria, and it provides the performance required to run developmental software. To understand what features the Marines would need, NRL deployed on numerous limited objective experiments (LOEs) that were run by MCWL. Feedback and lessons learned from participating in the LOEs and from conversations with individual Marines have been folded into the current system.

Hardware: The EUT is a ruggedized, wearable computer configured on a modular lightweight load-carrying equipment (MOLLE) vest. The EUT is a full-function 550 MHz Pentium III processor (Fig. 8), Windows NT touch screen computer. The system uses both a GPS receiver and a simple inertial navigation system (INS) to provide the wearer with current location. The INS is a pedometer coupled with a digital compass and inclinometer. This combination provides location updates in the absence of a GPS signal, such as indoors or underground. An internal 6 watt 2.4 GHz amplifier can be used to communicate via the IEEE 802.11 local area network protocol or to communicate with the Dragon Eye unmanned air vehicle. The 6-inch LCD display is heavily ruggedized and fits into a pocket on the MOLLE vest. The computer system, GPS, and RF transmitter are all powered from a Mil-Spec battery that provides approximately 3 to 5 hours of continuous operation. By using the SINCGARS family of batteries, the EUT user has access to the normal supply chain of BA-5590 LiSO2, BB-390 NiMH, and the new LiON BB-2590 batteries. Figure 9 shows a U.S. Marine wearing the EUT in the field; Fig. 10 shows a Marine holding the Dragon Eye UAV while wearing the GCS. He is also