Perceptual and Ergonomic Issues in Mobile Augmented Reality for Urban Operations

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Introduction

Twenty-five years ago a computing revolution occurred as computers moved to the desktop. Today, a similar revolution is beginning that will fundamentally transform how we access information. As computers become ever lighter and less expensive, they are moving off the desktop and are becoming mounted in vehicles, appliances and tools, as well as worn on our bodies. In twenty years imbedded and worn computers will be ubiquitous, and so effectively using them will be critical for the Navy-after-next. They will provide “information everywhere,” and they are going to require fundamentally new paradigms for displaying and interacting with information. An important sub-category of display and interaction, especially for worn and vehicle-mounted computers, will be augmented reality (AR), where information is rendered onto see-through glasses or windshields so that it overlays relevant parts of the real world (see Figure 1).

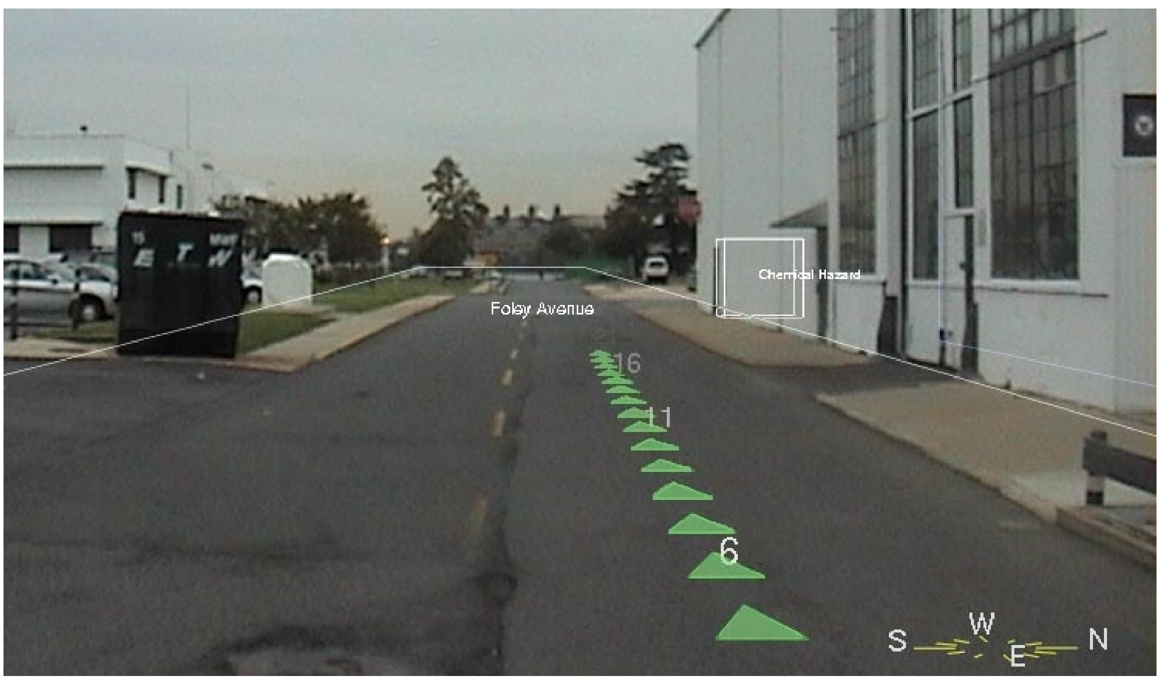

Figure 1: An example of augmented reality (AR), where graphical information overlays the user’s view of the real world. In this example, a compass shows which direction the user is facing, the triangles indicate a path the user is following, the numbers on the path indicate distances in meters in front of the user, a hidden chemical hazard is annotated, and the name of the street is given. The graphics are registered with the world, so for example the triangles appear to be painted onto the road surface. The result is an integrated display which allows *heads-up* viewing of the graphical information.

As Figure 1 demonstrates, AR devices provide *heads-up viewing*: information is integrated into a user’s view of the real world. To date, paradigms for displaying and interacting with computerized information assume the user is looking at a screen and manipulating various devices such as keyboards, mice, or (particularly for hand-held devices) the screen itself. For AR devices to reach their full potential, what is now required are new paradigms which support *heads-up* information display and interaction, seamlessly integrated with viewing and interacting with the real world. An example of such a new paradigm would be a multi-modal combination of pointing gestures (to select relevant graphics) and voice commands (to perform operations upon selected items). This would be similar to how two people viewing the scene in Figure 1 would discuss the information with each other.

However, to develop this or any other new paradigm, the field needs a much better understanding of the fundamental perceptual and ergonomic issues involving AR display and interaction. This area is so new that a survey, conducted in February 2003, of the 7 primary publishing venues for AR research[1] reveals only 14 reported user-based studies of AR systems (see below), out of a total of 880 papers. The PIs are requesting funding to conduct research aimed at both understanding the fundamental perceptual and ergonomic issues in AR display and interaction, and beginning the process of characterizing and quantifying this understanding. Our proposed research will be *user-centric*, in that it will involve studying actual users in realistic settings. And, it will be in the context of the Battlefield Augmented Reality System (BARS), a novel AR system for mobile, heads-up battlefield information currently in development at NRL, under a close partnership with Virginia Tech.

The PIs are proposing a joint effort between NRL and Virginia Tech to conduct this research. For the past 6 years, the PIs at NRL and Virginia Tech have been collaborating on user-centric research in virtual reality (VR) and, for the past 2 years, on AR as well. This collaboration has resulted in 6 publications (see below). These have been accepted at leading conferences and journals in the virtual and augmented reality fields, including *IEEE Virtual Reality* and *IEEE Computer Graphics and Applications*. Three of these publications [1, 3, 4] are in AR; four are user-based studies [1, 2, 5, 6], and one is a user-based study of an AR system [1]. Furthermore, this team has access to BARS, which is one of only 5 wearable, outdoor AR systems in the world, and is the *only* such system developed at a military facility to investigate military applications. BARS itself is unique in the field, and is the result of 4 years and approximately $3.5 million of engineering time and equipment. BARS makes it possible to conduct AR studies with a relevance to military applications that is unmatched by any other AR research group.

Our team's capabilities are also unique; we not only have extensive experience in developing VR and AR systems, but we also have unparalleled experience in usability engineering and conducting user-based studies on a broad variety of complex interactive applications. Of the 5 groups that have produced outdoor AR systems, we are the only one that includes usability engineers with this level and kind of expertise. This role is critical for producing user-centric Naval applications that have optimal user performance, safety, and satisfaction. NRL has pioneered VR/AR system development for Naval applications, and Virginia Tech has pioneered VR/AR usability engineering. In short, this team's expertise, record of published research in highly-selective journals and conferences, and access to BARS, make it uniquely qualified to conduct this research.

[1] Int. Workshop on Augmented Reality (IWAR) 1998–1999, Int. Symposium on Augmented Reality (ISAR) 1998–2001, Int. Symp. on Mixed Reality (ISMR) 1998–2002, Int. Symp. on Mixed and Augmented Reality (ISMAR) 1998–2002, Int. Symp. on Wearable Computers (ISWC) 1997–2002, IEEE Virtual Reality (VR) 1995–2002, PRESENCE: Teleoperators and Virtual Environments 1991–2002.

Previous Work

User-based studies of AR systems fall into three basic categories. Two of these categories, *manual tasks* and *social and communication issues for collaborating users*, encompass multiple publications. The third category consists of single papers on various topics.

AR-mediated manual tasks involve the user manipulating real-world items under the guidance of computer-generated graphical information [12, 13, 14, 19, 20]. These studies lay groundwork for the potentially large impact which AR could have on tasks such as manufacturing, maintenance, and repair, where specialized reference knowledge is often combined with manual manipulation. Currently, these tasks require reference books, often containing substantial graphical content — an example is auto repair manuals. One promise of AR is rendering this graphical content onto the actual machinery that must be manipulated. This category also encompasses the only industrial use of AR to date [13, 14], where AR was applied to assembling aircraft wiring harnesses.

The second category involves studying social and communication issues for collaborating users, where the user communication is at least in part mediated by the AR interface [7, 8, 9, 10, 11, 17]. A sub-category is a commonly expected use of AR, where a field user wearing an AR display consults with a remote desk-bound expert [8, 9]. Here the general goal is to allow the expert to widely and remotely apply their knowledge. The remaining studies [7, 10, 11, 17] investigated co-located users collaborating on local tasks. One of these studies [10] points out that the properties of wearable AR systems make them ideal for many Computer Supported Cooperative Work (CSCW) applications.

User-based AR studies have addressed three additional topics. One studied a tabletop architectural layout task [15], which also utilized a tangible user interface. This task qualitatively differs from the manual tasks discussed above in that it requires a substantial cognitive component, and “what if” trial and error. Another study involved urban navigation using an AR map visualization [18]; this work is clearly relevant to BARS. The study involved walking users, but the results could equally apply to driving users. A final study, also relevant to BARS, studied visualizing near-field objects hidden by walls in building interiors [16]. This study is the first research of the critical AR “x-ray vision” affordance, and is most closely related to our own work [1], which studies “x-ray vision” for far-field objects, such as personnel located behind the building in front of a user.

In addition to our AR user study [1], the PIs have published two additional AR papers in the context of the BARS system. One describes a domain analysis of urban operations which could be afforded by BARS [4]; the results of this work are summarized below. The other is a general description of the BARS system [3].

Urban Operations

Under the BARS project, we are developing a mobile AR system to support urban operations. While we are currently focused on a wearable system for on-foot tasks, most of our work is also applicable to vehicle-mounted AR systems. The urban operations that BARS could afford include [4, 21]:

Urban Patrol:

- Heads-up display of 3D maps of urban areas.
- Heads-down display of computerized 2D overview maps, which may be projected onto the floor or a wall.
- Heads-up display of routes to various areas, such as the situation objective or to the nearest exit.

- Heads-up display of registered "x-ray vision" information, including floor plans, sewer system schematics, power system schematics, etc.
- Integrated, heads-up display of chemical, biological, radiological, explosive, and other sensor data.
- Real-time display of automatic language translation as well as information on cultural customs.

Urban Operations:

- Heads-up display of dynamic situational awareness information such as location of friendly forces, military objectives, phase lines, known dangers such as sniper locations, etc.
- Integrated display of Identification of Friend or Foe (IFF) technology to track friendly personnel even when occluded by urban structures.
- Improved situational awareness during dynamic incidents, enhanced cohesiveness between unit members, and better coordination with command personnel.
- Integrated display of traffic and routing information.
- Integration of advanced sensor technologies such as thermal and infrared vision as well as zoom (binocular) vision.

Training:

- Training scenarios which simulate dangerous combat environments, superimposed on real-world MOUT facilities.
- Heads-up display of simulated urban training data from systems such as ModSAF.

Proposed Work

Over the past several years, considering both these urban operations and the state of the BARS system, our user domain analysis activities [4] have yielded the following areas of mobile AR that require study in the areas of perceptual and ergonomic science:

- Heads-up display of objects occluded by urban structures.
- Heads-up display of object distance.
- Simultaneous display of overlapping objects.
- Graphical clutter inherent in 'x-ray vision'.
- User tolerance of tracking and registration errors.
- Display of object importance.
- Heads-up textual information layout.
- Hands-free, heads-up system control.

There is a very compelling finding from comparing this list of urban operations to the literature review. To date, all of the reported work is for tasks in the near visual field. Such near-field tasks are natural when a user employs their hands. However, most of the urban operations listed above require looking at least as far as across a street, and thus use far-field perception. While the small number of results discussed above could hardly be considered a complete study of near-field AR perception, to date we could not find even one reported study (other than our own [1]) of a far-field task. Perception researchers have pointed out the very large perceptual differences between near-field and far-field perception [22], and we cannot expect near-field results to apply to far-field tasks. Furthermore, while it is true that far-field perception has been studied with VR and other optical stimuli [22] (and the same is certainly true for near-field perception), with AR tasks the view of the real world behind the graphical annotations, and the interaction between the graphics and the real world, make far-field AR perception qualitatively different from anything previously studied.

This motivates our desire to focus on far-field perception while investigating the above capabilities. The expertise of the current group, and the availability of BARS, makes this the right time for this lab to undertake this research program.

PI References

The three PIs on the proposal (J. Edward Swan II, Deborah Hix, Joseph Gabbard) are co-authors on all of these publications.

[1] Mark A. Livingston, J. Edward Swan II, Joseph L. Gabbard, Deborah Hix, Simon J. Julier, Yohan Baillot, Dennis Brown, Tobias H. Höllerer, "*Resolving Multiple Occluded Layers in Augmented Reality*", (in submission to) ACM Transactions on Graphics, SIGGRAPH 2003 Annual Conference Series.

[2] J. Edward Swan II, Joseph L. Gabbard, Deborah Hix, Robert S. Schulman, Keun Pyo Kim, "*A Comparative Study of User Performance in a Map-Based Virtual Environment*", (to appear in) Technical Papers, IEEE Virtual Reality 2003. (29 of 103 accepted; 28%).

[3] Mark A. Livingston, Lawrence J. Rosenblum, Simon J. Julier, Dennis Brown, Yohan Baillot, J. Edward Swan II, Joseph L. Gabbard, Deborah Hix, "*An Augmented Reality System for Military Operations in Urban Terrain*", Proceedings of the Interservice / Industry Training, Simulation, & Education Conference (I/ITSEC '02), Orlando, FL, December 2–5, 2002.

[4] Joseph L. Gabbard, J. Edward Swan II, Deborah Hix, Marco Lanzagorta, Mark Livingston, Dennis Brown, Simon Julier, "*Usability Engineering: Domain Analysis Activities for Augmented Reality Systems*", The Engineering Reality of Virtual Reality 2002, Proceedings of SPIE (International Society for Optical Engineering), January 24, 2002.

[5] Joseph L. Gabbard, Deborah Hix, J. Edward Swan II, "*User-Centered Design and Evaluation of Virtual Environments*", IEEE Computer Graphics and Applications, Volume 19, Number 6, November / December, 1999, pages 51–59.

[6] Deborah Hix, J. Edward Swan II, Joseph L. Gabbard, Mike McGee, Jim Durbin, Tony King, *"User-Centered Design and Evaluation of a Real-Time Battlefield Visualization Virtual Environment"*, Proceedings IEEE Virtual Reality '99, March 13–17, Houston, Texas: IEEE Computer Society Press, 1999, pages 96–103. **Winner of the "Best Paper" award at IEEE Virtual Reality '99, the premiere international conference in this field**.

User-Based Studies of AR Systems

[7] Balcisoy, S, Kallmann, M, Torre, R, Fua, P, Thalmann, D, "Interaction Techniques with Virtual Humans in Mixed Environments", *Proceedings of the International Symposium on Mixed Reality (ISMR)*, 2001.

[8] Bauer, M, Kortuem, G, Segall, Z, "'Where are you pointing at?' A study of remote collaboration in a wearable videoconference system", *Proceedings of International Symposium on Wearable Computers (ISWC)*, 1999, page(s): 151–158.

[9] Billinghurst, M, Bee, S, Bowskill, J, Kato, H, "Asymmetries in collaborative wearable interfaces", *Proceedings of International Symposium on Wearable Computers (ISWC)*, 1999, page(s): 133-140.

[10] Billinghurst, M, Weghorst, S, Furness, T, III, "Wearable computers for three dimensional CSCW", *Proceedings of International Symposium on Wearable Computers (ISWC)*, 1997, page(s): 39–46.

[11] Billinghurst, M., Kato, H., "Collaborative Mixed Reality", *Proceedings of the International Symposium on Mixed Reality (ISMR)*, 1999.

[12] Biocca, FA, Rolland, JP, "Virtual eyes can rearrange your body: Adaptation to visual displacement in see-through, head-mounted displays", *Presence: Teleoperators and Virtual Environments*, June 1998, 7(3), page(s): 262–277.

[13] Ellis, SR, "Operator Localization of Virtual Objects", *Proceedings of the International Symposium on Mixed Reality (ISMR)*, 1999.

[14] Ellis, SR, Breant, F, Manges, B, Jacoby, R, Adelstein, BD, "Factors influencing operator interaction with virtual objects viewed via head-mounted see-through displays: viewing conditions and rendering latency", *Proceedings of Virtual Reality Annual International Symposium (VRAIS)*, 1997, page(s): 138–145.

[15] Fjeld, M, Schär, SG, Signorello, D, Krueger, H, "Alternative Tools for Tangible Interaction: A Usability Evaluation", *Proceedings International Symposium On Mixed And Augmented Reality (ISMAR)*, 2002, page(s): 157–318.

[16] Furmanski, C.; Azuma, R.; Daily, M., "Augmented-Reality Visualizations Guided by Cognition: Perceptual Heuristics for Combining Visible and Obscured Information", *Proceedings International Symposium On Mixed And Augmented Reality (ISMAR)*, 2002, page(s): 215–224.

[17] Kiyokawa, H, Billinghurst, M, Hayes, SE, Gupta, A, Sannohe, Y, Kato, H, "Communication Behaviors of Co-located Users in Collaborative AR Interfaces", *Proceedings International Symposium On Mixed And Augmented Reality (ISMAR)*, 2002, page(s): 139–148.

[18] Lehikoinen, J, Suomela, R, "Perspective map", *Proceedings of International Symposium on Wearable Computers (ISWC)*, 2002, page(s): 171–178.

[19] Rolland, JP, Biocca, FA, Barlow, T, Kancherla, A, "Quantification of adaptation to virtual-eye location in see-thru head-mounted displays", *Proceedings of Virtual Reality Annual International Symposium (VRAIS)*, 1995, page(s): 56-66.

[20] Smets, GJF, Overbeeke, KJ, "Visual resolution and spatial performance: the trade-off between resolution and interactivity", *Proceedings of Virtual Reality Annual International Symposium (VRAIS)*, 1995, page(s): 67–73.

Other References

[21] Cowper, TJ, Buerger, ME, "Improving Our View of the World: Police and Augmented Reality Technology", report prepared for the *Federal Bureau of Investigation*, 2003, available at www.fbi.gov/publications.htm.

[22] Cutting, JE, "How the Eye Measures Reality and Virtual Reality", *Behavior Research Methods, Instrumentation, and Computers*, 29, 1997, page(s): 29–36.