Training Wayfinding Using Mixed Reality

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ABSTRACT

The Army needs a distributed training environment that can be accessed whenever and wherever required for training and mission rehearsal. This paper describes an experiment to investigate the effectiveness of a prototype of such a system, using mixed reality (MR) presented by the Battlefield Augmented Reality System (BARS), a mobile augmented reality system with a wearable computer, and see-through head mounted display (HMD). The users' positions were tracked wirelessly, while a graphic representation of their virtual surroundings was displayed on the HMD as they walked. Previous studies have shown virtual environments can be used to train navigation. The addition of natural movement to a type of virtual environment may enhance that training.

Sixty participants were randomly assigned to three conditions and memorized directions for a route through a complex area. Participants in the map condition performed three rehearsals of the route by drawing on a printed floor plan of the environment. Participants in the walker condition executed three rehearsal traversals of the route in the actual facility. Those in the MR condition did the same wearing the BARS system which provided a realistic environment, with landmarks, waypoints and virtual footprints. A scaling factor was used, with each step in the MR environment equal to three steps in the real environment, and the environment was broken into "tiles", much like atlas pages. Participants worked their way through each tile in succession until they completed the entire route. Transfer of training results from testing in the real environment found a significant but weak difference between walkers and MR, and walkers and drawing for route knowledge, with walkers committing fewer errors while completing the route more quickly. No differences were found among any of the conditions for survey knowledge. There were no symptoms of simulator sickness among the MR participants of this study.

ABOUT THE AUTHORS

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Glenn Martin is a Senior Research Scientist at the University of Central Florida's Institute for Simulation and Training where he leads the Interactive Realities Laboratory, pursuing research in multi-modal, physically realistic, networked virtual environments and applications of virtual reality technology. He has worked on numerous projects related to virtual reality including a testbed for evaluating VR for training uses, an investigation of network architectures, and a library for VR applications.

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The U.S. Army has a continuing need for training that ranges from basic training through mission rehearsal, and after action reviews, that provide opportunities for immediate feedback on specific skills, tactics and strategies. The use of simulation technologies provides the opportunity to train in realistic environments without the associated expense of creating physical replications of environments. Mixed reality (MR) technology has the potential to provide not only a simulated environment in which to train, but to do so while being mobile. MR has an advantage over an immersive virtual environment (VE) in that the Soldier can physically move through the simulated environment using natural movements with less computer equipment than that required for generating a VE. The particular system used in this experiment, the Battlefield Augmented Reality Systems (BARS) has been demonstrated to be compatible with global positioning system (GPS) technology, providing an opportunity for outdoor use. This experiment is designed to consider the utility of using MR technology in training wayfinding, a basic skill required of all Soldiers, and one that has been used previously in considering the effectiveness of training systems.

VE and Training

The use of VE in training has been explored through many efforts, each of which was a step in determining if the result of training in VE was equivalent to traditional training, while providing some additional benefit. Some of the potential benefits of training for dismounted infantry using VE identified by Nemire (1998) are the ability to conduct mission planning and rehearsal on simulated battlefields, providing spatial awareness that is not available with other training media, and minimizing risk to personnel, equipment or the environment.

The use of MR in training should provide the same benefits as those provided by the use of VE, and may be useful as a mission rehearsal tool in a theater of operations by providing the opportunity to train dismounted Soldiers to navigate through a specific combat zone by creating a rehearsal space built on information acquired through multiple sources including UAV reconnaissance, GPS, topological maps, city plans, and building plans. (Livingston, M.A., Brown, D., Gabbard, J.L., Rosenblum, L.J., Yohan, B., Julier, S.J., Swan II, J.E., and Hix, D., 2002; Columbia University, 2004; Simsarian, K.T., and Akesson, K., 2004)

If MR is as good as, or better than, traditional training, it is possible that further development efforts for MR, as a training tool would be recommended. In comparison to VE, the reduced programming requirements, the fact that the system can be human mounted and that the human moves on solid ground using natural movement, may make it preferable for training and mission rehearsal (Livingston, M.A., et al. 2002; Columbia University, 2004; Unguder, E., 2001). One step in determining the feasibility of using MR as a mission rehearsal tool, as suggested above, is to compare its effectiveness in training navigation skills.

VE has been shown to be at least as effective (Arthur, E.J., and Hancock, P.A., 2001) and perhaps more effective (Banker, W.P., 1997) in training navigational skills as paper map based training given a sufficiently complex environment and path to traverse. (Swan II, J.E., Gabbard, J.L., Hix, D., Schulman, R.S., and Kim, K., 2003; Conroy, R. 2001; Schlender, D., Peters, O.H. and Wienhofer, M., 2002; Darken, R.P., and Sibert, J.L., 1993)

Types of Navigational Knowledge

There are two types of navigational knowledge of an environment: route knowledge, which is egocentric and acquired by personal travel through an area, and survey knowledge, which is exocentric, and acquired through map memorization and or exploration of an area using different routes. Using route knowledge allows one to successfully move from one known point to another known point along a specific route, but doesn't allow for deviations from the route. Route knowledge allows one to know the approximate distance between landmarks along the route because learning is formed by sequential travel (Allen and Kirasic, 1985). Knowledge of relationships of places along this route will be better recalled when provided in the direction the route was learned (Allen and Kirasic, 1985).

Survey knowledge is typically acquired through multiple explorations of an environment while using different routes, and is characterized by the ability to take an exocentric viewpoint which is used to develop a mental representation of an area from a "bird's eye" point of view. This is similar to a mental representation of a physical map, which is often referred to as a cognitive map (Goldin & Thorndyke, 1982). Route knowledge does not guarantee survey knowledge though it's likely this will happen (Moeser, 1988). Survey knowledge built on personal experience gained through exploration of an area is a "primary" experience (Presson & Hazelrigg, 1984) while a secondary experience is based on map or picture study alone (Goldin & Thorndyke, 1982; Thorndyke & Hayes-Roth, 1982). Some studies indicate that learning survey data from paper maps is inferior to that learned through exploring the area (Presson & Hazelrigg, 1984 and Scholl 1993). When route knowledge and survey knowledge are combined, the result is complete navigational knowledge.

This experiment compared the effectiveness of paper map based training, physical route rehearsal, and route rehearsal in a mixed reality environment, to train participants in a complex route. This was performed in a manner similar to Witmer et al (1996), who compared training based on rehearsal of the actual route to training based on rehearsal of the route in a virtual environment.

EXPERIMENT

The route used for this experiment was on the fourth floor of a large office building, Partnership II, in the Central Florida Research Park, Orlando, FL. This five-story, 75,000-square-foot building houses several organizations from the University of Central Florida (UCF), the Institute for Simulation and Training offices, and offices for U.S. Navy, Army and Marine Corps. The route designed for the experiment wound through approximately 7,000 square feet of a secured area of the building made up of cubicle office spaces, to which we added 15 survey flags as landmarks. The route included 19 decision points: 12 turns without redundant coding (that is only one cue given to identify the turn), and 7 intersections with no direction change. Clipboards were hung at two specific orientation localization assessment stations along the route. Station one was located at 145° from the start of the route and 209° from the end of the route. Station two was located at 299° from the start of the route and 329° from the end of the route.

All participants first memorized a sequential listing of the turns and survey flag landmarks along the experimental route. Then the paper map condition participants' drew the route on a copy of the floor plan that showed the starting point and the locations of the survey flags for each of three rehearsal trials. Participants in the physical route practice condition were moved to the actual office cubicle space, within which the experimenter had located the survey flag landmarks. The participants were led to the starting point from which they traversed the route using the directions they had memorized.

To create the interactive virtual environment used in the mixed reality condition, a unique combination of hardware, software, and virtual model was used.

Experimental Hardware

The mixed reality condition required a wearable visualization system. The system used was the hardware component of the Battlefield Augmented Reality System (BARS), created by the Naval Research Laboratory. The BARS system consists of a Quantum3D Thermite Tactical Visual Computer (TVC) for visual simulation and rendering (Figure 1.), paired with a Sony Glasstron head-mounted display (HMD) (Figure 2.). The Thermite computer was equipped with a 1GHz Transmeta Crusoe CPU, an NVIDIA GeForce 5200 GPU, and 480 MB of RAM. While underpowered for the complexity of the environment, this configuration was sufficient to render and visualize the virtual environment at interactive frame rates, approximately 12 frames per second, and it satisfied the requirement for a wearable visualization system. The Glasstron HMD provides a monoscopic binocular view of the environment at 800x600 pixel resolution. While the Glasstron is capable of providing an optical see-through display, this feature was not used in this work. A wireless keyboard and mouse provided input control to the Thermite.

Figure 1. Quantum 3D Thermite

Figure 2. Sony Glasstron HMD

A second computer was used as a base station. This was a Dell Precision 530n workstation. It was equipped with a 1.5 GHz Pentium 4 CPU, an NVIDIA GeForce 4 Ti 4800, and 256 MB of RAM. This computer functioned as a host for the tracking system and provided the experimenter control, a stealth view, of the experimental environment.

For motion tracking, an InterSense IS-900VET tracking system was used (Figure 3.). This system uses a hybrid of inertial and acoustic technologies to calculate a position and orientation for each sensor worn by the user. In this work, the user wore a single wireless motion tracker (Figure 4), mounted on the display visor portion of the HMD, thus tracking the position of the user's head. The signal from the wireless sensor was transmitted to the InterSense base station, and the resulting tracking measurements were then sent back to the wearable computer via an ad-hoc 802.11b connection. A 10x10 foot area was used under the IS-900 sensor strips suspended from the ceiling (Figure 5).

Figure 3. InterSense IS-900 VET Base Station

The InterSense tracks the participant using six degrees of freedom which includes X, Y, and Z position data, along with yaw, pitch and roll orientation data. The SoniStrips have ultrasonic SoniDisc transponders that receive addressed signals from the Base Processor Unit and transmit ultrasonic pulses in response. The acoustic transmission beam width for each SoniDisc is adjusted for wide-angle coverage (approx. 70-degree cone angle) to maximize the tracking area. The IS-900 uses an acoustic time-of-flight (TOF) ranging system to prevent position and orientation drift. For maximum accuracy and resolution, acoustic range measurements are made with unidirectional measurements from the SoniStrip transmitters to the tracker.

The SoniDiscs' acoustic pulses are detected by where a command from the Processor first triggers a SoniDisc transmitter in the SoniStrips to send a 40 kHz ultrasonic pulse, while at the same time, separate timer counters are started in the tracker and then halted by the arrival of the unique acoustic pulse signature. Using the speed of sound (which is calculated from the measured ambient temperature), range measurements are obtained and used to compute position.

The tracker is a MiniTrax tracked station operated without cabling to the IS-900 processor by using the IS-900 Wireless Module. The Wireless Module has two components: the receiver component shown below on the left, that plugs into the IS-900 Processor, and a rechargeable, battery operated transmitter that is connected to a small body worn transmitter that is attached to the HMD using hook and pile tape, and plugs directly in to the MiniTrax Station.

Figure 4. InterSense Wireless Unit

Figure 5. InterSense SoniStrip

Experiment Software

Although the BARS system hardware was used, the BARS software was not used in this experiment. The simulation software was based on the Virtual Environment Software Sandbox (VESS) written by the University of Central Florida Institute for Simulation and Training. This particular VESS configuration made use of the Open Scene Graph as an underlying graphics library. VESS adds the capability to drive the

InterSense tracking system and convert the tracking measurements into motion in the virtual environment.

One challenge in this work was to devise a way to allow a 10x10 foot tracking area to provide a realistic walking interface for a virtual environment that was much larger. This challenge was addressed with two techniques. First, the user's real-world motion was scaled up by a factor of three in the virtual environment. This means that one step by the user translated into the equivalent of three steps in the virtual environment. However, the virtual environment was still larger than 30x30 feet. To address this, the software included a tiling system that allowed the user to move about in a single 30x30 foot section of the environment at a time. When the user moved outside the 10x10 foot tracking area, he or she implicitly left the current 30x30 foot tile in the virtual environment. When this happened, the user's display was blanked, and a spotter physically walked the user to the opposite edge of the tracking area. Once repositioned, the display was reactivated, and the user was free to move in the next tile of the virtual environment.

As a visual aid, the user left "footprints" in the virtual environment, showing where he or she had already walked. The footprints were shown as a texture resembling black shoe impressions drawn on the floor wherever he or she had previously been.

In addition to the virtual environment visualization capabilities, the software also included a module that collected the experimental data. The user's position and orientation were captured at 0.1 second intervals and the total route traversal time was also captured. Data was collected directly on the Thermite wearable computer.

The same software in a different configuration was used to drive the experimenter's stealth display. Instead of the first-person viewpoint the user was given, the stealth display showed the environment from above in a top-down view. An avatar was positioned on the display, showing the user's position and orientation, including the previously described footprints. The correct route was drawn as an easy reference for the experimenter.

Due to the Thermite's limited capabilities and the complexity of the virtual environment model, occlusion culling was used to reduce the number of triangles drawn, and thereby increase the frame rate to an average of 12 frames per second, to bring the simulation's rate up to interactive rates and to reduce the latency that can contribute to simulator sickness, to less than 0.02 seconds.

Experiment Model Environment

The bulk of the virtual model was created using the original CAD designs for the building as a basis. In addition to providing floor plans for the building and showing where each row of cubicles was positioned, actual 3D cubicle furniture was provided in the CAD drawings. The AutoCAD drawings were converted into the OpenFlight format used by MultiGen Creator. After converting and assembling the various CAD models, and creating the remaining building geometry, digital photos were taken of the actual building environment and converted to texture maps. These were then applied to the models.

Several of the CAD furniture models (those with curved surfaces) had a very high triangle count. In an effort to improve the frame rate, these heavyweight models were manually decimated (by selectively removing or combining triangles) without an appreciable loss of detail. After this was done, some of them were further decimated to create a lower level of detail that was used when the user's viewpoint was relatively far from the object.

After the basic environment was complete, it was noted that there were additional pieces of furniture and appliances, such as armchairs, copiers, laser printers, and water fountains, positioned at the ends of the cubicle rows. Since the participants could conceivably use these objects as positional cues, the most noticeable objects were modeled using measurements and digital photos as a reference. When complete, the virtual environment resembled the actual test environment with a high degree of fidelity.

Research Questions

The consideration of a MR environment as a training system generated a series of research questions concerning the effectiveness of such a training tool, as measured through transfer of training testing, with additional questions concerned with the experience of the individuals interacting with the MR, including the possible occurrence of simulator sickness. Specifically:

Is rehearsal in a MR environment as good as or better than rehearsal based on drawing the route on a floor plan, or walking through the actual space, as measured by tests of route and survey knowledge?

What is the incidence of simulator sickness during and after exposure to MR?

Experiment Participants

Sixty volunteer participants were randomly assigned, 20 to each practice condition, equally divided with 10 males and 10 females in each group, all of whom were unfamiliar with the office space used in the study. Each participant completed three spatial abilities tests, a survey of motion history, a survey of simulator sickness history, and a simulator sickness inventory prior to the study, and additional simulator sickness inventories at critical points, including the end of their practice sessions. Participants were informed that they were permitted to elect to decline further participation at any point in the study process without penalty.

Experiment Task and Procedures

The experimental task was to train participants through the use of three different rehearsal conditions to traverse a specific path through a complex area as quickly and accurately as possible, demonstrating egocentric or route knowledge, while also demonstrating an exocentric, or survey knowledge of the surrounding environment. A direct comparison between the three rehearsal conditions was undertaken by capturing participants' route traversal time, and by counting errors in route traversal. In addition, error data was collected concerning participants' orientation localization, by their identification the location of the start and end of the route in reference to their current position.

Each participant was allotted 15 minutes to memorize a set of directions, which described the route they would traverse, without the use of memory aids. Participants in the paper map practice condition rehearsed the route by drawing it on a printed floor plan of the office space environment that showed walkways, landmarks and the starting point. Participants in the rehearsal condition known as "walkers" would execute three rehearsal traversals of the route in the actual facility. Participants in the MR condition also executed three practice traversals of the route as it was presented in MR. To familiarize participants with the MR environment, a short practice session, using parts of the model that were not part of the experimental route, was conducted prior to the memorization period, to avoid any MR environment specific impact on participants' rehearsal time.

During the transfer of training assessment participants were instructed that speed and accuracy in traversal of the path were of equal importance. At two points along the route participants were stopped in front of a clipboard hanging from a cubicle wall, on which was posted an 8 ½ x 11 piece of paper showing a circle with an X in the center, and the numbers 12, 3, 6, and 9 around the edge for orientation points. They were asked to imagine themselves standing on the X facing the 12, and to mark where they believed the starting point of the route was in relation to where they were standing, by writing an S on the circle, and to mark where they believed the end of the route was by writing an E on the circle. The absolute error between the actual location of the start and end points of the route from each of the two reporting stations, and the participants' input as to where they believed the start and end points of the route to be located were used as scores of survey knowledge.

Experiment Results

Prior to analysis, descriptive statistics were examined for each experimental variable, and transformations performed to reduce the impact of outliers and missing data. Throughout the following statistical analyses SPSS version 11.5 was used, with alpha set to .05 unless otherwise specified.

Route knowledge: A between subjects analysis of variance was conducted, with rehearsal condition as the independent variable. As can be seen in Table 1, the analysis of variance was significant for both dependent variables, with total time to complete the route at $F\ (2, 59) = 9.68$, $p < .000$, and the logarithm of the number of errors made while traversing the route at $F\ (2, 59) = 8.26$, $p < .001$. In both instances however the effect was weak with η^2 values of .25 and .22 respectively. Post hoc tests, using a Scheffe adjustment for multiple comparisons, showed that participants in the walker condition consistently performed better than those in either the paper or mixed reality conditions. Participants in the walker condition averaged 1.99 minutes to complete the route as measured with the logarithm of total time, while paper map participants averaged 4.33 minutes, and MR participants 4.16 minutes. Walkers committed a mean of 0.11 errors, paper map participants a mean of 0.58 errors, and MR participants 0.60 errors in traversing the route.

Table 1. Analysis of Variance for Route Knowledge

Source	df	F	η^2	p
Total time to complete route	2	9.68**	.25	.000
Traversal errors logarithm	2	8.26**	.22	.001

Error	59	

**$p < .01$

Table 2. Post Hoc with Scheffe adjustment

Dependent Variable	Condition	Condition	Mean Difference	p
Total time to complete route	Paper Map	Walker	1.6675*	.001
		Mixed Reality	.1480	.940
	Walker	Paper Map	-1.6675*	.001
		Mixed Reality	-1.5195	.003
	Mixed Reality	Paper Map	-.1480	.940
		Walker	1.5195*	.003
Traversal errors logarithm	Paper Map	Walker	.4744*	.001
		Mixed Reality	.1641	.390
	Walker	Paper Map	-.4744*	.001
		Mixed Reality	-.3103*	.039
	Mixed Reality	Paper Map	-.1641	.390
		Walker	.3103*	.039

Survey knowledge: A between subjects analysis of variance was conducted using the independent variable rehearsal condition as the independent variable. As can be seen in Table 3, the analysis of variance was not significant for the four dependent variables that measured survey knowledge through the orientation localization task. The mean difference between station one scores and the actual start of the route was 11.56 degrees, and between station one and the end of the route was 10.06 degrees. The mean difference between station two scores and the start of the route was -8.32 degrees, and between station two and the end of the route the mean difference was -62.39 degrees. This analysis shows there are no significant differences among these means and that there is no advantage of any one rehearsal condition on the error values in orientation localization task.

Table 3. Analysis of Variance - Survey Knowledge

Source	df	F	p
Error to Start Station 1	2	1.173	.189
Error to End Station 1	2	1.020	.367
Error to Start Station 2	2	0.677	.512
Error to End Station 2	2	1.353	.267
Error	59		

Effectiveness of MR in Training: To show that route learning occurred during route rehearsal in the MR condition, an analysis of variance was conducted on the total time required to complete each practice trial. As expected the first rehearsal trial with a mean of 569.81 seconds was longer than the second rehearsal trial with a mean of 330.23 seconds, and the second longer than the third with a mean of 242.64 seconds. On average participants demonstrated a drop in the time required to execute a rehearsal trial from 9.5 minutes in the first trial to 4 minutes in the third trial, which can be used to indicate that learning occurred over the three rehearsal trials. Post hoc tests, using a Scheffe adjustment for multiple comparisons, showed that participants' time required to perform their first rehearsal trial was significantly longer than the second and the third trial.

Table 4. Analysis of Variance for Rehearsal Time

Source	df	F	η^2	p
Total time for rehearsal trial	2	26.843**	.51	.000
Error	51			

**$p < .01$

Table 5. Post Hoc with Scheffe adjustment

Dependent Variable	Trail #	Trial #	Mean Difference	p
Total time for rehearsal trial	1	2	239.58*	.000
		3	327.17*	.000
	2	1	-239.58*	.000
		3	87.58	.151
	3	1	-327.17*	.000
		2	-87.588	.151

* Mean difference is significant at the .05 level.

MR and Simulator Sickness: The tendency for participants to experience symptoms of simulator sickness with exposure to the MR was examined through analysis of variance using SPSS version 11.5, and an alpha level of .05. There were no outliers, and the results of evaluation of assumptions of normality were satisfactory. The analysis was conducted using the weighted simulator sickness values as described by Kennedy (1992), and there were no differences among the three rehearsal conditions in symptomology. As expected, the paper map condition and walkers did not experience any symptoms either pre or post rehearsal, but were included to ensure completeness of the analysis. Total Severity of sickness was not significant with F (2, 57) = 2.045, $p > .05$, nor was Nausea with F (2, 57) = 2.081, $p > .05$, or Oculomotor with F (2, 57) = 2.325, $p > .05$, or Disorientation with F (2, 57) = .735, $p > .05$. The results of these analyses would indicate that rehearsal conducted in this type of MR does not produce significant symptoms of simulator sickness.

CONCLUSION

The exploration and confirmation of the training capabilities of mixed reality as presented using BARS is an important step in the development and application of the system to the U.S. Army training mission. This experiment was designed to examine one potential training area in a small controlled environment. Given the demonstrated effectiveness in training this task, it would be reasonable to expect that using MR environments would be effective in training other soldier skills, an expectation that should be explored through further experimentation. The results of this experiment can be used as a foundation for experimentation with more complex tasks such as wayfinding through an urban environment, or the ability to use the system with multiple participants simultaneously.

As the power of electronics increases, with reductions in cost over time, MR utility and affordability are likely to increase, making the technology more attractive in multiple applications. The possibility of having small, easy-to-configure mobile MR units would expand the ability of the Army to enhance its training efforts in the future by quickly modeling an environment of interest to aid in Soldier familiarization and rehearsal prior to ingress.

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REFERENCES

Allen, G.L., Kirasic, K.C. (1985). Effects of the Cognitive Organization of Route Knowledge on Judgments of Macrospatial Distances. *Memory & Cognition, (3)* 218-227

Arthur, E.J., and Hancock, P.A., (2001). *Navigation training in virtual environments, International Journal of Cognitive Ergonomics,* Lawrence Erlbaum, 5(4), 387-400.

Banker, W.P., (1997). *Virtual Environments and Wayfinding in the Natural Environment,* Naval Postgraduate School, Monterey, CA.

Bernatovich, D., (1999). *The Effect of Presence on the Ability to Acquire Spatial Knowledge in Virtual Environments*, Naval Postgraduate School, Monterey, CA.

Cevik, H., (1998). *Map Usage in Virtual Environments*. Naval Postgraduate School, Monterey, CA.

Columbia University, (2004) http://www1.cs.columbia.edu/graphics/ New York, NY. Retrieved from the Internet, July 21, 2004.

Conroy, R., (2001). *Spatial Navigation in Immersive Virtual Environments.* Doctoral Dissertation, University College London, London, England.

Darken, R.P., and Sibert, J.L., (1993). A toolset for navigation in virtual environments. *Proceedings of the 6th Annual ACM symposium on User interface software and technology*, Atlanta, GA., 157-165.

Ekstrom, R.B., French, J.W., Harman, H.H., & Dermen, D. (1976). *Manual for Kit of Factor-Referenced Cognitive Tests 1976.* Education Testing Service, Princeton, NJ.

Guilford, J.P., (1948). The Guilford-Zimmerman aptitude survey. *Journal of Applied Psychology, 32*(1) 24-34.

Goldin, S.E., and Thorndyke, P.W. (1982). Simulating Navigation for Spatial Knowledge Acquisition. *Human Factors, 24(4),* 457-471.

Grammenos, D. Filou, M., Papadakos, P., and Stephanidis, C., (2002). Virtual Prints: Leaving trails in virtual environments. *Eighth Eurographics Workshop on Virtual Environments, The Eurographics Association, Aire-la-Ville, Switzerland*. 131-138.

InterSense IS-900 VET, VWT & SimTracker Manual Doc. No. 072-00060-0F00 Revision 2.1, InterSense, Inc., Burlington, MA.

Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203-220.

Kennedy, R.S., Stanney, K.M., Lane, N.E., Lanham, S., & Kingdon, K. (2001). Use of a motion experience questionnaire to predict simulator sickness. *Proceedings of HCI International 2001*, New Orleans, LA.

Livingston, M.A., Brown, D., Gabbard, J.L., Rosenblum, L.J., Yohan, B., Julier, S.J., Swan II, J.E., and Hix, D., (2002). An Augmented Reality System for Military Operations in Urban Terrain. *Proceedings of the I/ITSEC Conference, 2002*, Orlando, FL.

Milgram, P., Takemura, H., Utsumi, A., and Kishino, F., (1994). Augmented reality: a class of displays on the reality-virtuality continuum. *SPIE Vol. 2352, Telemanipulator and Telepresence Technologies*, 1994.

Moeser, S.D., (1988). Cognitive Mapping in a Complex Building. *Environment and Behavior, 20,* 21-49.

Nemire, K., (1998). Immersive virtual environment for dismounted infantry tactics training and mission rehearsal. *Proceedings of the I/ITSEC Conference, 1998*, Orlando, FL.

Presson, C.C., and Hazelrigg, M.D., (1984). Building Spatial Representations through Primary and Secondary Learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 716-222.

Schlender, D., Peters, O.H., and Wienhofer, M., (2002). The effects of maps and textual information on navigation in a desktop virtual environment. *Spatial Cognition and Computation 2*: 421-433.

Scholl, M.J., (1993). Cognitive Maps as Orienting Schemata. *Cognition*, 4, 615-628.

Simsarian, K.T., and Akesson, K., *Windows on the World: An example of Augmented Reality*, Swedish Institute of Computer Science, Stockholm, Sweden. Retrieved from: http://www.sics.se/~kalle/published/wow.pdf July 21, 2004.

Stanney, K., and Salvendy, G., (1997). Aftereffects and Sense of Presence in Virtual Environments: Formulation of a Research and Development Agenda. *HCI International '97, Seventh International Conference on Human Computer Interaction*, San Francisco, CA.

Swan II, J.E., Gabbard, J.L., Hix, D., Schulman, R.S., and Kim, K., (2003). A comparative study of user performance in a map-based virtual environment. *Proceedings of IEEE Virtual Reality 2003*, IEEE Computer Society. 259-266.

Thorndyke, P.W., and Hayes-Roth, B., (1982). Differences in Spatial Knowledge from Maps and Navigation. *Cognitive Psychology, 14,* 560-589.

Unguder, E., (2001). *The Effects of Natural Locomotion on Maneuvering Task Performance in Virtual and Real Environments*, Naval Postgraduate School, Monterey, CA.

Vinson, N.G., (1999). Design Guidelines for Landmarks to Support Navigation in Virtual Environments, National Research Council Canada, Institute for Information Technology, *Proceedings of CHI '99,* Pittsburgh, PA.

Witmer, B.G., Bailey, J.H. and Knerr, B.W., (1996). Virtual spaces and real world places: transfer of route knowledge, *International Journal of Human-Computer Studies*

Wothke, W., Bock, R.D., Curran, L.T., Fairbank, B.A., Augustin, J.W., Gillet, A.H., Guerrero, C. (1991). Factor Analytic Examination of the Armed Services Vocational Aptitude Battery (ASVAB) and the Kit of Factor-Referenced Tests. *Air Force Human Resources Laboratory Technical Report 90-67*, Brooks Air Force Base, Texas.