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VISUALIZATION OF CONSTRUCTION GRAPHICS IN OUTDOOR AUGMENTED REALITY

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ABSTRACT

This paper describes research that investigates the application of Augmented Reality (AR) in 3D animation of simulated construction operations. The objective is an AR-based platform that can be used together with corresponding equipment (HMD, GPS receiver, and a portable computer) to generate a mixed view of the real world and superimposed virtual simulation objects in an outdoor environment. The characteristic that distinguishes the presented work from indoor AR applications is the capability to produce real time updated output as the user moves around while applying minimum constraints over the user's position and orientation. The ability to operate independently of environmental factors (e.g. lighting conditions and terrain variations) makes the described framework a powerful tool for outdoor AR applications. This paper presents initial results and an AR platform prototype (UM-AR-GPS-ROVER) that is able to place 3D graphical objects at any desired location in outdoor augmented space.

1 INTRODUCTION

Discrete Event Simulation (DES) is a powerful objective function evaluator that is well suited for the design of construction operations (Kamat and Martinez 2002). DES models consider the different resources that are required to perform construction operations, the rules under which different tasks that compose the operations are performed and the resources are withdrawn and consumed, the managerial decisions made during the operations, and the stochastic nature of events.

In order to make real decisions based on the results of a simulation study, a simulation model must satisfactorily pass the verification, validation, and accreditation stages. Verification confirms whether or not a simulation model accurately reflects the intentions of the modeler. Validation, on the other hand, confirms whether or not a verified model accurately reflects the real world operation under study. Successful verification and validation together lead to accreditation of a simulation model at which point the model is qualified and approved for use in making real decisions based on simulation results.

One of primary impediments in the application of DES approach to plan and design construction operations is that decision-makers often do not have the means, knowledge, and time to check the veracity and the validity of simulation models and thus have little confidence in the results (Kamat and Martinez 2003). Visualizing simulated operations in 3D and taking advantage of 3D animation can thus be of substantial help in the verification, validation, and accreditation of simulation models. In addition, visualization and 3D animation can provide valuable insight into subtleties of modeled operations that are otherwise non-quantifiable and non-presentable.

When it comes to visualization and animation, there can be two main approaches applicable to construction operations: Virtual Reality (VR) and Augmented Reality (AR). Although VR has been the source of motivation for most of the previous work in this field, its application in real life is to some extent limited to the cases in which no combination of real environment and virtual graphics is necessary. In other words, in almost all VR applications such as 3D games there is no sense for the user of what is going on in his or her surrounding real space and the output of VR is totally independent of the real environment the user is located in.

In contrast, in Augmented Reality (AR) applications, there is always a combination of virtual objects and real scenes (Azuma et al. 1997, Azuma et al. 2001, Lawson and Pretlove 1998, Piekarski and Thomas 2002). That gives the user the ability to take advantage of the surrounding environment as so called "*background*" and superimpose virtual objects over that real background. Milgrim defined a continuum of real-to-virtual environment in which AR is one part of the general area of Mixed Reality. Figure 1 graphically presents the reality-virtuality continuum proposed by Milgrim.

Figure 1: Milgrim's Reality-Virtuality Continuum (Adapted from Milgrim and Kishino 1994)

The nature of a VR-based animation application requires a significant level of effort in order to create a virtual environment that faithfully presents the real world. The amount of time and expertise spent on 3D CAD *Model Engineering* in most cases is remarkable as VR simulation requires creating, obtaining, refining, archiving, and updating 3D CAD models of construction objects and resources for use in 3D animation (Brooks 1999). Things such as the jobsite terrain, existing structures and features, resources, and partially completed facilities should be all modeled in CAD prior to being used in a VR animation. Considering all the ordinary complexities of a construction project and the presence of above issues, use of VR to create 3D animation and visualized scenes can often be infeasible, impractical, and prohibitive in many simulation problems.

On the other hand, one of the main issues in AR-based visualization is blending virtual items and the real world in a way that the user feels like he or she is viewing virtual objects as they have been really placed in the scene (Azuma et al. 1999). That mainly comes into play when the AR user locates in *outdoor* environment which is literally *unprepared* compared to the case he or she is dealing with in an indoor prepared environment. The main reason is that in an unprepared environment there are several possible combinations of the user's location and orientation each of them requiring the application to use a unique set of virtual objects to fit the user's view. On the other hand, in indoor environments, the user's movement, location, and orientation are limited to a finite number of predefined states.

Despite the additional complexity, there are many cases where outdoor AR can be more useful compared to indoor AR mainly because the surrounding outdoor environment is the scene where the simulated activities take place (Behzadan and Kamat 2005). For the special interest of this research, that is the case in many construction projects such as excavation, demolition, road and highway construction, bridge construction, offshore structures, etc. Figure 2 is a schematic comparison between virtual and augmented reality in a bridge construction project.

2 PREVIOUS WORK

Researchers have explored AR for a number of applications. Webster et al. (1996) presented a system that shows locations of columns behind finished walls, and re-bars inside columns. Roberts et al. (2002) used AR to overlay locations of subsurface electrical, telephone, gas, and water lines onto real-world views. Both applications demonstrated AR's potential in helping maintenance workers avoid buried infrastructure and structural elements as they make changes to buildings and outdoor environments.

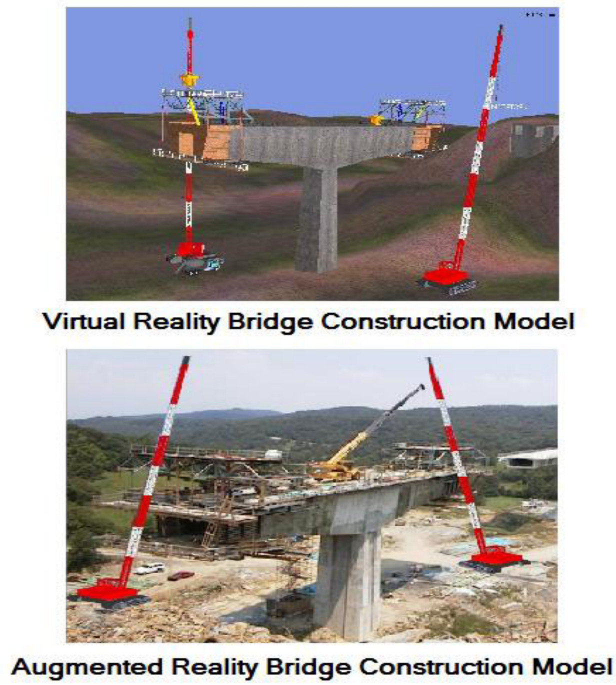

Figure 2: Schematic Comparison Between Virtual and Augmented Reality in a Bridge Construction Project

Webster et al. (1996) also presented an AR system to guide workers through assembly of a space frame. Hammad et al. (2004) augmented contextual information on real views of bridges to help inspectors conduct inspections more effectively. Thomas et al. (1998) and Klinker et al. (2001) explored AR to visualize designs outdoors. Dunston et al. (2002) have also demonstrated the value of mixed reality AR-CAD in collaborative design. To the authors' best knowledge, the use of AR to animate construction at the operations level detail and in outdoor environments has not been investigated before.

3 RESEARCH MOTIVATION

The ability of building facilities virtually before expending real resources has been of main interest to many constructors over a long period of time. Achieving this goal, they can visualize their operations on computer generated jobsites and study differences between alternate plans with speed and accuracy. They can also design their operations in a way that most of the undesirable events that usually happen during a construction project are taken care of well ahead of time. Putting these all together, construction contractors and owners can build facilities very fast and at minimal cost. The main motive for the current research project is to help make this vision a reality.

Accurate construction visualization in outdoor AR is a complex proposition. The work must address challenges in AR animation and include investigation of methods to accurately superimpose (augment) graphical images of operations over real-world jobsites, exploration of techniques for intuitive and safe user-computer interaction in AR, and study of approaches to make AR animation highly adaptable and mobile. The scope of the work is so broad that practical and accurate results can not be achieved unless the whole problem is split into several sub-areas so that each of the main challenges can be addressed separately in a thorough manner. For this reason, the presented work has been broken down into modules such as positioning, scaling, databases (i.e. GIS, GPS, etc.), and occlusion.

Positioning focuses on the ability to have complete control over augmenting (placing) virtual objects on real scenes and moving them across as desired. Scaling mainly deals with the capability of the AR system to dynamically acquire scale factors and update the size in every direction for each of the superimposed virtual object throughout the AR application runtime. GIS can be potentially used as a supporting tool for obtaining realistic and real-time data of the surrounding environment while GPS is essentially helpful for getting user's position after each movement he or she makes in an outdoor jobsite (Rogers et al. 1999, Roberts et al. 2002, Dodson et al. 2002). Finally, occlusion happens when a real object is placed between the user's view and the virtual object(s) in his or her view. In that case, appropriate procedures should be followed to take into account the effect of the interfering real object(s).

It is worth mentioning that each of these issues require an extended and detailed study and the results from each steps can be effectively used in the subsequent steps. The current stage of research mainly focuses on the first challenge of the AR system which is positioning.

4 AR SYSTEM STRUCTURE

The AR prototype developed in this research basically consists of two main components working in parallel. In addition to software part of the system, several supporting hardware devices are used to provide input and output data. These are mainly GPS receiver, orientation tracker, and Head Mounted Display (HMD) which are connected to the user's head or any known position on user's body. Figure 3 shows the main components of a basic AR system.

4.1 GPS Receiver and Orientation Tracker

A *Garmin eTrex Vista* WAAS (Wide Area Augmentation System) GPS receiver together with an *InterSense Intertrax2* head tracking system was used for the validation phase of the prototype. Although the accuracy level obtained from the GPS receiver used in this step is around three meters, the user's position and orientation collected in this phase still can be used in validation stage of current work by doing a one-time calibration just after the AR software starts capturing live scenes. However, for better practice in future, using a more accurate GPS system which can be easily adapted for use with this AR software will lead to more practical results.

The main issue in the application of GPS receivers in the AR platform is data reliability, which is a function of several factors including Line of Sight (LOS) from the receiver to the orbiting GPS satellites (Karimi et al. 2004). The less the LOS is obstructed by unwanted objects including buildings and trees, the more accurate and reliable are the data obtained from a GPS receiver.

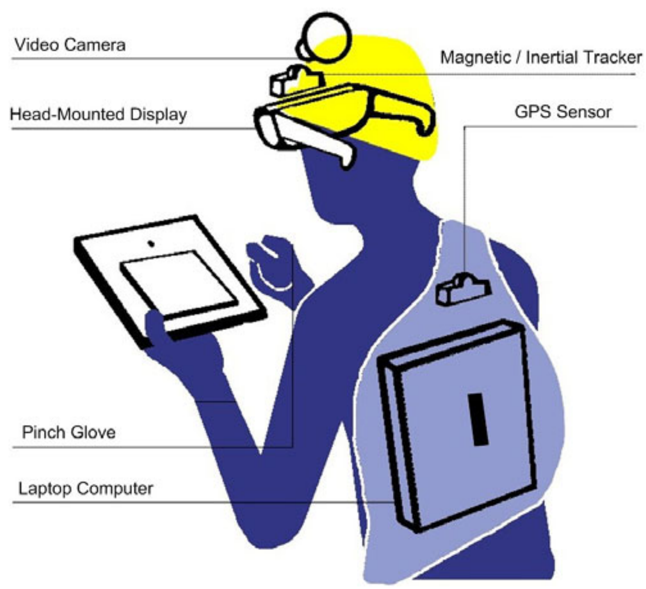

Figure 3: Basic Components of an AR System (Adapted from http://www.studierstube.org/projects/mobile)

4.2 Head Mounted Display (HMD)

The HMD mainly consists of two parts: a video input device and a see through display. Almost any kind of video input device can be used as the live video stream capture device (i.e. webcams, camcorders, etc.).

The video input device captures scenes from surrounding environment, and places them at the background of user's view. In the present work, a *Sony TRV33* digital camcorder which supports the resolution of 640 by 480 pixels is used as the video input device. Also an *i-Glasses SVGA Pro* HMD is used to superimpose virtual objects on live or recorded video scenes. Figure 4 is an example of how the components of an Augmented Reality system work together to produce the final result on the display.

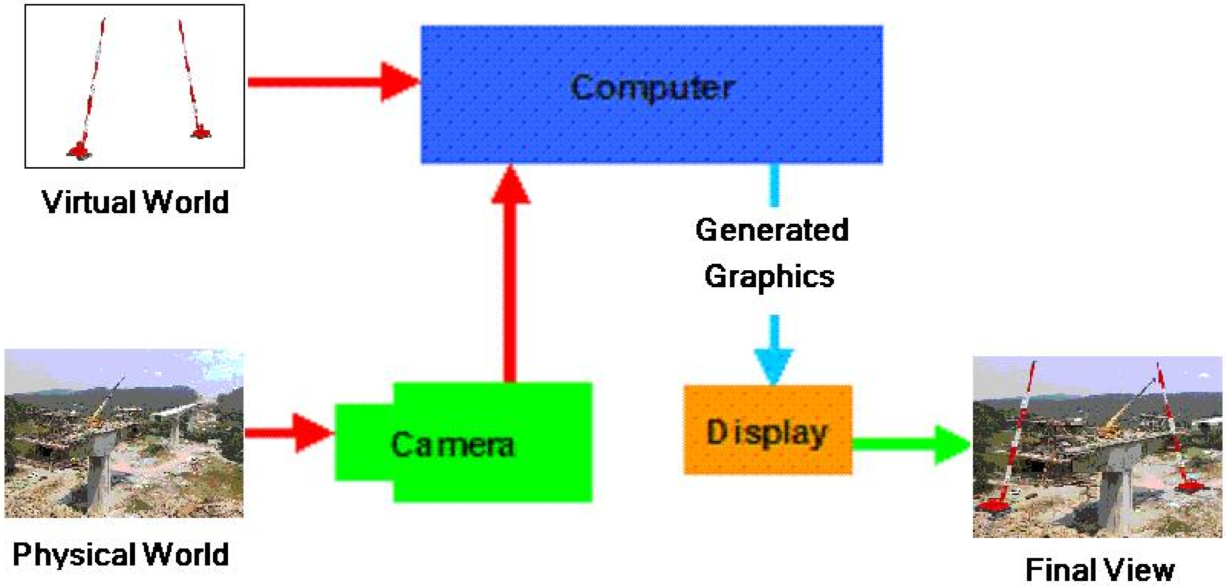

Figure 4: Interconnections Between Various Components of the AR System

4.3 Augmented Reality Software

Knowing the advantages of a modular compared to an integrated platform, the main goal of the authors has been to keep the software as modular as possible. Having done that, the final result is in a form of independent interconnected modules that can be simply replaced and/or updated as and when needed. A good example may be replacing an old module (such as an old GPS receiver) with a new one that produces the same output but with more accuracy and reliability. The current AR software is a platform on which four different modules act simultaneously and produce a unique output that can be seen through HMD by the user.

The first module is a unit that captures live video stream from the real environment using the video input device (see section 4.2). The second module is mainly a data collector from GPS receiver (see section 4.1) that provides the software with user's global position in form of longitude, latitude, and altitude. The third module is a data collector from the orientation tracker which basically gives out three head rotation angles around each axis in real simulation time. The fourth module is essentially a graphical module which reads data from linked files and places each virtual model on user's view on a real time basis. Using these modules and knowing that the location and orientation of objects should be kept independent of user's position and orientation, for any transformation of the user, a reverse transformation is calculated and applied to the objects in his or her view so that the graphics always appear fixed to a particular location (for details, see Section 5).

4.4 Portable Computer

For the user to be able to move freely around in the real world he or she is located in, the system should be placed in a manner that can be easily carried and accessed anywhere. To do that, a *Toshiba Satellite 2805-S705* laptop with 3Ghz CPU speed and 512 MB memory is used. Finding an optimum balance between processing power and battery life on one hand and portability on the other hand has been always an important issue in this step for almost any outdoor application (Gleue and Dahne 2002). That is basically because the more powerful a computer system is the more weight it has and hence the more difficulty the user faces carrying it around.

5 UM-AR-GPS-ROVER SOFTWARE

Having a modular platform in hand makes it possible to choose between a wide variety of input and output devices and resources and still get satisfactory results from the AR software. For example, data for virtual objects can be input to the software using any format of ASCII files and CAD models (e.g. 3DS, VRML, etc.). In any case, the software is capable of collecting usable data such as dimensions and global coordination for any virtual object presented in the data file and input them to the corresponding modules for further procedures such as translation and rotation. At the same time, the user's position and orientation is obtained from GPS receiver and orientation tracker connected to a known part of user's body and by using this data, the AR software can develop a perspective viewing frustum visible through the HMD. As the user moves around, his or her movements are detected and a relative transformation matrix is calculated and updated.

Applying the inverse of this transformation matrix to the virtual objects in the viewing frustum, the AR software tries to keep them in fixed position so that they are not affected by the user's movement. To give an example, a virtual object which is visible in a specific combination of user's position and orientation should not be visible when the user turns 180 degrees around. To do so, a -180 degree rotation should be applied to the object so that it goes out of user's view. Meanwhile, some new object(s) may become visible after applying -180 rotation matrix to their original coordinates which should appear in the new viewing frustum of the user. Figure 5 illustrates a schematic flowchart that is used by software when reading virtual objects' data from a CAD file.

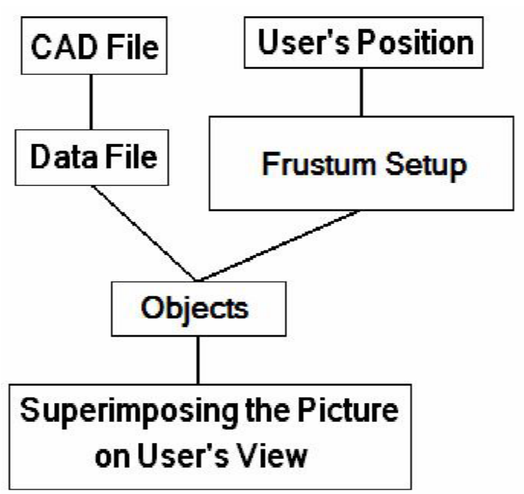

Figure 5: Basic Steps Taken by AR Software When Reading Virtual Objects' Data from File

One of the main issues in this step is to obtain homogenous coordinate data both for user and virtual objects. Most GPS receiver systems in North America use NAD83 geodetic datum as the basis for x, y, and z coordinates while many data sources that may be used as input to AR software (such as utility line coordinates) may have been stored according to a local datum or reference point and that may differ from one data provider (such as utility company) to another. So, before applying virtual data to AR software, a conversion procedure should be applied on them to make them compatible to NAD83 datum and as a result usable for AR software. Otherwise, the output may not be of desired accuracy and applicability.

6 RESULT VALIDATION

To validate the results of the research, a set of field experiments were carried out at the completion of each significant milestone. The first experiment was conducted in March 2005 using UM-AR-GPS-ROVER software in an outdoor environment (Behzadan and Kamat 2005). The objective of the experiment was to validate that the developed AR platform is capable of producing realistic results after implementation. To do so, a camcorder was used as the video input device and live video scenes were captured from an intersection outside the authors' office in the north campus of the University of Michigan.

A virtual excavator was then placed over the video stream and keyboard interaction was used to move the object across the scene. Figure 6 shows an output scene of this field experiment. The camcorder was placed in a fixed position and so it had no transformation in form of translation or rotation. User's position could be considered as known and fixed. It is clear that further improvements will be needed as the research goes on until the desired AR platform is obtained at the very last phase.

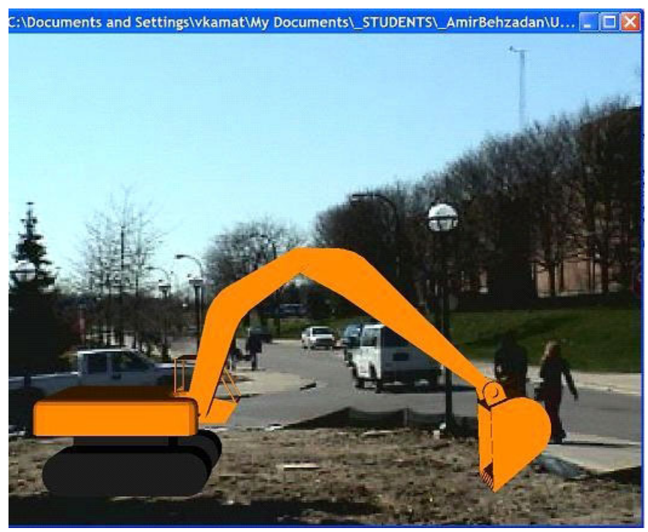

Figure 6: Captured Display Output from a Field Experiment of UM-AR-GPS-ROVER Software

7 FUTURE WORK AND CHALLENGES

As stated before, the current stage of the research is mainly focused on the positioning problem of virtual models in augmented space. There are also other issues that should be considered in future steps of developing the present AR platform that can be mainly grouped as scaling, geographical database interaction, and occlusion problems.

The very first step that should be taken after the positioning problem is solved (which is the main concern of this paper), is adding the ability to the AR platform to dynamically acquire scale factors and update the size in every direction for each of the superimposed virtual object throughout the AR application runtime.

Geographical database interaction mostly deals with adapting the AR platform to obtain data from GPS and GIS systems so the position of the AR system user and virtual objects and also the characteristics of the surrounding environment are more accurate, realistic, and easy to update. In order to do that, the use of GPS receivers and GIS database seems to be very helpful and practical as in an outdoor environment, reliable output can be well obtained using a GPS receiver with a high accuracy level.

Occlusion happens when a real object is placed between the user's view and the virtual object(s) in his or her view. In that case, as the distance between the real object and the user is less than that of virtual object(s) and the user, the real object can potentially block the user's view by moving into his or her view frustum. A possible solution for that is using the depth of field (z-buffer algorithm) in which the depth of the real object is detected and compared with the depth of each of those virtual objects. If this depth is greater than the depth of virtual object(s), the real object is not going to affect obstacle any virtual object and the user's view is not affected. Otherwise, appropriate corrections should be made to user's view to take into account the existence of such a close real object.

8 CONCLUSION

Designing and implementing an outdoor AR platform to visualize simulated operations is a complex proposition and tangible results may not be sometimes apparent in the short run. Although UM-AR-GPS-ROVER is in its first stages of development, the initial results are very promising leading the authors to be very optimistic about coming up with practical and useful final research results.

Having achieved promising results in this work, the intention is to develop an AR platform that can be used in almost any operational field ranging from design and construction, to manufacturing and assembly lines, and even to medical operations. To the authors' special interest, this platform will be applied to construction industry to help all players (i.e. owners, architects, and contractors) see beforehand what they want to build in the future. It is anticipated that operations visualization in AR will allow them to come up with more realistic planning, less cost and budgeting problems, more appropriate construction methods, and more accurate controlling and inspection techniques in the short term and at the same time better strategic planning and development programs in the long term.

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REFERENCES

Azuma R. 1997. A survey of Augmented Reality. *Teleoperators and Virtual Environments* 6(4): 355–385.

Azuma R., J. W. Lee, B. Jiang, and J. Park. 1999. Tracking in unprepared environments for Augmented Reality systems. *Computers and Graphics* 23(6): 787-793.

Azuma R., Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. McIntyre. 2001. Recent advances in Augmented Reality. *IEEE Computer Graphics & Applications* 21(6): 34-47.

Behzadan A. H., and V. R. Kamat. 2005. UM-AR-GPS-ROVER Augmented Reality platform: Visualization of construction graphics in outdoor Augmented Reality, UMCEE Technical Report No. 05-09, Department of Civil and Environmental Engineering, The University of Michigan, Ann Arbor, MI.

Dodson A. H., G. W. Roberts, and O. Ogundipe. 2002. Construction plant control using RTK GPS. *FIG XXII International Congress*, Washington, D.C.

Dunston P., X. Wang, M. Billinghusrt, and B. Hampson. 2002. Mixed Reality benefits for design perception. In *Proceedings of 19th International Symposium on Automation and Robotics Construction (ISARC 2002)*,191-196, Gaithersburg, MD: NIST.

Gleue T., and P. Dahne. 2002. Design and implementation of a mobile device for outdoor Augmented Reality in the ARCHEOGUIDE project. *VAST 2001 - Virtual Reality, Archeology, and Cultural Heritage International Symposium*, Athens, Greece.

Hammad A., J. H. Garrett, and H. Karimi. 2004. Location-based computing for infrastructure field tasks. Telegeoinformatics: Location-based computing and services, 287-314. CRC Press.

Kamat, V. R., and J. C. Martinez. 2003. Validating complex construction simulation models using 3D visualization, *Systems Analysis Modeling Simulation* 43(4): 455-467, London, UK: Taylor & Francis Group.

Kamat, V. R., and J. C. Martinez. 2002. Scene Graph and frame update algorithms for smooth and scalable 3D visualization of simulated construction operations, *Journal of Computer-Aided Civil and Infrastructure Engineering* 17(4): 228-245, Malden, VA: Blackwell Publishers.

Karimi H. A., X. Liu, S. Liu, and A. Hammad. 2004. GPSLoc: Framework for predicting Global Positioning System quality of service. *Journal of Computing in Civil Engineering* 18(3).

Lawson S. W., and J. R. G. Pretlove. 1998. Augmented reality for underground pipe inspection and maintenance. In *Proceedings of SPIE International Symposium on Intelligent Systems and Advanced Manufacturing*, *Telemanipulator and Telepresence Technologies V,* Boston, MA.

Milgrim P., and F. Kishino. 1994. A taxonomy of mixed reality visual displays. *IEICE Trans. Information Systems* E77-D(12): 1321-1329.

Piekarski W., and B. H. Thomas. 2002. The Tinmith system: Demonstrating new techniques for mobile augmented reality modeling. In *Proceedings of 3rd Australasian User Interfaces Conference*, Melbourne, Australia.

Rogers S., P. Langley, and C. Wilson. 1999. Mining GPS data to augment road models. In *Proceedings of the 5th International Conference on Knowledge Discovery and Data Mining*, 104-113. San Diego, CA: ACM Press.

Roberts G. W., A. Evans, A. Dodson, B. Denby, S. Cooper, and R. Hollands. 2002. Look beneath the surface with Augmented Reality [online]. Available via http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=9516 [accessed July 1, 2004].

Roberts G. W., A. Evans, A. Dodson, B. Denby, S. Cooper, and R. Hollands. 2002. The use of augmented reality, GPS, and INS for subsurface data visualization. *FIG XXII International Congress*, Washington, D.C.

Thomas B., W. Piekarski, and B. Gunther. 1998. Using Augmented Reality to visualize architectural designs in an outdoor environment. *DCNet'98 Online Conference,* Available via http://www.arch.usyd.edu.au/kcdc/journal/vol2/dcnet/sub8 [accessed: March 10, 2003].

Webster A., S. Feiner, B. MacIntyre, W. Massie, and T. Krueger. 1996. Augmented reality in architectural construction, inspection and renovation. In *Proceedings of 3rd Congress on Computing in Civil Engineering*, 913-919. Reston, VA: ASCE.

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