ANIMATION OF CONSTRUCTION ACTIVITIES IN OUTDOOR AUGMENTED REALITY

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ABSTRACT

This paper describes research that investigates the application of outdoor Augmented Reality (AR) for three-dimensional graphical simulation of construction activities. The objective of the research is an AR-based platform that can be used with corresponding peripheral equipment (Head Mounted Display, GPS receiver, orientation tracker, and a portable computer) to generate a mixed view of the real world and superimposed virtual construction graphics (CAD models) in an outdoor environment.

What distinguishes the presented work from indoor AR applications is the capability to produce real time output as the user moves around by applying minimum constraints over the user's position and orientation. In addition, the ability to operate independently of environmental factors such as lighting conditions makes the designed platform a powerful tool for outdoor AR applications. This paper presents the first results of our research and a prototype software called UM-AR-GPS-ROVER that is capable of interactively placing 3D CAD models at any desired location in outdoor augmented space.

The concept and the prototype are demonstrated with an example in which scheduled construction activities for the erection of a structural steel frame are animated with the passage of simulated project time in outdoor AR.

KEY WORDS

Augmented Reality, GPS, Position, Orientation, Transformation, Simulation, 4D CAD.

INTRODUCTION

Augmented Reality (AR) is the superimposition of computer-generated images over a user's view of the real world so that the user's view is enhanced or augmented beyond the normal experience. In other words, AR allows users to see and navigate in the real world, with virtual objects superimposed on or blended with their view. Virtual Reality (VR), on the other hand deals with only computer-generated models in a totally synthetic environment in which the surrounding real world is not contributing to the simulation process.

Figure 1 presents two snapshots of a graphical simulation of a bridge construction project in VR and AR. In the VR simulation portrayed on the left, all simulation entities are modeled

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in a virtual space. In contrast, in the AR simulation snapshot depicted on the right, the view of real world and existing structures (i.e. partially completed bridge deck) are used as the background, and CAD models of only the simulation objects under study (i.e. cranes) are superimposed over this view.

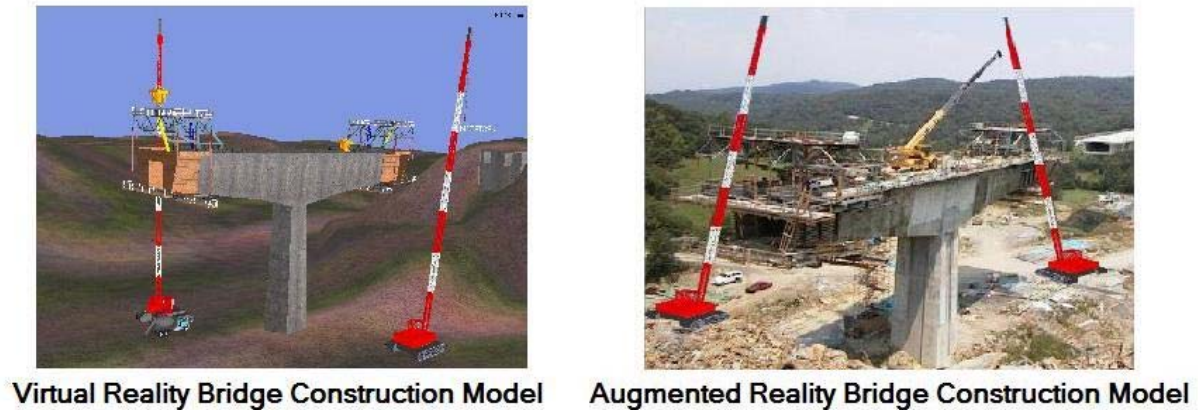Virtual Reality Bridge Construction Model   Augmented Reality Bridge Construction Model

Figure 1: Comparison of Graphical Simulation in Virtual and Augmented Reality

AR can be classified into two categories: indoor and outdoor. In indoor AR, the user takes advantage of a prepared and accessible environment and user's movements are usually restricted to a finite space. For a domain such as construction, however, indoor AR has limited applications because most construction activities are performed in outdoor, unprepared environments (e.g. heavy construction, roads, bridges, dams, buildings, etc.). Outdoor AR is thus more applicable.

The main requirement of outdoor AR is the need to accurately track the user's viewpoint, and to respond correctly to variations in user's movement and environmental characteristics (e.g. irregular terrain, lighting conditions, etc.). Unlike indoor AR where the user is limited to navigating in a restricted space, in outdoor AR the user needs the ability to navigate freely with minimum constraints. At the same time, the AR system must be capable of generating an accurate representation of augmented space in real time so that the user experiences a world in which virtual objects stay fixed to their intended location and seamlessly blend with real entities (Azuma et al. 1997).

TECHNICAL APPROACH FOR REGISTRATION

Figure 2 presents a schematic view of the hardware components selected for this study and the configuration in which they were assembled. A video camera models the behavior of the eye where all the real objects in the surrounding space appear in perspective view. It continually captures a view of the real world and transmits the images to the AR platform's laptop computer. A head-mounted display (HMD) device worn by the user is also connected to the computer's video port.

In addition, there are two important pieces of equipment connected to the user to keep track of viewpoint movements and basically provide the input for the registration computations. These are the GPS receiver and a 3-DOF orientation tracker. The GPS receiver provides the AR platform with real-time position data in the global space in the form of

longitude, latitude, and altitude (Rogers et al. 1999, Roberts et al. 2002, Dodson et al. 2002). The global position of the virtual object(s) can be read from an existing database file. Knowing these two point locations, the relative distance and the corresponding heading angle between the user and the virtual object is calculated. The distance calculation is based on Vincenty's method (Vincenty 1975). The orientation tracker on the other hand, provides the platform with three important pieces of information called yaw, pitch, and roll angles which represent the orientation of the user's viewpoint in 3D space (Behzadan and Kamat 2005).
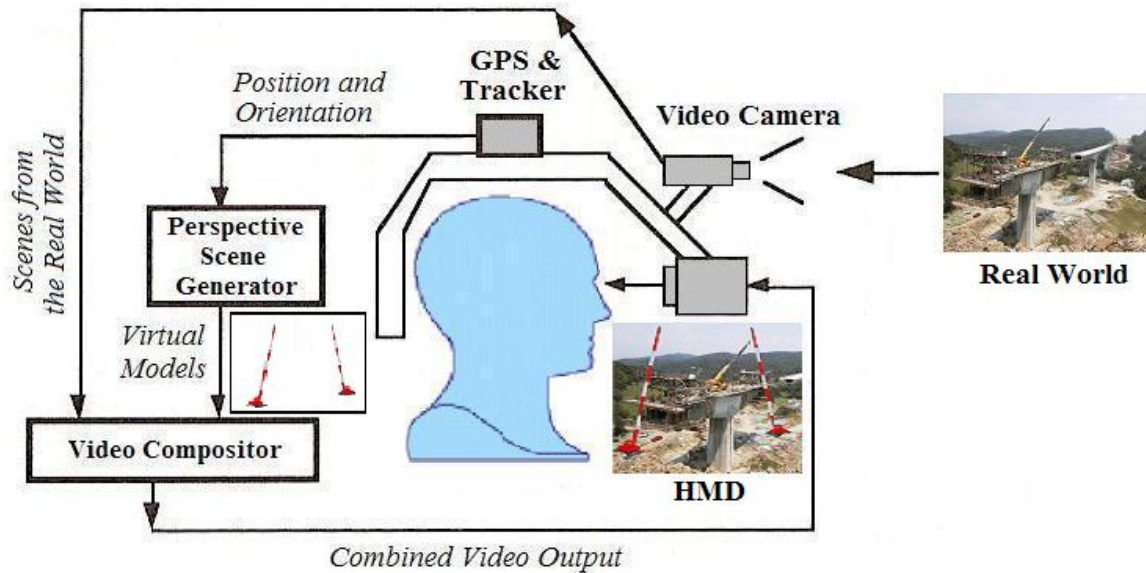

Figure 2: Hardware Setup for Mobile Outdoor Augmented Reality

Using these six pieces of information, the AR platform is capable of computing the user's viewpoint in real-time, and based on the computed viewpoint position and three-dimensional orientation, can correctly register virtual CAD objects in the user's viewing frustum. The CAD objects are drawn inside a standard OpenGL perspective viewing frustum. The OpenGL viewing frustum is reconciled with the truncated viewing pyramid of the video camera that captures the real world view. Accurate, real time alignment (i.e. registration) of the two viewing frustums (real and virtual) leads to a realistic augmented view where both real and virtual objects coexist. The AR platform transmits images of this augmented environment to the user's display device.

The most important requirement for realizing an AR scene in which virtual models appear to coexist with objects in the real environment is real-time knowledge of the relationship between the models, real world objects, and the video input device (Barfield and Caudell 2001). Registration in AR means accurate overlapping of the real and virtual object coordinate frames. Once accurate registration is achieved and maintained, CAD models placed in the augmented space are correctly located and oriented in the real world regardless

of where in the augmented space they are viewed from. Registration of virtual objects in the real environment requires accurate tracking of the user's viewpoint position and orientation.

Figure 3 shows a graphical illustration of the problem. It depicts an area on the University of Michigan north campus. The objective of this example is to superimpose a CAD model of an excavator over the real background at the location and with the orientation (facing north) indicated on the plan view in this figure.
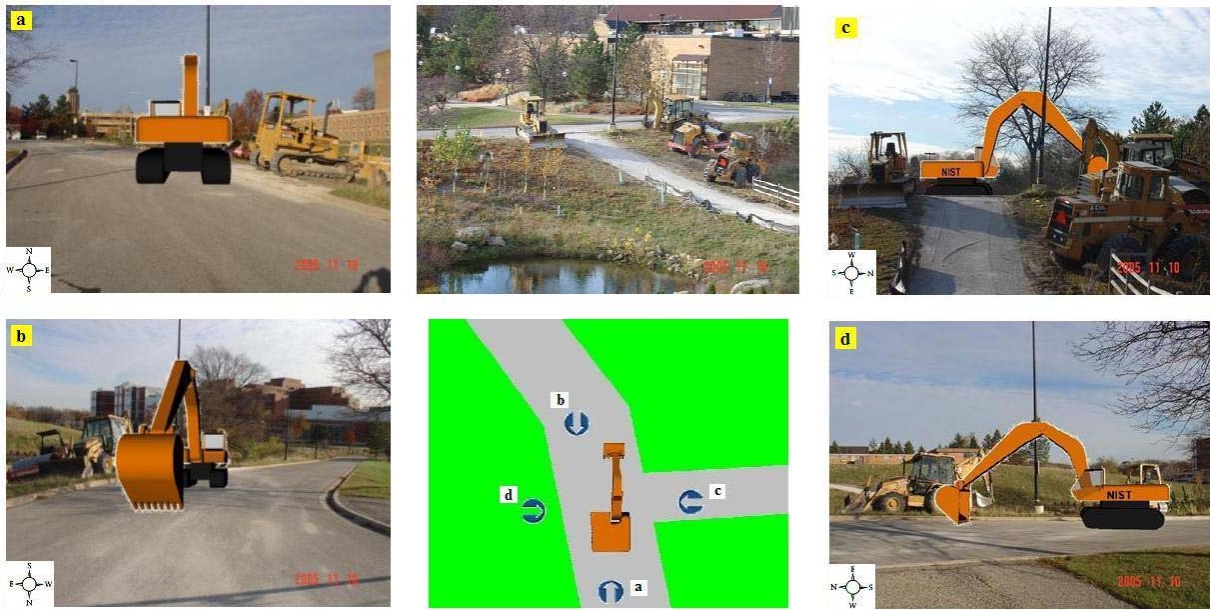

Figure 3: Concept of Accurate Outdoor Augmented Reality Registration

The snapshots on the left and right (a, b, c, and d) in Figure 3 show accurate augmented views an AR user expects to see when looking at the scene from the locations (a, b, c, and d) indicated on the plan view. In each case, the final result is a mixed view of real and virtual objects and is sensitive to the user's location and orientation. When the user stands at point (a) and looks towards the north, the rear end of the virtual excavator is expected to be seen (Figure 3-a). At location (b), the user is standing in front of the virtual excavator looking towards the south. In this case the user must see the excavator from the front (Figure 3-b). When the user is at location (c) looking west, the right side of the excavator must be visible (Figure 3-c). Finally, in location (d) when the user looks east, only the left face of the virtual excavator must be visible in the composite AR output (Figure 3-d). In summary, the augmented virtual excavator must stay fixed to its real-world location while the AR user navigates around it on the jobsite. In this study, this is achieved by using GPS and 3-DOF angular trackers to monitor the user's position and orientation.

UM-AR-GPS-ROVER AUGMENTED REALTY PLATFORM

The designed registration algorithms have been implemented in an AR prototype platform named UM-AR-GPS-ROVER that serves as a proof-of-concept, and also helps validate the research results. UM-AR-GPS-ROVER comprises of two main components working in parallel. In addition to the software components of the tool, supporting hardware devices are appropriately integrated to provide the necessary sensing, input, and output capabilities. The connected hardware devices primarily consist of a GPS receiver, a 3-DOF orientation tracker, an optional HMD, and a laptop computer.

A Delorme Earthmate WAAS enabled GPS receiver and an InterSense InterTrax2 head tracking system are used for user position and orientation sensing respectively. A Sony DCR-TRV33 mini-DV digital video camera recorder is used as a video capturing device and models the user's viewpoint. The GPS sensor and the orientation tracker are mounted on the camera using Velcro fasteners. Figure 4 presents photographs of the hardware setup used in UM-AR-GPS-ROVER.

Figure 4: Hardware Setup of UM-AR-GPS-ROVER

An i-glasses SVGA Pro 3D HMD is used as an optional wearable display. When the HMD is used, the video camera is switched to a Unibrain Fire-i digital firewire camera, and the GPS sensor and orientation tracker are mounted on top of the HMD to create a wearable computing user experience. In the presented work, a HP Pavilion laptop with 3 GHz CPU speed and 512 MB RAM is used as a mobile computing platform.

The software components of UM-AR-GPS-ROVER are independent interconnected modules that can be easily replaced or updated as necessary. The platform is basically implemented as a set of four loosely-coupled interacting modules. The first module captures a live video stream from the real world using the video input device. The second module is mainly a data collector for the GPS receiver and orientation tracker and communicates with the sensors via USB ports. This module provides the input for the third module which is the transformation module in which the viewpoint's movements are registered and appropriate transformations are applied to the virtual objects. The fourth module is essentially a graphical

module that reads graphical data from indicated CAD files and places each virtual model in the user's view in real time.

VALIDATION

To validate the research results and registration algorithms, UM-AR-GPS-ROVER platform was used to place several static and dynamic 3D CAD models at several known locations in outdoor augmented space. In particular, the prototype was successfully tested in many outdoor locations at the University of Michigan north campus using several construction models (e.g. buildings, structural frames, pieces of equipment, etc.).

In order to test the prototype's ability to augment dynamically changing graphical models in a user's view, a 4D CAD (Koo and Fischer 2000) model of a structural steel frame was registered at a known outdoor location. To be more specific, scheduled construction activities for the erection of the steel frame (columns, beams, girders, and connection) were graphically animated with the passage of simulated operation time which is defined as an extra dimension for each augmented virtual model such that an object (e.g. steel beam or column) is not superimposed in the augmented view unless the simulation clock passes its scheduled completion time.

Time tags for all virtual models are stored in a database file with their corresponding model ID number. At each frame in the graphical AR simulation, the database is searched to determine whether there are object(s) with a time tag smaller than the current simulation time. If an object falls into this category, its graphical data is read from a corresponding graphical file and is displayed in the user's view at the correct expected location. Figure 5 presents snapshots of the 4D graphical AR simulation.

FUTURE WORK AND CHALLENGES

An outdoor AR system should provide the user with the freedom to operate in a wide area and at the same time keep accurate track of the viewpoint position and orientation. In this research, the level of accuracy of each piece of data obtained from the orientation tracker is based on the quality and accuracy of the previously obtained data point. In other words, the tracker provides relative changes in orientation along the three primary axes.

Thus, phenomena such as rapid angular movements or fluctuations in ambient temperature induce a significant amount of drift in the orientation tracker's readings, making the tracked orientation unreliable. Similarly, an interruption in the WAAS signal severely degrades the quality of the reported GPS position. In order to address these issues, the authors are currently experimenting with a high-accuracy three-axis tilt compensated digital compass module for orientation tracking and an Omnistar-HP differential correction capable GPS receiver for positioning. The compass data at each instance reports the absolute magnetic heading (yaw), roll, and pitch, and is thus expected to be free from drift issues. On the other hand, Omnistar-HP corrected GPS locations are documented to be accurate within 10 centimeters of the real positions after convergence (OmniStar 2006).

Another important problem in outdoor AR is that of occlusion. Incorrect occlusion happens when a real object is placed between the user's view and the virtual object(s) in augmented space. In such a situation, as the distance between the real object and the user is

less than that between the virtual object(s) and the user, the real object should theoretically block (at least partially) the user's view of the superimposed models that lie behind it. This idea is conceptually presented in Figure 6. Under ideal circumstances, the hidden portions of virtual models should not be visible in the composite AR output as shown in the figure. That is, however, not currently the case because UM-AR-GPS-ROVER draws the pixels of all virtual models after painting the captured video image as a background.

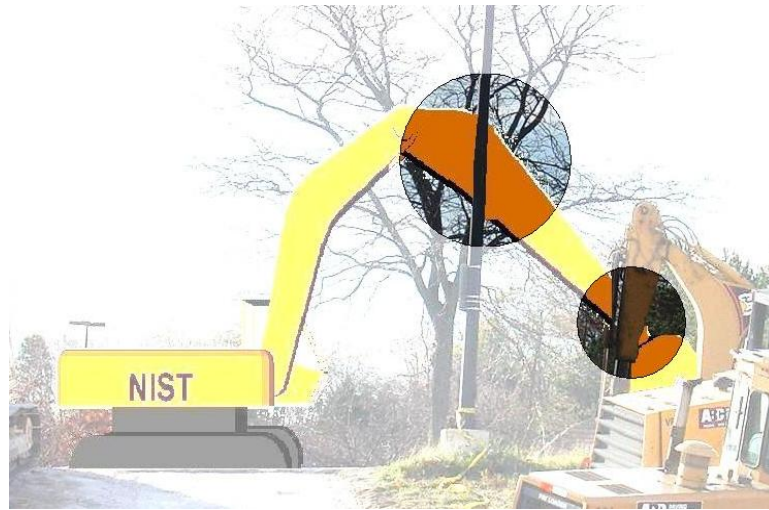Figure 5: Graphical Augmented Reality Simulation of a 4D CAD Model

Figure 6: Dynamic Occlusion Problem in Outdoor Augmented Reality

One of the solutions to this issue is using a combination of rapid geometric modeling of the surrounding environment or other depth sensing techniques (e.g. stereo cameras) and utilizing the graphics processor's z-buffer to draw the appropriate set of pixels in each composite AR frame. In other words, if this depth of real objects is greater than the depth of virtual object(s) for a given view, the real object does not occlude any virtual objects. In the opposite set of circumstances, appropriate corrections should be made to user's view to take into account the existence of an occluding real object.

CONCLUSIONS

The primary advantage of graphical simulation in AR compared to that in VR is the significant reduction in the amount of effort required for CAD model engineering. In order for AR graphical simulations to be realistic and convincing, real objects and augmented virtual models must be properly aligned relative to each other. Without accurate registration, the illusion that the two coexist in AR space is compromised.

Traditional tracking systems used for AR registration are intended for use in controlled indoor spaces and are unsuitable for unprepared outdoor environments such as those found on typical construction sites. In order to address this issue in the presented research, the global outdoor position and 3D orientation of the user's viewpoint are tracked using a GPS sensor and a 3-DOF orientation sensor. The tracked information is reconciled with the known global position and orientation of CAD objects to be superimposed in a user's view.

Based on this computation, the relative translation and axial rotations between the user's eyes and the CAD objects are calculated at each frame during visualization. The relative geometric transformations are then applied to the CAD objects to generate an augmented outdoor environment where superimposed CAD objects stay fixed to their real world locations as the user moves about freely on a construction site. Validation of the designed algorithms with construction models proved that this approach is not only feasible, but also very effective.

ACKNOWLEDGEMENTS

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