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STRUCTURE OF AN EXTENSIBLE AUGMENTED REALITY FRAMEWORK FOR VISUALIZATION OF SIMULATED CONSTRUCTION PROCESSES

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ABSTRACT

The presented work describes the recent research being conducted by the authors in the field of visualization of simulated construction processes. The underlying uncertainty involved in almost all construction operations makes it necessary to study and analyze the behavior of the acting resources in more detail and under different scenarios in order to come up with the most efficient method to perform a set of tasks and obtain the best possible result. Simulation and visualization of planned construction processes are powerful tools to achieve this objective. This paper focuses on the application of Augmented Reality (AR) for visualizing simulated construction processes in both outdoor and indoor environments and compares it to methods of visualizing modeled processes in pure Virtual Reality (VR). An AR framework and extensible class library are also introduced which can be used to verify and validate the results of simulation models and can be further applied to develop new AR systems.

1 INTRODUCTION

Construction operations include a variety of activities ranging from excavation and piling to bricklaying and erecting the structure. In all cases, the common characteristic of all such operations is that they all need resources (e.g. raw material and equipment) and acting entities (e.g. labor) to be completed. Every construction operation consists of a set of activities. Each activity requires a certain combination of resources to be performed. The completion of each activity marks the start of its proceeding activities and at the same time the applied resources are either released or transformed to a new form of resource(s) and flow through the system. This cycle repeats for as much time as needed to achieve a desired result such as a certain level of output.

Discrete-Event Simulation (DES) is a powerful objective function evaluator that is well suited for the design and performance study of construction operations (Kamat and Martinez 2002). Simulation as applied to construction operations planning and analysis entails the creation of models that represent how construction operations will be performed. These models consider the different resources that are required to carry out the construction operations, the rules under which the different tasks that compose the operations are performed, the managerial decisions made during the operations and the stochastic nature of events.

Once the models are created, the modeled operations can be simulated in the computer and the statistical measures of performance for the operations can be studied. The results typically include the cost and time of construction as well as statistics including but not limited to resource utilization rates, waiting time, and queue lengths. The results usually point out important parts of the operations with potential for improvements that may lead to cost or time savings. Considering these observations, the operations analyst may modify the controlling parameters of the models to reflect changes in operating procedures, resource allocations, space for temporary storage of materials, and the like. The modified models can then be simulated and analyzed, with the results used to further improve the operations. The procedure continues until the operations analyst is convinced that either no further improvements are possible or a certain level of improvement has been achieved.

2 IMPORTANCE OF VERIFICATION, VALIDATION, AND ACCREDITATION IN DES

One of the primary issues in the use of DES models in construction is that there are often no means to check the credibility of the models and the authenticity of the results (Kamat and Martinez 2003). Every simulation model needs to pass the verification, validation and accreditation stages before it can be reliably treated as a representative of the real system. 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 (Behzadan and Kamat 2005).

As a matter of fact, visualization and animation of simulated operations can play an important role in the verification, validation and accreditation of models. Therefore, both simulation modeling and visualization can be of significant help in enabling the performance of actual field operations, leading to the most beneficial decisions and providing a pictorial tool of how precisely activities relate to one another. By consequence, 3D animation objectives are to verify that code is free of errors, validate simulation models, and ensure the veracity and credibility of models once verified and validated. During recent years, several research efforts in the field of visualization of construction operations have been conducted (Kamat 2003).

3D visualization can also serve as a suitable communication tool between the people involved in managerial tasks who are the main decision makers and those who are more into the technical aspects of the job. At the same time it provides the modeler and the user with precious data about the layout of the system and involved processes, it reveals potential deficiencies that might be present in the real system as a result of any possible conflict between acting entities, resource allocation problems, and undesirable physical constraints over the movement of resources and entities. Note that while these issues can be taken care of beforehand using the output of a well organized and comprehensive visualization model, the consecutive problems caused by each of them in a real life operation can lead to significant waste of financial resources as well as project time. A simple unforeseen case sometimes puts an entire project weeks and even months behind the schedule before it can be resolved.

3 VIRTUAL REALITY 3D VISUALIZATION AND CORRESPONDING LIMITATIONS

There are basically two main methods to validate a simulation model using visualization technique. Models can be validated in a totally virtual world or in a combination of virtual and real worlds. While the former uses a technique known as Virtual Reality (VR), the latter can be best done using Augmented Reality (AR). Previous work has been done about the application of VR in visualization of construction operations (Kamat 2003).

In a pure VR approach, every element as well as the surrounding environment has to be modeled and integrated into the system. This concept which is often referred to as model engineering, includes creating, obtaining, refining, archiving, and updating 3D CAD models of involved entities in construction operations and resources for use in 3D animation (Brooks 1999). An AR approach to the same problem requires the modeler to model only those entities being on the focus of study. This way, a significant amount of time can be saved by switching from a heavy loaded to a relatively small scale model engineering job.

On the other hand, some elements existing in the model (e.g. site terrain, existing structures, and side operations) can be best represented by their corresponding real objects as opposed to artificial computer generated models. In order to have a complete and realistic VR scene and despite the fact that these elements might not be of any concern to the modeler, they should be modeled and shown in the background of the running system. In AR approach, this can be easily taken care of by allowing them to appear as a part of the real background of the model. Figure 1 shows the two visualization approaches for the same problem of a bridge construction site. For the case of this specific example, the modeler is only concerned with the crane operations. However, in the VR scene, the entire system has to be modeled while in the AR approach, the only elements need to be modeled are the two cranes and all the real surrounding environment can be a part of the system background.

Virtual Reality Bridge Construction Model

Augmented Reality Bridge Construction Model

Figure 1: Virtual reality and augmented reality approaches to visualize a bridge construction project

4 AUGMENTED REALITY SYSTEM STRUCTURE

Almost every AR system allows the user to move freely in the real world while observing the mixed virtual-real view of the scene. Such a system by definition needs a minimum number of peripheral devices to provide input and output data. These are mainly the positioning and orientation systems, a video camera to capture live real scenes of the environment, and a Head Mounted Display (HMD) to show the final view all of them are connected to the user's head or any other known position on user's body. Figure 2 shows the main components of a standard AR system.

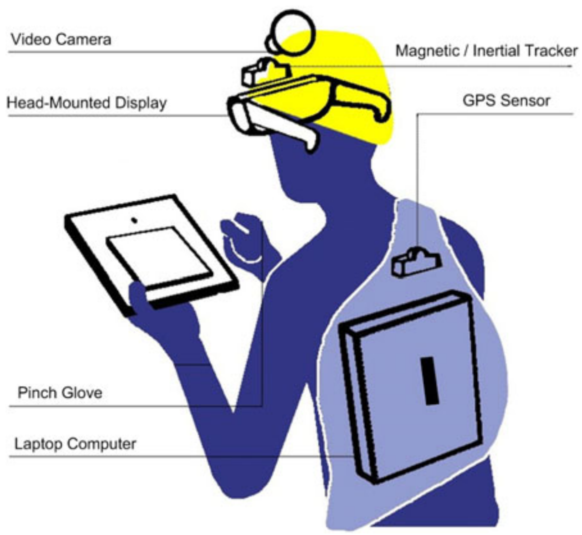

Figure 2: Hardware setup for a mobile outdoor AR system

The fact that in an AR system, the user has the minimum level of physical constraints over his or her movements and that he can move to and orient his head in almost every desired direction, introduces the necessity of tackling the most important challenge in the development of such an AR platform which is referred to as registration. Registration techniques in the context of an AR system development provide means and methods to keep track of each movement a mobile user can make and overlay the corresponding graphic based on the location data. In other words, registration points to the ability of the AR system to acquire real time positioning and orientation data of the user and update the graphical content of his or her mixed viewing frustum so that in every instance of time, the virtual objects in the view seem to be in their fixed position and orientation which is totally independent of where the user is standing and in what direction he or she is looking.

5 REGISTRATION PROCEDURE FOR OUTDOOR APPLICATIONS

For outdoor applications, the use of georeferenced positioning techniques seems to provide very promising results since the GPS satellites orbiting the Earth can continually provide the system with the global position of the user while at the same time the 3D orientation tracker feeds orientation data to the platform (Kamat and Behzadan 2006). The two devices together basically provide the platform with six pieces of vital data including the user's global position in form of longitude, latitude, and altitude as well as user's head orientation (or direction of look) in form of yaw, pitch, and roll angles (Behzadan and Kamat 2006).

Being provided by this information, the AR platform is able to construct a perspective viewing frustum with the user's eye placed in the center of the near plane. Each and every movement caused by either a physical displacement or a head rotation will directly change the orientation and location of this frustum. Based on the location and orientation of the field of view, data of virtual objects are analyzed and the objects are superimposed over the real scene as viewed by the AR user.

A simulation engine is running in parallel in a separate thread. Data for virtual objects obtained via this simulation engine are fed into the main AR platform. Examples of such data include operations logic, simulation entities and resources, and relations between different existing elements. This data goes further through a video composer engine which is responsible for providing a mix view of real and virtual objects to be shown on the user's final view.

The video composer engine uses OpenGL methods and Scene Graph concepts to create a realistic view of the augmented environment. It progressively builds a scene graph which consists of parent and child nodes based on the relative distance and orientation of each object and the user. Each node represents a virtual object together with its corresponding transformation methods. Objects in the scene are transformed relative to their parent node(s) in case an update is needed to refresh the screen.

To obtain the user's relative distance to each virtual object in the field, Vincenty algorithm is used which takes user's global position (in form of longitude, latitude, and altitude) and also the object's global position as input arguments and calculates a relative distance in default measurement units (Vincenty 1975). This distance can then be used in the transformation process during which the virtual object is going through a set of translation and rotation operations before it is placed in its final location inside the viewing frustum.

Figure 3: Augmented reality visualization of a steel structure erection operation

The final view consists of a live background of the real surrounding environment over which a complete simulation scenario is being performed and displayed using a set of virtual objects interacting together based on a set of rules and operational logic. Figure 3 shows the completion of a steel structure erection in an AR scene.

6 REGISTRATION PROCEDURE FOR INDOOR APPLICATIONS

Most outdoor technologies do not function once an AR user moves indoors and loses GPS connectivity. The reason that GPS technology is not reliable for indoor applications is because it becomes less accurate when there is no straight signal path between the satellite and the receiver. Therefore, the need to investigate feasible techniques of user position and orientation tracking in congested enclosed environments is an important step in providing site engineers, inspectors and other site personnel with project information through an AR environment. This is required to allow the visualization of simulated construction operations in indoor environments.

The same positioning and orientation tracking concepts are used for indoor applications. In a nutshell, the indoor AR process works as follows. The camera position and orientation in the local 3D augmented space are calculated. The camera captures video of the real world and sends it to the computer. Once the position and orientation of the camera are known, any computer graphics model (e.g. CAD image) can be drawn relative to the center of the camera's lens (which corresponds to the user's viewpoint).The augmented graphics are drawn on top of the video of the real world and so always appear relative to the user's viewpoint. The final output which consists of graphics overlaid on the real world can be viewed and analyzed on the user's display. As was previously stated, two pieces of information are vital in this process. The position where the user is located within the building, and the direction in which the user is looking are needed in order to interpret the construction entities that might be visible to an on-site indoor user at a given instant. The challenge is to accurately and continuously determine the user's line-of-sight and then align the viewing frustum with computer representations of objects expected to exist in that space.

In indoor AR as in all conventional AR systems, registration should be achieved and maintained by monitoring and tracking the movements (body motion and head rotation) of the user and using that information to continuously align augmented images with real world counterparts (Barfield and Caudell 2001). In comparing and contrasting different positioning technologies, it is important to first have a common definition of indoor positioning systems .These are systems that can determine the position of something or someone from a distance within a physical space.

Infrared (IR) systems (Aitenbichler and Muhlhauser 2003) are known for their capability of not being able to penetrate walls or other opaque materials. Within such systems, location of tagged devices determine where receiver should be placed. These devices emit IR light, and if the tagged device is in the same room as a receiver its position is known. IR-based systems have some disadvantages. First, there must be receivers; connected using special wiring, in every room where an asset might be located, which is time-consuming and expensive. Second, IR-based systems fail to function if the IR signal gets blocked. However, one main advantage of IR-based systems is the fact that support and solutions are easy to get.

Other indoor positioning systems include Radio Frequency Identification Tags (RFID) (Ayre 2004). There are two types of RFID systems: active and passive. In a passive RFID system an antenna transmits a radio signal to the RFID tag, which then disturbs the signal in an identified expected way and returns the modified signal to the radiating antenna. The biggest advantages of passive RFID systems are the low cost and long useful life of tags. The biggest disadvantage is that their read distance is very limited; tag can be read at very short distances. On the other hand, active RFID tags have batteries and transmit data either at a regular rate or when activated by other transmitters. They have the advantage of being able to transmit longer distances with smaller antennae, but aren't true location solutions since the distances are still typically only 2-3 meters.

Lately, a new type of mobile technologies, widely known as location-aware or positioning technologies, has been materialized enabling the design of applications with the capability to identify a user's location and modify their settings, interfaces, and functionality accordingly. The way in which location identification is achieved can be quite different in outdoor and indoor environments (Tseng et al 2001).

The Indoor GPS location identification system is a recent research in location-based computing. It focuses on exploiting the advantages of GPS for developing a location-sensing system for indoor environments. Although GPS signal does not typically work indoors because the signal strength is too low to penetrate a building (Chen et al 2000), indoor GPS solutions can be applicable to wide space areas where no significant barriers exist. Indoor GPS takes into account the low power consumption and small size requirements of wireless access devices, such as mobile phones and handheld computers.

In fact, indoor positioning technologies set the constraint of a limited coverage range, such as a building or other confined spatial area. These technologies are therefore not dependent on any 'external' network. However, they are dependent on a set of technologies used for transmitting wireless data in closed environments, such as radios, infrared sensors, wireless local area networks (WLANs) (Held 2000, Hightower and Borriello 2001, Want and Schilit 2001).

As a matter of fact, complementing data networking capabilities of RF wireless LANs can be of substantial help in locating and tracking mobile users, especially in in-building environments. This is achieved by using technologies similar to the ones used in the RF-based system RADAR (Bahl and Padmanabhan 2000). RADAR uses signal strength information gathered at multiple receiver locations to triangulate the user's coordinates. Triangulation is done using both empirically-determined and theoretically computed signal strength information (Bahl and Padmanabhan 2000).

Experiment conducted by Bahl uses three FreeBSD based stations equipped with a wireless adapter and placed on a second floor of a three-storey building and including a NIC mobile host carried by the user to be tracked. The Windows-based mobile host was chosen so as to broadcast packets called beacons periodically and have the FreeBSD base stations record signal strength information. This experiment showed that RADAR is able to estimate a user's location to within a few meters of his/her actual location. It was stated that the median resolution of the RADAR system is in the range of 2 to 3 meters, about the size of a typical office room. However, in the case of indoor inspection tasks and together with similar RADAR technologies, there is a need for more elaborated studies to reach a higher degree of accuracy.

7 UM-AR-GPS-ROVER PLATFORM AND AN INTEGRATED CLASS LIBRARY

In order to achieve the AR visualization objectives, a prototype framework called UM-AR-GPS-ROVER has been developed and validated by the authors (Kamat and Behzadan 2006). The presented platform consists of a number of main components (i.e. modules) each working interactively with others to produce the best and most reliable and accurate output in real time. The most important hardware components are a video camera (for capturing live real scenes), a tracking system (consisting of both positioning and orientation tracker devices), and a pair of wearable glasses (to see the final augmented output). These all are connected to a computing source (i.e. a wearable computer) and powered by separate battery sources. In addition to the hardware part, an AR software platform is responsible to communicate with the peripheral devices and provide input data as well as produce desirable output. Figure 4 shows the current hardware configuration of the UM-AR-GPS-ROVER.

The critical task that every AR system should be capable of doing is maintaining accurate and continuous registration of the user while he or she is moving almost without any physical constraints in the real environment. The presented AR platform uses a binary data transfer mechanism to communicate with the positioning and orientation devices through serial port connections. The main advantage of having such a relatively low level communication interface is that the established methods are almost generic and can easily be extended and reapplied to any other registration device providing that it parses out data following a standard format (e.g. NMEA format for GPS data). In the presented work, we are using a Trimble AgGPS 332 receiver and a TCM5 3DOF orientation tracker.

The data transfer methods have been exported in a number of class libraries which gives the ability to the future users of any other AR system to import them as separate modules and apply the provided methods to their application easily to communicate with the registration tools. Having such a modular structure, the presented AR system is capable of working in parallel to any existing visualization application such as VITASCOPE (Kamat 2003). Once the registration issue is taken care of using the abovementioned methods, the entire system can be easily plugged in to the graphical engine of existing 3D visualization software and takes advantage of the provided animation capabilities while it is continuously locating the user in the real world applying appropriate registration techniques. The result will be an accurate and realistic mixed view of the simulated system with all the required graphical features as well as live scenes of the real world.

Figure 4: UM-AR-GPS-ROVER hardware setup

8 CONCLUSION

Application of visualization techniques in the planning, decision making, and operation stages of complex construction processes can help save significant amount of time and financial resources by providing a means to preemptively avoid unforeseen deficiencies and difficulties that might happen while the real operation is in progress. AR visualization approach can even lead to more time and cost savings since it requires less model engineering effort and at the same time provides more realistic output.

The most important challenge in an AR system, however, is the need to keep track of the mobile user's position and orientation and use the acquired registration data to update the final output in real time. This can be achieved using different methods for outdoor and indoor applications.

The final result of the work has been presented in the form of an AR system framework called UM-AR-GPS-ROVER together with an extensible set of class libraries that can be exported and further used as separate modules in almost any other AR platform that uses standard format of registration data coming through the positioning and orientation tracking devices. The entire AR platform also has the capability to being plugged in to a VR-based visualization application and takes advantage of its graphical features while feeding registration data into the system to build an accurate and realistic augmented view of the simulated processes.

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