Automated Generation of Dynamic Walk-Through Animations of Simulated Engineering Operations in Augmented Reality Environments

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Abstract. 3D Visualization is an effective method to verify and validate a simulated operation and foresee potential space and resource conflicts that may occur during a project lifecycle. This paper presents ARVISCOPE, an Augmented Reality (AR) visualization tool capable of creating smooth walk-through animations of Discrete Event Simulation (DES) models. ARVISCOPE is equipped with a wearable backpack, and creates real-time augmented scenes by geo-referencing and registering virtual CAD objects over real world live videos, while the observer is immersed in animation. Several important research issues had to be addressed in designing and implementing ARVISCOPE. These include: 1) establishing and maintaining a spatial link between virtual objects and real scenes (registration); 2) creating CAD object hierarchies for dynamic manipulation of the graphical contents; 3) communicating with the process model to extract all elements describing a simulated scenario; 4) obtaining positional and orientation data of the mobile observer; and 5) resolving incorrect occlusion.

1 Introduction

The application of 3D visualization techniques has recently gained a significant amount of attention in several engineering and scientific fields (Kamat and Martinez 2001). Displaying 3D spatial views of engineering processes, and the ability to observe the visualized scene from different viewpoints and with different levels of detail has motivated many researchers to adopt visualization techniques in order to prove the functionality and integrity of a well engineered model, and verify that the model components can operate with minimum physical conflicts and logical errors. Traditional visualization tools typically rely on the paradigm of Virtual Reality (VR). A VR-based visualized scene consists of computer generated elements that operate in a fully synthetic model without interaction with the environment in which the corresponding real engineering operation is to take place (Kamat and Martinez 2001).

Besides the amount of time and effort required for Model Engineering (Brooks 1999) which includes creating, managing, manipulating, and modifying the graphical contents of a virtual scene, the degree of visual reality is largely dependent on the modeling details and precise rendering of the scene. As a tradeoff, a more realistic VR-based animation requires more computer processing time which directly translates to less animation speed. This becomes even more critical as the size and complexity of the modeled process increases and more elements are introduced into the visualized scene. An alternate visualization approach which has been explored by relatively few researchers in recent years is Augmented Reality (AR). The main difference between an AR-based and a VR-based visualization is that in AR, real existing elements serve as the background of the animation while all computer generated graphics are superimposed on the foreground. In fact, an AR visualized scene is a combination of both groups of real and virtual objects accurately overlaid in a single display.

The introduction of real world into the visualization leads to more realistic views of the modeled operation and helps project decision makers gain a better understanding of the environment in which the operation takes place. Using AR animations, they can perform real time walk-through tours inside the visualized scene in order to study the ongoing engineering operation with desired level of detail and from different viewpoints while the entire modeled operation is superimposed on the real engineering space (Behzadan et al 2008). Figure 1 shows a snapshot of an outdoor walk-through AR experiment conducted in this research in which the erection of a virtual steel structure is animated on top of live videos of the real existing environment.

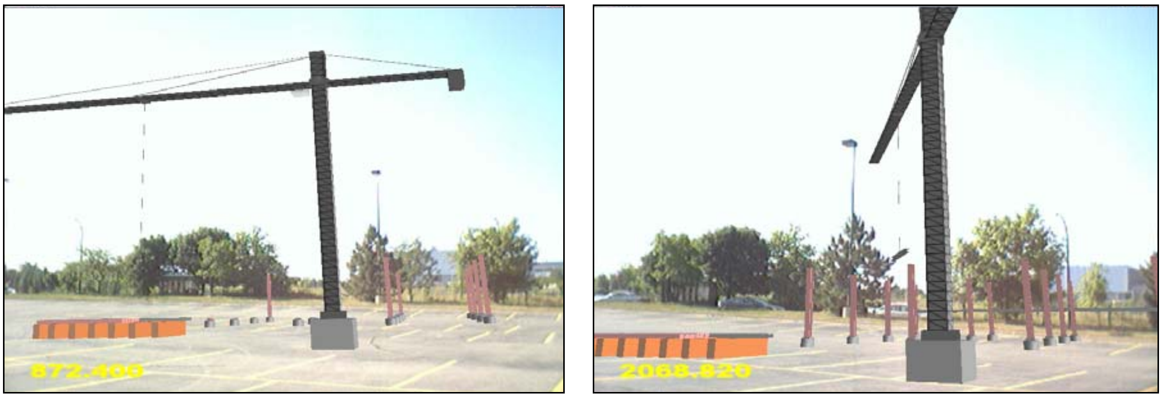


Figure 1: A Walk-Through Experiment in AR (Created in ARVISCOPE)

AR also has great potential in personnel training in assembly line and manufacturing plants. AR is currently used to address the visualization needs in several other fields such as medicine, computer gaming, military, tourism, and robotics. Unlike small scale and controlled environments in which many conventional AR platforms have been developed and implemented, the application of AR in areas such as construction and building inspection has been very limited. This is mainly due to the fact that engineering tasks in these fields are usually conducted in outdoor areas and in a wide operational range which requires the AR system developer to take into account unique parameters such as mobility, continuous tracking, and underlying uncertainty in the nature of the environment (Behzadan et al 2008).

In an effort to address these longstanding issues in the application of AR in wide range engineering operations, the authors have designed, developed, and implemented ARVISCOPE (acronym for Augmented Reality Visualization of Simulated Construction Operations). ARVISCOPE is capable of creating smooth animations of Discrete Event Simulation (DES) models of engineering processes. It runs on a fully mobile platform equipped with a wearable backpack and creates real time augmented scenes of simulated operations by geo-referencing and registering virtual CAD objects on top of live video backgrounds of the real world (Behzadan 2008). During the course of the AR visualization, the observer is embedded in the animation and can walk in the scene with minimum physical constraints to observe the ongoing augmented operations from different positions.

In order to fulfill the design requirements, research challenges such as establishing and maintaining a spatial link between real and virtual objects (i.e. registration), real time tracking of observer’s position and orientation, creating CAD object hierarchies to dynamically manipulate CAD objects, and handling visual discrepancies have been successfully addressed and overcome. These major design criteria will be discussed in more detail in the following

Sections. The main contribution of ARVISCOPE to the current state of knowledge in creating AR visualizations is that it is capable of creating realistic animations of simulation models created in a variety of DES tools. In addition, the fact that the observer is physically involved and able to interact with the animation while looking at the animated scene with the highest available graphical and operational level of detail makes ARVISCOPE a powerful visualization tool that can be effectively used to enhance the current practice of verification and validation of DES models.

2 Accurate Spatial Registration

The first step in superimposing 3D computer generated graphics in the form of CAD objects on top of real world views is to precisely calculate the position and orientation of each CAD element in the augmented scene. This is often referred to as registration (Behzadan and Kamat 2005). In AR visualization, the observer plays a central role in the scene since the viewpoint is always defined with the observer's eyes located at the origin. CAD objects are placed in the animation by calculating their distance relative to this origin. At the same time, since the observer has the freedom to move inside the visualized environment, the origin constantly changes position. As a result, the process of position calculation has to be done in real time and for each CAD object to take into account all changes in the observer's location.

In this research, Global Positioning System (GPS) data are used to obtain the observer's position in the 3D augmented space. GPS data represent the observer's position in form of three absolute values: longitude, latitude, and altitude (Behzadan et al 2008). In order to calculate the distance between the observer's eyes and each CAD object, the same set of data has to be obtained for CAD objects. This data can be stored and retrieved from a text file (referred to as an animation trace file) which is read though and interpreted by the AR application. Having obtained the global position of the observer and that of each CAD object, a geo-referenced positioning method called MTM (acronym for Modified Transformation Method), adopted from Vincenty (1975), is used in this research to calculate the relative distance between each CAD object and the observer of the augmented scene. Using MTM, the relative distance between two points with known global coordinates (i.e. longitude, latitude, and altitude) is calculated along the three major axes (i.e. X, Y, and Z) (Behzadan 2008). Figure 2 shows the input and output variables of the original Vincenty algorithm and MTM.

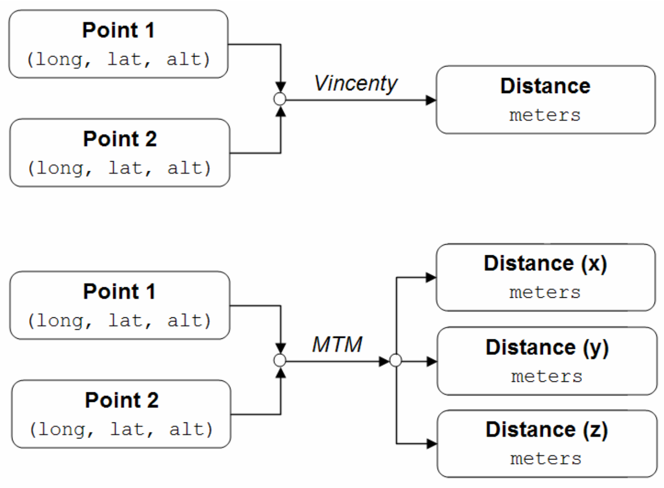


Figure 2: Comparison between Vincenty Method and MTM

Figure 3 shows a virtual dozer placed fixed in front of an observer while the observer is changing his global position in the augmented scene.

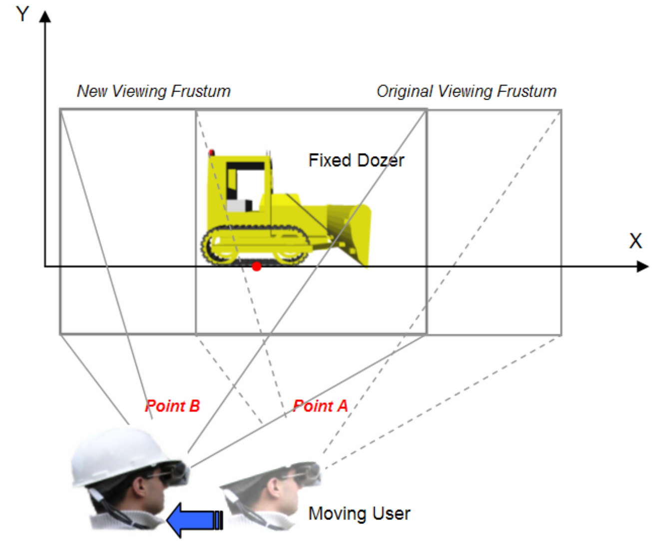


Figure 3: Virtual Dozer Stays Fixed While the Observer Changes Global Position in the Augmented Scene

Another important factor in placing CAD objects relative to the observer is the observer's direction of look or what is commonly referred to as 3D head orientation. Head orientation is extremely important in identifying the contents of the augmented scene visible to the observer since even though the observer's global position is constant, a minor change in head orientation about the three major axes can cause a change in the position and orientation of all the CAD objects present in the augmented scene. 3D head orientation is usually represented by three distinct angles: pitch (about X axis), yaw (about Y axis), and roll (about Z axis). Without tracking the observer's head orientation and placing the CAD objects only by taking into account their relative distance to the viewpoint, the entire graphical contents of the augmented scene constantly revolve around the observer's head. Figure 4(a) shows a virtual truck initially placed in front of the observer's eyes by providing its distance relative to the viewpoint.

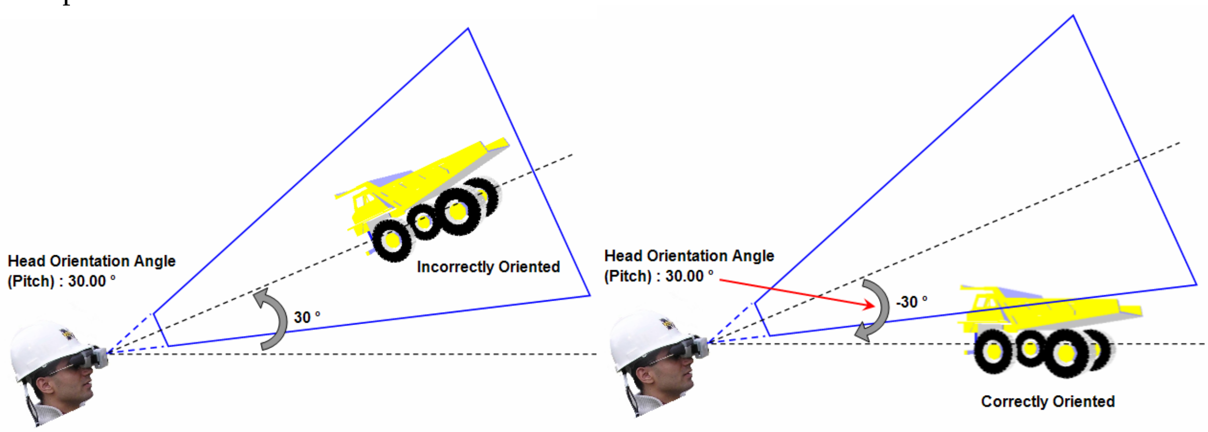


Figure 4: Effect of the Observer's Head Motion on the Graphical Contents of the Augmented Scene

As shown in this Figure, when the observer of the scene rotates his head about X axis, the CAD model also undergoes the same rotation. This is essentially because without tracking the three head orientation angles, the AR application always places CAD models at a certain distance in front of the viewpoint. An intuitive approach to resolve this issue is to include the observer's head orientation angles in the spatial computations. In this research, a magnetic head tracker is used to track the observer's head rotations (Behzadan et al 2008). The orientation data obtained this way is used to adjust the orientation of each individual CAD object inside the augmented scene. For the virtual truck shown in Figure 4, a negative rotation about the X axis equal to the observer's head rotation will correct the described issue. This is shown in Figure 4(b). Figure 5 shows the observer's profile equipped with the tracking devices. As shown in this Figure, The animation is shown to the observer through a Head Mounted Display (HMD) installed in front of the observer's eyes. A video camera is also attached in front of the hard hat. A 3D magnetic head orientation tracking device (hidden in this Figure) is installed inside the hard hat.

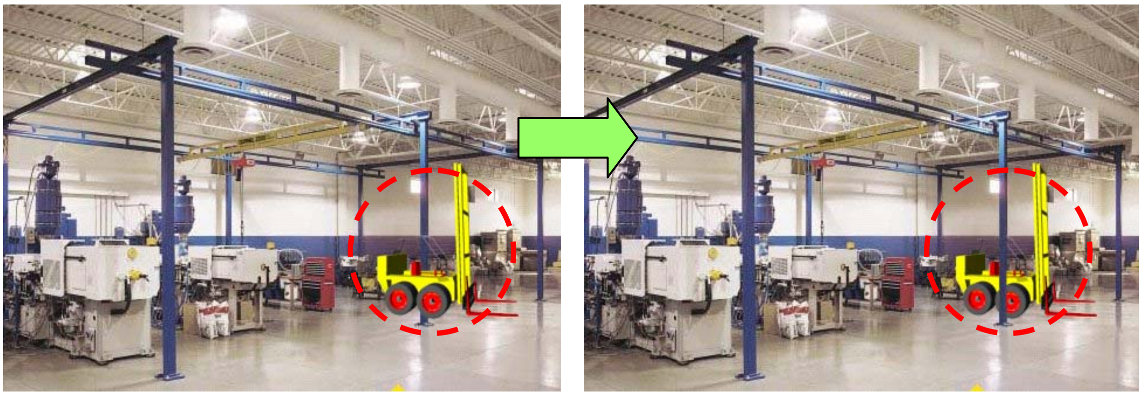
Figure 5: Observer Equipped with Position and Orientation Tracking Devices

The observer can walk freely in the AR animation with minimum physical constraints. The heart of the system is a laptop computer which is installed and secured inside a backpack. Other devices included in the backpack are a GPS receiver unit (to obtain the observer's global position), and an external battery pack. A miniature keyboard and a touch pad are also connected to the laptop and carried by the observer to provide full interaction capability during the course of the animation when there is no physical access to the laptop computer (Behzadan et al 2008).

3 Automated Occlusion Handling

In AR, the animation has to be capable of handling two distinct groups of objects: virtual and real. This is very essential in AR as the observer of the animation expects to see a mixed scene of seamlessly merged real and virtual objects in which both groups of objects operate and interact in a realistic manner. This introduces a number of challenges unique to creating AR animations. One of these challenges is incorrect visual occlusion. Incorrect occlusion occurs when a real object blocks the observer's view of a virtual object (Behzadan 2008). In a dynamic AR environment, incorrect occlusion can occur very frequently and unexpectedly because the real and virtual objects can move freely with no constraints.

Figure 6 shows a snapshot of an AR animation of a manufacturing plant in which a virtual CAD model of a forklift is superimposed on the real scenes of the manufacturing facility. In this Figure, the CAD model is farther away from the viewpoint than the column of the bridge crane and hence has to be partially blocked in the AR animation. However, the observer of the scene sees the snapshot in 6(a) as opposed to the visually correct view shown in 6(b) since incorrect occlusion can not be automatically handled unless appropriate methods are designed and integrated into the AR application. The fact that in all traditional AR applications, the real world is captured and displayed in the background while all virtual CAD objects are displayed on the foreground causes the final animation to be unable to show the correct occlusion effect since the two groups of objects are completely separate. As a result, automated real time occlusion handling becomes a critical step in creating AR visualizations. The authors have successfully designed a depth-based approach to address the problem of incorrect visual occlusion (Behzadan 2008).



(a) (b)

Figure 6: Example of Occlusion in an AR Scene

Following this approach and as shown in Figure 7, after the depth values for all real and virtual objects are obtained, a comparison is made at the pixel level to decide which object is closer to the observer's eyes and hence has to be painted last. Using this approach, for a specific pixel on the screen, if the value of the real world depth is less than that of the virtual world, a real object occludes a virtual object. Further steps are then taken in order to update the color scheme of that pixel so it is not painted in the color of the virtual object. The depth acquisition and color manipulation process depicted in Figure 7 has to be executed continuously by capturing the latest depth values for all the pixels on the screen. Depth values of the real world can change if the viewpoint is moved (i.e. observer changes position and/or head orientation) or there is a change in the contents of the real scene. Depth values of the virtual world can also change if CAD objects move in the scene. By comparing these two sets of values, the depth effect can be included in the augmented world to handle incorrect occlusion cases. In this research, depth sensing devices (e.g. flash LADAR cameras) are proposed to obtain the depth values of real objects. Depth values of virtual objects are obtained using the z-buffer content of the ARVISCOPE's graphical engine.

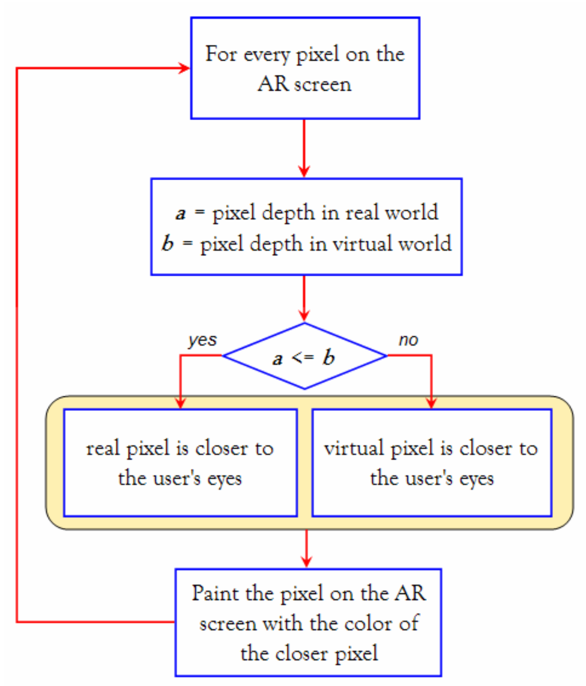


Figure 7: Designed Occlusion Handling Algorithm in ARVISCOPE

4 Validation of Results

Several experiments were conducted to validate the ability of the developed AR platform in creating smooth animations of modeled engineering processes. Figure 8 shows an experiment in which an earthmoving operation was animated in AR. In another set of experiments, the designed automated occlusion handling method was validated. Figure 9 shows an experiment in which a virtual concrete truck is partially occluded by a real brick wall.

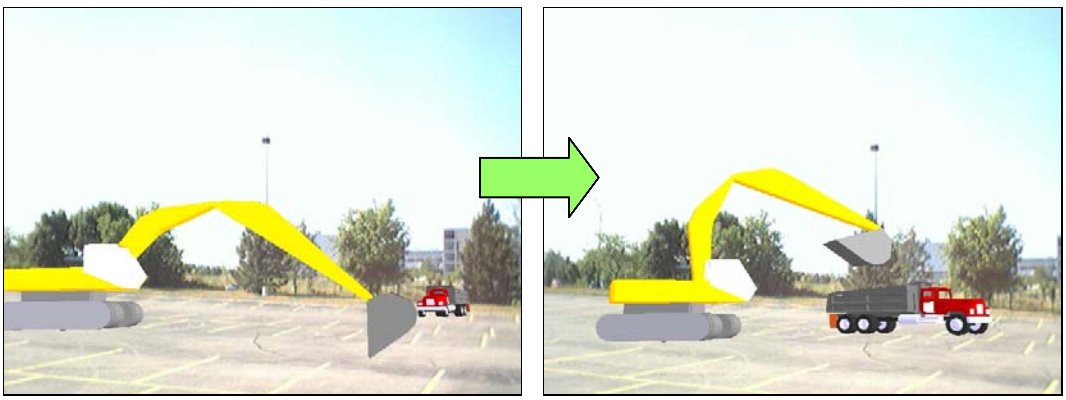


Figure 8: AR Animation of an Earthmoving Operation in ARVISCOPE

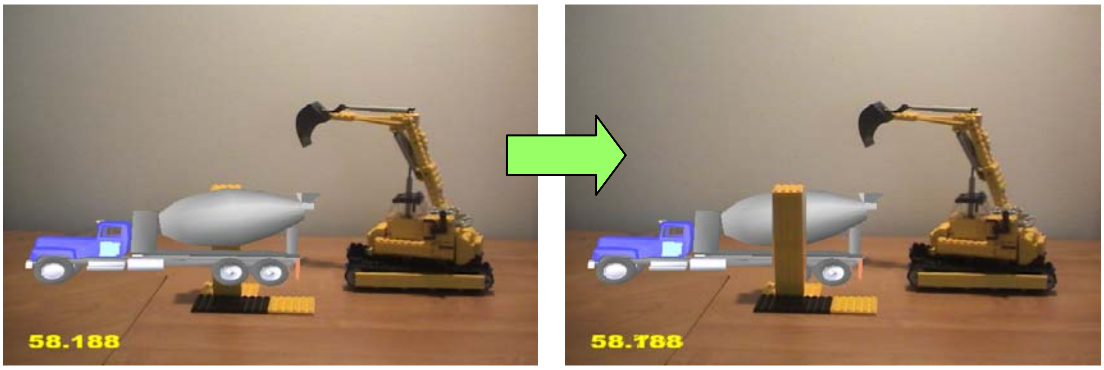


Figure 9: Automated Occlusion Handling in ARVISCOPE

4 Conclusions and Future Work

This paper presents the design and implementation of ARVISCOPE, a mobile visualization platform capable of creating and displaying smooth continuous animations of modeled engineering processes in outdoor AR. In order to fulfill the design requirements, a number of challenging issues have been successfully addressed in this research. These issues include but are not limited to: 1) establishing and maintaining a spatial and logical link between the objects of the virtual world and the scenes of the real environment (i.e. registration); 2) creating CAD object hierarchies that enables fast and dynamically handling and manipulating the graphical contents of the animation; 3) communicating continuously with the process model to extract all required elements describing the scene; 4) obtaining positional and orientation data of the mobile observer in real time to be used in constructing a precise viewing frustum and registering the CAD objects accordingly; and 5) resolving visual discrepancies such as incorrect occlusion in the final augmented scene. The ability of the designed AR visualization platform to create accurate animations and automatically resolving incorrect visual occlusion cases in real time has been validated in several experiments.

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