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COLLABORATIVE VISUALIZATION OF SIMULATED PROCESSES USING TABLETOP FIDUCIAL AUGMENTED REALITY

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ABSTRACT

In typical scenarios of construction planning, engineers communicate ideas primarily using paper based media (e.g. drawings) spread across table surfaces. Even though the traditional communication approach offers convenient interaction among participants, the media used are cumbersome to handle. Moreover, they present static information that cannot reflect the dynamic nature of a jobsite. These limitations can be somewhat overcome by computer based virtual environments. However, the convenience of interactive collaboration among participants is lost. This paper introduces tabletop fiducial Augmented Reality to bridge the gap between paper based static information and computer based graphical models. A software named ARVita is developed to validate this idea, where multiple users wearing Head-Mounted Displays and sitting across a table can observe and interact with visual simulations of planned processes. The applications of collaborative visualization using Augmented Reality are reviewed, and the technical implementation of ARVita is presented.

1 INTRODUCTION

1.1 Dynamic Simulated Construction Activity Visualization

Traditional visualization media used in construction planning include drawings, scheduling bar charts, sand table models, 3D CAD models etc. However none of them are capable of effectively conveying information on every aspect of the project, e.g. 2D/3D models do not reflect temporal progress, while scheduling bar charts do not demonstrate corresponding spatial layout. Numerous studies are conducted on linking 3D CAD models with the construction schedule, so as to exploit the dynamic 3D nature of the construction engineering at the project level. These kind of visualization techniques are well known as 4D CAD, where based off of original planned sequence, individual CAD components are added to the target facilities as time advances. At the project level, 4D CAD model proves its value in minimizing misinterpretation of the project sequence by integrating the spatial, temporal, and logical aspects of construction planning information. (Koo & Fischer, 2000)

Unlike project level visualization techniques where only major time-consuming processes are animated, operation level visualization represents explicitly the interaction between equipment, labor, materials, and space. (e.g. laying bricks, lifting columns). Operations level visualization is good at elaborating details such as the maneuverability of trucks and backhoes in excavation operations, the deployment of cranes and materials in steel erection etc. Such tasks require careful and detailed planning and validation, so as to maximize resource utilization as well as identifying hidden spatial collision and temporal conflicts. Therefore operations visualization can help engineers in validating and verifying operational concepts, checking for design interferences, and estimating overall constructability. (Kamat & Martinez, 2003)

VITASCOPE (acronym for VIsualizaTion of Simulated Construction OPErations) visualization system is designed for articulating operation level construction activities. (Kamat & Martinez, 2001) Firstly, it defines a comprehensive and extensible authoring language for depicting modeled processes along a time line. The VITASCOPE language is an abstract layer to make the visualization engine (VE) independent of any particular driving processes (e.g. a specific simulation system). Incoming operation events and data generated by simulation model, hardware control, or real-time sensor can be documented in the way of conforming to the syntax of VITASCOPE language and fed into the dynamic VE. (Kamat & Martinez, 2003) Secondly, the VE is built on top of scene graph architecture and the frame updating algorithms (Kamat & Martinez, 2002), to interpret the instruction sets and render the depicted activities sequentially in the virtual environment.

1.2 Limitation and Extension of VITASCOPE

Despite the fact that VITASCOPE is capable of visualizing simulated construction operations in smooth, continuous, and animated 3D virtual worlds, there are a few limitations inherent in the software. Several extension research projects have been made to address those issues.

Firstly from the modeling perspective, replicating the construction jobsite in the virtual environment always involves quantities of modeling work (e.g. terrain and existing facilities). Even though most of them are not involved in the simulation process, their existence is necessary to faithfully represent the jobsite context. Such 3D CAD modeling engineering demands a significant amount of effort in acquiring, creating, and maintaining the models. (Brooks, 1999) ARVISCOPE (acronym for Augmented Reality VIsualization of Simulated Construction OPErations) visualization system shares the same capability with VITASCOPE in creating dynamic, smooth and continuous construction activity animations. However it cuts off the efforts of context modeling by blending simulated graphics with real scene. (Behzadan & Kamat, 2007) The Georeferenced registration algorithm applies user's geographical position tracked by GPS, and 3D orientation tracked by electronic compass to calculate the correct pose of construction graphics in the outdoor Augmented Reality (AR) environment.

Secondly from the interaction perspective, VITASCOPE, by its nature, is a post-processing animation engine, that does not allow users to alter the course of simulation dynamically. It thus degenerates the validation confidence to one single realization of the simulation, while other possible cases are not discovered and analyzed. This constraint can somewhat be reduced if the simulation and animation can run concurrently, and users observe the subsequent changes based on their interaction with the animation. This idea motivates VITASCOPE++ to extend the scale of VITASCOPE to message-based architecture. It enables users to communicate from animation to the state of simulation that drives it, and consequently affects the remaining course of the simulation. (Rekapalli & Martinez, 2007)

Thirdly, from the collaboration perspective, the convenience of traditional paper based discussion is somewhat lost in computer-based virtual environments, where users' discussion is restricted to the scale of the screen. On the other hand, even though paper based media is difficult to handle, maintain and update, it is a natural collaboration platform allowing people to promptly exchange ideas. (Figure 1) Group discussion cultivates face-to-face conversation, where there is a dynamic and easy interchange of focus between shared workspace and the speakers' interpersonal space. The shared workspace is the common task area between collaborators, while the interpersonal space is the common communication space. The former is usually a subset of the latter one. (Billinghurst & Kato, 1999) People can use a variety of non-verbal cues to quickly shift the focus of shared workspace accordingly and thus work more efficiently.

1.3 Main Contribution

The collaboration limitation of computer-based visualization drives the motivation of this paper. The authors attempt to identify an interconnecting media that bridges the gap between computer based dynamic visualization and paper based collaboratively shared workspace.

AR is one of the promising candidates because it blends the computer generated graphics with the real scene background using real time registration algorithm. Users can work across the table face-to-face, shift the focus of shared workspace instantly, and jointly analyze dynamic construction scenarios. This idea is developed and implmeneted as a software named ARVita (acronym for Augmented Reality Vitascope) in which multiple users wearing Head Mounted Displays (HMD) can observe and interact with dynamic simulated construction activities laid on the surface of a table.

This paper first reviews the related work done in the collaborative AR domain. Then it elaborates the technical implementation of ARVita: i) The software scheme of ARVita (section 3.1); ii) The realization of software scheme in OpenSceneGraph (OSG) (section 3.2); iii) Multiple views and its limitation (section 4).

Figure 1: The traditional paper based media is ideal for collaborative work, despite of its disadvantages such as difficulty in handling, maintaining and updating.

2 RELATED WORK

The collaborative features of Augmented Reality have been discovered many years ago, and so far significant work has been done in different application domains. A brief review is provided in localized and remote collaborative AR, with its applications in industry, and especially in the construction area.

2.1 Localized Collaborative AR

Some early works in localized collaborative AR are found in (Rekimoto, 1996), (Szalavari, Schmalstieg, Fuhrmann, & Gervautz, 1997), and (Billinghurst & Kato, 1999). The TRANSVISION developed by (Rekimoto, 1996) is a pioneering work in collaborative AR, and multiple participants use palmtop hand held display to share the computer generated graphics on the table. Collaborative Web Space (Billinghurst & Kato, 1999) is an interface for people in the same location to view and interact with virtual world wide web pages floating around them in real space. Studierstube (Szalavari, Schmalstieg, Fuhrmann, & Gervautz, 1997) mainly targets at presentation and education. Each viewer wears magnetically tracked see-through HMDs, and walks around to observe 3D scientific data.

Other related works then follow this trend, and collaborative AR game and task-oriented collaboration are two attractive branches that have been explored. Art of Defense (Huynh, Raveendran, Xu, Spreen, & MacIntyre, 2009) is a typical AR board game, in which gamers use handheld devices to play social games with physical game pieces on the tabletop. (Nilsson, Johansson, & Jonsson, 2009) did comparison experiment on cross-organizational collaboration in dynamic emergency response tasks. Actors hold positive attitude towards AR, and would like to use it in real task.

Besides the traditional Head Mounted Display and Hand Held Display, a number of other AR media exist, e.g. projection table and multi-touch table. Augmented urban planning workbench (Ishii, Underkoffler, Chak, & Piper, 2002) is a multi-layered luminous table for a hybrid presentations like 2D drawings, 3D physical models, and digital simulation overlaid onto the table. The system was used for graduate course supporting the urban design process. Multi-Touch Mixed Reality ((Wei, Zhou, & Xie, 2010) allows designers to interact with multi-touch tabletop interface with 2D models, while 3D models are projected to their 2D counterparts.

2.2 Remote Collaborative AR

Avatar is a necessity in remote collaborative AR system. WearCom (Billinghurst & Kato, 1999) enables a user to see remote collaborators as virtual avatars in multi-party conferencing. (Minatani, Kitahara, Kameda, & Ohta, 2007) develop a remote face-to-face AR system, then recreates each participant's facial appearance in real time, and represents user's upper body and hands above the table as a deformed-billboard. (Stafford, Piekarski, & Thomas, 2006) invents an interactive metaphor termed "god-like" for improving communications of situational and navigational information between outdoor and indoor AR users. The gestures of indoor users will be captured by video-based tracking and shown as "god-like" style guidance to the outdoor users.

2.3 Industrial Collaborative AR

Industrial collaborative AR is mainly used in product design and factory planning. MagicMeeting (Regenbrecht, Wagner, & Baratoff, 2006) is used in concrete test cases where experts from the automotive industry meet to discuss the design of car parts and aggregates through a tangible AR interface. Fata Morgana (Klinker, Dutoit, & Bauer, 2002) on the other hand, also demonstrates car design case but using real-life size model in BMW show room. At Siemens Corporate Research, A fully implemented system called CyliCon (Navab, 2003) enables users to move around the environment and visualize as-built reconstruction in real site and on industrial drawings. Roivis is another successful example for factory design and planning at Volkswagen Group Research (Pentenrieder, Bade, Doil, & Meier, 2007). This project puts strict demands on system accuracy, e.g. interfering edge analysis, aggregation verification, etc.

AR has also been widely studied in construction area like construction operation visualization, computer-aided operation, project schedule supervision, components inspection, etc. However there are few examples in collaborative AR domain. (Wang & Dunston, 2008) develop AR face-to-face design review prototype and conduct the test cases for collaboratively performing an error detection task. (Hammad, Wang, & Mudur, 2009) apply distributed AR for visualizing collaborative construction tasks, e.g. crane operation, to check spatial and engineering constraints in outdoor jobsite. However, none of these works allow users to validate simulated processes by collaboratively observing dynamic operations animations. In the remaining paper, we will describe technical implementation of ARVita, and demonstrate its capability for supporting collaborative visualization of dynamic construction operations.

3 TECHNICAL IMPLEMENTATION OF ARVITA

3.1 Model-View-Controller Software Architecture of ARVita

The software architecture of ARVita conforms to the classical Model-View-Controller (MVC) pattern. (Figure 2) Model class is responsible for initializing, archiving, and updating VITASCOPE scene node. VITASCOPE visualization engine has exposed a list of APIs (Application Programming Interface) granting developers full control of the animation process. (e.g. open and close files, start and pause animation, etc.) Controller class communicates users' interaction commands to VITASCPE API wrapped inside Model. FLTK (acronym for Fast Light Toolkit) is used for user interface as well as translating and dispatching mouse/key messages to itself and OSG. The continuously updated VITASCOPE scene node is displayed by the subscribed View Class, where tracking and rendering procedures take place. Firstly, camera projection matrix is set based on the calibration result, to make sure the OpenGL virtual camera and real camera share consistent view sight; Secondly, the ModelView matrix is updated every frame based on the fiducial marker tracking results so that CAD models are aligned with the marker in correct pose. The arrow in the Figure 2 diagram indicates 'belong to' relationship.

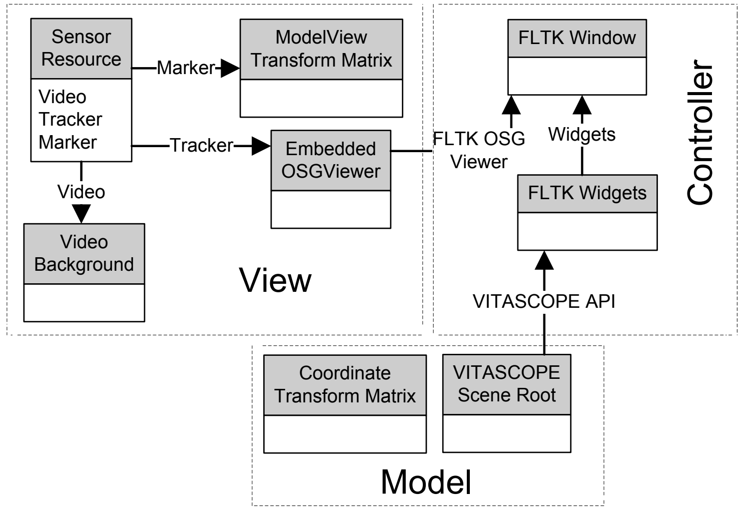

Figure 2: Software architecture of ARVita conforms to Model-View-Controller pattern.

3.2 Implementation of Model-View-Controller Using OpenSceneGraph

OSG is chosen for implementing the MVC pattern described above. OSG uses acyclic directional graph to express the scene holding geometry, state, and transformation nodes. Its update and event callbacks mechanism makes it convenient to update the simulated construction operations. (Figure 3)

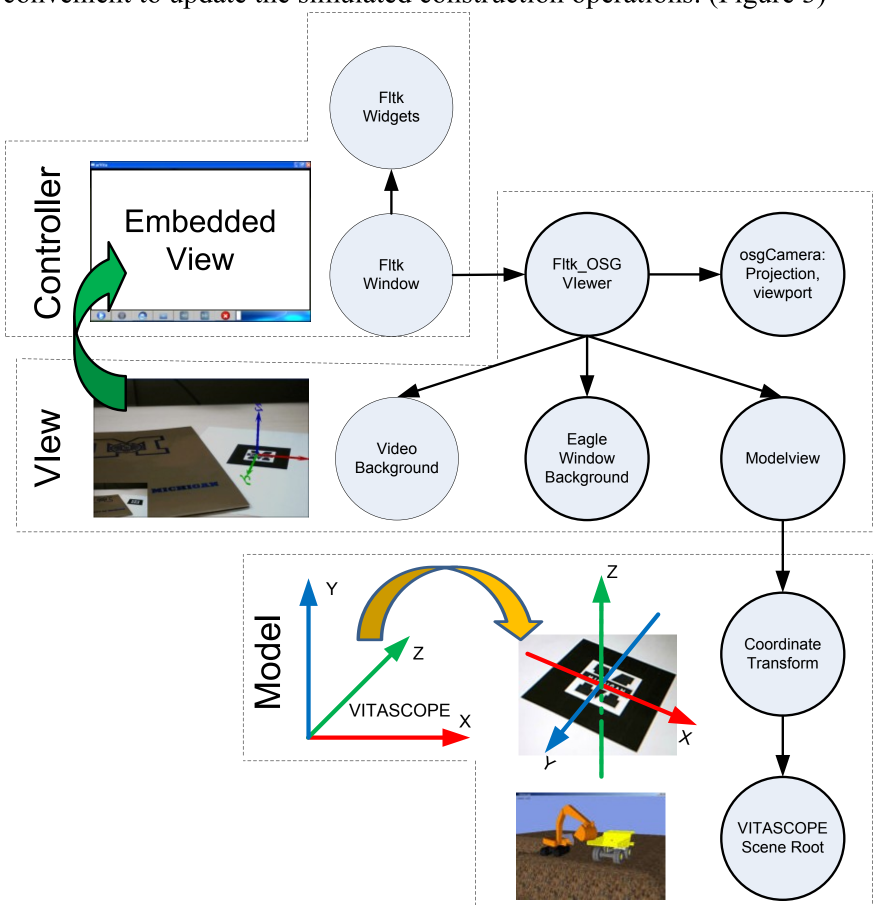

Figure 3. The realization of Model-View-Controller model with OpenSceneGraph

3.2.1 Model

VITASCOPE scene node resides at the bottom of the graph. vitaProcessTraceFile() function is called every frame to update the animation. Above the scene node is a coordinate transformation node. Since ARToolkit adopts Z axis up coordinate system, this transformation converts VITASCOPE's left hand and Y axis up to left hand and Z axis up, so that the jobsite model is laid horizontally above the marker.

3.2.2 View

The FLTK_OSGViewer inherits from both FLTK window and osgViewer, and thus plays as the glue between the two platforms. Under the hood are the ModelView transformation node and video display nodes.

ARToolkit is used as the underlying fiducial marker tracking technique in this research. Furthermore, osgART (OSG ARToolkit) has developed the Tracker and Marker updating mechanism to bundle ARToolkit and OSG together. Both Tracker and Marker are attached as event callbacks to the scene graph. (Figure 4) Tracker reads updated video resource and stores the detected physical marker descriptor in Marker. Consequently Marker calculates the camera's pose in the world coordinate system based on the descriptor, and updates the ModelView transformation node. ARVita chooses to comply with this Tracker and Marker mechanism because it is an abstract layer to separate the tracking and rendering logic. For example, the authors have been working on natural marker tracking techniques, which will be used as tracking logic for ARVita in the near future. With Tracker and Marker, this change can be easily hidden from the remaining rendering logic to minimize the impact to the entire structure.

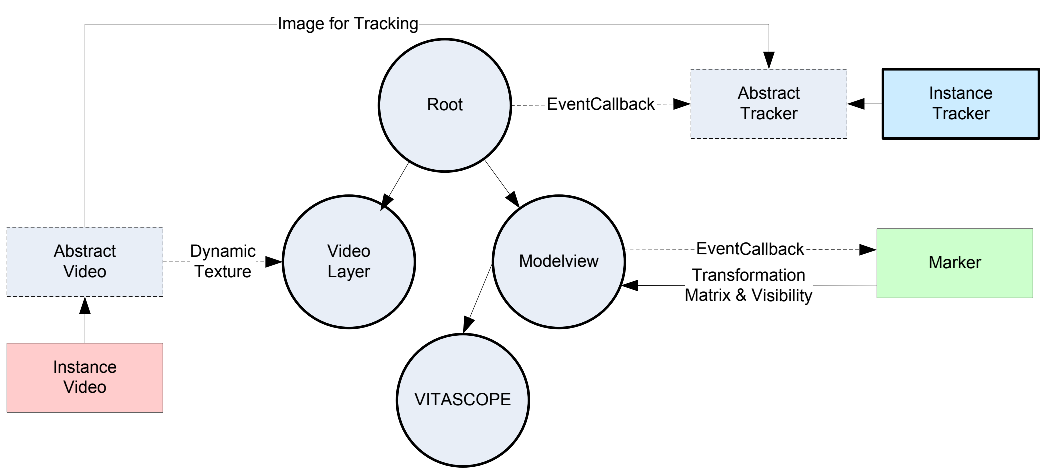

Figure 4: osgART's Tracker and Marker updating mechanism.

The video resource is pasted as dynamic texture on the background. Despite the stability of ARToolkit, it has known limitation of requiring the whole marker being captured by the video. Otherwise the CAD models immediately disappear as soon as a tiny corner of the marker is lost. This limitation is much more apparent when the animated jobsite covers the majority of the screen, which makes it very difficult to cover the marker within the camera range. The authors are working on natural marker based techniques to overcome these flaws, however currently an eagle window is shown to somewhat mitigate the flaws. The eagle window can be toggled on and off by the user. For example, when the user moves the camera to look for a vantage point, the eagle window can be toggled on so that the user is aware of visibility of the marker. When the camera is set static, and the user is paying attention to the animation, the eagle window can be toggled off so that it won't affect the observation.

3.2.3 Controller

The motivation for ARVita is to allow multiple users to observe the animation from different perspectives, and promptly shift the focus of shared working space in a natural approach. These natural interactions include rotating marker to find vantage points; and pointing at part of model to attract others' attention. (Figure 5) Given that the scale of the model may prevent users to get close to interesting regions, ARVita provides users with basic zooming and panning functionalities.

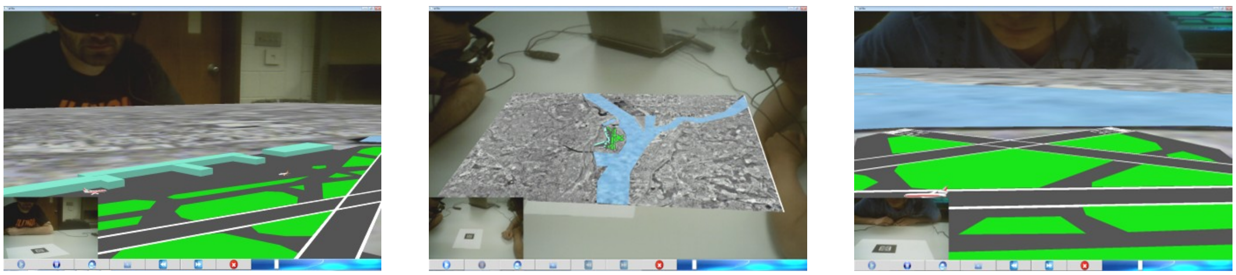

Figure 5: Two users are observing the animation laying on the table.

The focus of shared working space can not only be switched spatially, but also temporally because of the underlying dynamic models. Users can choose to observe the animation at variable-speed, or jump instantaneously along the time line. (Figure 6) ARVita Controller wraps the existing VITASCOPE APIs like vitaExecuteViewRatioChange, and vitaExecuteTimeJump in a user-friendly interface as most media players do, using fast-forward, progress bar etc.

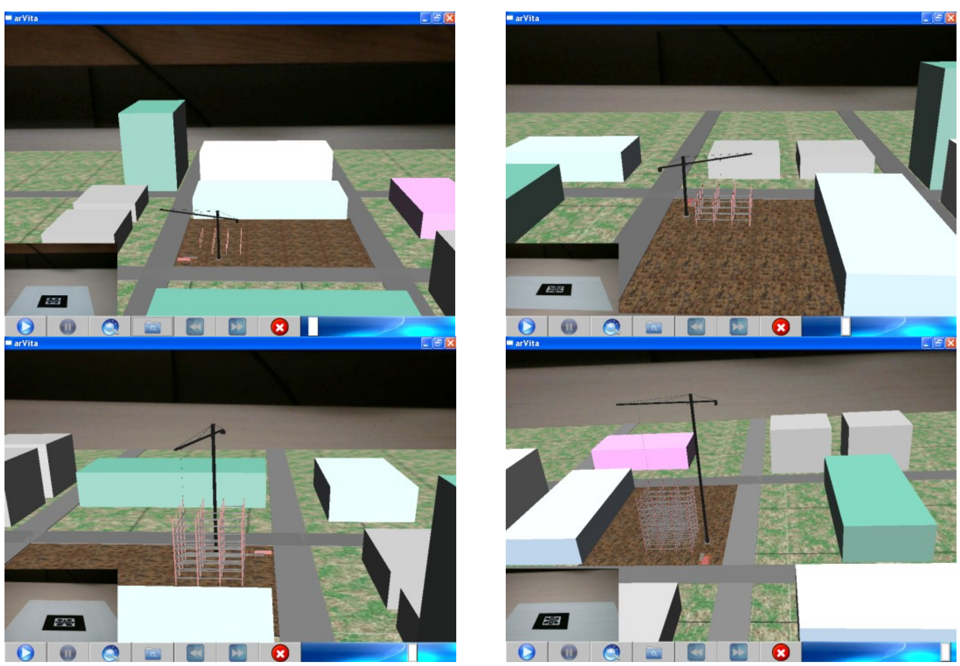

Figure 6: Steel erection activity at different time stamp.

4 MULTIPLE VIEW OF ARVITA

4.1 Technical Implementation of Multiple View

OSGCompositeViewer is the key to upgrade single view ARVita to multiple views version. Composite Viewers is a container of multiple views and keeps them synchronized and threaded correctly. Each view plays the same role as FLTK_OSGViewer does in Figure 3, and maintains its own video, tracker, marker resources, and ModelView matrix independently. However these views share only one single VITASCOPE scene node (Figure 7) for two reasons: 1) synchronizing the animation across different views. 2) saving memory space by only maintaining one copy of scene node.

The number of instance views depends on how many video capture devices are available. Based on their device ID, ARVita presents the users with a list of available web cameras as program starts, and let the users choose the number of views and corresponding webcams. When one user interacts with the model like rotating marker, zooming, or dragging progress bar, all these spatial or temporal updates will be reflected on all the other users' augmented space, so that a consistent dynamic models are shared across all users.

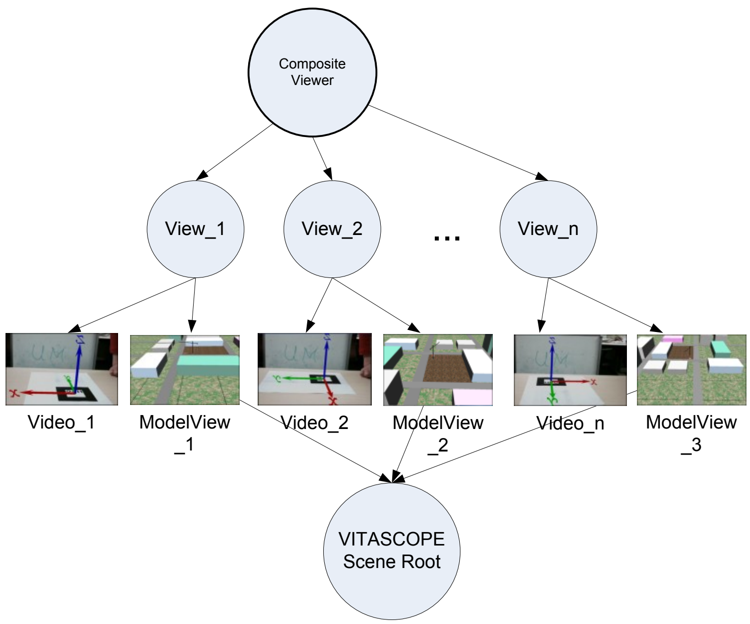

Figure 7: The collection of views possess their own video, track, and marker objects, but point to the same VITASCOPE scene node.

4.2 Limitations of Multiple View on Single Computer

The current version of ARVita supports running multiple views on a single computer, indirectly limiting the maximum number of participants. As more "viewers" join, the computer will be overloaded quickly by maintaining too many video resources and tracking procedures. The authors are currently pursuing an alternate distributed computing approach to overcome this limitation. As a generic architecture for distributed computer simulation systems., HLA (High Level Architecture) can not only integrate heterogeneous simulation software, and data sources, but also communicate between computers, even platforms. It thus presents itself as a promising solution for a distributed ARVita. However it is still useful to have multiple views on one computer. For example, in multi-view ARVita, one can observe the animation from different aspects simultaneously, and thus acquire a broader comprehension of the whole simulated processes.

5 CONCLUSION AND FUTURE WORK

In this paper, we present a software termed ARVita for collaboratively visualizing dynamic 3D simulated construction operations. Users sitting across a table can have a face-to-face discussion about 3D animations "laid on" the table surface. Interaction functionalities are designed to assist users in transiting smoothly between focus of shared workspace. VITASCOPE API and ARToolkit are used for the underlying animation engine and tracking techniques respectively, and OSG is used for incarnating the designed software structure. ARVita and its source code are both available for download from the authors' website at http://pathfinder.engin.umich.edu/software.htm

Currently, the authors have been working on two thrusts of improvement. The first one is to replace fiducial marker based tracking with natural marker based tracking, so that user won't suffer from loss of virtual models even though only part of the marker is visible. Secondly, efforts are being put on making ARVita comply with rules of HLA, so that it can be distributed and synchronized across computers.

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