

VISUALIZATION FOR AN AUGMENTED REALITY CONSTRUCTION MACHINERY SIMULATOR

Alvaro Segura
VICOMTech
Mikeletegi 57
E-20009 San Sebastin, Spain
email: asegura@vicomtech.es

Gino Brunetti
Fraunhofer IGD
Fraunhoferstrae 5
D-64283 Darmstadt, Germany
email: gino.brunetti@igd.fraunhofer.de

Aitor Moreno
VICOMTech
Mikeletegi 57
E-20009 San Sebastin, Spain
email: amoreno@vicomtech.es

Thomas Henn
Fraunhofer IGD
Fraunhoferstrae 5
D-64283 Darmstadt, Germany
email: thomas.henn@igd.fraunhofer.de

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ABSTRACT

This work presents a versatile real-time simulator for training workers in the operation of construction machinery. With the aim of reducing the accident rate in the construction sector, a realistic AR scene improves the user experience.

Our work addresses two stages of the training process. First, the instructor designs the working environment and the exercises with a specifically developed Scene Editor tool. Then, these exercises are run by the simulator. The simulation setup consists of a real cabin placed on a motion platform in order to provide a realistic interaction with the system and a stereoscopic augmented reality system for visualization. Visualization has been implemented as a chroma-key-based mixed reality system.

This paper describes the development of the Visualization subsystem of this simulator.

INTRODUCTION

The work described in this paper was carried out as part of project VAR-Trainer (Barrera et al. 2006). The general objective of VAR-Trainer is to develop a versatile real-time simulator, based on the integration of mechanics, electronics, automated technologies, and mixed reality (virtual augmented reality) in order to train workers in the operation of construction machinery. Special attention is paid to safety aspects with the aim of reducing the accident rate in the construction sector.

Although the use of machine simulators for training purposes is expanding nowadays, no commercial simulator exists for



Figure 1: The excavator cabin on the motion platform

training workers in the use of construction machinery. Likewise, there is no European certified training in matters of safety when using this machinery. Most of the available simulators are specifically oriented towards a single machine or process type and are not open platforms that could be reconfigurable to cover different machine types, different levels of realism or different pedagogical aspects. Besides, machine training simulators usually aim to cover training in all the machine's functionalities and are not focused on specific training points, such as safety issues, for instance.

The system is *versatile* in two aspects: the same simulator core has to adapt to different machine types (from wheeled excavators or dumpers to mast climb platforms), and the same simulator core has to run on an average desktop PC, and on a complete integrated platform that includes a real vehicle cabin with its real control devices, a motion platform and an immersive AR visualization helmet. Four machine types have been included in the simulator: a wheeled excavator, a dumper, a mast climb platform, and a work goods

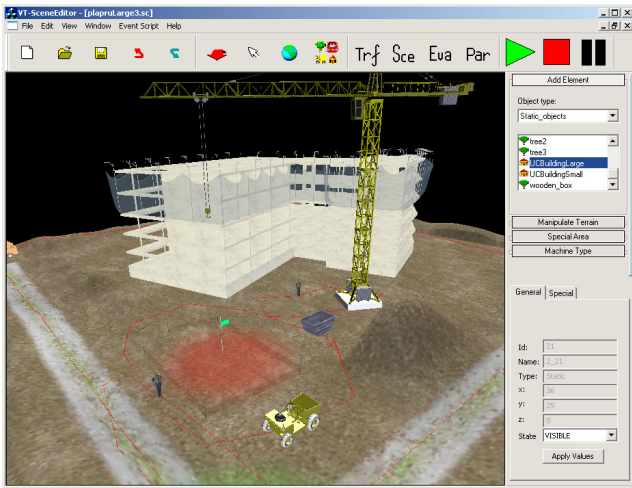


Figure 2: The Scene Editor main screen with the control panel on the right, tool bar on top, and 3D virtual view on the left

lift.

Most other comparable simulators are focused on one specific machine type and model, and often use large projection screens to display the environment. Our design is innovative in several aspects including its versatility and the special use of augmented reality, as will be explained, to provide immersion into the virtual world while interacting with true cabin controls.

As part of the versatility of the developed system, the instructor can design the virtual environments where the training exercises take place. A specific *Scene Editor* tool was created for this purpose, which is described in its own section.

The simulator has a modular architecture whose main parts are the *Exercise Manager*, the *Dynamics Module* and the *Visualization Module*. The Exercise Manager controls and evaluates the tasks that the user has to perform and the behavior of the external elements such as other vehicles. The Dynamics Module (Pujana et al. 2006) is responsible for simulating the dynamics of the machine by mathematically modelling its motors, hydraulics, joints and actuators. This paper discusses the design and development of the Visualization Module.

THE SCENE EDITOR

The Scene Editor is a graphical interactive tool that allows instructors to design the environment for the simulated exercises. It is not a generic 3D modelling application, but a system that knows the specific elements that are relevant to the simulation.

The first step in designing a scene consists of defining the shape of the terrain. When starting a new scene the editor

presents the user a flat square area that he can interactively deform, adding slopes, hills, etc.

Then the designer would add objects, buildings, vehicles and workers to the scene. Mobile elements such as vehicles and people are assigned a path that they will move along during the simulation. A screenshot of the Scene Editor is shown in figure 2.

Some object types are configurable: when the user adds a building, the system will ask for the kind of building and its number of floors. The editor generates the appropriate geometry.

The user can also define special areas in the environment with specific meanings. Examples of such areas are start or parking zones, waypoints and excavation areas. Only specially designated areas can be excavated by the driven excavator.

Finally, the instructor uses separate module, the *Exercise Editor*, to create an exercise defining the behaviour of the elements in the scene and their reactions to driver actions. A scripting system specifies what will happen when the driven machine approaches another vehicle, or what task the trainee will have to perform after driving into an excavation zone.

VISUALIZATION MODULE

The visualization module is responsible for different tasks:

- Realize a mixed reality visualization environment by rendering the virtual environment and the visible parts of the driven machine.
- Report to the dynamics simulation module detected collisions of the driven machine with the virtual environment, e.g. with static objects like buildings, but also with moving objects like other vehicles or virtual workers.
- Report the penetration of wheels in the ground to drive the ground wheel interaction.
- Manage all animated and simulated objects (workers, vehicles, etc.) in the virtual construction site.
- Display a realistic impression of materials, e.g. soil, and different weather conditions.
- Visualize augmented system and instructor messages.

Rendering of the virtual scene is implemented with the OpenSG graphics library. In order to simulate the physics of some objects and detect collisions and interactions with the driven machine the *Open Dynamics Engine* (ODE 2007) was integrated into the visualization module. This interaction events are sent as input to the Dynamics Module for it



Figure 3: The view captured by the HMD cameras (left) and the view as seen by the user (right): the virtual background, the real interior and the information messages layer

to react accordingly, or are reported as risks to the Exercise Manager. For every visible scene object the module creates an associated scene graph node containing its visual representation and an associated collision geometry.

Visualization Hardware Setup

As we said there are two types of hardware setups where our versatile simulator must work: a common desktop PC, and our especially equipped integrated platform.

Visualization for the PC target consists of a virtual reality 3D view based on the *OpenSG* (OpenSG 2007) rendering library. All elements in the view, including the interior of the machine's cabin, are virtual representations.

The integrated platform, on the other hand, implements a novel Augmented Reality approach based on the chroma-key technique. The platform integrates a high-end PC with a professional Nvidia Quadro graphics card, and a specifically designed AR-oriented head-mounted display.

The adopted mixed reality setup for visualization is motivated by the different layers of information that should be visible to the trainee, maintaining low hardware costs. The layers are (in back to front order):

1. the virtual construction site scenario and the virtual part of the vehicle being the virtual background of the scene
2. the real parts of the cabin in front of the virtual scene, i.e. the real foreground
3. the augmented messages on top (in front) of the real foreground to display messages or to provide hints.

This AR approach is quite novel because classical AR has a real background with superimposed virtual elements (Seibert and Dhne 2006). Our system reverses the real and virtual layers and adds an additional layer for information messages for the user. Figure 3 shows what the user of the simulator sees while driving the excavator.

Because of the costs, driving simulators typically are equipped either with monoscopic non-immersive visualization systems, or with a head mounted display (HMD), the latter reducing the visual quality because of the typically low resolution and limited field of view. For VAR-Trainer, however, the decision had to be in favor of a low-cost fully stereoscopic immersive setup, as it is mandatory to provide a full panoramic view outside the cabin and because of the importance of depth when accomplishing a given training task.

The used HMD partially overcomes or improves some of the limitations stated above. It is the *eMagin Z800 3D Visor* that contains two high-contrast SVGA 3D OLED micro-displays delivering a bright, crisp image, and weighs less than 230 g. The HMD has a diagonal field of view of approximately 40 degrees.

To cope with the situation that the virtual background has to be overlaid with the real foreground, the *chroma-key* technique has been adopted. Chroma-key is a filmmaking technique of shooting foreground action against an evenly-lit monochromatic (often blue) background for the purpose of removing the background from the scene and replacing it with a different image or scene. The term also refers to the visual effect resulting from this technique.

Applied to VAR-Trainer, the chroma-key video technique is combined with the *AR Video See-Through* technique, where real images are captured into a computer through two cameras mounted on the HMD, one for each eye. The captured real images are mixed with computer-generated virtual images, and the mixed images are shown to the user in the HMD. In order to generate the correct view, the computer needs to know the current position and orientation of the user's head. We finally used an optical pose tracking system based on a ceiling mounted camera (Santos et al. 2006a) (Santos et al. 2006b) for this purpose. Initial trials with a commercial magnetic tracker were very problematic inside the metallic cabin (Nixon et al. 1998). Figure 4 shows our prototype Augmented Reality HMD visor.

The chroma key effect in our setup is realized by coating the windows of the cabin with a translucent blue foil (as seen in figure 1). The real interior of the cabin (and the trainee him/herself) are then extracted from the video images captured by the two cameras mounted on the HMD, whereas the blue portions are substituted by the virtual background environment.

For non-driven machines such as mast climb platforms we had a completely blue cubic box. Here the trainee stands inside and feels surrounded by the virtual environment by means of the same AR-HMD.



Figure 4: The prototype AR-HMD developed with its front-mounted cameras and a square fiducial marker needed for tracking

Weather Conditions

It was an important requirement to represent environmental conditions as accurately as possible, in order to train workers in reduced visibility situations, for example. We thus developed special algorithms to render the virtual world in different configurable weather conditions. The simulator can work in varying rain intensities, with different fog densities, clouds, wind and time of day.

Since the system must work on average PCs and on our high-end integrated platform, we developed separate techniques for each. For the integrated platform, where we can control the installed hardware, we developed programmable GPU shaders to render rain (including drops hitting the windshield), clouds and sky light. Shaders were implemented in the GLSL language as described in (Kalantary et al. 2006) and (Engel 2005). Figure 5 shows a rendering of the sky in special conditions. But since many average PCs may not support these advanced graphics features simpler methods were also implemented as a fallback solution based on more traditional OpenGL rendering methods.

Excavation

In our project, the most often demanded construction machine for training simulation is the retroexcavator, and its main task is obviously to excavate. We developed a graphical simulation algorithm to allow the machine dig on our virtual terrain.

The algorithm is inspired on the 2.5D material removal methods used in machining simulators. The diggable zone is sub-

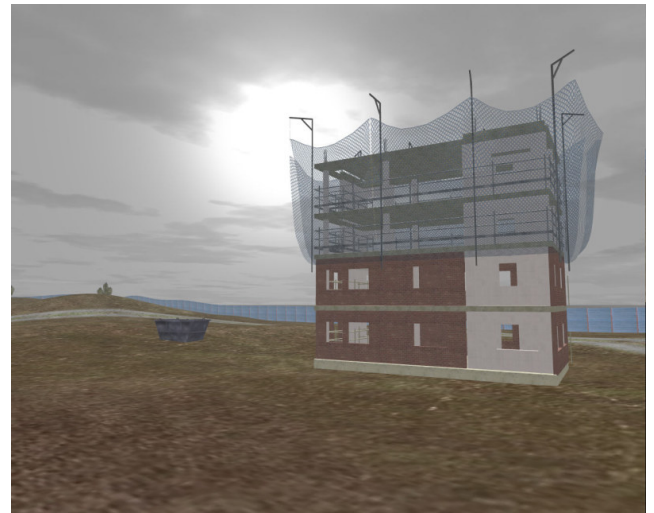


Figure 5: Scattered sky light simulation rendered with GLSL shaders

divided into a fine regular grid of height samples. When the excavator's bucket intersects the ground surface, the corresponding height values in the matrix are reduced down to the intersection points. Additionally the system estimates the amount of removed material and visually fills the bucket accordingly. The volume of material in the bucket is passed to the dynamics module that takes its weight into account when simulating the whole machine behaviour.

Dropping the soil excavated is also simulated. This is accomplished through a particle system emitted by the bucket and controlled by gravity, providing a convincing effect. In the area where particles reach the ground the soil is accumulated forming a visible heap. Particles falling on the excavation area affect the heights matrix by adding a small value specially calculated to give the appearance of a growing heap.

In the integrated platform rendering the soil on the excavation areas also uses specially written GLSL shaders to improve realism. The shader implements a bump and displacement mapping technique. Moreover, it takes depth into account when rendering each pixel producing a color gradient looking like strata in the digged holes.

Avatars

Another important element for training in safety aspects is of course human characters, i.e. workers moving around. Their behaviour is defined in the paths and scripts created with the Scene Editor. We developed a simple animation algorithm that allows these avatars to walk. The movement characteristic itself was recorded with a motion capture system and applied to the 3D characters. Figure 6 shows a couple of these avatars in the work environment.

Avatars can walk on the free-form terrain and in the floors of



Figure 6: Animated workers and loadable objects as part of the environment.

under- construction buildings.

Loads

Some of the simulated machines can transport goods and loads, such as the dumper or the mast climb platform. The whole system is aware of this and there are special objects representing loads. The loads can be placed in the environment with the Scene Editor and participate in the exercise tasks. For example, an exercise may require the dumper to pick and drop a certain load in a specific place. The editor can define loading and unloading areas in the environment where this process is allowed.

We implemented methods to load and unload the driven machine at the request of the user. An animation shows the user the loading or unloading process. Figure 6 shows a few loads on the ground ready to be picked up.

CONCLUSIONS

We have presented here the work carried out to provide a suitable visualization subsystem to a versatile construction machinery simulator. Our developments in this subsystem include graphical simulations such as simple excavation and realistic representation of weather conditions.

Professionals from the construction sector have examined and tested the simulator. The system was presented to associations participating in the project specification (some focused on risk prevention), and recently in the German BAUMA 2007 Construction Fair. The impressions were positive and a good potential for training was seen by professional visitors.

This work proves the feasibility of implementing versatile

simulation cores which can be adapted to different machines and run different hardware platforms. Four machines have been integrated into this platform but more could be simulated on the same simulation and visualization core.

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