Interactive Discrete-Event Simulation of Construction Processes in Dynamic Immersive 3D Virtual Worlds

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ABSTRACT

In discrete-event simulation analyses of construction processes, the ability to interact with a running simulation model and proactively influence/control the model's behavior and/or outcome in real-time have the potential to add significant value to the analyses as far as operations design, learning, and training are concerned. This paper describes the authors' vision of a Virtual Reality based scheme that will enable proactive participation in a running discrete-event simulation. This scheme, termed Virtual Interactive Discrete-Event Simulation, will allow human participants to interactively control the actions of one or more simulation entities (i.e. resources) in a running model via a Virtual Reality interface. A description of the proposed scheme is outlined. In addition, the challenges likely to be encountered in the work, the potential benefits, and the expected advancements to the state-of-the-art are identified.

KEYWORDS

3D Visualization, Animation, Construction Operations, Discrete-Event Simulation, Equipment Simulators, Virtual Reality.

INTRODUCTION

Dynamic 3D visualization of construction processes modeled using discrete-event simulation can be of significant help in the verification, validation, and accreditation of simulation analyses (Kamat and Martinez 2003). The authors' recent research in the field developed the knowledge and understanding that allows post-processed, passive visualization of simulated construction processes in 3D virtual worlds (Kamat 2003). In this visualization scheme, a running simulation model records a time-stamped animation trace of events that occur during a simulation run to a disk file. This file is then post-processed by the animation tool and the recorded simulation events are faithfully recreated in a 3D virtual world using CAD models of the pertinent simulation entities (i.e. resources).

Users can freely navigate in the resulting virtual environments, can vary the speed of the viewed animations, and can quickly and easily jump forward/backward in simulated time to specific points of interest. However, since such animations are run after the authoring simulation models have finished execution (i.e. post-processed), the nature of the achieved visualization is passive. In other words, users can only view (in 3D) the events that have already taken place in a simulation run and that have been successfully recorded in an animation trace file. There is no interactivity between users and simulation models.

The possibility of interacting with a simulation-driven virtual construction world and thus directly controlling the underlying simulation model in real-time, however, have the potential to add significant value beyond the currently-possible passive, post-processed visualization as far as operations design, learning, and operator training are concerned. In particular, the ability to interact (via Virtual Reality) with a running discrete-event simulation model can allow users to directly change and/or influence model variables in real-time and dynamically control the sequence of future simulation events and the very outcome of a simulation run.

VIRTUAL INTERACTIVE DISCRETE-EVENT SIMULATION - DEFINITION

Virtual Interactive Discrete-Event Simulation of construction processes means that human participant(s) interactively control the actions of one or more simulation entities (i.e. resources) during a simulation run. The interactive participation in a running simulation model is achieved via a Virtual Reality interface, i.e. a virtual world driven by the running simulation model defines the human participants' interface to the model. On the other hand, the participant's interactive actions inside this virtual world directly control the outcome of the simulation and the course of the future activities that will take place in that particular simulation run. In such a setup, each participant may potentially operate on a computer separate from the one running the simulation model itself.

Examples of simulation resources whose actions in a running simulation can be interactively controlled by external human participants include different pieces of equipment or indeed human workers. In the former case, a human participant takes the role of the operator for a particular, interactively-controlled piece of equipment. In the latter case, the human participant represents the simulation resource itself. In both cases, appropriate Virtual Reality gear is required to enable interactive participation in the running simulation. For instance, a human participant controlling a virtual excavator (a simulation resource) will require a setup of joysticks, control levers, handles and/or pedals to mimic the machine's controls. On the other hand, a participant representing a human worker itself will require an elaborate setup of input devices (e.g. Tracking systems, Pinch gloves, Virtual tool-belts, Keyboards) and interaction techniques (e.g. Travel, Selection, Manipulation) to accomplish the worker's tasks inside the virtual environment.

EXPECTED DESIGN AND IMPLEMENTATION CHALLENGES

The design and implementation of the technologies that will permit interactive simulation of construction processes in 3D virtual worlds presents numerous interesting challenges. A 3D virtual world driven by a running simulation model will define the participants' interface to the model. A running simulation model must thus generate such a virtual world in real-time, i.e. at each instant, the state of the generated virtual world must exactly match the state of the running model. When the running model reaches states where user input is required (i.e. action by participant-represented simulation resources is necessary), the particular thread of execution (i.e. sequence of activities) must suspend and prompt the appropriate participant for response via the participant's virtual interface. Once the participant interactively completes (or abandons) the assigned task, the simulation model's suspended sequence of activities must be notified of the participant's actions. This will determine the future course of activities in the running simulation. The virtual world must also be updated on the fly as the participant performs the assigned task.

To realize these capabilities, the implemented Virtual Reality framework must continuously communicate bi-directionally and at high speed with discrete-event simulation models running in another process and perhaps in another machine. In addition, depending on the application, visualization has to be possible on all hardware platforms (immersive and non-immersive). Since the contents of the generated virtual world will be modified in real-time by both simulation models as well as by participants, the implemented Virtual Reality framework must provide a suitable animation authoring interface to both software processes (i.e. running simulation models) and hardware controls (e.g. joysticks used by participants). The design of an animation authoring interface is, in fact, the first of several research stages required to accomplish this work.

Current technology that enables passive (i.e. walkthrough only) 3D animation of simulated construction processes does provide the specification of this interface and can form the basis for advances that will enable interactive 3D visualization of discrete-event construction simulations. In particular, the tangible product of the authors' recent work, VITASCOPE, is an open, loosely-coupled 3D animation description language designed to animate (in passive, post-processed mode) discrete-event construction simulations in smooth, continuous, dynamic virtual worlds (Kamat 2003). VITASCOPE's language-based animation approach defines a layer of abstraction that effectively separates visualizations from the processes (i.e. running simulation models) that generate them.

This approach is advantageous to passive 3D animation of simulated processes in several ways. In addition, it is critical to the achievement of the proposed work's objectives because an open, loosely-coupled interface such as VITASCOPE's can allow multiple processes and controls to simultaneously interact with a dynamic virtual world in real-time. This is essential for virtual interactive simulation of construction processes. The language-based approach for passive, post-processed animation of simulated processes thus provides a suitable launch pad for exploring the issues involved in enabling the proposed scheme. Some of the specific research questions that need to be answered in extrapolating the language-based animation approach to address the problem include:

- Can a 3D animation description language be implemented so that it can execute a straight-line program concurrently being generated by another process that is entirely decoupled and possibly running in another machine?
- What latencies will exist in doing so?
- Can the latency be minimized so that it is imperceptible?
- How can a virtual environment communicate events generated by user interactivity back to the driving process (i.e. a running simulation model)?

A major component of the work required in accomplishing the objectives of the proposed research is to design the interaction between users and running simulation models via the Virtual Reality interface. The ability to allow participants to operate virtual resources (e.g. equipment) in a running simulation requires an hardware input interface that can interpret signals from a wide range of input gadgets (e.g. joysticks) and transmit the digital representation of those signals to the host computer (e.g. through a serial line). Depending on the application, such an interface needs to be capable of representing the actual controls of a particular piece of construction equipment (e.g. cranes, excavators, etc.). An interpreter must then translate the information into simulation system commands and execute them thereby updating the running simulation model. The running simulation model will then drive the visual display which in turn will provide the feedback to the participant controlling the virtual simulation resource.

POTENTIAL BENEFITS OF THE TECHNOLOGY

In Virtual Interactive Discrete-Event Simulation, objects under the control of simulation models will be aware of, and react to, virtual humans and human controlled virtual machines. Success in this work promises several distinct advantages over the current state-of-the-art. Examples of potential benefits include the ability to:

- Proactively participate in an executing discrete-event simulation model
- Directly influence/control the outcome of a simulation run
- Perform real-time, visual what-if analysis
- Evaluate constructability and/or estimate productivity by introducing real equipment operators or workers as human participants in simulations

Success in this work can also significantly advance the state-of-the-art in the field of Virtual Reality equipment simulators by providing a discrete-event simulation-driven framework for equipment simulator design. When a human participant interactively controls a piece of equipment that is a resource in a running simulation model, the setup (from the perspective of the participant) closely resembles that of a Virtual Reality equipment simulator (e.g. Park 2002, Caterpillar 1999). Training scenarios for equipment simulators must currently be hard-coded using high-level programming (e.g. C++) or graphics (e.g. OpenGL) languages.

In Virtual Interactive Discrete-Event Simulation, the dynamic behavior of all virtual entities (other than the ones controlled interactively) will be driven by the currently executing simulation model. Thus, the task of creating training scenarios for use by equipment simulator users will reduce to the intuitive creation/manipulation of schematic discrete-event process models of the activities in which the interactively controlled machine participates. Thus, the proposed scheme also suggests an integration of Virtual Reality equipment simulators and discrete-event simulation-driven 3D construction operations visualization.

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