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A 3D immersive Discrete Event Simulator for enabling prototyping of factory layouts

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Abstract

There is an increasing need to eliminate wasted time and money during factory layout design and subsequent construction. It is presently difficult for engineers to foresee if a certain layout is optimal for work and material flows. By exploiting modelling, simulation and visualisation techniques, this paper presents a tool concept called immersive WITNESS that combines the modelling strengths of Discrete Event Simulation (DES) with the 3D visualisation strengths of recent 3D low cost gaming technology to enable decision makers make informed design choices for future factories layouts. The tool enables engineers to receive immediate feedback on their design choices. Our results show that this tool has the potential to reduce rework as well as the associated costs of making physical prototypes.

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Keywords: Immersive; Simulation; Factory Layouts; Oculus Rift; Gaming

1. Introduction

Due to the raising competitiveness of the global market, there is an increasing need to get factory layout designs right the first time. This is because errors and sub-optimal designs will impact the flow of work and material as well as the safety of employees. Currently, many factory layouts are performed by a plant manager using a CAD package that is arguably 2D. In order to understand the effects of various operational factors, discrete event simulations are also often used sometimes in 2D and sometimes with a 3D representation. These techniques and software packages can lack a full sense of presence of the factory layout and hence may lead to layout errors. Due to the recent advances in computing hardware resources, it is now possible to develop 3D immersive environments that provide a sense of presence and enable designers to visualise the factory layouts before actual construction. Nevertheless, these immersive environments do not allow the designer to receive live event feedback of design choices through visualisation of work flows as well as material flows and other operational factors that could affect the factory. In order to receive feedback as well as understand the effects of various operational factors, discrete event simulations are often used. However, most discrete event simulations are restricted to 2D environments and are often abstracted making them lack any representation to the real 3D world.

In order to solve this dilemma, this paper presents work on how current systems are augmented through the use of the realism offered by immersive virtual reality technology. The immersive virtual reality environment is provided by an off-the-shelf low cost gaming platform called Oculus rift. The

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need for this type of technology is echoed by a representative from industry who stated: "*We are interested in leveraging pioneering low cost gaming technologies to enhance simulation modelling and visualization of their manufacturing facilities. Application cases have been identified in many of our operational sectors with the view to fully optimize operations. The potential benefits of combining these technologies are substantial.*"

Our aim is that through combining immersive virtual reality and live event feedback capabilities with DES, we can use the resulting technology to address the barriers that limit more effective use of modelling and simulation in designing new-built factories and managing the operations of existing factories.

2. Literature review

The notion of combined virtual reality (VR) and DES use has been present since the late 1990's; an example work can be found in Page and Roger [1], who examine the use of DES in the production of military training simulations. Mention is given in this paper to virtual and live simulations. An example of a virtual simulation is given as a flight simulator used to train pilots. Although 3D environments are not explicitly discussed in this paper many of the model interaction types are, in that human motor control skills and their input into a virtual simulation are seen as key. The paper of Kim and Fishwick [2] notes, in part, the opportunities offered to DES through web based simulations. Various technologies, many based on XML (Extensible Markup Language), are discussed along with the provision of a web based modelling framework composed of best of breed techniques and technologies.

Waller and Ladbrook [3] make the case for VR and DES simulation presenting the initial version of the WitnessVR simulation package and its use in simulating factory production lines. While pointing out the limitation of VR in addressing mathematical simulation challenges, the authors note that the ease of understanding and enhanced ability to explore simulation models of, for example alternative factory layouts, provides benefits at the corporate management decision making level. Furthermore, Nielebock et al [4] make a compelling case for combined DES and VR use through their assertion that through the use of both tools additional aspects about the model may be learnt that are not obvious from the use of DES alone. In this way VR and DES can provide a much more detailed description of a situation from a wider variety of viewpoints in their combined use. In alternative work, Fumarola et al [5] discuss the development of a library of DES model components that may be described in 2D and 3D form. In separating the 3D visualisation from the DES model loosely coupled animation sequences for model elements may be swapped in with little or no development expense. The authors point to their 3D simulation environment as an example. In addition the work of [6] and [7] involves DES and the integration of 3D animations for construction industry applications, putting forward ways of linking the two tools.

The summaries provided by the studies of Akpan and Brooks [8] give a good indication of the value of VR DES combined systems. Akpan and Brooks [8] confirm that DES and VR used together allow for the identification of more modelling error and omissions than with DES alone. In the practitioners' survey, by the same authors, it was found that the ease of understanding afforded by VR DES models and the notional decision making quality achieved from them was higher than with a 2D model [9]. This study found out that the time taken to develop 3D models was longer than with 2D [9]. The message from surveys in this area is that VR DES combinations allow both a modeler and the user to better understand a subject area than would otherwise be possible with 2D alone [10].

Since the late 90's another term has been in use; relating to advanced factory management, the virtual factory has encompassed a wide range of digital technologies and has in part driven forward the integration of DES and VR. A definition of the Virtual Factory concept has been given by Jain et al. [11] as an 'integrated simulation model of major subsystems in a factory that considers the factory as a whole and provides an advanced decision support capability'. Discrete Event Simulation is seen by Jain et al. [11] as a core component of a holistic model of the factory where DES enables an integrated view, encompassing all major subsystems, to be formed. Data Analytics is central to the enablement of the Virtual Factory in the opinion of Jain and Shao [12], with modelling and simulation essential tools to leverage and make sense of the data available. In the opinion of these authors the Virtual Factory is, and should be, 'a virtual reality representation' for a factory, with 3D environments and visualisation essential for understanding and knowledge share.

Choi et al [13] note the increasing prevalence of VR use in manufacturing applications in recent years, noting the availability of Big Data in manufacturing and the increasing maturity of VR technologies as drivers for the uptake. Although not the primary subject of their research many of the works cited involve the use of simulation in combination with VR, suggesting an increase in the combined use of these two software tool sets. They also note a lack of real life case study examples of combined VR and DES use within manufacturing in literature. Kelsick et al [14], an early proponent of VR DES, does outline the use of a CAVE environment for the 3D visualization of DES models of a manufacturing cell. Similarly, in Dangelmaier et al [15] a two tier framework is outlined for real time immersive presentation of simulation model for material flow. In a recent work, Usman et al [16] presented a tool called VDSim towards the goal of aiding engineers to verify process and resource design through visualisation. This paper also explores the point in time which a user can best interact with a virtual simulation, examining the notion of pre-simulation where some calculations are made offline to model elements of certain scenarios in advance.

In this paper, our contributions are: (i) development of a feedback link from an immersive virtual reality software package (Visionary Render) to a DES software package (WITNESS) (ii) the ability to modify the operational parameters of models in a virtual world towards affecting the parameters of the DES simulation and (iii) immediate visualisation of live event feedback of parameter choices on factory performance in the virtual world.

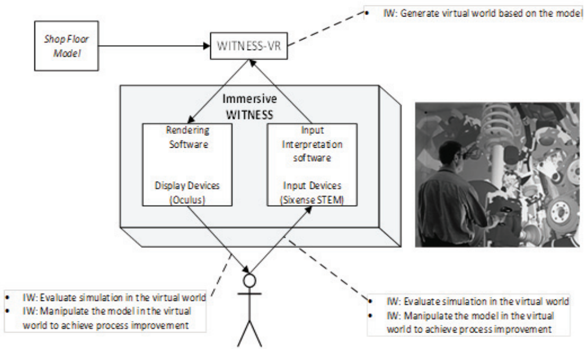

Figure 1. Architecture of concept

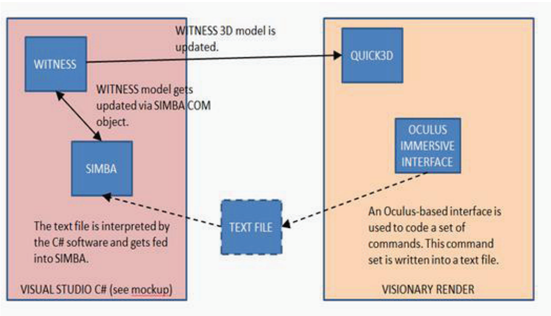

Figure 2. Communications between components

3. Technical Approach

The disparate software components used in this work called for a protocol to enable communication of events and models in DES to the VR environment and vice versa. However, the existence of a preferred method of communication between DES and VR tools has yet to be established in research. Casas et al [17] put forward a simulation model representation based on SDL (Specification and Description Language). This model was then transformed into an XML description for transmission to the VR application. But no discussion was carried out on how this transmission took place. Nevertheless, WITNESS has the ability with communicate with the immersive environment software used in this work via a socket communication protocol. This enabled us to use a well-tested industrial communication capability to extend WITNESS into an interactive immersive tool using the architecture discussed in the next section below.

3.1. Architecture

The architecture shown in Figure 1 was developed. The architecture enables factory floors to be modelled in a discrete event simulator such as WITNESS. After modelling, WITNESS will communicate with a 3D visualisation software package capable of providing an immersive environment via a gaming device such as Oculus Rift. This environment can be visualised by a user that can interact with objects via their parameters. These interactions are communicated to WITNESS where they are updated. The update affects objects seen by the user in the immersive environment thereby completing the loop. In order to achieve the above in practice, the communication architecture in Figure 2 was developed. This communication architecture was made up of a Visual Studio and the Visionary Render environment connected together via an API called SIMBA. These components will be explained further in the following sections below.

3.2. WITNESS

WITNESS, is a discrete event simulation package offered by Lanner Group, based in the United Kingdom. It can provide insight into the performance, capacity and constraints of a factory. It enables manufacturers to perform changes to a factory model until the desired performance is achieved, with the expectation that the new-built factory or newly reconfigured production line is “right-first-time” thereby reducing the need to physically prototype the process.

3.3. SIMBA

SIMBA is an API (Application Programming Interface) provided within certain versions of the WITNESS software tool. SIMBA allows a developer to access WITNESS functionality from an externally hosted program that they have written. In the example shown in Figure 2 the XML encoded instructions within a text file are passed to SIMBA via the TEXT FILE module. The calls from SIMBA are used to enact changes within a simulation model hosted by the WITNESS environment. In the work depicted in Figure 2 the following actions are called within the simulation model (shown below in Figure 3):

- Set a breakdown on machines
- Repair a machine
- Stop and start the simulation

For the work featured in this paper, SIMBA functionality is utilised via the C# programming language running within the Microsoft Visual Studio software development environment. SIMBA is an integral part of the VR-DES communication loop explored in this work.

3.4. Visionary Render

Visionary render is a visualisation software package offered by Virtalis, based in the United Kingdom. It allows users to access and experience a real-time, interactive and optionally immersive Virtual Reality environment through a variety of hardware platforms. It includes drivers that enable an Oculus Rift to be connected to it as one method to achieve an immersive 3D environment. Visionary Render provides 3D views as part of the WITNESS software package with options to include full immersion in the full Visionary Render package. Furthermore, communication from WITNESS to Visionary Render was achieved via socket communication and through the use of XML scripts. The XML scripts embed 3D machines properties, their layout and their position in the immersive environment.

In this work, the Lua programming language was used to write scripts to achieve auto loading and placement of other Lua scripts into the tree structure of Visionary Render. Another script that was written enabled events such as moving objects as well as manipulation of machine states in the immersive virtual environment to be detected. Machine states that were implemented in Lua scripts for manipulation were breakdown and repair states. This was achieved by allowing the user to look at a machine via the view cursor and then through key presses, the user could either break or repair a machine. XML messages were generated at each key press for sending to SIMBA.

To achieve communication with SIMBA, a file based system was initially used. This was done for the purposes of debugging and in order to facilitate the development of a common XML file format for both applications. However, due to synchronization issues with files, this system was replaced with a socket communication approach.

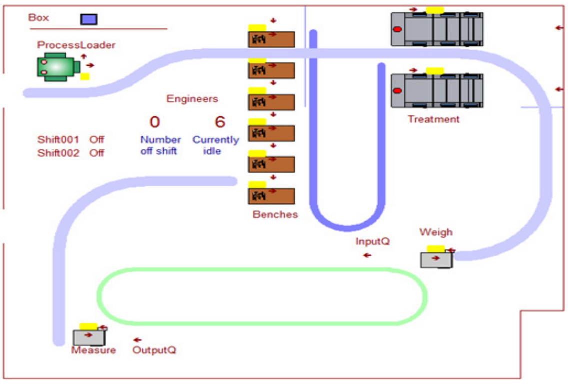

Figure 3. 2D WITNESS environment showing machines and factory floor layout.

3.5. Integration

The file-based communication system was used to establish that the same XML protocol used in WITNESS-to-VisRen communication can be used in the back link. As mentioned previously, socket communication is already utilised as the main means of carrying these XML messages. However, the back link from VisRen to WITNESS had not been implemented. However, the inherent expandability of Lua enabled us to add socket communication capability to VisRen by adding the appropriate libraries. This makes it possible for users of this extended Immersive WITNESS to issue commands to the underlying WITNESS model, and see the impact of their commands as it is implemented.

4. Experiments

An experiment was carried out using the VR environment in Figure 4. The aim of the experiment was to establish the ability to impose breakdown and repair of machines as well as visualise the event of the decisions on work flow. As depicted in Figure 5, the user is able to navigate to a position of interest in front of a bank of benches. The user then looks at a bench (Figure 5(a)) , positioning the 3D cursor on top of a bench and issuing a command that sends a breakdown signal. This signal is sent from VisRen to the SIMBA interface using socket communications. The impact of the breakdown can be seen by the rapid pile up of unattended work items on the conveyor belt (Figure 5(c)). Figure 5(b) shows the normal operational buffer of materials on the conveyor belt in the absence of a breakdown signal.

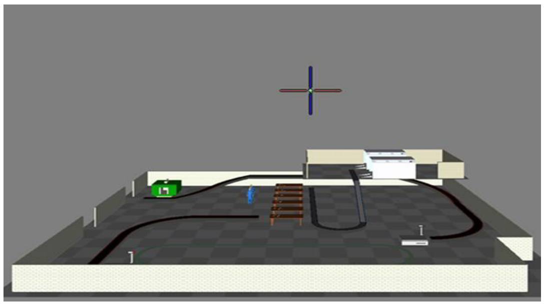

Figure 4. Immersive Virtual Reality Interface to the 2D WITNESS environment.

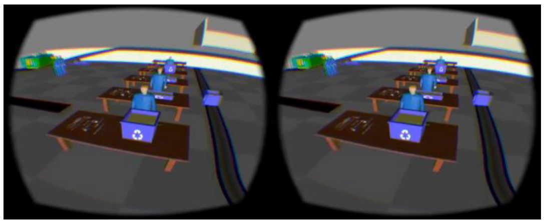

Figure 5(a). User looking at a bench in the immersive environment. A bench is used in the immersive environment to process materials.

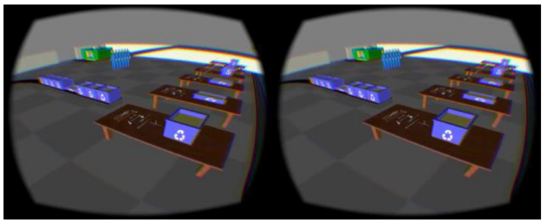

Figure 5(b). Material flow and small material lag on the conveyor belt in the immersive environment when bench is operating normally.

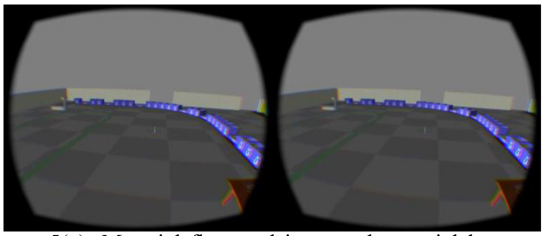

Figure 5(c). Material flow and increased material lag on the conveyor belt in the immersive environment when bench has been broken by the user.

Figure 5: Showing how user choices affect material flow on the factory layout during operation.

5. Discussion

Navigating and issuing commands using standard keyboard and mouse is difficult while wearing Oculus is challenging as we cannot see our hands. This is a common issue and not unique to Immersive WITNESS. In our experiments, Spacemouse was found to be essential. Leap Motion VR is being considered for more intuitive operation and to allow pass-through vision of the user's surroundings, but this is not currently possible to implement using the Lua library alone. With immersion, there is also a need to look into the fidelity of graphics models. While generic 3D models may be sufficient for many purposes, many WITNESS users generally express a preference for more realistic renderings. The 3D packages such as Visionary Render certainly allow for very high levels of fidelity but the appropriate level of fidelity of 3D simulation models such as in WITNESS is still unclear.

Furthermore, there is also a need to create separate visualisation of DES parameters and statistics in VR. For instance, vital statistics of a machine (e.g. current cycle times) could appear when the user approaches a machine. Important events can also be highlighted. For instance, the breakdown of the bench is only discernible by its effects, i.e. the pile of unattended work items. Ideally a marker should be available that point out the breakdown of machines to the user.

Communication between the virtual reality and DES environments was a critical factor in the successful development of the concept Immersive WITNESS tool. By relying on WITNESS' API called SIMBA, any interaction in the virtual reality environment can be passed onto the DES model. Presently, out implementation requires a custom SIMBA interaction function for every model element. As such, adding or removing new model elements requires software re-compilation. This leaves the following question which will be addressed in future work: "Can massive user layout changes in the virtual environment be seamlessly migrated to the corresponding DES model using SIMBA-based software?"

6. Conclusion

In this paper, we have presented a tool concept called immersive WITNESS that enables factory layout designers to visualise how work and material flow as well as other operational factors will be affected as a result of layout design choices. We also created a feedback communication link from Visionary Render to WITNESS so that it is now possible to modify the parameters of the DES from the corresponding models in a virtual world thereby introducing a sense of presence to a DES though via a Virtual Reality platform. As a result, immediate live event feedback of parameter choices on factory performance in a virtual world can be received and this can be used by designers to improve their layout designs.

However, there is much more that can be improved. As mentioned in the discussion section, the method of interaction with virtual objects can be augmented. Furthermore, the effect of changing object positions in the virtual environment on DES needs to be investigated.

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