ARTICLE IN PRESS
DECSUP-12477; No of Pages 17
Decision Support Systems xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Decision Support Systems
journal homepage: www.elsevier.com/locate/dss

Experimental evaluation of user performance on two-dimensional and three-dimensional perspective displays in discrete-event simulation

Ikpe Justice Akpan [a,*], Roger J. Brooks [b]

[a] Department of Management & Information Systems, Kent State University, 330 University Drive, New Philadelphia, OH 44663, USA
[b] Department of Management Science, Lancaster University Management School, Lancaster LA1 4YX, UK

ARTICLE INFO

Article history:
Received 8 June 2013
Received in revised form 31 March 2014
Accepted 4 April 2014
Available online xxxx

Keywords:
Discrete event simulation
Visual display
Model validation
Model verification
Two-dimensional display
Three-dimensional perspective

ABSTRACT

Several experiments were carried out to compare the impacts of using a two dimensional (2D) plan view or a three dimensional (3D) perspective view in discrete event simulation visual displays. The experiments measured the performance of participants in spotting errors, describing the model, and suggesting improvements to the system. The participants using the 3D perspective display performed much better in spotting errors, taking on average about one third of the time of participants observing the 2D display. They also did much better in describing the model. There was no significant difference in suggesting improvements although this may have been because this task was easy. Most participants preferred the 3D perspective view when asked to compare the displays. The experiments indicate that the detailed design of the visual display may have a considerable effect on some of the tasks in a simulation project and hence on whether the overall project is successful.

1. Introduction

Three-dimensional (3D) visual display and virtual reality (VR) technology were first introduced in discrete event simulation (DES) in the mid-1990s [7,20]. Since then, there has been tremendous increase in the recognition and implementation of 3D and VR applications, and its use for modeling activities within the DES community [15,30,39,41]. This recognition has led to a strong consideration and adoption of 3D visualization and VR technologies as new evolving modeling techniques, and valid next steps in the advancement of DES [14,33].

Presently, most visual simulation applications and DES modeling activities involve the use of visual display in 2D and 3D. Unlike the 2D visual display, 3D visualization employs stereographic images to represent the model elements and other parts of the real system [32]. Numbers, charts and texts can also be utilized to display key statistics on the interface to complement the graphics, as also applicable in the 2D display.

In the DES literature, 3D visualization and VR are defined loosely to simply mean displays that give a three dimensional perspective view [30]. Although such displays can provide the ability to alter the viewpoint of the observer including being able to “fly through” the system, it is not really VR in the conventional sense as known in human–computer interaction (HCI) [23,32,33,36]. In HCI, VR represents variety of systems with different levels of immersion, including full-immersion into the virtual environment [22,32]. Immersive VR uses specialized hardware devices such as gloves and head mounted displays [27].

Generally, many of the benefits and claims of 3D visualization and VR in DES are similar to the advantages of visual interactive modeling and visual interactive simulation (VIS) [5,8–10], as decision support system [9,12,13,18] using 2D display [11]. The major difference is that, 3D display and VR provide greater enhancement to the benefits of visual simulation compared to the 2D display. For example, it is claimed that, 3D visualization and VR are more interactive, enhance generation of ideas about a simulated system [41], are more effective for model testing, validation and verification [1,20,36] of model credibility and usability, and overall success of the simulation project [1,2]. While the importance of 2D visual display and 2D animation in DES is well established [8–11,17–19], the same cannot be said of 3D visualization and VR, with many ongoing debatable and unsubstantiated claimed benefits and costs.

We carried out a survey of simulation practitioners focusing on user perceptions of the differences between 2D and 3D displays [1], including perceived benefits and costs. But the survey results were not known at the time of the experiments reported in this paper. Generally the survey respondents with experience of both 2D and 3D considered 3D to be better than 2D for spotting errors, improving understanding of the real system, and communication with the client. One result that

* Corresponding author. Tel.: +1 330 339 3391; fax: +1 330 339 3321.
E-mail address: iakpan@kent.edu (I.J. Akpan).

http://dx.doi.org/10.1016/j.dss.2014.04.002
0167-9236/

Please cite this article as: I.J. Akpan, R.J. Brooks, Experimental evaluation of user performance on two-dimensional and three-dimensional perspective displays in discrete-event simulation, Decision Support Systems (2014), http://dx.doi.org/10.1016/j.dss.2014.04.002

stood out was that 61% had the view that 3D resulted in a better solution for decision makers (with none saying that the solution would be worse) compared to using 2D. This effect is likely to be due to the 3D display facilitating better interaction with the client and helping the client to be more involved in the project. The respondents were also asked about the importance of five aspects of the visual display (3D perspective, realistic colors, detailed graphics, interactivity, accurate scale dimensions) in communicating with decision makers. A majority thought that each aspect was helpful with the responses being stronger from 3D users. However, there were a small number of comments in the survey that 3D could be a hindrance with unnecessary graphical detail making it harder to see important aspects of behavior.

Based on user opinions and evaluation results from 3D DES software vendors [1,7,8,31,39], it appears that the 3D visual display and the 3D animation can have a very significant effect on several tasks in a simulation project and on the overall outcome of the project, thus extending the benefits of the visual display. However, it is not clear precisely what factors of the visual display that 3D visualization can bring added benefits or the aspects of DES modeling process where 3D can affect the performance of developers or users of DES models. Therefore, the aim of the study was to investigate this through the use of experiments. Since 3D displays are increasing in popularity and prevalence in simulation, it was considered most useful to look at a 3D perspective view. The experiments compared a 2D display with a 3D perspective display and were designed to look at the effect on the ability of users to spot errors in the model and to understand the behavior of the model (two of the benefits advocated for animation and visual display [5]), and make decisions on improving the business operations. We also examine the effects of the 3D perspective view on model credibility and acceptability. A display with just a 3D perspective view is sometimes described as 2.5D to distinguish it from displays with more capabilities, e.g. the ability to change viewpoint [39].

In the experiments reported in this paper, we are considering displays with just a 3D perspective view and we will use the term 3D display so as to give a clearer and simpler distinction in the text from the display with a 2D perspective. The experiments took place in 2004. Even though the use of 3D visualization in DES has become more widespread with many simulation packages developed considerably since then, the comparison of 2D display and 3D perspective view is still important and relevant in understanding the effects of this aspect of visual displays, especially as this aspect of empirical work yet remains overlooked.

The rest of the paper is organized as follows: Section 2 presents the theoretical background; Section 3 highlights the research hypotheses; Section 4 explains the experimental design and method. The results of the experiments and test of hypotheses are presented in Section 5. Section 6 discusses the implications of the study and limitations of the study, while Section 7 summarizes the main findings and concludes the paper.

2. Theoretical background

2.1. Overview

The dramatic advances in computer hardware and software, the revolution in the Internet and its multimedia front-end, and the World Wide Web have enabled the development and implementation of sophisticated user interfaces on diverse applications including DES as a decision support system [9,13,23,33,34]. While the benefits and costs of 3D visualization and VR in DES are still debatable, the application and implementation of these technologies are already well established in training simulations, entertainment industry, communication and media, and education with great successes [29,46]. For example, 3D games, 3D film productions and training simulation are very extensive [29,46]. In the area of training simulation, significant benefits have been recorded in flight simulation, military training and medical and surgical procedures [29,40,42].

The need for enhanced visualization in training simulation is often to make the display look realistic. On the other hand, such visual display may also be simplified to highlight the important features and it may show aspects that are not visible in the real system. Quarles et al. [29] describe a mixed reality approach to learning how to use an anesthesia machine. An existing virtual simulation model showed the workings inside the machine when the controls are altered, including showing the flow of invisible gases using colors. The mixed reality system was designed to make it easier for students to match the model with the real machine. It included altering the model display to match better with the real layout and using a magic lens to show the relevant components of the model display on a hand held screen as the user looks at part of the real machine. The model was also linked to the real machine in that control movements on the machine were detected and applied.

The benefits of 3D display and VR in other fields as discussed above appear to have greatly influenced the quest to implement similar technologies in DES. It is claimed that, a realistic display may be necessary for simulation to have credibility as a cutting edge problem solving approach when compared against sophisticated computer graphics in other areas such as computer games [30], films [31], television, architecture, and archeology. The public consumption of information such as news and current affairs is increasing through video rather than the written word, and video is becoming more and more widespread on the internet.

2.2. Visual display in discrete event simulation

Most discrete event simulation (DES) applications and models have a visual display that provides a dynamic pictorial representation of the system being modeled. Our use of the term visual display follows the general usage in simulation [11,19,26] in referring to the use of images and graphics to represent the model elements in the simulation software. The visual display is usually dynamic in that, the model elements can move and change appearance at run time to indicate changes in states. Such a display may also include some text such as labels for the elements, as well as showing some key statistics through numbers or charts. This is generally termed animation. We distinguish the visual display from other aspects of simulation software and the simulation model such as computer code and detailed statistics. Simulation software also usually includes interaction in that the user can stop the model at run time to make changes to the model and then continue the run, thus making it possible for users to perform experimentation and analyses (e.g. "what if" analysis) [12].

As in most decision support applications [18,12,34], visual display has long been used in simulation through the implementation of visual interactive modeling (VIM) [3,9,17,19,37] and visual interactive simulation (VIS) [5,8,19,28]. The application of visual display has not only increased DES modeling and simulation activities, but also revolutionized the modeling process [30], and remains an important part of a DES modeling till today.

2.2.1. Benefits of visual display

One benefit of visual display is the animation it provides, which can play a major role in achieving the overall objectives for most simulation projects. Simulation is generally used to model complex non-linear systems with many interacting components. Solutions are typically obtained by experimentation and it is often difficult to understand or anticipate precisely how the different parts of the system will affect the overall system performance. The ability to see the model running on the visual display can help considerably in understanding the behavior of the model and the system it represents. This can lead to new insights regarding ways of improving the system [39]. The visual display is important in other simulation tasks as well, such as model verification and validation [6]. Observing model behavior is a useful test as part of

Please cite this article as: I.J. Akpan, R.J. Brooks, Experimental evaluation of user performance on two-dimensional and three-dimensional perspective displays in discrete-event simulation, Decision Support Systems (2014), http://dx.doi.org/10.1016/j.dss.2014.04.002