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► To cite this version:

Lucile Faure, Artin Koochakan, Jonatan Berglund, Erik Lindskog, Björn Johansson. 3d Movie Creation from Discrete Event Simulation Software Models of Manufacturing Industries. 9th International Conference on Modeling, Optimization & SIMulation, Jun 2012, Bordeaux, France. hal-00728583

HAL Id: hal-00728583

<https://hal.science/hal-00728583>

Submitted on 30 Aug 2012

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3D MOVIE CREATION FROM DISCRETE EVENT SIMULATION SOFTWARE MODELS OF MANUFACTURING INDUSTRIES

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ABSTRACT: *Movies made from simulation tools can be used to present results of simulation models to people who have no knowledge about simulation or how to validate and optimize models. This is why it is important to present models that reproduce reality as accurately as possible. One important mean to achieve this is to capture the 3D depth which humans become aware of due to our set of two eyes. Actual simulation models include 3D-objects but are normally viewed in 2D on regular computer screens. There is a gap in terms of perceiving reality here. Nowadays the movie industry use stereoscopy to fill this gap. However industrial companies are not as far in this technological use yet. This paper presents a method to include stereoscopy when watching simulation models created with different programs. The method involves accessing the code which describes camera point of view in the simulation software and record two movies of the same scenario with slightly different camera positions and angles. Afterwards the two recordings can be integrated to create a stereoscopic movie.*

KEYWORDS: *Discrete Event Simulation; Visualization; Stereoscopy*

1 INTRODUCTION

Simulation is a powerful tool for decision support in areas where high complexity prevents closed form solutions. Simulation is often used to validate and optimize settings and parameters based on large amounts of input data. The simulation result may be observed by people, which sets requirements on understanding and visualisation during presentation and discussion on results.

It is often said that a good drawing is better than ten thousand words (Larkin and Simon, 1987). This is due to the fact that the human brain continuously associates words with pictures. If somebody tells you about a table you picture a table in your mind. The same saying can be applied to the presentation of a simulation model.

In fact, between reality and the model lies the human brain. This intermittent part is the most difficult to satisfy because it is not possible to accurately predict how people visualize their mental model of things in their mind. Some inaccuracies will inevitably be introduced through the visualization. Considering these inaccuracies, how can we reduce them and thus aid the human brain in creating a more coherent link between the inner model and reality.

The research approach presented in this paper tries to establish a synchronized understanding of the analyzed

production system, see Figure 1. For our purposes, synchronized understanding requires coherence between:

1. Real/physical production system
2. Virtual model of the physical production system
3. Mental model of the physical production system

The intended users are engineers working with production system development. The core of this paper focuses on making the “*Virtual representation of a production system*” more realistic, hence aiding a person in producing a “*Mental model of a production system*” looking more like the “*Real production system*”. I.e. the virtual, the physical and the mental model triangle will be more coherent.

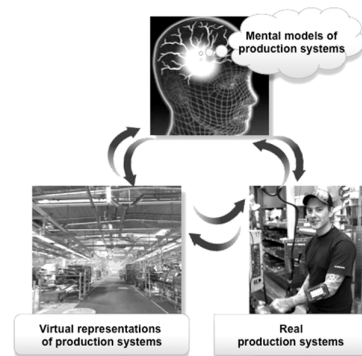


Figure 1: The research model is based on three views of the production system (Vallhagen *et al.*, 2011)

The important question to ask based on this observation is: *How is it possible to increase the coherence between reality and the perception of reality using simulation models?*

The approach demonstrated in this paper is to add stereoscopy viewing ability to movie sequences from simulation models.

Thus, the purpose is to show the 3D objects and models in stereoscopy and not in 2D. Doing this requires a display, double projector system, or similar equipment with stereoscopic functionality. The sought effect is to enable a more realistic representation of a factory and to allow people to experience the sensation of being inside the factory.

The next section covers the history and current state of both simulation and visualization – especially in stereoscopy. Section three presents a methodology for generating stereoscopic movies using off-the-shelf simulation software packages with 3D visualization support. In section four the method is applied in two different software and in two different viewing environments. The fifth and final section provides a discussion of the results and recommendations for future work.

2 STATE OF THE ART

State-of-the-art knowledge and technologies in the area of simulation, visualization, and stereoscopy – as described in the following sections – clarify the relations between these areas and illuminate to what extent such relations can enhance the coherence between reality and perceived reality in simulation of production systems.

2.1 Simulation

Broadly speaking, simulation imitates the behaviour of an existing or conceptual system or process over time. Thus, it is used to describe and analyze the behaviour of a system, it helps to answer “what if?” questions about the system, and to facilitate the design of the real system based on given simulation results (Banks, 2004). In addition to this definition, Banks also states that simulation is a basic and essential tool for solving many real-world problems (Banks, 2004).

Discrete event simulation (DES) is a particular kind of simulation which considers the many states of a system, production or other, over time and how internal and external events trigger transitions between these states. It is discrete in the sense that all changes occur at well-defined points in time, i.e. changes applied to values are invoked only at a countable number of points in time. (Law and Kelton, 1982)

Computerized simulation as a tool has been around for about sixty years by now. At the end of the 1950s and 1960s, simulation was a very costly and special tool used

mostly by large companies within the steel and aerospace industry. During the 1970s and 1980s, much thanks to the evolution of computers, which resulted in higher performance at a lower cost, simulation became a more commonly used tool to determine causes of problems. (Kelton *et al.*, 1998)

At the end of 1980s, simulation was still being used mainly to analyze failed systems. Gradually, the users began to utilize simulation in order to evaluate their systems before starting production. By that time, the value of simulation was more and more recognized by many other companies and industries, yet smaller firms did not, or did very rarely, make use of the technique. In the early 1990s, simulation expanded and usage spread increased towards smaller companies which began to utilize simulation to validate decisions in the early phases of projects. As computers continued to evolve and provide better performance and animation capabilities, simulation became more and more established as a standard practice in many industries. Accordingly, the scope of use for simulation models broadened to include the early phases of the design process, followed by continuous updates as changes were made to their respective real world systems. By the end of the 1990s simulation was employed in most fields of industry. (Kelton *et al.*, 1998)

Since the 2000s, simulation has been known and utilized more as an evaluation tool rather than a solution tool. It means that it does not necessarily determine how a defined system should be designed, rather it describes how a system behaves in particular situations. Simulation should be considered as an extension of the human mind which helps the user to comprehend complex systems and not as a substitute for thinking. (Harrell *et al.*, 2000)

The fact is that simulation, in theory and practice, has been developed and improved for about sixty years. As predicted by Kelton *et al.* in 1998, simulation models are now able to incorporate virtual reality (VR) representation techniques (Kelton *et al.*, 1998). Nowadays, the simulation model does not only provide tables and numbers to facilitate decision making in terms of investments, it also offers a virtual and graphical environment in which the user may validate a decision in terms of layout, equipment, logistics, etc. and even optimize a process. As explained in the next section, visualization deeply influences the ability of the human mind to understand a simulation model.

2.2 Visualization

Many authors define the term visualization as a cognitive activity that takes place in the human brain to help us create an internal representation of the real world. The internal representation is termed a mental model by Robert Spence (Spence, 2001), and prior to him by Kenneth Craik (Craik, 1943) in the context of describing how humans construct knowledge from the surrounding

environment. (Mazza, 2009, p. 7) (Spence, 2001) (Ware, 2004)

But how is this mental model formed in the human brain? Humans perceive their environment with aid of their perceptual system. This system acts as a link between the human brain and the world surrounding it. It is composed of several perceptual channels, i.e. visual, auditory, haptic, tactile, olfactory and gustatory, and kinesthesia perception. Such channels sense physical stimuli from a surrounding environment translate them into information and convey the information to the human brain. The brain then processes some of the information on a very low level without any conscious thought, known as pre-attentive processing. For perceiving other information attentive processing with conscious thought is required. (Ebert, 2005)

In visualization, where the visual perception channel is the most crucial communication tool, pre-attentive processing is required for grouping large set of information (Ebert, 2005). One belief is that inputs from the visual perception channel are automatically, simultaneously and visually processed for the entire field of view (Ebert, 2005). Based on this sensory input, humans can pre-attentively perceive and process 3D shapes and features like form (line orientation, length, width, co-linearity, size, curvature, spatial grouping, added marks, numerosity), colour (hue and intensity), motion (flicker and direction of motion), and spatial positions (2D position, stereoscopic depth, convexity and concavity) (Ware, 2004). Such pre-attentive processing of the visual sensory inputs facilitate forming of the mental model in the human brain and consequently boosts the cognitive process. Larkin and Simon in their article "Why a Diagram is (Sometimes) Worth Ten Thousand Words", shed further light on the importance of visual representation in easing the formation of mental models (Larkin and Simon, 1987).

As computer graphics has evolved over time, it has played a key role in offering powerful visual aids that assist humans to comprehend visualized objects. 3D models, stereoscopy and augmented reality are examples of visual aids that narrow the gap between the real and the virtual world and help the observer perceive and shape their mental model based on more realistic objects.

2.3 Stereoscopy

The term stereoscopy creates or enhances the illusion of depth in a flat picture and covers a group of techniques for this purpose. Commonly stereoscopy is spoken of as just 3D, as in 3D movies or 3D pictures. A human perceives depth and the methods used to realize stereoscopy are normally based on this perception. When focusing on an object, each eye sees the object from a slightly different point of view, with a slightly different angle; this is because the human eyes are set apart by approximately 50-70 mm (Mohr and Wray, 1976). This phenomenon is called binocular vision and means that

each of the two retinas receives a different image. Our minds superimpose these two images and allow us to judge the form of objects and also distances in perspectives (Watch, 1895).

Thus, to create a stereoscopic effect in a flat picture it has to be able to present two pictures of exactly the same scene; one picture for each eye, at the same time. These two pictures, the left and the right, have to be viewed simultaneously and our brain has to be able to superimposed them to produce the stereoscopic effect (Watch, 1895).

2.4 Methods for recording in stereo

One of the most frequent applications of stereoscopy is found in the movie industry. Two methods, both requiring different sets of equipment, are commonly used when producing stereoscopic movies, namely:

1. arrange two recording cameras together
2. use one stereoscopic camera, which has two lenses

In both cases, to achieve a realistic stereoscopic effect the distance between the camera lenses has to be around 65 mm, corresponding to the mean distance between a human's eyes. Recordings, for both eyes, have to be started at the same time or synchronized afterwards in order to enable the creation of a stereoscopic effect. Thus, the both cameras are set to record one scene, at the same moment in time, but with two slightly different points of view.

Yet another solution is to use only one camera and record the same scene twice. This solution requires that nothing is altered or moved in-between the capturing of the two sequences. This makes it more or less impossible to utilize the method in a real world setting, however when recording cartoons or other computerized scenes it is feasible.

2.5 Methods for viewing in stereo

After recording the two views (left and right) it is necessary to watch them simultaneously in a way that allows the mind to superimpose them correctly. Here, again, there are several solutions; some are more common than others. The more common can be separated in two categories depending on their technology: passive or active viewers. These technologies are described in the two following sections.

All methods, however, require some processing of the two movies before viewing them as one. The amount of processing needed depends on the intended viewing software; some support separate inputs for the left and right eyes while others require the user to merge two movies into one file. The process can also include applying a filter on the recorded movies to accommodate the subsequent viewing technology.

2.5.1 Passive stereoscopic viewer

The most commonly used principle for passive viewers is to separate the left and right views by different polarization or colour. The spectator must wear special glasses which have been correspondingly polarized or coloured. In the case of polarization of pictures: either linearly or circularly polarizing filters can be used to separate the pictures. The main benefit of polarizing filters is that colours are kept intact, however, to allow proper filtering the viewer has to keep their eyes horizontally level to the screen. Another solution is to use complementary colour anaglyphs, the most common colours used are red-cyan (Watch, 1895). This technique has traditionally had some limitations with colour reproduction. Modern systems exist and are able to filter by colours while keeping the degradation of colours to a minimum (Mendiburu, 2009).

2.5.2 Active stereoscopic viewer

Active stereoscopic viewers are based on using specific types of glasses which communicate with the stereoscopic display. Using this technology, the observer is equipped with e.g. liquid crystal shutter glasses that are synchronized with the stereoscopic display.

The concept used to separate the left and right image is called alternate-frame sequencing. This means that the images for the left and the right eyes alternately and quickly appears and disappears on the screen. Simultaneously, the active glasses shut and open the left and the right lens, blocking every other image for each eye. If both the screen and the glasses work with the same frequency (for example 120 Hz) the human brain perceives the two images as being shown simultaneously and is hence able to superimpose them to create the illusion of stereoscopy.

3 METHOD

A step-by-step walkthrough of the method presented in this paper can be found in Figure 2. The method was developed based on the idea of the three views of the production system, as defined by Vallhagen *et al.* 2011 (see Figure 1). This section talks about how the method was carried in this study and is presented on a general level, for software specific implementation see the case studies in section four.

Step one in the method is to select a simulation software. In this study two different off-the-shelf software packages that were readily available for University educational use were chosen. The two software's used have 3D visualization capabilities and support movie capture but lack the built in ability to capture stereoscopic movies. Therefore they were deemed fit for the purposes of this study.

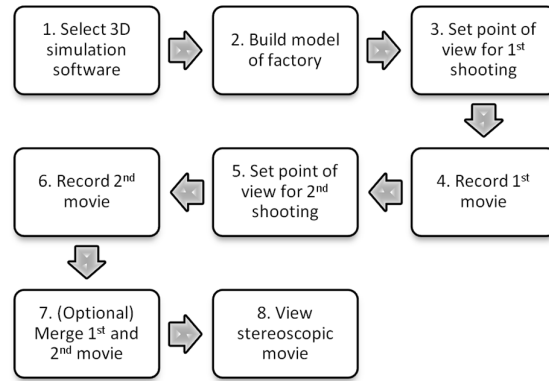


Figure 2: Method used for creating the stereoscopic movies in this study

In the second step, two separate production flows were modelled, one within each of the DES software packages. Both models contain 3D objects representing the equipment and products.

Because both DES software were constrained to just one point of view at a time, the dual lens solution was not possible to incorporate. Therefore the video capturing was divided into steps, three through six in Figure 2, and the double recording technique described at the end of section 2.4 was used. The technique was made possible due to the fact that all events in the models can be controlled and repeated in an identical fashion for the second recording. This enables two identical scenarios of events during the recordings.

The fifth step in the method is key to producing the stereoscopic effect. The camera position needs to be translated sideways while its point of focus is kept at the same location, this will in effect emulate the view of the second human eye. The actual procedure of translating the camera can be broken down in to three steps. First, access the code which defines the camera's coordinates. Secondly, isolate the related part of the code. Thirdly, alter the camera's coordinates by modifying the isolated code. A schematic view of the procedure is presented in Figure 3.

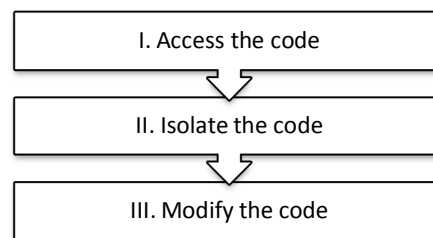


Figure 3: These steps were identified as necessary to alter the camera position for capturing the second view

Steps three through six in Figure 2 were carried out after a suitable camera placement/movement in the model was selected for capturing. The selection included consideration of both perspective and movement to

enable the sensation of depth. E.g. by ensuring that objects both near and far from the camera are captured in the view and that there is movement into or out of the view.

The seventh step is optional and depends on the capabilities of the playback software that is used in the eighth and final step. It might be necessary to merge the two videos representing each of the views into one video file. The combined file can either place the two movies side by side, over and under, or alternate between them every other frame. Figure 4 shows a screenshot when the movie files are showed separate and then merged into one overlay view.

The eighth and final step concerns the viewing of the stereoscopic video. This can be done on a number of different systems, using different techniques for producing the stereoscopic effect. In this study two separate setups were employed, they cover the domains of both active and passive viewing technology:

1. Stereoscopic display: 46" LED screen with active stereoscopic technology using liquid crystal shutter glasses
2. Dual projector system: 226" cinema screen and two full HD projectors equipped with colour filters to enable viewing with passive stereoscopic glasses.

4 CASE STUDIES

This section describes the application of the method in two separate DES tools. The description focuses on steps three through six of the proposed method, see Figure 2. The two tools that were used are Applied Material's AutoMod (Applied Materials, 2011) and Visual Component's 3DCreate (Visual Components, 2011). The results are then qualitatively evaluated based on the

effectiveness of the visualisation. The evaluation is based on impressions from using both sets of viewing equipment

Both DES software packages have similar visualisation capabilities and objects can be represented with externally generated 3D geometries. Both software packages allow the user to create dynamic graphical environments and provide the ability to navigate these environments during the simulation runs.

Additional software that was utilized in this study was chosen mainly because of its accessibility and functionality. The choices made does not imply that the software used is necessarily the best available for the purpose. In Table 1 a listing of all the software used in this study and their application can be found.

Name and reference	Application
3DCreate 2010 SP1 (Visual Components, 2011)	Build DES model
AutoMod 12.3 (Applied Materials, 2011)	Build DES model
Stereo Movie Maker 0.95 (http://stereo.jpn.org/eng/stvmkr/index.html)	Merge video files for stereoscopic playback
Stereoscopic Player 1.7.2 (http://www.3dtv.at)	Play stereoscopic video file
VideoMatch 5.8.5 (http://gromada.com/videomach/)	Render video file

Table 1: Software that was used during the study

4.1 Method using AutoMod

To record a movie in AutoMod the module AutoView is required. AutoView is an add-on that can display predefined scenarios in a model and capture them to video files. The different steps that were taken to specify the position of the camera are explained below.

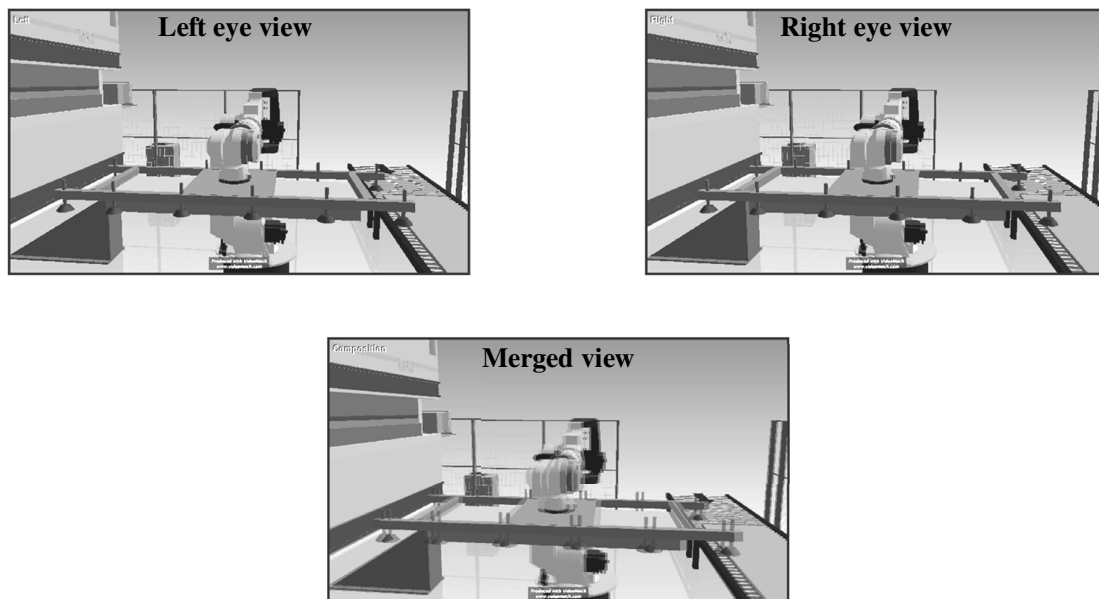


Figure 4: Merging of the left and right views into one

4.1.1 Access and isolate the program code

The file handling the movie script and camera position is called *camera.des*. It gives the possibility to define two types of views: static view and dynamic view. This study makes use of the dynamic view.

To create such a view it is necessary to define an object to which the camera position is related and an object in focus to set its direction. For example, if

- The camera is focused on the object *Man*
- The object *Man* belongs to the path mover system *pm*
- And the camera is located on the object *Machine*

Then the program code should be written as follows:

```
view focus relative to object pm:Man
camera relative to object Machine
```

4.1.2 Modify the program code

By default, the focus point of the object *Man* is at the position (0,0,0) in *Man*'s local coordinate system and the position of the camera is at (0,0,0) in the local coordinate system of the object *Machine*. It is possible to change both these positions using a script:

```
view focus relative to object pm:Man
pos 80, 100, 120
camera relative to object Machine
pos 0, 0, 160
```

In this case, the camera focuses on a point at position (80,100,120) relative to the object *Man* and is fixed at the position (0,0,160) relative to the object *Machine*.

Referring to Figure 2, we should record two movies from two point of views (camera positions) while both are focusing at the same positions. In this example, for the first movie, these settings are applied:

```
view focus relative to object pm:Man
pos 80, 100, 120
camera relative to object Machine
pos 0, 0, 160
```

For the second movie the camera is moved 65 mm horizontally toward the Y-axis. Thus, the final coordinates for the camera position and the focus point are as below:

```
view focus relative to object pm:Man
pos 80, 100, 120
camera relative to object Machine
pos 0, 65, 160
```

4.1.3 Results

The result obtained in AutoMod corresponded with what was intended. The movie sequence demonstrated a stereoscopic effect on both of the viewing set-ups. The sensation of being inside the factory increased when viewing the movie in stereoscopy compared to viewing the same movie in 2D. The perspective in the picture changed depending on the position of the viewer and there was a clear sensation of depth. The larger cinematic screen gave the best effect in terms of depth sensation and likeness to reality.

4.2 Method using 3DCreate

To create a movie in 3DCreate the two add-ons *Frame Recorder* and *View Scripter* are required. The add-on *Frame Recorder* captures a sequence of screen shots from a predefined model scenario, these screens can then be fused into a video file. The add-on *View Scripter* is used to set the camera views for the scenario, and particularly in this case, handle the camera translations. With these add-ons we can adapt the steps described in Figure 3, as explained below.

4.2.1 Access and isolate the program code

The file which saves the position of the camera is included in the add-on *View Scripter*. To save a view the following two steps have to be performed:

1. Choose the position of the camera
2. Push on the button *Add View* or *Add Animated View*

These buttons are linked to a script which is coded in Python language. This script can be accessed through the *View Scripter* module by clicking the *Create*-tab and then the *Behaviour*-tab.

This file allows the user to save the coordinates of the current view in a matrix called *CameraMatrix*. This matrix contains the coordinates of the saved view. The *current view* is the camera's point of view at time, or in other words what the user sees on the screen. Its coordinates are described by a vector called *Eye*. In Python language, the *Vector* class is used to represent for example 3D points (x,y,z). Thus the camera orientations are not represented by this vector. Instead they are defined as the target of the camera, called *Center of Interest* (COI). The vector *Eye* and the COI are presented in a matrix called *Matrix*. Below is a part of the Python script that was created in *View Scripter* in which the parameters of *Matrix* and *CameraMatrix* can be manipulated, and also the current view of the camera can be saved.

```
app = getApplication()
cam = app.findCamera()
defcreateView(arg):
view = app.createView(comp.ViewName)
```

```
comp.ViewName = view.Name
# Assign current camera viewpoint to
  view
view.CameraMatrix = cam.Matrix
```

4.2.2 Modify the program code

The values of *Matrix* are dynamic and are updated each time the camera position and/or COI move. Thus, translation of the *Matrix* will result in translation of both camera position and COI. In order to move only the camera position while keeping the COI fixed, it is crucial to apply translation on the vector *Eye* before saving the view and also prior to reconstructing *Matrix*. Therefore, the following line should be added to the above code in order to translate the vector *Eye*. For example, using the below code the camera position is translated 20 mm along X axis, 50 mm along Y axis, and 0 mm along Z axis:

```
c = cam.Eye + vec.new(20,50,0)
cam.Eye = c
```

Using this method it will be possible to save the first view, called *Lefteye*, then move the camera and save the second view for the right eye. In this method it is important to note that the camera position has to be modified using Python code and not the graphical interface. The program code for the first view is as follow:

```
app = getApplication()
cam = app.findCamera()
defcreateView(arg):
view = app.createView(comp.ViewName)
comp.ViewName = view.Name
c = cam.Eye + vec.new(0,0,0)
cam.Eye = c
view.CameraMatrix = cam.Matrix
```

This means that no translation is applied to the position of the camera.

After saving the view for the left eye, the camera position in the Python script is translated 65 mm toward Y axis, i.e. (0,65,0), and saved as the second view. The second view can be named e.g. *Righteye*.

```
app = getApplication()
cam = app.findCamera()
defcreateView(arg):
view = app.createView(comp.ViewName)
comp.ViewName = view.Name
c = cam.Eye + vec.new(0,65,0)
cam.Eye = c
view.CameraMatrix = cam.Matrix
```

The next step is to use the *Param* module from *View Scripter* to write the scenario of the movie. The work consists of first recording a movie with view *Lefteye* written in the script, and then change the scenario by replacing *Lefteye* with *Righteye*, thus altering the view.

4.2.3 Results

The result obtained in 3DCreate software corresponded with what was intended. When using either the 3D display or the dual projectors the movie demonstrated satisfactory stereoscopic effects. Objects were clearly differentiated from each other by their relative distance into the displayed environment.

Using the software 3DCreate and the add-on *Frame Recorder* creates a series of frames, static images, and not a movie file. Therefore some extra processing was required to fuse the images into the two movies needed; this was done with rendering software.

One issue was that when parts of objects were too close to the *camera's* position they were clipped and not fully rendered. This left the objects looking hollow and decreased the sensation of objects coming out of the screen.

4.3 Case study conclusions

This case study implements and evaluates a method for creating stereoscopic movies in two DES software packages. The two DES software used, AutoMod and 3DCreate required slightly different approaches in order to apply the proposed method. However, the in large part closeness of the execution suggests that the method could be extended to other DES software without too much alteration. As long as the DES software contains some type of image capturing functionality and the ability to control the viewpoint for said image capturing.

The stereoscopic effect was found to be especially useful for visually separating similarly coloured objects that were lined up in front of each other. The contribution of the perspective was most noticeable when objects are passing each other, e.g. a forklift passing behind a machine.

Regarding the viewing setup the most noticeable difference came from the disparity in viewing screen size. The cinema screen in this case was five meters in width and close to three meters in height. Using a resolution suited for the bigger screen was the key to making the movie watchable on both setups. Otherwise, the perceived quality of the movie shown on the bigger screen was significantly reduced.

5 DISCUSSION AND CONCLUSION

To be perceived as realistic, a simulation model has to resemble reality very closely. Stereoscopy was identified as on step on the way to increase the coherence between reality and the perceived reality of simulation models.

This paper describes an approach to introduce stereoscopic capability inside two simulation models created in different software tools. Arguably, it is difficult to evaluate the quality of the results as it is

subjective in its nature and hard to quantify. As explained in the beginning of the paper, the results are gauged by the perceived sensation and not by any physical sensors. Objectively, the results from this study show that stereoscopy in simulation models is achievable based on available off-the-shelf technology.

In order to achieve more quantitative results a study in which a sample of a population uses 3D visualisation described as above and another sample uses standard 2D material. After the use of the material a set of interview questions is used to catch the experience. This approach could provide more quantitative results showing how valuable the 3D techniques are for the perception.

Nevertheless the fact that the camera is always focused on an exact point may sometimes create imperfections on the environment around this point, especially when the camera moves to follow a dynamic object. This is why it is important to make a proper choice of both the camera's point of view and the focus object. The method proposed in this paper works best when both the camera position and focus point remain static. The selected background is also important because it represents an additional graphical element which affects the perceived quality of the simulation model. Hence, the perceived stereoscopic effect is related to many other factors than the chosen stereoscopic equipment. Taking these factors into account, there is room for improvements to further the results from this initial study. E.g. refining the scripts so that it is better at handling camera panning and translation would extend the usability of the implementations.

It is conceivable that, as stereoscopy becomes a more common practice, future upgrades of the software packages used in this study, as well as simulation software across the board, will include support for automated capturing of stereoscopic video. Until the technology is embedded there is however a need for home grown solutions such as the one presented in this paper if models are to be captured in stereoscopic video.

Possible future work may be to include stereoscopy in an augmented reality environment in a similar way to what was done in the simulation models. The combination of these two fields may hold the potential to come even closer to the envisioned endpoint, which is a model inseparable from reality.

ACKNOWLEDGEMENTS

The authors would like to acknowledge support from Erasmus and Institut Français de Mécanique Avancée which enabled Lucile Faure to join Chalmers University of Technology as a guest researcher for six months. This work is also funded by ProViking, VINNOVA (Swedish Agency for Innovation Systems), and the NFFP5 program. This work has been carried out within the Sustainable Production Initiative and the Production

Area of Advance at Chalmers. The support is gratefully acknowledged.

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