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COMBINING POINT CLOUD TECHNOLOGIES WITH DISCRETE EVENT SIMULATION

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ABSTRACT

Utilizing point cloud models from 3D laser scans for visualization of manufacturing facilities and systems provides highly realistic representations. Recent developments has improved the accuracy of point cloud models in terms of color and positioning. This technology has the potential to generate savings in time and money compared to traditional methods. Visualization in terms of accurate geometrical factory data has traditionally not been feasible when developing discrete event simulation (DES) models. Currently, methods for utilizing point clouds in DES models are lacking. Better visualization could improve communication of results and make them available to a wider target audience. Creating methods to combine point cloud technologies with DES would enable realistic visualization and improved accuracy including level of detail regarding geometric representation in DES models.

1 INTRODUCTION

Development projects for manufacturing systems are usually very costly, with much time spent and resources invested. It is therefore important to consistently make decisions that achieve positive results. Mistakes and misunderstandings between coworkers could result in costly and time consuming issues on an already tight budget and time schedule. Company management groups are interested in a short time-to-market process, which demands a highly time effective developing process of manufacturing systems (Cohen, Eliashberg, and Ho 1996). Growing strategies towards globalization makes communication between sites and engineers worldwide necessary. Today companies try to prevent costly mistakes in the development process by using virtual simulation tools at an early phase to create representations of new products and manufacturing systems (Becker, Salvatore, and Zirpoli 2005).

To predict system behaviors in manufacturing system development projects discrete event simulation (DES) is used to study and visualize the manufacturing flow (Taylor and Robinson 2006). However, those models do not consider all details of the manufacturing system and lack in graphical representation. A potential problem with those models is the ability to effectively communicate the result between simulation engineers and the rest of the project group, which usually consist of experts from different parts of the organization. An improved level of visualization could make the communication process smoother and faster as well as help to increase the level of knowledge in the target audience. The level of details and quality of visualization in DES models has been improved over the years. It is generally accepted that visualization is useful for a number of applications in DES models. Traditionally, models have been created with simple 2D layout representations of the manufacturing system and facility. 3D simulations have become popular in the last few decades, which has resulted in more realistic representations of manufacturing systems. However, due in part to the time consuming task of 3D modeling, the level of detail and accuracy of those 3D representations are lacking in comparison to the real world systems. (Rohrer 2000)

3D and spatial data capture technologies have developed and become more readily available during the last decade, especially 3D laser scanning seems to hold great potential through its speed, accuracy and ease of use (Bi and Wang 2010). By utilizing point cloud models, generated from 3D scans of the factory, highly detailed and realistic 3D models can be created with very little effort. In addition, as will be discussed in this paper, having a 3D copy of the factory environment will bring additional benefits. Manufacturing environments is so far a relative undeveloped area of use for 3D scanning. The technology holds great potential in the area and development work is ongoing. Numerous software providers support hybrid modeling techniques allowing combination of point cloud and computer aided design (CAD) models. Hybrid modeling could either be used to create CAD models from point cloud data or place existing CAD models into the context of the point cloud.

This paper will discuss the potential contribution of using point cloud data for visualization in DES models and the current state of technologies supporting this combination. A general description of the point cloud technology is presented as well as the background of visualization in manufacturing industries and previous work with visualization of DES models. Possible work strategies for this combination are discussed together with potential benefits and barriers for further development. To sum up the paper a vision of the future within this area and conclusions are presented.

2 STATE OF THE ART

Manufacturing system development projects involve people with different competencies and positions who represent different parts of the organization. They often have different stakeholder interests to look after and, as a consequence, they will have different views of a manufacturing system. To be able to cooperate they need to communicate using similar language and share the same view when discussing. To narrow the gap between their various interpretations of the system, effective means of visualization is a powerful tool. Used correctly it enables the synchronization of reality, virtual models, and mental models to create a common view of the manufacturing system. This approach to create a common mental model is described in Figure 1. (Vallhagen, Stahre, and Johansson 2011)

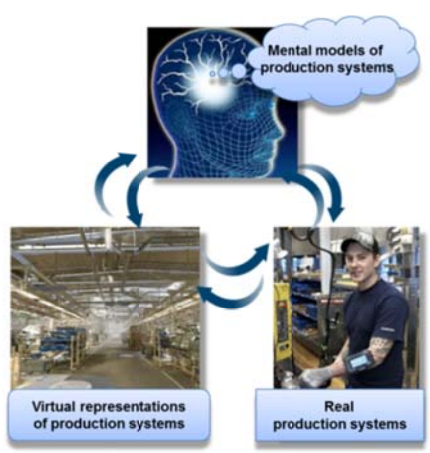

Figure 1: Different views of a manufacturing system (Vallhagen, Stahre, and Johansson 2011)

To cover this gap there is a need for a realistic virtual representation of the manufacturing system. This section will discuss the theoretical aspects of visualization in the manufacturing industry as well more specific in DES models. The section also includes a general description of point clouds and the technology of 3D scanning.

2.1 Visualization in manufacturing industry

Working close to manufacturing companies has shown how they work with virtual tool as well as a few problems and mismatches in methods used for visualizing the manufacturing systems. This section will cover the authors views of how visualization is used as a virtual tool in manufacturing industries today.

There are many different tools available that can be used for visualization of industrial applications. In many cases CAD based applications are used to design and document the factory building and its facilities. It is also used to design and visualize equipment for manufacturing, transport and material handling, tooling and other hardware installations. Thus the tools used and the work done is for different purposes and functions in the organization. CAD is the most commonly used kind of tools and there are many different software available.

DES software are used to calculate and analyze the expected performance of the manufacturing system such as capacity lead-time, queues, buffers, etc. This is used as a decision support and to support the tuning and optimization of the current or future system. Some of the tools have very good functions and opportunities for visualization and this is used to some extent. A third type of tool is used for off-line programming of equipment and also to visualize the movements of equipment. Such tools usually have functions to assess the risk for physical interference or collisions, which is a very important function.

There is however a limited amount of tools used in practice due to several reasons, especially for the second and third kind of tools. First, the cost for some of these tools are high, not only for a software license, but also for the training and support needed to use it. This is especially the case using 3D tools and they are mainly used when designing new equipment, cells or production lines. If models are not maintained and updated during the whole project, and verified with the actual physical installation, there is a risk that the models cannot be used at a later stage when changes are made and new simulation runs are required.

2.2 Visualization in DES models

The first graphical integration in simulation software was made in the early 80s to visualize manufacturing systems in 2D. During the last two decades 3D simulations have become frequently used in simulation software. Most software providers currently support 3D visualization with either functionality to import CAD models or through a predefined internal model library. Visualization technologies for automatic capture of the real manufacturing system was discussed already in the late 90s (Jain 1999). (Rohrer 2000)

There are several instances when visualization is important and preferred in DES projects. According to Rohrer (2000) these are some of the main instances; verification and validation, understanding and communication of results, getting buy-in from nonbelievers, and achieving credibility for the simulation. Verification and validation is the foremost important argument for graphical representation. By analyzing virtual animations of the simulation model it becomes possible to compare its behavior to that of the real system or conceptual model. When “walking through” the model a verification process can be made by visual studies of the processes. To validate the model a typical method is to demonstrate the proposed system to a group of individuals with different expert knowledge (Robinson 1997). Presenting animations from a simulation model allows non-simulation experts to understand and analyze the result and processes in more detail compared to when they are presented with text based statistics. With visualization, the simulation model results will also become easier to sell to persons skeptical of simulation as well as help in achieving a higher credibility from those who already are believers. (Rohrer 2000)

To describe graphic representation in simulation models the following key elements are discussed by Rohrer (2000); interactivity, realism, performance, flexibility, and ease of use. By combining those elements it is possible to get a good visual experience from the simulation model (Rohrer 2000).

The gaming industry of today is using advanced graphical technologies that may be suitable to implement in DES software for increased realism and performance. By improving rendering performance, appearance, and usability the user would get a better visual experience. An example of how to improve the appearance is to add textures onto 3D objects. This has shown to be one of the most important 3D features for marketing, validation and analysis of simulation models. (Bijl and Boer 2011)

To improve the user experience and interaction with the simulation model previous work has been made towards working with DES models in a virtual reality environment. One such project is the VRFactory, where the user gets the impression of being inside the factory using a head mounted display and navigating through the model by use of special gloves. The purpose of the VRFactory project was to create a realistic simulation model that the user was able to easily interact with (Kelsick et al. 2003). Another approach to creating better understanding and depth to the animation is to use stereoscopic 3D effects (Faure et al. 2012). The above mention methods has the common aim to create highly realistic and understandable 3D visualizations of simulation models, but all of them are rather time consuming.

2.3 Laser based capture of spatial data

Accurate measurements of spatial data is one key in solving many industrial engineering problems, including to but not limited to, component tolerance, quality validation and automation system equipment. Measurement methods are often categorized as either contact or non-contact methods (Várady, Martin, and Cox 1997). Contact methods comprise of measurement probes physically touching an object to record its position. Non-contact measurements are taken using sensors to detect for example optical, acoustic or magnetic signals. The signals can be pre-existing or be emitted by the measurement device for the purpose of analyzing their interaction with the surroundings. Here follows a closer look at laser based data capture to give an insight into the technology and methods that are proposed in this paper.

There are several techniques for laser based measurements, e.g. Time of Flight, Triangulation, and Phase Shift. The equipment used in the examples below is based on phase shift measurements of a emitted laser beam. It is suitable for fast data capture at ranges from about one to seventy five meters (FARO Technologies 2012). The range is dictated by the wave lengths, of the emitted laser. The phase of the reflected laser is analyzed and compared to reference beams to determine the phase shift and calculate the distance to the reflecting object.

During data capture with a 3D laser scanner, the scanner rotates around the x and the z axes to achieve a spherical field of view. Each laser measurement is gathered at an unique angle, reflecting back from the first object in its path. The resulting distance measures are stored as coordinates centered at the scanner. Anything beyond the first intercepted object is invisible to the scanner, therefore in most cases it is required to scan from several positions to acquire usable sets of data. Multiple scans are most likely required to adequately capture an area such as a manufacturing system. The scans can then be combined into one data set using reference objects that are static in position and common to the separate data sets. The process of performing a 3D laser scan could be divided into the following three sub-processes:

- Prepare Scanning – Plan the scanning and reference objects positions to ensure that all necessary data can be captured. The line of sight from the scanner to the objects of interest has to be considered as well as the line of sight to the reference objects. At least three corresponding reference objects have to be visible in two scans if they are to be combined successfully.
- Perform Scanning – Position the scans on the planned positions and execute the data capture mechanism. For good results, it is important that the scanned environment remains motionless throughout the scanning process. The scan time is about two minutes without color and five minutes with color, per scan position, using a resolution that is suitable for larger indoor areas.

- Process Scan Data – Register the scans to align and combine them into one data set and clean the data from any unwanted artifacts. The alignment is done using the reference objects mentioned. Examples of artifacts are sensor noise and partially captured moving objects.

The resulting data set can be visualized in a realistic manner using specialized point cloud software. Close to photo like results are obtained even when navigating freely through the data, even away from the scanned positions, see Figure 2. While the scene looks like a photo, moving closer to any object reveals the pattern of the point cloud that makes up the model, see fold in of Figure 2. Point to point accuracy for any two points in a data set is about 1.2 millimeters (FARO Technologies 2012). For the combined data sets the accuracy is dependent on the quality of the scan registration which in turn relies on factors such as the number and position of reference objects. See for example Rabbani et al. (2007) and Liu (2006) for more information on scan registration techniques.

The software used in this research supports automatic generation of 2D layout views as the one seen in Figure 3 (FARO Technologies 2012). This model representation can be viewed using only a web browser, not requiring any additional software. The technology described above is available of the shelf and does not require extensive amounts of formal training to use, especially if purely visualization is the objective.

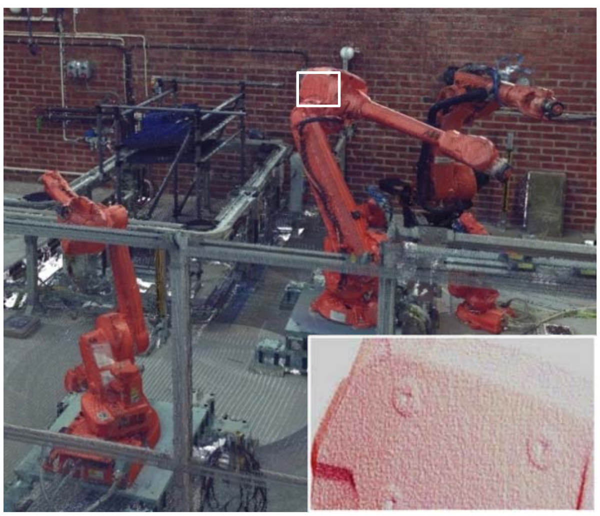

Figure 2: An example of point cloud data visualized in 3D (fold in: close up of the robot)

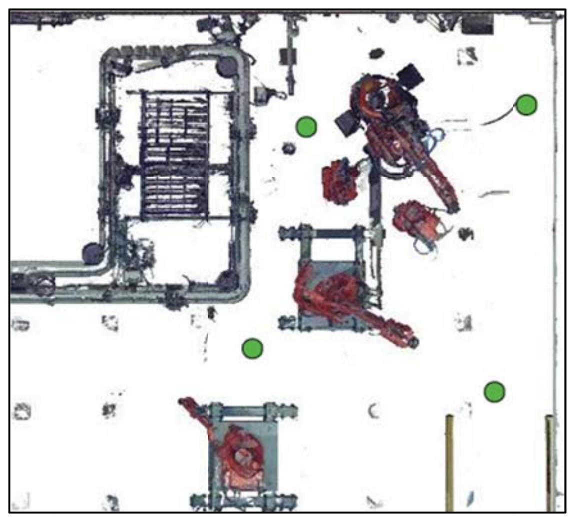

Figure 3: An auto generated 2D layout (green dots represent scan positions)

3 USING POINT CLOUDS IN DES MODELS

Combining the point cloud models and DES makes it possible to create visually realistic simulation models with a very detailed surrounding environmental. Using point clouds from 3D scanning would overcome the issue of time consumption connected to 3D modeling and at the same time provide an environment that is, within a number of millimeters or centimeters, a replica of the real world factory. This level of visualization enables easier communication of results through its photorealism as well as being an information source for the simulation engineers when modeling an existing system. While the point cloud technology is still rather new, there are several companies providing products for editing and working with point clouds and even more provide the opportunity to open and view point cloud models. In the area of DES software however, there are still very limited possibilities to use and integrate point cloud data. This section covers advantages with using point cloud models along with barriers to overcome before the combination could be totally implemented and used by simulation experts.

3.1 Opportunities

The main advantage of using point cloud data in DES is to achieve better visualization with more realistic representations of real manufacturing systems. This could be done by building the simulation model based only on point cloud models or in combination with CAD models, also known as hybrid modeling. An example of hybrid modeling is shown in Figure 4 where equipment has been imported as CAD objects and the point cloud model is used to represent the surrounding factory building. This method could be compared with building the model based only on CAD models which in most cases would be a more time consuming process than capturing a point cloud model of the environment. When visualizing a DES model with CAD objects usually only the most necessary parts are included, when capturing point cloud data instead, no extra activities are required to include details from the surrounding environment.

Figure 4: Hybrid model with point cloud data representing the manufacturing facility and CAD objects representing the manufacturing equipment

As mentioned earlier, realistic visualization of DES models has several areas of applications and maybe the most important area is to communicate results to a wider audience. Compared with 2D layouts and 3D CAD representations the audience will get a better understanding and feel more familiar with the manufacturing system. This will add an extra dimension to the discussion and analysis of the simulation model, which hopefully results in a smoother process where different parties and stakeholders will understands each other better. It will also help to prevent ungrounded doubts about whether the model is correct or not, which would have taken focus away from more important discussions. The validation and verification process will gain from the added number of people that can understand the results and therefore take part in the process without any previous simulation knowledge. Those people could then concentrate their expert knowledge to specific problems by giving their views on potential problems.

It would theoretically be possible to create an entire simulation model based on point cloud data for the purpose of reconstructing an existing manufacturing site. As a result of its high accuracy, the complete model could be used to carry out factory measurement to for example evaluate if new equipment will fit into the existing environment. Resources or equipment could in that case be imported, either as point cloud models or as CAD objects. Compared to taking measurements from potentially inaccurate and outdated CAD drawings or taking real time measurements at the factory site, point cloud measurements are both less time consuming and less error prone.

3.2 Barriers

Even as the point cloud technology holds great potential to become a key part of DES modeling, there are still barriers to overcome. The main barrier is to gain interest from providers of DES software to develop support for point cloud data integration. A possible work process in the first phase could be to use one software to edit the point cloud and import static point cloud models to the DES software. The next step could be to enable the possibility to edit point cloud models in the DES software. When saving the point cloud models the file size will be quite large, which could result in performance issues while running the simulation model. This is mainly due to how the computer renders the points. With better computer performance and more advanced graphical engines in DES software this should not be an issue in the future.

A general problem when working with graphical representations or CAD models is interoperability, different software providers have their own proprietary formats and algorithms. The same problem exists for point cloud models. This produces a need for converting data between different formats which involves the risk that information will be lost resulting in quality issues. A solution may be to try to create a common file format accepted by all parties, one such ongoing effort is the ASTM Standard E2807 which targets 3D imaging data exchange (ASTM Standard E2807, 2011).

The increased level of data detail creates questions regarding what is part of a resource and what is not, take the picture in Figure 5 below for example. The CNC machine is clearly defined by its cover and protective screen. But in addition to that there are auxiliary objects such as power rackets, an operator table for preparing tools, and an ergonomic mat in front of the machine to ease the stress on the operators knees and feet.

Figure 5: Point cloud of a CNC machine

This is a clear example of a symptomatic difference between a CAD representation of a manufacturing facility and a point cloud representation. There are no objects or semantic information present in the point cloud, only a single very large point cloud object, or if you will, an enormous amount of single particle objects. The user has to somehow structure the data and add context to make it useful. This can be done manually by partitioning sets of points, such as the CNC machine mentioned above. This type of work requires manual labor at present, there are however ongoing work towards automatic object recognition. If successful, this approach obviously holds great potential.

A manufacturing company should be considering how to spread the information after performing a scan of a factory. This is due to the fact that the entire site will be scanned as built and all details will be included. There are mainly two different categories to consider; the level of classified information in the facility and personal integrity. This could be compared with Google Street view that in some cases handle the same type of information and level of details. In those pictures both human faces and vehicle plates are censored to protect the privacy of individuals. Even if the data may not go public the companies needs to carefully consider how the data should be spread and to whom.

4 VISION

The vision for the future held by the authors is to include point cloud technology as a natural part of manufacturing system development projects, especially, but not limited to, those involving DES. There is a need for standardized methods and work procedures to gain the most out of this combination. To get support from the simulation community, the process of including the point cloud models needs to be smooth and effective. After scanning a facility it should be easy to import the point cloud model into the DES software. For easy modifications, different objects should be predefined in the model and possible to move around freely. Logic should be added to different parts of the model and it should be possible to edit the point cloud model within the DES software. It would then be possible to use the point cloud model as an accurate system representation to validate and verify the logic of the simulation part, as well as for studying a virtual representation of the system with a high level of visualization.

When changes are made to the real manufacturing system it should be possible to preform new scans and import the updated data into the existing model. The purpose of this process would be to always have an updated model where it is possible to evaluate new changes without requiring the time consuming process of manually re-creating an updated model.

In the next phase the simulation model could be used as the main layout and virtual representation of the factory. It should then be possible to analyze the situation from different perspectives, such as material handling, logistic issues, ergonomics, and assembly stations.

The simulation interface should be easy to use, to allow non-experts to make smaller changes while discussing different solutions at project group meetings. It would also be preferred if the simulation was a part of a larger software package, for example a product lifecycle management (PLM) system, where the point cloud model was used as the base for all factory information. To get a wider usage the package should also include other tools to get cooperation between functions in the organization. All project members should have easy access to the model for updated information.

5 CONCLUSIONS

In this paper the focus has been directed towards the potential benefits of using 3D scan data to achieve a higher level of visualization to enable more accurate DES models, but there are also other important benefits with this new technology described in this paper. Point cloud models holds a great potential for contributing to realistic representation of the manufacturing system in. While some work has been done, there are still gaps to cover and issues to be addressed before this is feasible, mostly due to undeveloped simulation tools.

The technology implementation is in its initial phase and much work is required before a full integration and standardized work methods can be realized. Two important areas of use are identified as planning of new manufacturing systems or rebuilding existing manufacturing systems where facilities are preexisting, point cloud models could then provide accurate representations of existing constraints. Additionally a big effort needs to be put towards integrating point cloud technology into the daily work with developing manufacturing systems.

The visualization of simulation models has shown to be very important for communicating the simulation result to a wider audience. Point clouds could add an extra level of detail to the simulation models and make it even easier for a non-simulation expert audience to understand the result. Some key elements (see section 2.2) for good graphical simulations, such as realism, flexibility, and ease of use are met either partially of fully using this new technology.

The prospect of using point clouds have several advantages; it promises to be both faster and cheaper than CAD based modeling in 3D and it could assure that the actual current version of the manufacturing system is used when performing simulations.

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