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Visualization support for virtual redesign of manufacturing systems

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Abstract

Rapidly changing products and market demand call for manufacturing systems to be continuously adapted and developed. The process of modifying manufacturing systems requires large amounts of planning involving contributions from personnel across an organization. These people need a shared understanding of the future system, including but not limited to its design, functions, and expected performance. One common representation in the virtual manufacturing system domain are 2D CAD layouts. Typical problems with such traditional 2D models are that only experts understand the content fully. For increased understanding, 3D CAD models could bridge the gap between different areas of expertise. However, creating 3D models representing the complete system is traditionally time-consuming, resulting in oversimplified models or limited to parts of the system. Furthermore, such models normally contain uncertainty about building-related geometries that could incur costly mistakes if used as basis for decisions, e.g. realizing during installation of a machine that roof-beams interfere with the planned placement. This paper evaluates what type of problems can be solved with better visualization support, e.g. issues concerning workshop-layout, production flow, workplace design, etc. The evaluation is based on two case studies at different manufacturing sites during ongoing system redesign processes. The case studies implemented visualization using a combination of CAD models and 3D laser scanned as-built data of the current system and facility. The vision is to implement the Lean concept of "Go to Gemba" for a future state in a virtual environment. Bringing this concept into the early phases of manufacturing system redesign has the potential to facilitate the creation of a shared understanding of the future system within cross-functional project teams.

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1. Introduction

Manufacturing companies in prosperous countries are continuously struggling against competitors on the global market, which requires manufacturing systems with high margins on profitability [1]. The time-to-market needs to be reduced to fulfill this request by highly time effective development projects [2]. Those projects are normally under tight budget and time schedule, which leaves no room for mistakes and misunderstandings [3]. As a tool, to detect and prevent mistakes and misunderstandings early in the process, companies use virtual representations of products and manufacturing systems [4]. One critical type of project, often initiated by external pressure and changes, is redesign of existing manufacturing systems.

Visualization of manufacturing system layouts is normally done using 2D computer aided design (CAD) data or simplified 3D CAD representations [1]. However, due in part to the time consuming task of modeling, the level of visual detail and accuracy of those representations are lacking in comparison to the real world systems. A potential problem with this lack is the ability to effectively communicate solutions between persons with different areas of expertise to create a common understanding of the future system inside the organization [5]. An improved level of visualization support could reduce the gap in understanding between persons and detect potential problems early in the development process.

To create detailed and realistic 3D models of the manufacturing system rapidly a proposed method is to use 3D laser scanning technology. The technology holds a potential through its speed, accuracy and ease of use [6]. From the 3D scan data it is possible to create a point cloud that visualizes the as-built factory in a photorealistic 1:1 scaled 3D model. Such a model could

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be modified to visualize and evaluate future changes. The evaluation could be based on hybrid modeling where the point cloud model is combined with CAD objects of new factory equipment. Manufacturing environments is so far a relatively undeveloped area in terms of 3D scanning, but the technology holds potential in the area and development work is ongoing [6].

An important research goal is to develop a solution to support cross-functional teams of manufacturing development engineers in the decision process. The aim is to provide a common view of the manufacturing system, which facilities a common understanding to make the right conclusions and decisions at a certain point of time. Within Lean production the ”Go to Gemba” approach to better understanding and problem solving is an important concept [7-8]. The concept stresses the importance of visiting the real place where a problem exists, in this case the shop floor, to get firsthand information and understanding [7-8]. If the team of engineers could “Go to the future Gemba” they would be able to get a better common understanding of what they are about to create and make better decisions.

This paper will discuss the potential contribution of using point cloud models for visualization support when redesigning manufacturing systems. In section 2 visualization methods used for factory planning are summarized along with a description of the 3D laser scanning technology. Two case studies are presented in section 3 detailing how the technology has been used to evaluate pending manufacturing system redesigns. Based on experiences from those studies a discussion, conclusions and future work are presented.

2. State of the art

Developing effective manufacturing systems is a complex process involving and affecting persons all across an organization. Based on their expert knowledge those persons often have different interests in and views of the manufacturing system. To prevent mistakes they need to understand each other and share the same system view during planning and discussions. This is not always possible without support from some type of tool, such as a virtual representation of the system. Creating a representation with realistic visualization could enable everyone to relate to and create the same view and mental model of the system. Such an approach is described in Fig 1 where the relationship between the mental model, virtual model, and reality are presented [9].

This section will discuss the theoretical aspects of visualization in factory planning and give a description of the 3D scanning technology used to create point cloud models.

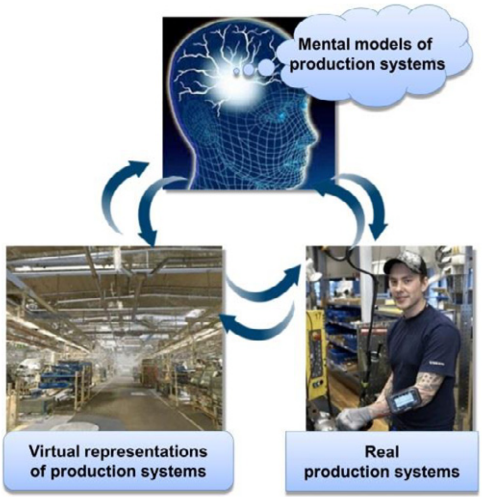

Fig. 1. The three views of production systems [9]

2.1. Visualization in factory planning

Redesigning a factory is a complex process where the solution needs to be optimized and evaluated based on several factors, such as material handling, product flows and factory logistics [10]. A number of different solutions of how to construct the manufacturing system based on a digital factory model has been discussed and presented over the years. Virtual models used to visualize planned factory layouts has shown to be helpful during the evaluating process and to avoid costly mistakes [11]. Users will get better perspectives if 3D models are used in the planning process instead of traditional 2D models [11]. There are several additional benefits from using detailed visualization in those virtual models. E.g. increase in planning speed, decrease in planning costs, and increase in planning quality are some of the benefits that have been discussed [1], [5]. The level of visual detail in those models could however differ as well as how the user interacts with the models.

Virtual reality is an example of a technology used to increase the level of interaction between the user and the model, which was discussed for example by Wiendahl et al. [5] and Menck et al. [12]. In this context the user experience is discussed and how to create a realistic model of a manufacturing system based on 3D CAD objects, where the user could get the feeling of being inside the virtual factory. To increase the user interaction in the initial step of the planning process a proposed method by Dangelmaier et al. is to create a factory model based on augmented reality [3]. The model will then be presented in a virtual reality environment for further discussions. Using the proposed method enables effective cooperative factory planning [3]. A challenge and common problem with these types of tools are how to make them user-friendly and easy to access for a wide scope of users [1].

2.2. Spatial data collection

One key to solving many industrial engineering problems is accurate measurements of spatial data. 3D imaging is a field within measurement science dealing with capture of three-dimensional spatial data. There are many different technologies for that purpose, see e.g. Bi and Wang [6], or Sansoni et al. [13] for an overview. A phase based 3D laser scanner has been the technology used to capture spatial data in the study presented in this paper. The scanner has a near 360 degrees field of view and typically captures tens of millions of data points in a few minutes. While the technology is rather new, there are ongoing efforts to standardize testing and assessment of equipment and the data formats for storing the measurements [14]. The technology is being used across a number of different fields, e.g. heritage documentation, forensics, and tunnel mapping [13], [15].

A brief description of the workflow pertaining to data capture using a 3D laser scanner is [16]:

- *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 separate scans if they are to be combined successfully.
- *Perform Scanning* - Position the scanner on the planned positions and execute the data capture. For good results, it is important that the scanned environment remains motionless throughout the scanning process. The measurement process duration per scan position is about 5 minutes 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 result is a large dataset containing measurement points described by x, y, and z coordinates and an RGB-color code (also normal direction and reflection intensity). A section of a factory 50 by 50 meters could typically consist of 500 million points, and generate a file size of approximately 4 gigabytes. There are many vendor specific data formats, which could potentially lead to reduced data interchangeability and transparency. However, standardized formats have recently been brought forth as a remedy to this, see ASTM E2807 [14].

The data is simply a large amount of points in space, which has coined the commonly used name point cloud. The point clouds can be made sparser by filtering away a percentage of the points. This reduces data size and can be done to various degrees depending on the target application and processing performance. To be able to use the data for purposes beyond visualization of static backgrounds, manual intervention is necessary. Typical operations performed in a factory environment are object based selection and grouping of a subset of points, an example of such a model is presented in Fig 2. This could e.g. be used to separate a machine body from the data and save it as a stand-alone point cloud file. Most software designed to work with point cloud data also have the capability of rendering and/or editing CAD data in parallel, which is useful for a number of applications.

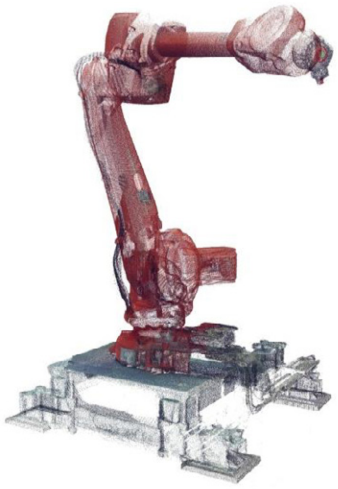

Fig. 2. Example of a point cloud model representing a robot

3. Method

This paper is based on case studies at two manufacturing sites producing high-end engine components to the aerospace industry. The current manufacturing systems in the two factories are mainly organized as functional layouts, but the company aims to change the systems towards a more product-oriented layout. 3D scan data has been used in both studies in parallel with the normal work method for visualization consisting of basic 2D CAD layouts and for some specific parts 3D CAD models. The point cloud models were used to support the visualization of the current situation as well as future changes. The research goal with the two studies was to evaluate potential benefits and issues with the scanning method.

The case studies were performed in three steps as follow:

1. *3D scanning of the factory*
2. *Pre-work of the scan data*
3. *Work meeting and discussion*

The scanning process was performed as described in section 2.2. The first case study was used as a feasibility study and experiences were taken into consideration when performing the second study. The two case studies are presented in this section in the same sequence as they were performed.

3.1. Case study A

The section of the factory studied in this case was undergoing a major reconstruction. Most of the old machines were moved to another location and replaced with new machines to create a new manufacturing system. The goal with the study was to evaluate if the new layout proposal would fit and be suitable for the existing factory building.

To cover the selected part of the factory the scanning process required 13 scan positions. The complete part of the factory for the new manufacturing system was captured with a focus on building geometries. Static reference points were mounted in the building to enable synchronization with future complementary scans. Most of the old machines and equipment had been moved when the scanning was performed which resulted in a more or less empty facility with reservation for some construction-work equipment and material.

Based on the 3D scan data a point cloud model was created. In the model construction material and equipment was removed to get a clean model of the factory building. Fig 3 shows a section of the point cloud model before any modifications had been made. The point cloud model was synchronized to the factory coordinate system and compared with the 2D CAD layout to find possible differences. To visualize the outcome from the scanning process, other than the actual point cloud model, a fly-through movie of the factory was created.

Fig. 3. The point cloud model before modification and cleaning

The result was presented to the project group consisting of experts from departments across the organization. With assistance from one of the authors the project members were able to walk around in the model and make measurements of interest. For example distances between pillars and walls as well as other building geometries.

3.2. Case study B

The second case study was performed in a factory with production running at full speed. The work content in this study can be separated into two steps. The primary goal of the case was to evaluate a proposed layout considering a new machine and its attached equipment before start of installation. To free up room for the new installation an existing machine was moved to another location.

Two people carried out the 3D scanning process in one workday during full production but limited to the section of the factory affected by the reconstruction. To cover enough detail regarding the machines and other equipment 22 scan positions were required.

The first step in the modification of the point cloud model was to select the points representing the existing machine and move them to the machine's planned new location. The main body of the machine was placed onto an existing machine foundation, resulting in that attached equipment overlapped with the material-handling aisle. Points representing the equipment were moved around the machine to evaluate new locations.

In step two a hybrid model was created where 3D CAD models of the new machine and necessary equipment were imported and placed according to the proposed 2D CAD layout solution. A section of the hybrid model is presented in Fig 4.

Fig. 4. The hybrid model

The prepared hybrid model was discussed during a work meeting with the cross-functional project group. Project members had the possibility to come up with suggestions for alternative solutions. Based on the discussion; 3D CAD objects in the model were moved as well as parts of the point cloud to create alternative solutions. Different solutions were studied from several perspectives and measurements were taken to verify the model.

4. Result and discussion

Project members in the two case studies were impressed by the visualization possibility point cloud models holds and found possible areas of application for their specific interest. Those thoughts and main reflections are presented and discussed in this section.

As mentioned in section 3, case study A was used as a feasibility study to evaluate the potential of the technology. This study did show that the technology was well accepted in the project group. Presenting the result to the group did have a positive outcome, especially for persons working with layout planning and machine acquisition. During the discussion some typical problems regarding the layout planning came up. Even if the project meetings normally are held in close contact to the factory section the group did find it very useful to have a digital copy of the actual factory building. They would then have the possibility to quite easily and in a short time study the model or take measurements when certain issues were discussed. Normally they would either go out onto the factory floor to see for themselves during the meeting or postpone the task to the next meeting. Issues solved by such information are for example the height between the floor and ceiling or other parts that could interfere with the planned machine location. This information would not have been possible to acquire from the 2D layout, which they normally use for most of the planning.

The first modification in case study B was to move the existing machine to the new location. By moving the point cloud in the model representing the machine it was possible to visualize the machine at the new location and evaluate different installation alternatives. Comparing the model with the real installation, the result of the installation was very close to what was visualized in the model. A problem with moving specific parts of the point cloud is to define all points belonging, in this case, to the machine.

Before the work meeting regarding the installation of the new machine the project group had already decided upon a layout solution to be used. This layout was mainly based on a 2D CAD drawing with some support from simplified 3D CAD models. Based on that layout a hybrid model was created by importing the 3D CAD objects into the point cloud model including all surrounding support equipment. All persons present at the meeting realized by analyzing the hybrid model that the machine and supporting equipment require more space than was available. With the first proposed layout it would not have been possible to store enough trollies with material and products close to the machine. With this new information at hand, the group discussed alternative solutions, which were then tested in the hybrid model. 3D CAD objects and point cloud objects were translated in the model to positions suggested by the group, ultimately resulting in a new layout proposal. Measurements were made in the hybrid model to validate the model to the real world and to support further discussion topics. Without the visual support from the hybrid model and the fact that experts from different parts of the organization were gathered at the same discussion, the installation would have been made based on the first layout proposal, which could have resulted in problems during and/or after the installation.

A known layout issue described by the project group was to get the proposed solution accepted by the operators. Traditionally, a 2D layout is presented to the operators, most often receiving approval. But after the new machine or workstation had been installed and the operators were fully able understand the changes, they were not always so approving of it, at times this has resulted in costly rebuilding activities. Therefore, an operator was invited at the work meeting and came with valuable insights based on experiences from the operation phase.

The method of presenting and working with the hybrid model could also be discussed. In these cases a projector beam was used with a connected laptop, from where the model was navigated and modified. The authors believe that it may be more suitable to use some sort of interactive solution instead. A reflection from the case studies was to use an environment that encourages creativity. Currently the tools used in the case studies require an expert to be used to its full potential. However, it could be discussed whether this should be necessary or not. If the tool and model enable interactive use by everyone it may improve the outcome of the discussion even further.

Another interesting improvement could be to couple this scanning method with other visualization technologies such as augmented reality and virtual reality. The common factor and overarching goal remains; improving the ability to provide a good understanding of the future situation for all users.

5. Conclusions

The initial studies presented in this paper have shown that a realistic virtual model of the factory with high level of details and accuracy can be used as high-level visual support when redesigning manufacturing systems. Using 3D laser scanning to create point cloud models holds the capability to provide this realistic visualization and enable a better understanding throughout an organization. Visualizing the manufacturing system so that people with different prior knowledge and interest can understand it and create the same mental model will enable the model to be more efficiently used in discussions and as a decision support tool. The hybrid model used in the second case study did to some extent enable the possibility of "Go to the future Gemba" and to discuss the proposed solution based on a common view of the manufacturing system.

To achieve good results during such discussions it is important to gather a cross-functional team of people with different background and knowledge. The elevated form of visualization that has been proposed in this paper holds the potential to be especially useful for including operational personnel in the discussions. During the discussion everyone should, based on the virtual representation, have the possibility to present their view of the solution and highlight possible problems in their respective working areas. This would make it possible to prevent mistakes early in the planning process that may not have been found otherwise.

The solution may not be limited to point cloud models, but the focus should be headed towards an effective method for creating virtual representations of the future factories with realistic visualization and high level of detail in a short time.

6. Future work and visions

Further user studies with experts from different areas of the organization will be performed as the next step of this research. Based on experiences and demands from users in those studies a method will be proposed. This method should include a structured approach for analysis and synthesis work in cross-functional teams to fully utilize the potential of high-level visualization support. There are different factors that need to be covered in this approach such as the overall material flow, material handling within the workstation, tasks for replacing tools, maintenance etc.

The future goal and vision is that the method is developed into a support tool used in all suitable projects working with developing manufacturing systems. An envisioned scenario is to use the tool throughout the whole project by users from a wide scope of areas and to use the 3D scan data to create the main factory representation.

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