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A novel VR tool for collaborative planning of manufacturing process change using point cloud data

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Abstract

Today, manufacturing industry is facing increasing demands of customized products and global competition. Companies need constant and efficient changes in manufacturing process to meet the challenges and to stay competitive. However, a successful manufacturing process change is not easy to accomplish due to the fact that any change in the manufacturing system will affect various actors involved. Previous research has shown that active engagement of all involved actors in the planning phase improves the quality and success rate of the manufacturing process change outcome. The conventional supporting tools used mostly in this process such as documentation tools for text, numbers and static pictures typically requires an experienced user to be fully understood. Thus, some of the involved actors are not able to participate in the manufacturing process change (MPC) on equal terms.

Over the last decade, the advancement of virtual technologies has shown the potential to improve the quality and efficiency of the planning of MPCs. Specifically, 3D laser scanning technologies can produce realistic virtual representation of factory environment with rapid point cloud data capturing. Immersive experience with rich context in combination with e.g. the virtual reality head-mounted display (VR HMD) could be provided, which is beneficial in the assessment and usable for several actors.

This paper presents a novel supporting tool for the MPC design and planning, which incorporates point cloud data of real-world truck factories visualized using VR HMD technologies. It provides a collaborative and immersive environment for all involved actors to actively contribute in the MPC process. Tests and interviews have been conducted with various actors from industry for evaluation and validation of the proposed tool and its findings. The test data were analyzed and discussed with regard to the benefits and problems found as well as potential for future research studies and development.

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Keywords: Point Cloud; Virtual Reality; Manufacturing Process Change

1. Introduction

In today's global market, manufacturing companies are facing the shift from mass production to mass customization [1]. It becomes essential for companies to fast adapt to the new trend. The ability and efficiency of improving production so that it can meet the end users' requirements become pivotal for companies to stay competitive in the new market. However, manufacturing process change is not an easy task, as any change will affect both internal and external operations throughout production. Conventional process of improving manufacturing heavily depends on the expertise and experience of the professionals [2] and it usually brings unwanted disruptions to the ongoing production [3].

The latest advancement of virtual technologies such as 3D scanning and virtual reality have brought possibilities to change and improve the work procedure needed for improving existing manufacturing. 3D scanning technologies are known for rapid

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capturing the physical environment and turning it into realistic virtual environment [4], while virtual reality can provide users the immersive experience in the virtual environment without physically visiting the sites [5]. In this paper, we propose a virtual manufacturing approach which integrates the point cloud data of the real factory with existing generic CAD library. Visualizes the data and enables interaction through a VR HMD, with the aim of widening the scope of potential users, whom can participate and contribute to the process of designing and validating the new Manufacturing Process Changes (MPCs).

The paper is organized as follows. In section 2, previous studies are presented. The proposed VR approach is described in section 3. In section 4, an industrial case is implemented to demonstrate the VR approach. Results and discussion follows in Section 5 and 6 respectively. Conclusion and recommendations for future work are drawn based on the study, which finalizes the paper.

2. Related studies

2.1. Manufacturing process change

Manufacturing companies need to make continuous changes or adaptations throughout time for many reasons. It may be the need to gain efficiency or flexibility in production. Increasing awareness of environmental concerns may also lead to changes in manufacturing [6]. The introduction of new products as well as the demands for higher productivity and quality are also driving forces for the changes. Westkämper [7] described manufacturing as a multi-scale (time and room) chaotic system and identified the turbulent influencing factors for the continuous changes of factory structures, see Fig. 1.

Fig. 1. Influencing factors in manufacturing systems (Adopted from [7])

However, previous studies have shown that it is difficult to achieve successful MPCs as any change will affect various actors in the process, so that a coherence procedure that can facilitate the active participation and contribution of all actors is essential [8].

Ishikawa and Deming suggested that workshops conducted by related workers are a systematic way to achieve improvement in manufacturing systems [9], [10]. Each workshop is a one to five days period conducted by the workers in the manufacturing area that needs to be improved, together with engineers from other functions while the production is temporarily stopped. The joint participation of all actors involved ensures proper outcomes from the workshops which can be the reduction of set-up times or improvements of layouts [11]. Aurich et al. further developed this workshop approach and proposed the workshop-based Continuous Improvement Process (CIP) [12]. The workshops are supposed to carry out in a fixed time intervals to ensure the continuous improvements. The typical CIP procedure is shown in Fig. 2.

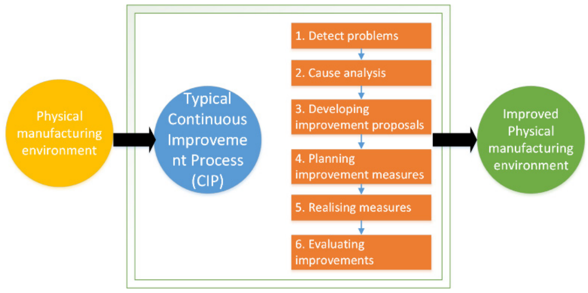

Fig. 2. Typical CIP procedure. (Adopted from [13])

It is not difficult to find out the drawbacks of the conventional workshop approach. The quality of the workshop outcome heavily relies on the experience and expertise of the involved actors [10]. It also would interrupt running manufacturing by imposing unwanted stoppages which would in turn reduce productivity and raising problems in scheduling and maintenance [11]. During MPCs, the cost of the disruption unwanted stoppages in production is often proven to be often more than that of the new equipment purchased [12].

The development of VR technologies is promising to improve the previous CIP approach with regard to reducing interruption and facilitate collaboration [12].

2.2. Virtual reality for manufacturing

In 1965, the initial idea of virtual reality was proposed as "A system that can display information to all senses of the user with an equal or bigger resolution than the one that can be achieved in a natural way so that the user cannot say that the artificial world is not real." [14]. In 1968, the first VR system was successfully implemented with a HMD that presents a user with stereoscopic 3D view slaved to a sensing device, which tracks the user's head movement [15]. Ever since then, VR is starting to draw much research attention and various definitions and implementations have been developed [16]–[19]. Korves and Loftus described VR systems based on the different set – ups and thus categorized them as:

- Desktop system.
- Wide-screen projection system.
- Immersive CAVE system.
- Immersive VR system using HMDs [20].

Over the years, as the maturity of VR technologies increases, so is its presence in the manufacturing domain. At the same time, the use of VR as a collaborative tool for exchanging data and information has increased significantly in production related area [21]. VR is seen as a helpful technology in achieving better understanding and decision-making by providing immersive experience and visualization. These are promising merits for the manufacturing industry. Wiendahl and Harmschristian have shown that immersive VR is an important tool for collaborative factory planning, especially when multiple viewpoints of users are visualized [22]. Menck stated that the VR based collaborative planning tool can extend the communication and facilitate cooperation beyond existing organizational boundaries, which would reduce the complexity of work and increase the work efficiency [23].

In order to better leverage the full potential of VR in manufacturing, several frameworks were developed and proposed to guide and standardize the procedure [20], [24]. Aurich further developed the CIP workshop approach with the integration of advancement of VR technology and proposed a VR based CIP workshop approach [13]. Despite all the benefit VR promises in the above studies, the process to virtualize the manufacturing environment still needs expert knowledge and takes time in building the virtual model, which prevent its wider implementation in the industry.

2.3. 3D laser scanning

3D laser scanning, often also termed LIDAR, is an active, non-contact, range measuring technology [25]. The media is a laser beam which is either overlaid with a modulated wave pattern for phase based distance measurements or pulsed intermittingly for time of flight (TOF) based distance measurement. To capture spatial information the 3D laser scanner is positioned inside the area of interest and will emit the laser while capturing the returned reflection to measure the distance to the reflecting surface.

The device articulates the laser beam 360 degrees around the area using a rotating mirror which is spun methodically to face all directions around the device with a given increment. Each measurement taken, typically tens of millions per scanner position, is stored as a coordinate in space referenced to the center of the LIDAR. Many modern LIDAR devices also incorporate an RGB sensor to enable capture of the color of the measured coordinates.

In areas that are densely populated with machines and equipment, such as a production system, the line of sight of the LIDAR will be limited and the data capture needs to be repeated on several positions throughout the area in order to capture all the objects and surfaces. This results in multiple data sets which needs to be registered together into a common and coherent coordinate system.

The resulting combined data set is popularly called a point cloud, owning to the nature of the data; millions of measurements organized in space. When rendered on a computer screen the point cloud represents a photorealistic 3D environment in scale 1:1 with the captured area [4].

3. An industrial case

A truck manufacturing plant in United States was selected to demonstrate the VR collaborative tool which incorporate 3D scanned point cloud data for the planning of manufacturing process change. In the aliment of master process across Volvo plants, the firewall production cell has become one of the most evident bottom neck to cope with the increasing product variants and production flexibility. New equipment and production flow are needed to upgrade the current firewall production, thus new production layouts need to be designed and evaluated before implementation.

3.1. Point cloud capturing through 3D scanning

Data collection was conducted during two days and resulted in a total of 82 individual scans, covering a large portion of the main assembly line in the plant. The firewall subassembly production cell was selected as the focus for the demonstration. Its core components were mainly captured in five scans, but data from surrounding areas were also included in the visualization to provide context to the cell as a part of the whole production system.

3.2. Post-processing and integration in Unity

The biggest advantage of 3D laser scanning is the rapid capturing of spatial data into point cloud data set. It can save company from the costly and time-consuming process of model the whole virtual environment in conventional CAD software. However, one drawback is the automatic objectification of equipment in the point cloud data set is difficult. The point cloud data has no mesh, but thousands of points, some manual process are needed to cut out the objects which are needed to be intractable in the VR layout planning tool. Existing CAD models can be included in the virtual environment together with point cloud data. This hybrid approach of integration point cloud data with existing CAD can be useful when introducing new equipment or robots into the existing production line.

In this case, the post-processed point cloud data was then combined with CAD data to form the virtual model in a Unity 3D environment. In the test environment, the firewall production cell can be accessed by users for performing the tasks of changing and evaluating the layouts. The tool was developed as a collaborative virtual environment with the following interaction functions available:

- Navigation through walk or teleport
- Visualize realistic virtual factory and augmented information (User feedback and machine status)
- Relocation of intractable machines/equipment
- Save/load layouts
- Leave feedback messages

Provided with the above functions, it is possible for users with various background to easily access the virtual factory as well as creating and assessing possible new production layouts. It adopted the concept of CIP [13] with iterative procedures to verify new layout designs before implementation. The basic concept for the collaborative VR tool is shown in Fig. 3.

It starts with the data preparation for the virtual factory. 3D laser scanner will capture the point cloud data set of the real factory, which will be the major data needed for the virtual model. Another data source is the CAD models of any machines that are intended to be implemented during the layout change. The data can be further enhanced with the connection to the existing ICT systems, so that the virtual model not only shows the realistic factory environment, but also has the possibility to augment additional machine specific information in the virtual model for the better support of the decision-making in new layout design.

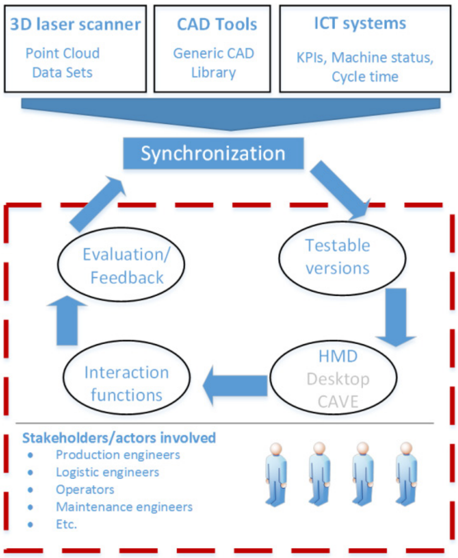

Fig. 3. Conceptual model of the collaborative VR tool.

Depending on the specific requirement of each layout planning scenario, the above data can be prepared and feed into the Unity development tool for synchronization, so that the virtual tool is ready for later layout creation and evaluation.

After the virtual tool is prepared and deployed to the server, all the stakeholders can access the virtual tool anywhere in the world provided that an immersive VR HMD is available. In the virtual environment, each stakeholders are provided with the information they need to create new layouts or assess and leave comment to existing layouts based on their own expertise. Thus, different layout proposals and feedback are gathered in the system for the synchronization which will either reach the idea solution for implementation or repeat the same process until the idea solution is reached.

3.3. Test setups

The demonstrator was set up at Volvo headquarter in Göteborg, Sweden, where its global function in research and development situated. An auditorium with a stage area and a back projected screen. The setup is consisted of a stationary PC with demonstrator software, two positioning sensors on tripods to track the VR space, HMD and hand held controllers for interacting with the VR environment and a presentation screen used to give instructions before the test and to duplicate the VR user's view for onlookers and researchers during the test. The test environment setup is illustrated in Fig. 4.

Nine participants from different actor groups within Volvo and one senior researcher in the field of virtual production from the research team at Chalmers took part in the test.

Fig. 4. Illustration of test environment setup.

3.4. Test process

The test subjects were guided through a short training scenario and then presented with the VR model of the factory as shown in Fig. 5. During the demonstration the test subjects were able to freely navigate in the layout using the virtual environment. They were asked to finish the following open tasks:

a) Navigate in the 3D point cloud virtual factory.
b) Modify the layout.
c) Save and load new layout.
d) Give feedback on the presented layout in the system based on their expertise.

Fig. 5. A test subject is exploring in the virtual factory.

After the test subjects finished their tasks in the virtual tool, they were given a questionnaire of both open-ended questions and close-ended scale ratings to fill out regarding their experience on using the virtual environment.

3.5. Test results

The results are consisted with two parts, the qualitative feedback which leaves room for the respondents to express in words their experience, and to motivate their scale ratings in the quantitative part. The quantitative part asked the respondents to rate different aspects of the demonstration and the value of the proposed system to different stakeholders across the organization. Fig. 6 summarizes the rating scores, which were given by the test subjects.

It is clear that the majority of the test subjects were positive with the potential benefits of this VR approach and would like to share or recommend the system for a wide usage. Due to the fact that the tool is in prototype phase of the concept, so that the user experience related ratings were not as good as the potential benefits.

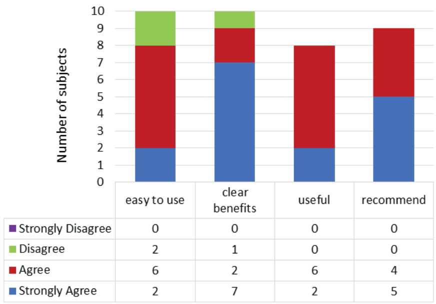

Fig. 6. Test subjects' rating feedback on the VR tool.

The test subjects were also asked in what areas within the manufacturing system that they saw uses for the collaborative VR tool. "In which areas of manufacturing do you think this system can be beneficial for the improvement of current work practice?" The listed categories are based on the work of Nee et al. [26]. The most promising application areas were chosen as layout planning, training and education, and simulation. In Fig. 7. It lists the results from the questionnaire. The result also provides certain hints are the future research focus.

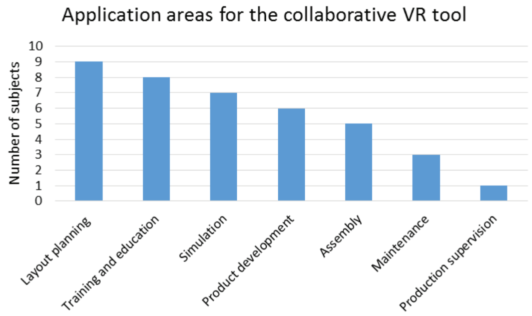

Fig. 7. Result of promising application areas.

For the qualitative part of the questionnaire, the feedback were analyzed and some reoccurring themes were identified. With the positive benefits such as easy to use, visually representative of the real factory, accurate and "near" life like experience. At the same time, some obstacles were detected as one test subject experienced dizziness while using the HMD, another one had problem of disorientation in the virtual environment. Additionally, two test subjects believed that the tool as such is different from what they used to, thus it takes time to learn and get familiar with.

Towards the end of the open questionnaire the test subjects were asked: "What challenges do you anticipate if your company is going to implement this VR systems?" The answers given can be categorized into three different challenges: data compatibility, organizational attitudes, and cost. Data of the various aspects of the production system resides in many internal systems and in different formats. Accessing all of it seamlessly is not an easy task.

4. Discussion

In this study, we first proposed a hybrid approach for virtual factory modeling. The hybrid approach shows the potential to take advantage of existing 3D models as well as using 3D laser scanning for rapid capturing of realistic virtual factory. 3D laser scanning is fast and requires little specialized knowledge to capture the realistic representation of the actual factory environment. With the hybrid approach, the virtual modelling process is improved with regard to development time, knowledge requirement and virtual model quality.

The immersive HMD and trackable controllers were used to access and interact with the developed virtual model for layout plan. Compare to the desktop virtual planning, the immersive HMD provides the real-scale environment that users can walk around, interact and assess production layouts. With the immersive HMD and trackable controller, the virtual planning experience is much closer to the real life workshop at the actual production site, thus potentially resulting with better decision-making in the continuous process of upgrading existing production systems.

However, there are still many identified challenges, which need to be addressed before it can be widely implemented in industry. In the development process of the integrated VR tool, there is a lack systematic methodology available to guide the work. It was also brought up by the test subjects that various systems and data formats could pose a barrier for the efficient and effective integration. Therefore, related standards or frameworks for integrating VR technologies need to be developed constantly.

Additionally, while the current 3D laser scanner is capable of rapid capturing realistic virtual representation of the real world without much expert knowledge, the technology has certain constraints as well. First of all, the captured point cloud data needs some post-processing procedures such as objectification to make the data applicable for more application scenarios. Automatic objectification algorithm is still in the premature phase, while manual process can be tedious and time-consuming. Another challenge is to keep the point cloud data always up-to-date, as production systems are not static. So there is the need to have the equipment and infrastructure in place to handle the continuous 3D scanning and updating of the point cloud data. At the same time, the increasing demand of higher computing power is also a hinder. This is especially important in the VR applications as any lag of image or lower frequency rate would make the user suffer from dizziness and other ergonomic issues.

Besides the technological challenges, the organizational attitudes and user acceptance towards the VR technologies are the key factors of successful adaption. This requires education and training of users, incorporation into existing work methods as well as standardize VR interaction design. VR applications have brought new ways of presenting information and interacting with the production system. Users will need time to learn and get familiar with the new input and output methods. At the same time, further studies of standardized VR user interface and interaction design will help to ease the learning process.

5. Conclusion

This study has shown that the incorporation of 3D laser scanning technology in the development of virtual manufacturing tools could help reduce the time of modeling the virtual factory. By introducing the virtual manufacturing tool to the wider range of involved actors in the company, it can be beneficial for the companies and improve the decision-making quality in the production and factory layout engineering. However, the potential of the rapid capturing point cloud data to construct realistic virtual environments is constrained by the current computing power. More importantly, further studies need to be conducted on verified and validated frameworks for supporting the integration as well as evaluation and measurement methods for better development of applying virtual technologies in general into the manufacturing industry.

6. Future work

The next step of the work will focus on the development and validation of generic frameworks that will guide the integration of VR into the existing production systems.

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