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Layout planning and geometry analysis using 3D laser scanning in production system redesign

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Abstract

Production system layouts are traditionally redesigned and modelled using CAD tools. Frequent system changes, i.e. equipment is replaced or moved to new locations, necessitate time-consuming measurement and modelling work to keep the models valid and up-to-date. 3D imaging has been proposed as a means for rapid and accurate spatial modelling by digitalising real world objects. This paper analyses the method and result from five industrial studies where 3D imaging, specifically 3D laser scanning, were used to support layout planning and geometry analysis of production systems. The results show promise to reduce time, risks, and cost when redesigning production systems.

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Keywords: 3D imaging; 3D laser scanning; Digitalisation; Production systems; Facility layout planning

1. Introduction

In the redesign process of production systems, layout planning is an important task to achieve good overall effectiveness of the final systems [1]. The layout planning requires several prerequisites and criteria to be considered, such as geometrical aspects of the existing production system and factory building [2]. The layout is most often modelled using 2D CAD tools, with data of the existing production system from previous layout models or blueprints. A problem is that such data not always truly represent the real world, which typically originates from measurement errors or undocumented changes [3]. This can result in costly design errors found when the redesigned layout is implemented [4]. There is a need to ensure that the data used in the layout planning are geometrical accurate and up-to-date to the existing production system [5]. To capture and digitalise an existing production system, different 3D imaging technologies can be used [6]. Terrestrial 3D laser scanning has shown to be promising, concerning accuracy and speed of data capture. The resulting data from a 3D laser scanning is a point cloud, which can be used to verify that the layouts are redesigned using the correct geometrical prerequisites [5].

The aim with this paper is to evaluate how 3D laser scanning can support layout planning and geometry analysis when redesigning production systems. The support were evaluated by analysing the method and results from five industrial studies. In these studies, 3D laser scanning were used to support industrial projects installing new production systems in existing shop floors. The result of the paper is an analysis of common observations and outcomes from using 3D laser scanning in the studies.

2. Frame of reference

The research area of production system design include a number of different topics, where layout planning is one important part. The following sub-sections will cover the overall production system design, virtual layout planning, and terrestrial 3D laser scanning.

2.1. Production system design

The design of production systems is a complex task and comprises a large set of criteria to be considered. Over the years, a large number of publications have described the overall approach and context for production system design

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[7,8]. Moreover, in the literature about Lean, there are also a number of principles and guidelines for how to design the value stream for short lead-times, high efficiency, etc. [9–11]. That literature points to the importance of production system layout, but mainly in a principle way the preferred models for layout alternatives. In general, there is little practical advice or methods for how to do the physical, spatial, design taking all the different considerations and compromises into account. However, [12] and [13] provide some hands on systematic procedures, methods, and tools to use for the spatial layout planning. A systematic procedure is needed to collect information, define requirements and model and evaluate the relations between the production steps and their resources, as well as the physical constrains at the shop floors. To support the communication and evaluation of different alternatives in a project team, good visualisation is a powerful help [14,15].

2.2. Virtual layout planning

Virtual tools can be used to design and evaluate production system layouts before making the actual physical installations [2,16,17]. These tools are for example 2D CAD layout applications or production simulation applications. Regardless of what type of tool that is used, a well functional and effective layout requires numerous criteria to be consider [1,18]. Companies has traditionally worked with the different virtual tools in parallel, but efforts has been made to combine different types of tools in to one application [19]. The aim with such an application is to reduce the required planning time [19]. The development of new virtual tools are mainly driven by the leading application providers [19].

Virtual and augmented reality has been introduced as technologies for visualising the planned layouts and production system [20]. Those technologies are used to increase the users understanding and interaction with the planned production system. The user experience relies on that the models presented using those technologies are true and realistic to the real system.

2.3. 3D laser scanning

The type of 3D laser scanner addressed in this paper belongs to the group terrestrial 3D laser scanners [21]. These scanners operate by emitting laser-beams at surfaces and capturing their returned reflection to measure the travelled distance [22]. Each captured reflection represents a sample of the surface of the closest object along the beam direction, which is referred to as a measurement point [22]. The measurement points store information about the surface's spatial position and its reflectance value [21,23]. This type of scanners have a typical field of view in the horizontal axis of 360 degrees and in the vertical axis of 300 to 320 degrees, as exemplified in Fig. 1 [24]. Systematic capturing of distance measurements in the entire field of view generates a spatial representation of the environment. This systematic capturing is referred to as a scan in which the scanners have the capability to capture tens of millions of measurement points during a few minutes [22]. The measurement points can be complemented with colour data, generated from photos taken by a built-in camera [23]. The process of creating a representation of a complete environment, most often requires scans from a number of positions. To combine two or more scans into one dataset most often requires reference objects. The reference objects are typical white spheres, black and white checkerboards, or natural features in the environment. The 3D laser scan data from the different positions need to be aligned and combined into one dataset using a semi-automated registration process [23]. The scan dataset can be used to generate a point cloud, which consisting of all the individual measurement points.

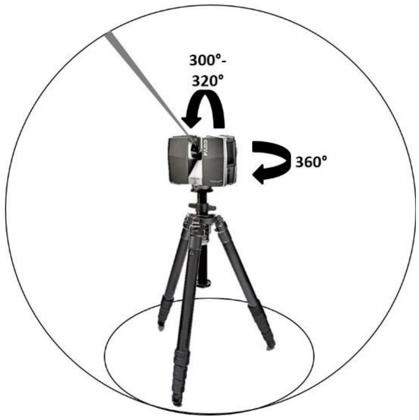

Fig. 1. A terrestrial 3D laser scanner's field of view.

3. Description of industrial studies

The five industrial studies were carried out at different factories during 2012 to 2015. These studies followed industrial projects tasked to plan and install new production systems in existing shop floors. The aim of the studies has been to evaluate how to support the industrial projects by using 3D laser scan data of the addressed factory sections. A FARO Focus3D S 120 was used to scan the existing shop floors, which had the sizes of 400-1900 m^2 and required 8-23 scan positions. The scanner was set-up to meet the requirements of each study, resulting in a time spent of 5-8 minutes and around 28 million measurement points for each scan position. The reference objects used were primary 139 millimetres white spheres and, in some of the studies, 150 x 150 millimetres black and white checkerboards. The scanning for each study was made during less than one day. The 3D laser scan data were processed in FARO SCENE to generate the point clouds. The process includes combining scans from different positions, applying colours, and defining the spatial alignment. In addition, unwanted points were removed by automatic filtering and manual editing of the point clouds. This process results in point clouds that are true to the scanned shop floors with an accuracy of a few millimetres. The time spent for processing the scan data were approximately 8-20 hours for each study. The point clouds were used differently in the industrial studies, which the following sub-sections will describe along with the focus, addressed problem, and result of each study.

3.1. Industrial study A

The industrial project addressed in study A was changing the layout of the production system from function oriented to product oriented. This layout change included two machine installations, which were analysed using the point cloud of the existing production system. The first machine installation was an existing machine that should be moved to a new location in the same production system. The point cloud and a 3D CAD model of the machine were used to evaluate the location and reconfiguration of the machine and its equipment. This evaluation verified that it was possible to install the machine at the new location and risks with the installation could be eliminated. A comparison between the 3D CAD model and the point cloud of the machine showed differences, which could have been critical for the installation. In the previous location of that machine, an installation of a new machine cell with additional equipment was planned. By combining the point cloud with 3D CAD models, located according to a previously created 2D CAD layout model, a 3D visualisation of the planned installation was created. The project group and a shop floor representative were analysing the visualisation. This analyse revealed design errors originated from the 2D CAD layout model. The work taking place around the machine would require more space than available and a process fluid system was rather larger than expected. To manage these design errors a new layout was conceived, which fulfilled installation requirements and regulations, and supporting production flow through much better use of the floor space. The analysis also made it possible to find consequences and motives for making additional investment and installation, compared with the gained productivity and work environment improvements.

3.2. Industrial study B

In study B, the industrial project was working with increasing the production capacity of a robotic cell for x-ray quality inspection of components. The point cloud was used to ensure available space around the robotic cell would be enough for the increased capacity, with new work routines and increased material handling requirements. The analysis considered material flow, handling of tools and fixtures, changing films, work routines, and installation possibilities. The support from the point cloud was exemplified in several steps of the redesign process and used to create a simulation model of the production system, as presented in Fig. 2. The simulation model showed the spatial possibility to duplicate the robotic cell to increase the capacity. This simulation model was used to analyse consequences of the installation related to the investment, available physical space, and workplace design. The analyse involved machine operators, technicians, manufacturing engineers, and industrial engineers.

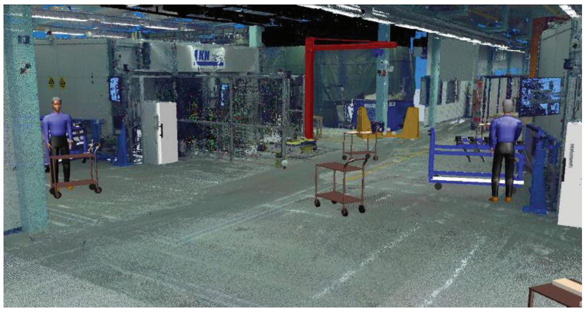

Fig. 2. The simulation model with a duplicated robotic cell.

3.3. Industrial study C

The industrial project addressed in study C planned the installation of a new assembly line. The project was used in the study to evaluate how to include 3D laser scan data in the company’s current method and computer applications for layout planning. The current layout planning method used 2D CAD model for designing the layout. A comparison of the point cloud and the current 2D CAD layout model of the shop floor showed important differences in building specific details. These differences were for example pillars with incorrect position in the 2D CAD layout model. The study showed that it was possible to include point clouds in the company’s current computer applications. However, to be able to introduce 3D laser scanning in the overall method a management driven structure was found necessary. To make such structure possible required future investigations and investments.

3.4. Industrial study D

The task for the industrial project addressed in study D was to redesign a production system for a newly introduced product. The system included a number of new machining centres, a washing machine, deburring, inspection, and robotic welding cell. The aim with the study was to evaluate how a 3D visualisation of the point cloud in combination with 3D CAD models can be used to design, analyse, and verify layout alternatives. The 3D visualisation, as presented in Fig. 3, was created based on a previously modelled 2D CAD layout. The visualisation was used in different phases of the redesign process with focus on analysing the product flow, installation and maintenance, workplace designs, and to some extend the workplace ergonomics, safety and health. These focus areas were analysed at three workshops. To cover as many aspects of the production system as possible, the participants at the workshops were representing different engineering roles, shop floor personnel, and safety engineers. The workshops resulted in a number of changes to the layout, which were made to the 3D visualisation to minimise risks and design errors.

Fig. 3. 3D visualisation of the production system layout, combining point cloud of the factory building with 3D CAD models of the machine centre and other new equipment.

3.5. Industrial study E

In study E, the aim was to evaluate how 3D laser scan data can be used for layout planning and geometry assurance in a robotic cell. The industrial project was changing the current setup of a robotic cell. This cell was scanned and the resulting point cloud was used in the evaluation. During the evaluation, it was shown that the point cloud could be used to plan the layout of the robotic cell and to verify the 3D CAD models used for robot programming with the real cell. The point cloud lacked some information to be able to be used directly for offline programming and simulation of the robotic cell. A comparison between the point cloud and the 3D CAD models, it was noted that building specific parts were missing, such as ventilation pipes.

4. Result

The use of 3D laser scanning in the industrial studies resulted in a number of observations and outcomes, which were grouped into six categories. These categories describes the potential use and gain from using 3D laser scanning when redesigning production systems, with focus on layout planning. How the six categories relates to the industrial studies are presented in Table 1. In the following sub-sections, the categories are further explained and observations from the studies are exemplified.

Table 1. Observations and outcomes from the industrial studies (the X indicates when observations and outcomes related to the category can be found in the industrial study).

Study	CAD data reliability	Risk reduction/ management	Project goals fulfilment	Total investment	Productivity improvements	Ergonomics assessments
A	X	X		X	X	X
B		X	X	X	X	X
C	X		X			
D		X	X		X	X
E	X			X		

4.1. CAD data reliability

The companies in the industrial studies usually model their layouts using 2D CAD. In some of the studies, it was possible to compare the point clouds of the existing shop floors with the 2D CAD layout models or 3D CAD machine models. These comparisons showed a number of differences mostly related to the building geometries, such as lack of ventilation pipes or incorrect positions of pillars in the CAD models. These differences can be critical in the design work, resulting in costly design errors. The lack of details is usually related to the time consuming process of modelling the entire shop floor. A reason for incorrect positioning of objects is that the CAD models are not always updated after the actual installations has been made, creating an assumption that the actual installation was made true to the CAD models. The participating companies confirmed that these differences are very common and there are always reasons to questioning the reliability of the CAD models.

4.2. Risk reduction/management

The industrial studies revealed the possibility to reduce the risk of making design errors in the layout planning by using 3D laser scanning. The resulting point clouds are true and accurate models of the real shop floors, which were used to verify that the redesign layouts would fit into the real environments. Without this type of verification, there is a risk that some of the equipment will be virtually positioned where it is not physically possible. To prevent such risks, 3D visualisations based on the point clouds and 3D CAD models were created to analyse and verify possible layout alternatives. Design errors from the initial 2D CAD layout models were found and corrected in the 3D visualisations, which otherwise might have been identified after implementing the layouts. Thus, continuously updating and systematically assessing an accurate model, is an effective way to reduce and manage risks.

4.3. Project goals fulfilment

The industrial studies has indicated that the use of 3D laser scanning has the potential of reducing the overall time and cost for redesign projects. The cost reduction derives partly from the possibility to find design errors early in the process to prevent costly corrections in the real production systems. This possibility relies on that the layouts can be verified against the point clouds. In addition, with a point cloud visualisation of the current shop floor at hand the actual design work of the layout can be reduced. A common statement from the industrial participants has also been the benefit of having such visualisation available at e.g. project meetings, which can avoid unnecessary discussions on the current state. The time can be reduced by fewer discussions and work done based on right criteria. For the full potential, the industrial studies has shown a need for a method of how to work structured with 3D laser scanning along the redesign process.

4.4. Total investment

The industrial studies made it possible to evaluate necessary investments needed to put the equipment into the planned location and integrate it into the shop floor. This part has a strong link to risk analysis and elimination, and can prevent time and cost consuming problems during installation and start up. There are numerous examples in each company, that the machines does not have enough room to be installed, running the operations, maintenance, or even be transported to the right location.

4.5. Productivity improvements

The combination of point clouds and 3D CAD models to visualise the future production systems has made it possible to better analyse the production flow and material handling in the systems. As a first and basic step, the space requirements for handling and storing material, tools, etc. can be verified. Such problems will cause a lot of waste that will affect lead-time as well as resource utilisation and create possible safety issues. Production flow simulation tools can also use the combination of 3D CAD models and point clouds [25]. This will enhance the visualisation and possibilities to better see details of the cell and workplace design and help to optimise the layout and flow of material, people, tools etc. in terms of positioning, reachability and performance. From a simulation model building perspective, the point cloud will be a valuable support while creating the simulation models.

4.6. Ergonomics assessments

Workplace design, the evaluation of different ergonomic as well as safety and health aspects can be assessed using the combination of point clouds and 3D CAD models. This type of evaluation requires involvement of machine operators, production supervisors, maintenance engineers, managers, technicians, specialist in ergonomics, and safety engineers. These functions at the companies has traditionally not been involved in the actual redesign process. The possibility makes it easier, not only to evaluate risks with non-ergonomic work load and lifting items, but also to “see” and question potential issues related to work environment such as noise, temperature, and light conditions. The experiences from the industrial studies shows opportunities to spot potential risks and problems as well as room for more creativity and discussions for how to make changes and improvements.

4.7. Summary of benefits

In the six categories of observations and outcomes, the following common benefits of using 3D laser scanning and 3D visualisations can be identified:

- Understanding current state of the shop floor
- Reduce need for physical shop floor visits
- Enables discussions in cross functional groups
- Reduce subjectivity in group work
- Concretising various potential problems
- Requires integration in existing work processes
- Holistic and detailed understanding by subject experts

These benefits have impact on the lead-time for redesign projects by making it possible to verify the planned redesign in a true digital copy of the real shop floor. This verification results in that design errors can be found and prevented during the planning, and an implementation without complications.

5. Discussion

The observations and outcomes from the industrial studies cover different aspects of the production system redesign. 3D laser scanning is the common factor in the studies, but is in such only a technology for real world digitalisation. The use of the point clouds differ, either to visualising current shop floors or as the base for 3D visualisations of the redesigned production systems. A point cloud of the current shop floor can be important for the common understanding. For example, at project meetings when details in the shop floor are discussed that are of importance for making right decision of the layout. By viewing a point cloud of the shop floor, unnecessary discussions and physical visits can be avoided.

The combination of point clouds and 3D CAD models of machines and equipment has shown to be an effective method for evaluating layout alternatives. This method has some limitations, such as to ensure all parts of the production system are accounted for that have important influences. These parts not only include machines and equipment, but also in some of the studies material handling has shown to be equal important. For larger products, the position of pallets and fixtures can be important to analyse.

Point clouds are mainly used for static visualisations, but the possibility to include them in simulation applications exist. Such applications can be production flow simulation or robotic simulation. This possibility was partly evaluated, which provided an extra dimension to the visualisations. From the perspective of a simulation engineer, the point clouds can be useful when creating the simulation model based on existing production systems.

The industrial studies has focus on discussing and analysing visualisations of the future production system layouts within groups working with designing or working within the addressed production system. Addressing this kind of groups has shown the important to include different functions at the company in the redesign process. The shop floor personnel that is not usually involved in the design has provided important information that otherwise might not have been noticed until the system is installed. To be able to address different functions, it is important to ensure that everyone can understand the visualisation. The realistic point cloud can be used to increase the understanding.

A common theme in the industrial studies is the possibility to foresee potential problems and possible risks of many different kinds. The 3D visualisation can be used when doing a formal risk analysis or ergonomic assessment, but it has also proven to be useful in any kind of situation as an interactive visualisation to try different design alternatives. It is recommended to have a clear definition of activities or a process definition as a base, not to forget any important aspects of the production system and its design.

The participants in the industrial projects were very positive to the use of 3D laser scanning. They pointed out several advantages and motives to implement 3D laser scanning in the redesign process, but find that there are a need to define a structured work procedure. Such a procedure need to be well planned to make use of the opportunities with this kind of technology. However, another problem is to define who should be responsible for the technology and work procedure. One aspect to this it the problem of give a number of how much a company gain from the implementation. Most people agree that costly problems can be found and risks be reduced, but the problem is to show the cost reduction. An approximation of the time spent for the scanning and preparation of the point cloud for a redesign project as those in this paper is around 16 hours in total. This time spent can be saved in just a couple of project meetings if the time spent can be reduces by some minutes. The reduction can come from questions regarding the actual system that are answered by viewing the point cloud. One of the companies in the industrial studies has now a scanner at the company to evaluate further application areas. However, the main cost savings might come from design errors that are prevented before the implementation. There are examples from participating industries that errors often are found during installation and commissioning, and can cause serious delays and extra costs, up to several million SEK.

Future development of the how to use 3D laser scanning would be to integrate more functions to support the evaluation and analysis. An example is the spatial design, to make sure all requirements, legislations, and directives are met. Another example is more systematic method for the layout planning in combination with visualisation, simulation, and the spatial design requirements.

6. Conclusions

The observation and outcomes from the five industrial studies has shown 3D laser scanning to be an important technology for supporting the redesign process of production systems, and specifically during the layout planning. Benefits from using the technology drives from the access to accurate and realistic point clouds of the existing shop floors. Those point clouds can be used to verify that the planned layouts will be possible to implement in the real shop floors. In redesign project, this verification can reduce the necessary time for planning and discussions as well as the risk for costly design errors. 3D visualisations of the future production system has shown to be easier to understand than traditional 2D CAD layout models, making it possible to involve an additional number of different functions and roles at the company in the redesign process. For the full implementation of 3D laser scanning, a structured method of working with the technology during redesign projects is necessary.

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