Simulation in Produktion
und Logistik 2021
Jörg Franke & Peter Schuderer (Hrsg.)
Cuvillier Verlag, Göttingen 2021

System concept for semi-automated generation of layouts for simulation models based on point clouds

Systemkonzept zur teilautomatisierten Generierung von Layouts für Simulationsmodelle auf Basis von Punktewolken

Reinhard Zeiser[1], Felix Ullmann[2], Thomas Neuhäuser[1,3], Andrea Hohmann[1], Johannes Schilp[1,4],
reinhard.zeiser@igcv.fraunhofer.de, felix.ullmann@hoermann-rawema.de, thomas.neuhaeuser@igcv.fraunhofer.de, andrea.hohmann@igcv.fraunhofer.de, johannes.schilp@igcv.fraunhofer.de

[1]Fraunhofer Institute for Casting, Composite and Processing Technology IGCV, Augsburg (Germany),
[2]Hörmann Rawema Engineering & Consulting GmbH, Chemnitz (Germany),
[3]Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb), Garching b. München (Germany)
[4]University of Augsburg, Chair of Digital Manufacturing, Faculty of Applied Computer Science, Augsburg (Germany)

Abstract: The turbulent market accounts for decreasing product lifecycles, which results in more frequent factory replanning processes. To support this process 2D and 3D simulation models are already widely used. Those virtual representations are usually generated once and never updated again. Factory planning in general needs a comprehensive data acquisition. This task usually takes up to around 50 % of the time required for planning projects. To reduce this, a continuous data management for continuous replanning is crucial. The combination of laser scanning a factory and 3D Computer Aided Design (CAD)-models of production facilities can help minimize some of the effort. Therefore, a system for semi-automated generation of layouts for simulation models based on point clouds is presented. The system consists of two modules, a model library and a module to register CAD-models of production facilities in the point cloud to obtain their position.

1 Introduction

With a share of 22.9 % of gross value added (as of 2020), the manufacturing sector is the second largest economic sector in Germany (Statistisches Bundesamt, 2019). However, companies in the sector face a turbulent market environment and are thus dependent on constant product and consequently process innovations (Abele and Reinhart, 2011; Pawellek, 2014). This means that existing production systems have to be replanned more frequently and decisions have to be made faster (Wiendahl et al., 2014). An important factor in factory replanning is the material flow. The material flow of a factory can account for 20 to 50 % of the factories operating costs, 30 % of these costs can be saved by efficient planning (Hawer et al., 2015). Besides material flow optimizations like utilization rate and order of production, optimizing the layout in regard to transport routes, accessibility and surface utilization is important. One way to support factory replanning is the use of a simulation model. For efficient replanning a location-accurate representation of the as-is condition of a factory is mandatory. In a survey, 76 % of respondents state that a detailed geometric representation plays an important role in the concept of the digital factory (Navvis, 2021). 62 % of the respondents even state that in the next two years methods for a continuous data management of the as-is condition must be created (Navvis, 2021).

A decisive basis for valid planning decisions is provided by comprehensive data acquisition and processing (VDI 5200 Blatt 1, 2011). However, this initial step is often difficult because plans are often not digital and only available in 2-dimensions (2D) and the complete information and data are distributed over several people (Sinnwell et al., 2018; Feldmann, K. and Reinhart, G. 2000). In addition, data is not continuously maintained and often does not reflect the actual as-is condition.

With recent developments in laser scanning, a location-accurate as-is condition can be determined in a relatively short time (Wunderlich and Wasmeier, 2013; Faro; Leica-Geosystems). Laser scans generate 3-dimensional (3D) point clouds in which the points have no semantics or relation to each other (Nurunnabi et al., 2012). Alongside laser scanning, automated guided vehicles (AGVs) are also developing in a vast manner (Rozsa and Sziranyi, 2018). AGVs often detect obstacles using light detection and ranging (Lidar) technology (Rozsa and Sziranyi, 2018) and thus are able to generate 3D maps of the environment. These point clouds can be used as input for continuous sensing of production systems (Neuhäuser et al., 2020) and therefore bridge the gap between factory replanning and continuous data management for location-accurate simulation models. Besides the comparatively simple task of scanning the factory, the manual effort required to prepare and make this data usable is considerable and requires a certain level of expertise. To make use of the point cloud, the positions of the production machines can be defined by measuring distances inside the point cloud and then the 3D Computer Aided Design (CAD)-models can be placed in a software tool. Some software tools support the loading and processing of point clouds. In these tools the production machines can be placed directly inside the point cloud. However, with an increasing number of production machines to be placed depending on the required accuracy, this can lead to an enormous time expenditure.

In addition, for factory replanning a certain set of tools is required to be able to analyze the as-is condition and based on the results integrate the new requirements and optimize the whole factory. Often these tools lack in interoperability and do not provide interfaces or common exchange formats, which can result in modeling the same factory in multiple tools. For example, plavis visTABLE for calculating the floor utilization rate and transport routes and Tecnomatix Plant Simulation for analyzing the material flow. A generic approach can support the layout generation in both tools by extracting the position information of the individual machines from the point cloud. This information can then be automatically transformed for the different software tools to construct the layout for the simulation model, so the expert only has to add the software specific logic.

Therefore, in this paper, a system is presented, which is able to support the construction of the layout for a simulation model for different simulation tools. For this, the system extracts the position of production machines from a non-semantic and reference-free point cloud. This information supports the construction of a location-accurate simulation model without requiring any expertise in point cloud processing.

2 Related work

Denkena et al. (2019) describe an approach to generate a digital twin from laser scan data. Due to the complex data collection required for this approach, it is difficult to meet the requirements for frequent replanning as well as the integration with different planning tools. Stojanovic et al. (2018) address the continuous updating of a digital Building Information Modelling (BIM)-Model using point clouds. This approach uses location data extracted from the Industry Foundation Classes (IFC) file to align the point cloud and the BIM 3D geometry. This information cannot be extracted from CAD models, thus this approach is not possible. Melcher et al. classify objects based on images using a machine learning algorithm. However, the algorithm requires labeled data for training, making a generic approach difficult. In Braun and Borrmann (2019) a method is proposed for automatic image labeling based on registering a BIM-model and a point cloud generated by Photogrammetry. Bosché (2012) present a registration method consisting of a coarse and fine registration. This method is used to register a 3D model in the whole point cloud, instead of extracting the positions of objects inside a point cloud. Kim et al. (2013) also propose a method consisting of a combination of coarse and fine registration. The coarse registration is carried out using a principle component analysis (PC) and the fine registration is done by invoking the Levenberg-Marquardt iterative closest points (LM-ICP) Algorithm.

The aforementioned methods are all dealing with the automatic registration or detection of 3D models in point clouds and therefore give a good overview over different registration techniques in various domains. However, none of them is specifically concerned with supporting the factory replanning process and therefore dealing with an approach which is able to support the generation of factory layouts for different software tools. Thus a system concept for providing a generic approach to extract coordinates of objects inside a laser scan is presented, so that the creation of a location-accurate layout for simulation models of the current factory as-is condition can be achieved in different software tools.

3 System concept for semi-automated generation of layouts for simulation models based on point clouds

In this chapter the overall approach is presented to detect objects inside a point cloud, extract their positions and place their digital representatives in different software tools. The structure of this chapter is based on the process which is outlined in Fig. 1. First, the module *model library* is introduced followed by the module *layout extraction*. The *model library* is responsible for handling CAD-models, it is able to import, filter and export CAD-models to different software tools, e. g. the *layout extraction* module. This module handles the process of extracting positions from a point cloud by placing CAD-models in defined regions and gives an idea on how to construct the layout for a simulation model in different software tools. For this, the module is divided into three tasks: First, the *definition of regions*, second the four-step algorithm for the *registration of CAD-models* and third the *generation of the layout* for a simulation model.

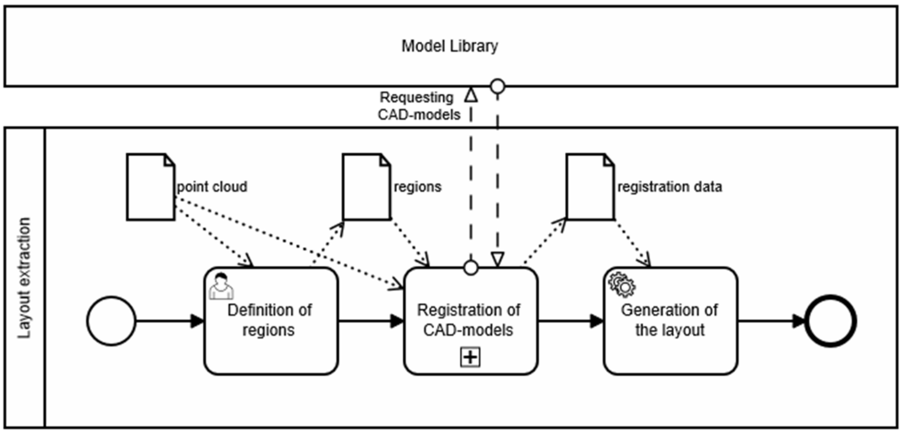

Figure 1: *Process for registering CAD-models in the defined regions and extracting the factory as-is layout.*

3.1 Model library

The model library is a standalone software written in the programming language python. It is designed as a central data management system for CAD-models and associated metadata to allow software tools to query specific models using an application programming interface (API).

The model library has three major functions. It is able to import new models, filter models and return a list of the filtered models and metadata.

To import a CAD-model it has to be placed in a specified directory on a file transfer protocol (FTP) server. Whilst importing, the model library automatically calculates metadata for the model based on the CAD object. The calculated metadata currently includes length, width, height and volume of the object bounding box, additionally the filename is saved. Supplementary, tags can be used to describe the object, e.g. the function of an object can be described as a “conveyor”.

The filtering function in the model library is required to reduce the computational effort in the automated matching process of CAD-models to point clouds (compare chapter 3.2.2). In order to avoid that every CAD-model is tested for a match, a preselection of possible CAD-models can be made, for example by transferring criteria like volume or maximum length of the defined region in the point cloud. In addition to the filter criteria, a relative tolerance value can be passed to compensate for differences between the CAD-models and the scanned objects but also to account for the rough bounding box. The communication with the model library is done via a Representational State Transfer (REST) Interface.

To receive a list of reference models, the filter has to be passed in a JavaScript Object Notation (JSON) format, which contains the filter criteria, the filter value and a relative tolerance. The model library applies the filter and returns the matching models as a JSON containing the absolute file paths of the CAD-model files and the associated metadata. The files can then be externally loaded and further processed.

3.2 Generation of layouts for simulation models

3.2.1 Definition of the regions

In the first step of generating the layout for a simulation model, the definition of the regions takes place in the point cloud. This task needs user interaction. A region in this context is defined as an area which encloses an object, also referred to as *target*, which has to be matched with a CAD-model. To create a region, a cuboid envelope, i.e. a bounding box, is drawn around the object. For the bounding box a rough indication of the region is sufficient. A bounding box can be drawn by just defining two points, e.g. the upper right corner and the opposite bottom left corner. This simple procedure allows a user to define many regions within a short time. An example of a defined region containing a production machine and noise can be seen in Fig. 2. After the definition of all regions, this information needs to be passed to the next step, the registration of CAD-models.

a) Top view b) Side view

Figure 2: *Defined region containing a production machine. a) displays the top view and b) is showing the machine from the side. Also the region is containing the floor and other noise.*

3.2.2 Registration of CAD-models

In the CAD-model registration, the point cloud as well as the region information are imported from a local directory, then the pre-selection of the CAD-models takes place. First, the defined regions are cropped from the point cloud. Description criteria, such as width, length and height are calculated from these segments. Based on these criteria, the model library preselects suitable models by the calculated metadata. Optimally the model library returns only the matching model, but often those criteria match multiple models and a final selection has to take place as last task in this process.

After loading, the selected CAD-models are registered in the region. For this, a two-stage algorithm is used. Since the point cloud may contain noise as well as interfering contours that do not belong to the target, the first stage is a rough placement. For this step, the Random Sample Consensus (RANSAC) is used. This algorithm is largely tolerant to noise (Schnabel et al., 2007), but the accuracy of the placement is often insufficient. With the help of the second stage, the fine registration, the model can be placed precisely in the region. For the fine registration, the Iterative Closest Points (ICP) algorithm is used. The ICP algorithm is susceptible to noise and interfering contours and thus depends on the quality of the rough registration. An example is shown in Figure 3. The left figure a) shows the registration after the RANSAC took place and the right figure b) shows the registration result after execution of RANSAC and ICP. The black solid lines are for visual indication of the target.

Based on the result of the fine registration, the Mean Squared Error (MSE) is calculated to quantify the registration quality. At this stage of development it is assumed that the region contains the best-scored model. For this CAD-model, the metadata is exported. The metadata contains the transformation information as well as the information returned from the model library, which for example contains the type of the model, e.g. “conveyor”, which can be used in some simulation software to spawn a fitting object.

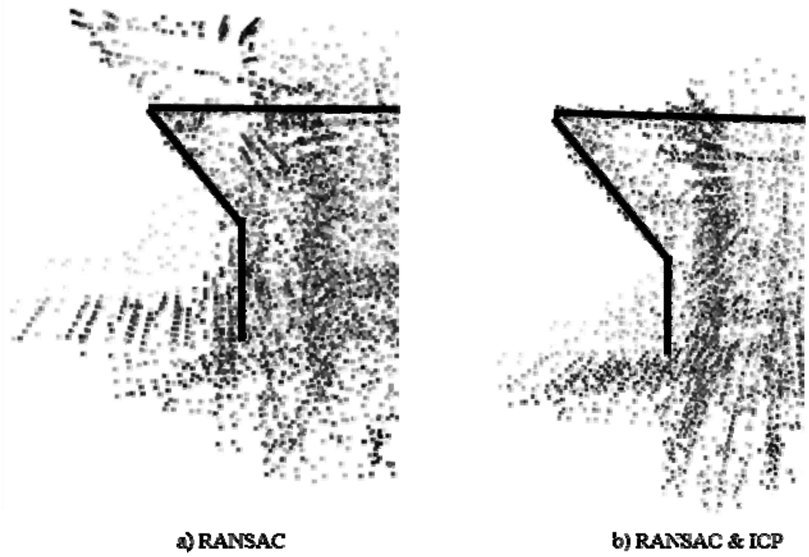

Figure 3: *Example for the registration of a source CAD-model in the defined region. The left image a) shows the registration result after the application of the RANSAC-Algorithm and the right figure b) shows the registration result after execution of RANSAC and ICP. The black solid lines are for visual indication of the target.*

3.2.3 Generation of the layout for a simulation model

The exported transformation and metadata of the registration process for the detected CAD-models inside the point cloud can be used to generate the layout for a simulation model. Therefore, the data has to be transformed to fit the requirements of the specific simulation tool. Below the process for transforming the data for plavis visTABLE and Tecnomatix Plant Simulation is outlined.

For plavis visTABLE the positions have to be transformed in a block layout and exported in a Microsoft Excel format (XSLX). Therefore, the CAD-models are loaded in a python program and positioned according to the transformation matrix. This representation is then used to calculate the important parameters for the block layout. Besides the x, y, z-Position in millimeters, this is the rotation of the block, width, length, height and volume of the object. Name, surface type, layer and color can be defined by the user or loaded from the model library.

Importing the Layout in Tecnomatix Plant Simulation can be achieved by writing a method in Simtalk. The method loads the metadata from disk, containing the calculated position, its rotation and the type of object to spawn, e.g. a "conveyor". With this information, the type of object, which is loaded in form of a string has to be mapped to the internal classes of functional elements to get the class type references. Using the class type references the objects can be instantiated and transformed to the correct position and rotation.

4 Discussion

The described procedure delivers a possibility to semi automatically extract positions and information of objects out of point clouds with the goal of generating the layout for a simulation model. The defined regions are cropped from the point cloud, to increase the accuracy and speed of the registration process. Therefore, the calculations are done on a subsample. Additionally the different models returned by the model library are registered in parallel. To register and extract the positions of four identical machines with a width of 4 meters, length and height of 2.5 meters each it took under one Minute on a standard office laptop with no graphics card. This time includes registering every returned CAD-model in the region. In this specific case, 5 different CAD-models were returned by the model library for each region. Thus, the efficiency of the registering workflow depends mainly on the pre-selection of the CAD-models. Currently, the pre-selection can be optimized by precisely calculating the filter criteria or having very few similarities in the reference data. Using additional filtering criteria, e.g. key point features or characteristic faces, could also counter these problems.

In most cases the method is able to reliable place the models, but if real objects are too similar in size and shape it happens that the wrong models are placed inside a region. This can be explained by the current registration process selecting the CAD-model with the lowest MSE as the correct model. By handing this decision over to a user, two benefits, besides a growing user acceptance, can be achieved:

1. If there is no fitting CAD-model for the target, a dummy can be placed and manually be enriched with metadata, like the functionality.
2. If the placement of a CAD-model is not accurate enough, the user can trigger a recalculation of the registration process or manually improve the placement.

In terms of an automated generation of simulation models, only the structure of machines and components are captured by the laser scan data. The resulting layout is a location-accurate representation of the as-is layout. There is no automatic method to provide functionality. Nonetheless the generated layout contains enough information for calculating key performance indicators (KPIs) like the floor utilization rate and transport routes in certain simulation tools. For functionality comprehensive simulation models, additional information like material flows, movement sequences, transport sequences, simulation parameters have to be added manually by an expert.

5 Summary and outlook

The presented system concept is able to generate the layout for a simulation model based on point cloud data acquired from laser scans. The layout is generated in a user-supported process. Therefore, regions are defined in the originally context-free point cloud. In these regions, facilities are located, which in turn are matched with CAD-models via a two-stage registration algorithm and afterwards evaluated by calculating the MSE. The information obtained is then used to construct a location-accurate layout for simulation models. Besides the task of generating a layout for a simulation model, the implemented model library can be used to reduce effort, as CAD-models can be stored centrally and provided with metadata. Nevertheless, the overall benefit of the system has yet to be quantified. The presented process has laid the foundation for further work aiming at automated model generation and continuous data management in the context of continuous factory replanning.

One way to achieve this is to update existing simulation models with changes in the real production environment. As stated, replanning factories is done in ever-shorter cycles (Wiendahl et al., 2014). By using the point clouds created from AGVs as an input and additionally implementing an automatic point cloud segmentation (Nurunnabi et al., 2012), it should be possible to register the 3D CAD-models in a background process. Those results can then be used to continuously update the layout for a simulation model according to the current, real environment. Also the system can be the basis for an automatic transport time calculation depending on the mode of transport or a future collision analysis in case of a change of the plant configuration.

Acknowledgement

A grateful acknowledgement goes to the Bavarian Research Foundation (BFS), which made these research activities possible within the research project “BIMPro - Bestandsdigitalisierung zur Nutzung von Building Information Modeling in bestehenden Produktionsumgebungen”

References

Abele, E.; Reinhart, G.: Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen. s.l.: Carl Hanser Fachbuchverlag 2011.

Bosché, F.: Plane-based registration of construction laser scans with 3D/4D building models. Advanced Engineering Informatics 26 (2012) 1, pp. 90–102.

Braun, A.; Borrmann, A.: Combining inverse photogrammetry and BIM for automated labeling of construction site images for machine learning. Automation in Construction 106 (2019), pp. 102879.

Denkena, B.; Stobrawa, S.; Dittrich, M.-A.; Stjepandic, J.: Automated Generation of a Digital Twin Using Scan and Object Detection for Data Acquisition (2019).

Faro: Produktüberischt FARO FOCUS. Online verfügbar unter https://www.faro.com/de-de/produkte/bausektor-bim-cim/faro-focus/, zuletzt geprüft am 22.04.2021.

Feldmann, K.; Reinhart, G. (Hrsg.): Simulationsbasierte Planungssysteme für Organisation und Produktion: Modellaufbau, Simulationsexperimente, Einsatzbeispiele. Berlin, Heidelberg, s.l.: Springer Berlin Heidelberg 2000.

Hawer, S.; Ilmer, P.; Reinhart, G.: Klassifizierung unscharfer Planungsdaten in der Fabrikplanung. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 110 (2015) 6, pp. 348–351.

Kim, C.; Son, H.; Kim, C.: Fully automated registration of 3D data to a 3D CAD model for project progress monitoring. Automation in Construction 35 (2013), pp. 587–594.

Leica-Geosystems: Produktübersicht Laserscanner Leica Geosystems. Online verfügbar unter https://leica-geosystems.com/de-de/products/laser-scanners/scanners, zuletzt geprüft am 22.04.2021.

Melcher, D.; Küster, B.; Stonis, M.; Overmeyer, L.: Optimierung von Fabrikplanungsprozessen durch Drohneneinsatz und automatisierte Layoutdigitalisierung, 2018,

Navvis: Digital Factory Survey 2021: A time of change for manufacturing industries. Hg. v. Navvis, 2021, zuletzt geprüft am 29.04.2021.

Neuhäuser, T.; Chen, Q.; Rösch, M.; Hohmann, A.; Reinhart, G.: Building Information Modeling im Fabriklebenszyklus. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 115 (2020) special, pp. 66–69.

Nurunnabi, A.; Belton, D.; West, G.: Robust Segmentation in Laser Scanning 3D Point Cloud Data. In: International Conference on Digital Image Computing Techniques and Applications (DICTA), 2012, Fremantle, Australia, 12/3/2012 - 12/5/2012, 2012, pp. 1–8.

Pawellek, G.: Ganzheitliche Fabrikplanung. Berlin, Heidelberg: Springer Berlin Heidelberg 2014.

Rozsa, Z.; Sziranyi, T.: Obstacle Prediction for Automated Guided Vehicles Based on Point Clouds Measured by a Tilted LIDAR Sensor. IEEE Transactions on Intelligent Transportation Systems 19 (2018) 8, pp. 2708–2720.

Schnabel, R.; Wahl, R.; Klein, R.: Efficient RANSAC for Point-Cloud Shape Detection. Computer Graphics Forum 26 (2007) 2, pp. 214–226.

Sinnwell, C.; Haße, A.; Fischer, J.; Aurich, J.C.: Kollaborative Produktionssystemplanung unter Verwendung eines modellbasierten, PLM-gestützten Entwicklungsprozesses. at - Automatisierungstechnik 66 (2018) 5, pp. 406–417.

Statistisches Bundesamt, 2019: Anteil der Wirtschaftssektoren an der Bruttowertschöpfung* in Deutschland im Jahr 2019. Online verfügbar unter https://de.statista.com/statistik/daten/studie/36846/umfrage/anteil-der-wirtschaftsbereiche-am-bruttoinlandsprodukt/, zuletzt aktualisiert am 01.01.2020, zuletzt geprüft am 17.02.2021.

Stojanovic, V.; Richter, R.; Döllner, J.; Trapp, M.: Comparative visualization of BIM geometry and corresponding point clouds. International Journal of Sustainable Development and Planning 13 (2018) 01, pp. 12–23.

VDI-Gesellschaft Produktion und Logistik: VDI 5200 Blatt 1, Februar 2011.

Wiendahl, H.-P.; Reichardt, J.; Nyhuis, P.: Handbuch Fabrikplanung: Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten. München: Hanser 2014.

Wunderlich, D.-I.T.; Wasmeier, D.-I.P.: Objektivierung von Spezifikationen Terrestrischer Laserscanner – Ein Beitrag des Geodätischen Prüflabors der Technischen Universität München. Blaue Reihe des Lehrstuhls für Geodäsie (2013) 20.