Digital human modelling in a virtual environment of CAD parts and a point cloud

Mahdavian, Nafise[1], Castro, Pamela Ruiz[1], Brolin, Erik[1], Högberg, Dan[1], Hanson, Lars[1, 2]

[1]School of Engineering Science, University of Skövde, Skövde, Sweden
[2]Industrial Development, Scania, Södertälje, Sweden

Abstract

Manual assembly is a time and cost consuming phase of production. It is crucial to design the assembly process so that overall system efficiency, quality output and human well-being meet desired levels. Since manual assembly involve humans, one support in the production design process is to use digital human modelling (DHM) tools to model and assess different design scenarios prior to the actual production process. In the traditional way, various CAD tools are used by engineers to model the production layout and the workstations. Then, these models typically are imported into a DHM tool to simulate human work, and to apply ergonomic evaluation methods on the simulated work tasks. This work, supported by CAD and DHM, can be a time consuming and iterative process as precise information and measurements of the actual assembly environment are needed, e.g. related to actual geometries of factory premises or of facilities surrounding the workstations. However, introducing point cloud scanning technology can provide the user with a more correct and realistic virtual representation of the environment, which allows for a faster and more precise design process.

The aim of this paper is to present the developments and capabilities of the DHM tool IPS IMMA (Intelligently Moving Manikins) in an assembly process and in a virtual environment provided by point cloud scanning.

Keywords: digital human modelling (DHM), point cloud, assembly, IPS IMMA

1. Introduction

There is a tight competition between automotive companies to continuously improve the value of their products while reducing costs. One approach for companies to reduce costs is to improve their production processes so that they are efficient and flexible. The objective to improve production processes can be supported by the concept of digital factories, i.e. by doing virtual simulations of the production systems before realizing the systems in the real world (GLÄSER et al., 2016). This as a way to support communication between different team members and to facilitate testing of different design alternatives to identify successful solutions, while saving time and money by not having to build physical prototypes or having to do large modifications afterwards (GLÄSER et al., 2016; LINDSKOG et al., 2016; YU et al., 2016)

Different methods and tools have been developed and used to help in designing assembled products, assembly tools and assembly processes (BOËR et al., 2001). In the digital modelling world, CAD modelling has been used for many decades to create 2D and 3D virtual models of products, production lines and factory layouts. However, to simulate assembly tasks, besides having the rough geometry of parts and working areas, exact plans of the workstation and tool installations are needed (LINDSKOG et al., 2016; YU et al., 2016). However, geometries in CAD models do sometimes not conform completely with the reality that the CAD models aim to represent, especially in the area of production facilities. This may cause design errors and force costly redesign actions (LINDSKOG et al., 2016). 3D point cloud scanning technology is an efficient way to gather exact and current environmental data, and can hence provide more detailed and realistic layout planning and geometry analyses than CAD models (LINDSKOG et al., 2012; MARUYAMA et al., 2016; REX AND STOLI, 2014). Improvements in texture, colour and positioning in virtual simulation modelling improve the rendering quality and user experience for designers (LINDSKOG et al., 2012). 3D scanning provides, in contrast to *as-planned* environments in CAD models, *as-is* environments, which provides a more precise basis for doing studies of human work, movements and accessibility (MARUYAMA et al., 2016). Hence, 3D scanning can be used for representing the shop floor, but also to facilitate redesign of production systems (LINDSKOG et al., 2016). The combination of CAD and point cloud geometries (hybrid models), improves interaction, planning, understanding of the virtual environment, finding errors in advance and evaluating different design alternatives (LINDSKOG et al., 2016; REX AND STOLI, 2014; YU et al., 2016).

Humans typically play a main role in assembly processes. Humans have certain capabilities that are either very hard or costly to make machines to carry out. Hence there is a need to simulate humans within the digital factory concept. Digital human modelling (DHM) tools have been developed to support such virtual production design processes. DHM tools assist analyses of system behaviour of digital factories, and can facilitate planning and simulation of manual tasks easier compared to experiments or physical mock-ups used in traditional ways (BOËR et al., 2001; GLÄSER et al., 2016). In most DHM based simulations, the virtual environments (such as workstations and equipment) are either modelled in the DHM tool itself, or created by importing CAD data. It is rarer that virtual environments in DHM based simulations are built up from point clouds. The aim of this paper is to present the developments and capabilities of the DHM tool IPS IMMA (Industrial Path Solutions - Intelligently Moving Manikins) in a production process and in a virtual environment provided by point cloud scanning.

2. Method

The IPS software platform was used for simulation (IPS, 2017). The three components used in IPS were: IMMA, a digital manikin (HÖGBERG et al., 2016), a rigid body path planner (HANSON et al., 2014) and point cloud tools (INGELSTEN et al., 2016). To illustrate the functionality, a pedal car assembly scenario was established. Four sources were input in the simulation: 1) a pedal car, 2) assembly sequence of the pedal car, 3) anthropometric descriptions of workers, and 4) a point cloud scanned environment.

The pedal car was modelled in the CAD software CATIA, encompassing 23 main components that were assembled at four main stations. Every station was divided by its main tasks, and tasks were divided by detailed steps of making that part from scratch. The pedal car frame was positioned on the first station's assembly stand. To prevent a crowded environment and large file size, all parts and stations were removed except the selected first station's parts.

A family of digital manikins was imported into the scene and placed in front of the first task of the first station. The manikin family was based on Swedish population data. The key anthropometric measurements were defined and a manikin family covering the majority of the population considering those criteria was automatically generated (BROLIN, 2016). All the family members were instructed simultaneously using view and grip points, which are components that cause the manikins to move, look and act. Controlling the motions in a way so that the manikins act naturally is based on motion controller parameters and algorithms (BOHLIN, 2012).

Different technologies available for capturing spatial data can be traditionally classified into tactile methods and non-contact methods(BERGLUND et al., 2016). For this study, non-contact method, a Faro terrestrial laser scanner, was used to scan the factory area and the data, gathered from different camera sources, was modified and combined to one coherent dataset containing millions of points through registration in FARO Scene software. A 3D laser scanner provides comprehensive data in short time. One scan indoors takes something between 5 and 10 minutes and typically collects 30-50 Million data points(BÖHLER, 2005). Structure light and photogrammetry are the low cost alternatives for 3D laser scanning if the workstation area is small and the quality is not an important issue.

The size of the point cloud is manageable by using central hosting of the files, selective streaming of data or neutral standard file format .e57 (BERGLUND et al., 2016).The point size, the quality of render and the region of the work to be visible, were modified afterwards. To make the desired parts visible, the ceiling of the point cloud was cut out. Then, extra points showing sections other than the target area got cut and saved as a *new region* to reduce the visible area and make it focused on the selected work station for pedal car assembly (see Fig 2.1).

The company premises was visited in order to recognise the factory sections, specifically the assembly stations in the point cloud file.

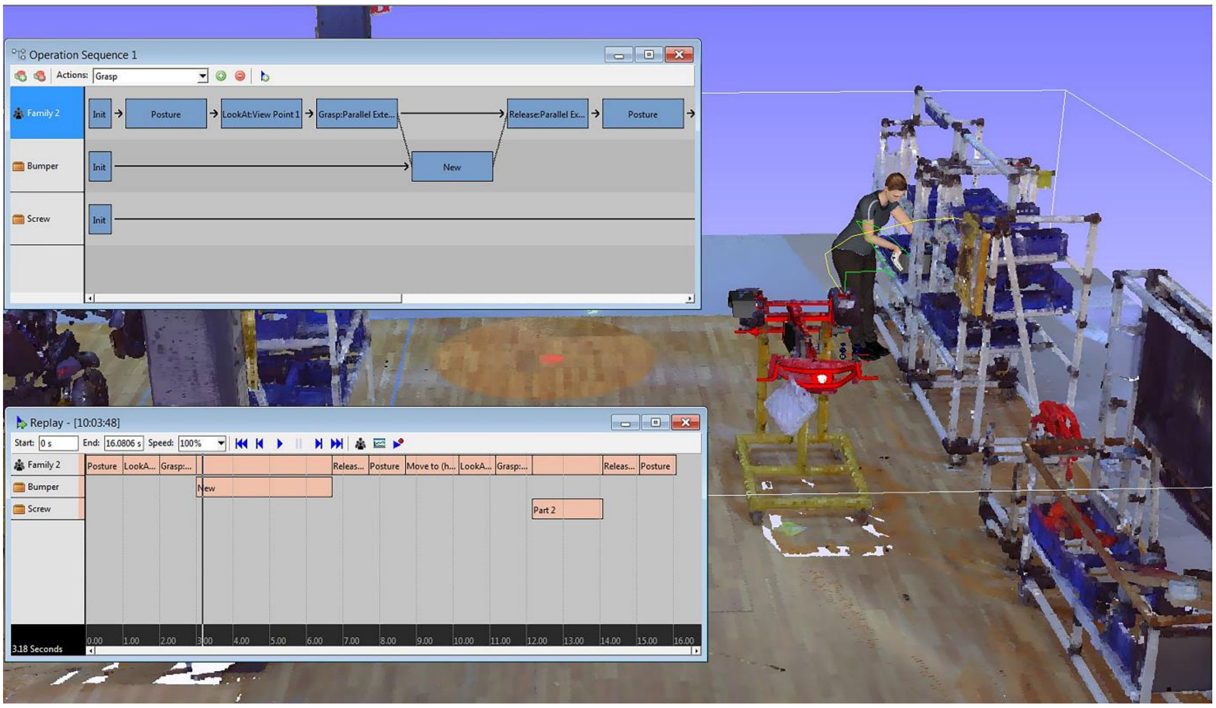

Figure 2.1 Manikin assembling a pedal car in a point cloud environment

2.1 Simulation procedure

The general steps of the procedure of assembling each part were quite the same, only some modifications in options of the steps were required. As an example, the procedure of how to instruct the manikins to assemble one of the mudguards is explained below.

First, the manikin took the part, i.e. the mudguard, from the shelves. The mudguard was converted to a *rigid body* to work with the path planner tool. To define the task, a *parallel extension* grip was selected in the hand grip library available in IMMA (HANSON et al., 2014). Left and right hand grips were inserted into the scene, assigned to the manikin, moved and rotated to get the right place and direction on the object. Then, a view point was created and assigned to the mudguard to define the place for the manikin to look at.

Second, the manikin carried the object to the station where other parts of the frame were already assembled. To control these actions, an automatic *path* through the *rigid body planning* window was created by: setting up the points on the path, assigning the mudguard as the rigid body and selecting obstacles in the manikin's way from taking the part to assembling it; here shelves, the pedal car and its stand were obstacles.

Third, the manikin went back to take the nuts from another basket on the shelves and finally assembled the mudguard.

Fourth, the *operation sequences* that specifies actions for the manikin on the path were specified. In the operation sequence window, the manikin family, the mudguard and nuts were added as *actors*. *Grasp/release*, *look at/stop look at*, *move to* and *posture* were the available actions for the manikin. To move the mudguard and the nuts, related paths were created by the rigid body path planner and then assigned to the items. The operation sequence was continued by doing the same actions for all the assembly parts. It was only needed to instruct one manikin family member of how to perform all assembly tasks. The other family members followed the same instructions, but automatically used other postures and motions due to different anthropometry.

The next action was to execute the simulation. As a last step, ergonomics assessment was done within the DHM tool, looking at the ergonomic load exposure of the following body sections: *Left Wrist*, *Right Wrist*, *Left Forearm*, *Right Forearm*, *Back* and *Neck* for each member of the manikin family. The method for ergonomics assessment was a subset of the EAWS method (SCHAUB et al., 2012). As a complementary input for work assessment, the DHM tool calculated the walking distance used when performing the assembly tasks.

3. Result

The results showed that IPS is capable to work with the IMMA manikins, CAD models and point cloud simultaneously (see Fig 2.1). All the components were editable in the software after importing. Then, the pedal car got assembled based on the assembly scenario steps.

A manikin family was proposed by the software based on the constraints applied. The manikins' postures and walking collision free paths were set precisely using predefined postures and grips; individual settings for each part's assembly were applied. The ergonomics assessment results were represented in colours (see Fig 3.1), where different colours express the degree of health risks: green means risk-free action, yellow requests more evaluation and red calls for immediate consideration (SCHAUB et al., 2012).

Figure 3.1 Part of the ergonomics assessments of the simulated task

Various paths were tried, by modifying the way points, to find the shortest and most ergonomic paths, using ergonomics and walking evaluation results as indicators of successful solutions. For instance, for the mudguard simulation, a path was defined that gave green indication for all body parts and all manikins, except for the back of one manikin. Two reasons that may have caused this outcome are: 1) the manikin was relatively tall compared to the lower storage shelf, 2) the manikin was staying a long time in a risky position.

4. Discussion

The research stemmed from problems caused by lack of correctness between real and virtual geometries of premises and workstation layouts. These differences normally occur due to the time consuming process of CAD modelling. Lack of correctness leads to reduced confidence and precision in production design processes, which can cause costly design errors (LINDSKOG et al., 2016). IPS IMMA provides a good virtual interaction and integrity between different related software via its different modules and import possibilities, e.g. the point cloud module. This combination makes the virtual environment in IPS IMMA more similar to the reality, both related to geometrical agreement between the real and the virtual environment, but also related to the completeness of the virtual representation since all physical items in the real world are being scanned into the virtual model. Another valuable feature is that the scanned representation resembles the real world to a high degree as the scan captures colours of the environment, creating a photo-like 3D representation. These characteristics are considered to support the designer to better visualise, understand, design and evaluate human-system interaction issues (HÖGBERG et al., 2016).

The sequence of importing components into the simulation does not make difference in the simulation. However, for this simulation, based on the component size and volume and work needed for a specific modification, importing point cloud, CAD geometry and manikins respectively eases the workflow. Additionally, to avoid a crowded environment, using hide/show options for every part of every component is advised to ease the simulation work.

It is possible to import the complete point cloud of an entire factory building into IPS IMMA. However, to have a better visualisation and to use the point cloud more precisely in the simulation, it is better to cut it to the intended area. The scanned area helps in understanding the spatial relationships between objects and assembly constrains, which makes the assembly simulation process more precise (YU et al., 2016).

There were some points in the point cloud file that were not accurate or some extra and irrelevant points. This normally happens due to disturbances such as reflections, blockings or moving objects (REX AND STOLI, 2014). The point cloud properties were modified to make the simulation smoother; when the render quality or point size was reduced it was easier to orient around the factory model and work on the simulation. Otherwise it sometimes took time to execute certain commands, e.g. move or zoom. In addition, it would be a great development if it was possible to convert point cloud information to mesh or NURBS. Clash detection features available in CAD software can be used also in point cloud to detect collisions (REX AND STOLI, 2014). However, if the file size is big, this function is currently not applicable directly in IPS.

Besides working with point clouds, IPS IMMA is considered as competitive to other similar DHM tools in terms of providing realistic postures and motions, having collision detection, instructing manikins by a high-level language, ability to work with manikin families to consider human diversity and assessing full work sequences (BJÖRKENSTAM et al., 2016; GLÄSER et al., 2016; HÖGBERG et al., 2016; MÅRDBERG et al., 2014). The purpose of having manikin families is to be able to apply the same tasks to different people in a range. This reduces the time for giving manikin instructions, and enables the consideration of human diversity among the assembly staff (HANSON et al., 2014).

The predefined postures and hand grips ease the manikin movement settings. However, manikins' postures can be set manually if needed, which takes more time but can be more exact. The manikin can also move in different ways, e.g. *walking*, which makes the movement more natural. However, to apply walking, distance of some steps is currently needed between the start and the end position.

Having digital manikins to simulate a work does not mean that real humans would act exactly as the manikins. Rather, the ambition of the DHM tool is to support engineers to make better and quicker decisions in production design processes, so that design solutions that offer expected levels of human well-being and overall system performance can be found (HÖGBERG et al., 2016).

5. Acknowledgment

This work has been carried out within the 3D-SILVER project, supported by VINNOVA and by the participating organizations. This support is gratefully acknowledged. Special thanks go to Scania CV and FCC (Fraunhofer-Chalmers Centre).

6. References

Berglund, J.; Lindskog, E.;Johansson, B.: On the trade-off between data density and data capture duration in 3D laser scanning for production system engineering: Procedia CIRP 41 (2016) 697-701.

Björkenstam, S.; Delfs, N.; Carlson, J.S.; Bohlin, R.;Lennartson, B.: Enhancing Digital Human Motion Planning of Assembly Tasks Through Dynamics and Optimal Control, in: R. Soderberg (Ed.), 6th CIRP Conference on Assembly Technologies and Systems, CATS 2016, Elsevier B.V., 2016, pp. 20-25.

Boër, C.R.; Pedrazzoli, P.; Sacco, M.; Rinaldi, R.; De Pascale, G.;Avai, A.: Integrated computer aided design for assembly systems: CIRP Ann Manuf Technol 50 (2001) 17-20.

Bohlin, R., Delfs, N., Hanson, L., Högberg, D., & Carlson, J. S. : Automatic creation of virtual manikin motions maximizing comfort in manual assembly processes, In Technologies and Systems for Assembly Quality, Productivity and Customization : Proceedings of the 4th CIRP Conference on Assembly Technologies and Systems, 2012, pp. 209–212.

Brolin, E.(2016). Anthropometric diversity and consideration of human capabilities: Methods for virtual product and production development.(Doctoral dissertation,Chalmers University of Technology)

Böhler, W.: Comparison of 3D laser scanning and other 3D measurement techniques: Recording, Modelling and Visualisation of Cultural Heritage (2005) 89-99.

Gläser, D.; Fritzsche, L.; Bauer, S.;Sylaja, V.J.: Ergonomic Assessment for DHM Simulations Facilitated by Sensor Data, in: R. Teti (Ed.), 48th CIRP International Conference on Manufacturing Systems, CIRP CMS 2015, Elsevier, 2016, pp. 702-705.

Hanson, L.; Högberg, D.; Carlson, J.S.; Bohlin, R.; Brolin, E.; Delfs, N.; Mårdberg, P.; Gustafsson, S.; Keyvani, A.;Rhen, I.-M.: IMMA–Intelligently moving manikins in automotive applications: Proceeding of ISHS (2014).

Högberg, D.; Hanson, L.; Bohlin, R.;Carlson, J.S.: Creating and shaping the DHM tool IMMA for ergonomic product and production design: International Journal of the Digital Human 1 (2016) 132-152.

Ingelsten, S.; Mark, A.; Edelvik, F.; Logg, A.;Österbring, M.: Urban CFD Simulation Using Point Cloud Data, 29th Nordic Seminar on Computational Mechanics, Gothenburg, Sweden, 2016.

IPS:Industrial Path Solutions (2017) http://industrialpathsolutions.se/

Lindskog, E.; Berglund, J.; Vallhagen, J.;Johansson, B.: Layout Planning and Geometry Analysis Using 3D Laser Scanning in Production System Redesign, in: R. Soderberg (Ed.), 6th CIRP Conference on Assembly Technologies and Systems, CATS 2016, Elsevier B.V., 2016, pp. 126-131.

Lindskog, E.; Berglund, J.; Vallhagen, J.; Berlin, R.;Johansson, B.: Combining point cloud technologies with discrete event simulation, 2012 Winter Simulation Conference, WSC 2012, Berlin, 2012.

Maruyama, T.; Kanai, S.; Date, H.;Tada, M.: Motion-capture-based walking simulation of digital human adapted to laser-scanned 3D as-is environments for accessibility evaluation: Journal of Computational Design and Engineering 3 (2016) 250-265.

Mårdberg, P.; Carlson, J.S.; Bohlin, R.; Delfs, N.; Gustafsson, S.; Högberg, D.;Hanson, L.: Using a formal high-level language and an automated manikin to automatically generate assembly instructions: International Journal of Human Factors Modelling and Simulation 2 4 (2014) 233-249.

Rex, D.;Stoli, S.: Applications of 3D Laser Scanning in a Production Environment: Chalmers University of Technology (2014).

Schaub, K.G.; Mühlstedt, J.; Illmann, B.; Bauer, S.; Fritzsche, L.; Wagner, T.; Bullinger-Hoffmann, A.C.;Bruder, R.: Ergonomic assessment of automotive assembly tasks with digital human modelling and the ‘ergonomics assessment worksheet’(EAWS): International Journal of Human Factors Modelling and Simulation 3 (2012) 398-426.

Yu, A.; Liu, Z.; Duan, G.; Tan, J.; Che, L.;Chen, X.: Geometric Design Model and Object Scanning Mode Based Virtual Assembly and Repair Analysis, in: R. Soderberg (Ed.), 6th CIRP Conference on Assembly Technologies and Systems, CATS 2016, Elsevier B.V., 2016, pp. 144-150.