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Evaluating a Digital Twin Concept for an Automatic Up-to-Date Factory Layout Setup

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Abstract. Today, manufacturing factory layout setups are most often manually designed and kept up-to-date during their lifecycle with computer-aided design software's, so that analyses, verification simulations, and decisions can continuously be done. This manual approach is a cumbersome iterative process to collect the necessary information, with a high risk of faulty inputs and updates. Often the virtual descriptions do not match the physical version of the factory setup. This research presents a digital twin solution where physical equipment is connected to a virtual representation of the same equipment and automatically updates the virtual environment with the spatial position of the physical equipment and a proposed way to evaluate it. The physical equipment either has inbuilt sensors or has been equipped with external wireless sensors to track the spatial position. The metadata are distributed via Node-RED (a tool to visualize Internet of Things) to the simulation software Industrial Path Solutions, where the virtual equipment is repositioned based on data from the physical equipment. The result shows that it is possible to send spatial position information from a physical equipment and update the corresponding virtual description of the equipment in its virtual environment. The accuracy of the updates has been evaluated with manual measurements. Hence, the virtual environment of the factory setup, i.e., the digital twin, updates automatically based on the data sent by the physical equipment. With an up-to-date virtual environment, more accurate simulations and optimizations of the factory setup can be achieved. Examples of such possibilities are to evaluate ergonomic conditions or to optimize robot paths for robot cells in realistic and up-to-date virtual environments. Also, one could imagine making virtual reality visits to hazardous or sensitive factory environments in a safe way or studying things that otherwise would be hard or impossible in the real world.

Keywords. Digital Twin, Automatic, Factory Layout Setup

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1. Introduction

Preparations of manufacturing factory setups are today most often made by experts, using their experience as a basis for decisions. It is also most often manually performed with computer-aided design (CAD) modelled environments and simulations [1]. Most often the work depends on inputs from several cross-disciplinary preparation processes and activities [2]. Different virtual tools are used to assess different aspects of the preparation; examples of such aspects are product development/design, process development/preparation, resource setup/installation/preparation, often achieved in relation to building information models (BIM). Then the prepared content is often simulated and digitally tested for feasibility (e.g., collision detection, ergonomics, capacity, quality, handling, etc.) [3]. Exactly how these preparations are distributed and presented differs from company to company, an example is given in Figure 1.

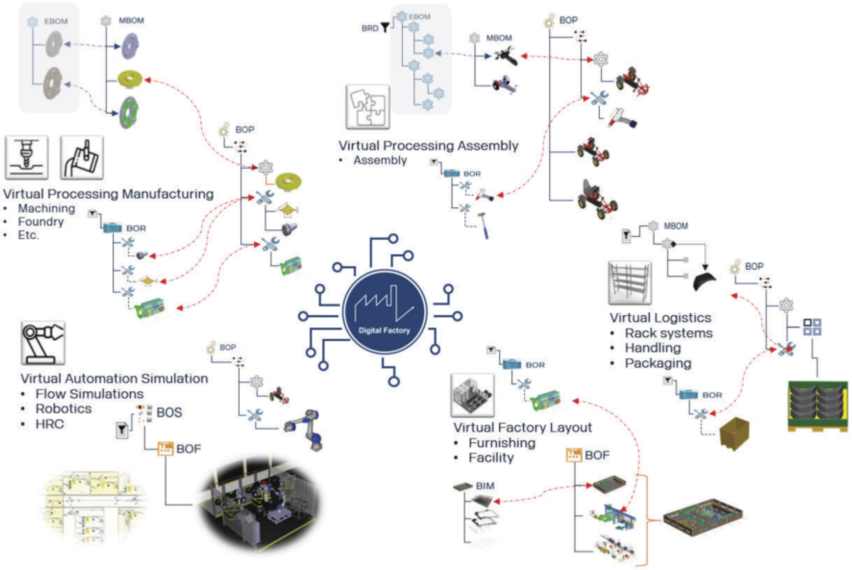

Figure 1. Virtual preparation includes several different activities, frequently done separately.

During the lifecycle of the factory it is of great importance to keep an up-to-date virtual layout of the factory setup so that activities such as analyses, verification, and simulations of new product or resource introductions can be performed [4]. These activities are often used to create documentation and descriptions for presentations to management and thereby used as a ground for decisions for the factory and the company. Therefore it is necessary to keep these virtual environments up-to-date so that decisions are based on updated accurate datasets.

Most frequently virtual descriptions of equipment are made before those of the physical counterpart. The CAD models are designed first, and the physical equipment is built after the blueprints and drawings of the 3D CAD models. The CAD models are used in ways to evaluate and optimize intended factory setups in advance in the virtual environments, but also during realized factory setups to verify or optimize the running manufacturing setup.

The digital twin concept has been introduced to achieve better simulations, verification, and optimization of equipment [5], [6]. The concept requires a physical artifact and a virtual description representation of the artifact (Figure 2), where the physical equipment is connected to its virtual twin representation; the concept also includes the information exchange between the physical equipment and its virtual representation [6], [7].

Figure 2. The physical equipment and its corresponding virtual representation.

However, the digital twin concept is not yet implemented at a broader range in the automotive industry and for manufacturing factory setup and therefore not yet evaluated in a large extent. Most often the update of the virtual environment is performed manually, often measured with laser measurements, 3D point cloud scans, or other measurements, and then manually edited and updated in the virtual environment [8]. This manual approach of physical measurements is time-consuming and costly in the sense that the measurements often need to be performed when the equipment is not in movement, hence often scheduled when production is stopped. As a result, such manual measurements and updates of the virtual environment are not done frequently. The manual approach presents a risk of human errors, but also a risk of not having the virtual environment up-to-date. Usually, with every new product or resource introduction, there is a need to manually re-measure and update the virtual environment to have a description of how the factory is currently performing and then plan ahead for future setup.

Therefore there is a need for an automatic and objective process to make virtual and physical twins consistent with each other. The aim of this paper is to present and evaluate an automatic and objective approach to connect the real with the virtual environment with the purpose of having an accurate, valid, and reliable up-to date virtual replica, based on the near-time occurrences in the physical environment.

2. Method

The design science research (DSR) concept [9] has been used as methodological approach for this research, due to this concept allows for gathering descriptions of issues from end users and then create an artifact e.g., a software or demonstrator to propose a solution for the issue.

The software tool Industrial Path Solutions (IPS) connected with the software Node-RED was used to create a proof-of-concept demonstrator. The IPS software is a math-based tool used for simulations of virtual environments. IPS facilitates simulations with rigid body path planning and flexible components [10], ergonomics simulations [11], robot simulations [12], and surface treatment processes [13].

The software Node-RED is a flow-based programming tool, originally developed by International Business Machines Corporation (IBM); it is used to present and make use of Internet of Things (IoT). IoT is known as “things” that are equipped with sensors or software technologies with possibilities of exchanging data with other “things” over the internet [14].

2.1. The Concept of the Demonstrator

The demonstrator enables sending data between reality and a virtual environment with a one way directed data flow. The physical equipment is connected to Node-RED and streams its spatial position via Node-RED to the virtual environment setup in IPS. Thereby the virtual environment reads and updates the corresponding virtual description (Figure 3).

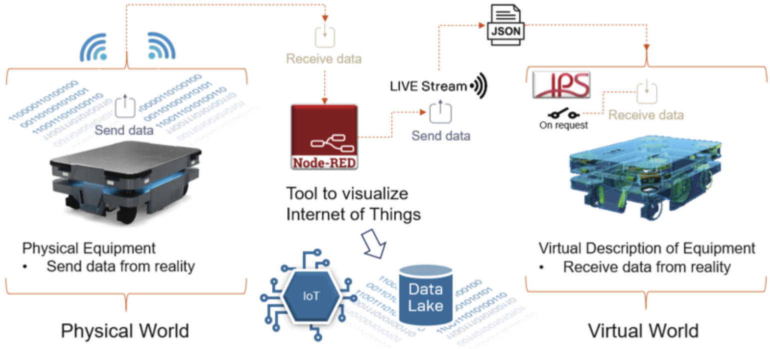

Figure 3. The concept of the data exchange for the demonstrator.

2.2. The Virtual Descriptions

For this demonstrator a part of a Scania factory building, BIM content, was used; it was designed with AutoCAD Architecture software and exported and converted for IPS import. The virtual BIM content holds the master origin (Figure 4). The XY-plane is considered as the floor level with the Z-axis pointing up. This is important, since when sending the spatial position from the physical equipment it is necessary to address a transformation matrix to match the corresponding position in the virtual environment.

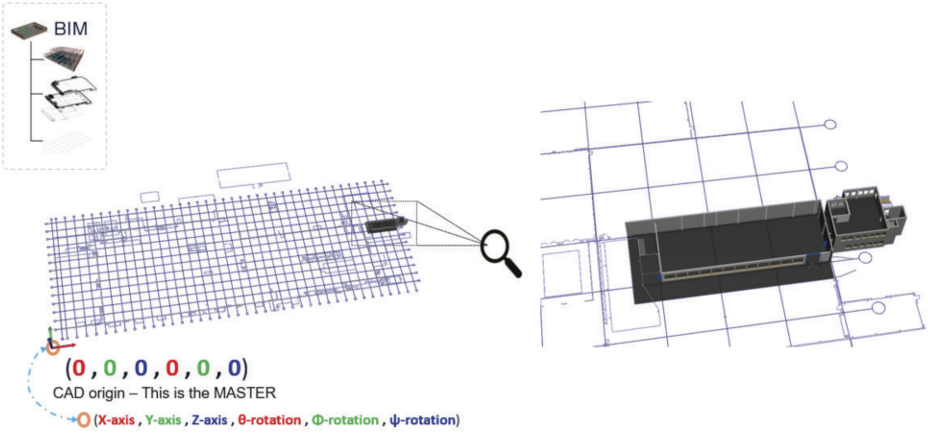

Figure 4. The selected BIM content of the demonstrator and its origin.

The virtual resource equipment used for the demonstrator consists of two separate entities: an Automated Mobile Robot (AMR) and a rack system. The virtual model of the AMR was received in STEP format from the supplier and the rack system was CAD modelled in-house. The virtual descriptions of the equipment were imported and redefined with the Dassault software Catia V5 so that it shares commonalities such as insertion point/origin definition with the actual corresponding physical equipment (example in Figure 5), then exported and converted to other formats and read by IPS.

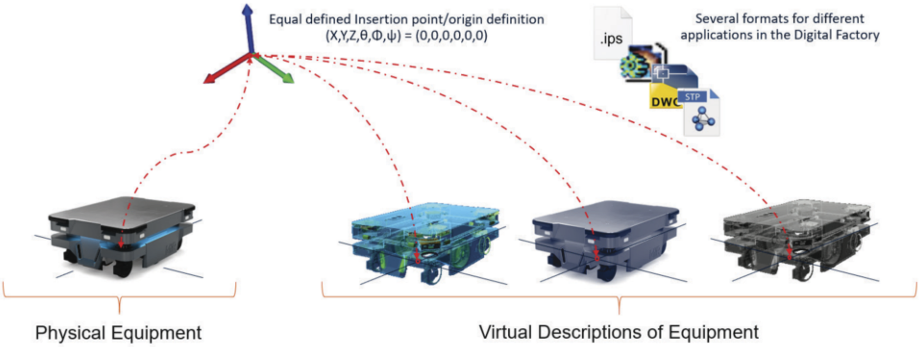

Figure 5. The resource equipment and its definitions of insertion point/origin.

Notable is that, like the BIM content, the Z-axis is directed upwards for the resource equipment defined insertion point/origin definition. This insertion point/origin definition is harmonized for all virtual formats used and matches the physical equipment, which should be built after the virtual model, so that potential data information of spatial position can be transferred between virtual and physical environments (Figure 5).

2.3. The Physical Equipment

The physical equipment consists of an AMR, which has an inbuilt position handling system that 3D scans its surrounding to orientate and calculate its position (Figure 6), and a rack system, which is equipped with four external sensors (H&D Wireless sensors) to track the spatial position of the rack system (Figure 7).

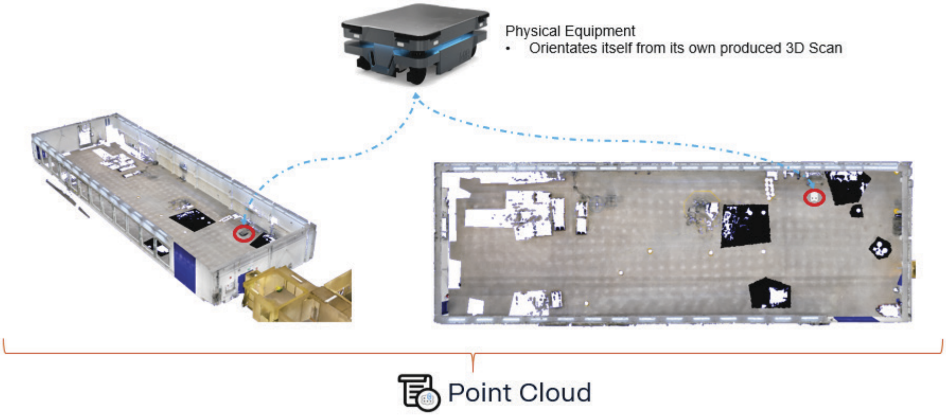

Figure 6. The physical equipment 3D scans a point cloud to orientate itself.

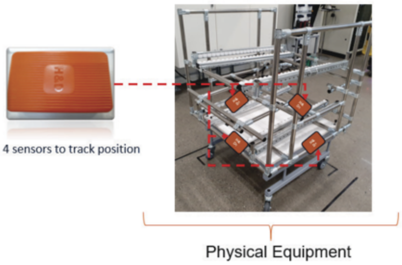

Figure 7. Four external sensors are placed on the physical rack system to track the spatial position.

The rack system sensors are connected to a cloud based solution and to Node-RED. When combining the spatial positions of the sensors, calculations are done to set the insertion point of the corresponding virtual equipment (Figure 8).

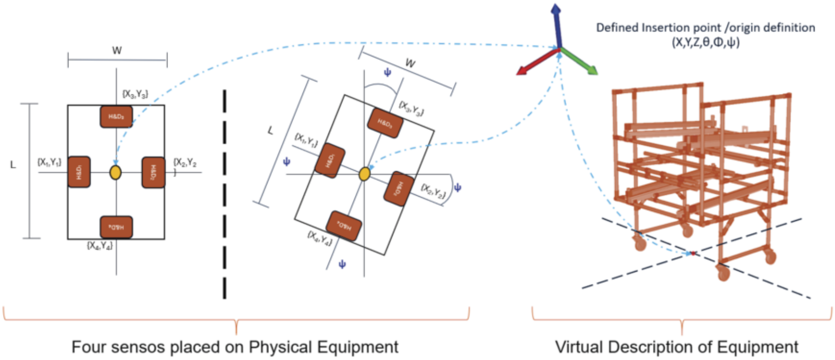

Figure 8. Illustration of how the four sensors of the rack system correspond to the insertion point/origin defined by the virtual description of the rack system.

Both the AMR and the external sensors have their own locally defined zero coordinates, exemplified for the AMR in Figure 9, and send their coordinates and orientations in relation to their own origin to the Node-RED software.

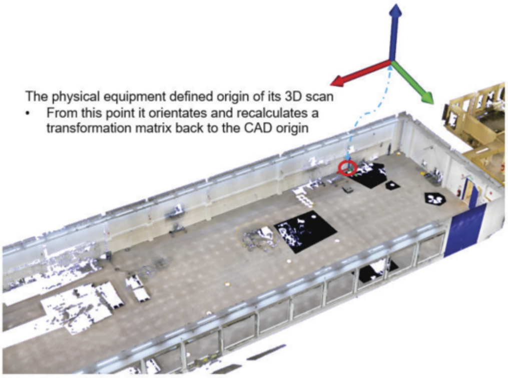

Figure 9. The physical equipment has its own local zero coordinate definitions.

Since the virtual environment has its own defined CAD origin (the master origin) (Figure 4), it is necessary to recalculate the incoming data from the physical equipment and external sensors using a transformation matrix before updating the virtual environment (Figure 10).

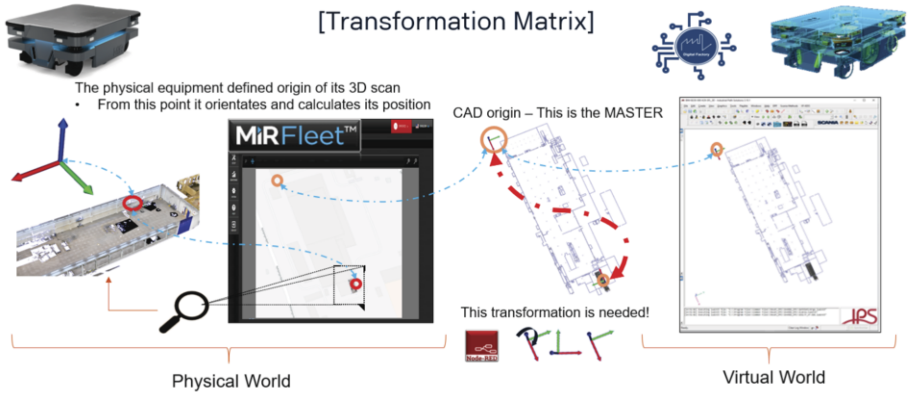

Figure 10. An example of the AMR's own local zero coordinate and the transformation matrix needed to convert to the BIM CAD origin.

2.4. The IoT Platform

The software Node-RED acts as an IoT platform that distributes and transports the data messages from the physical equipment and sensors to the IPS software. The Node-RED is setup with MQTT brokers which act as a post office and distribute specific topics for the physical equipment connected to subscribing nodes in IPS; for this demonstrator it is an AMR (with inbuilt sensors) and a rack system to which four sensors have been attached.

2.5. Evaluation

To evaluate achieved and updated spatial positions in the virtual environment from the physical equipment, a digital laser rangefinder (model GLM30 from the company Bosch) was used. The device is suitable for measuring indoor distances, has a stated precision of plus to minus two millimetres, and measures in meters with three decimals. The digital laser rangefinder measures from the rear edge of the device and reflects a beam on the target (Figure 11).

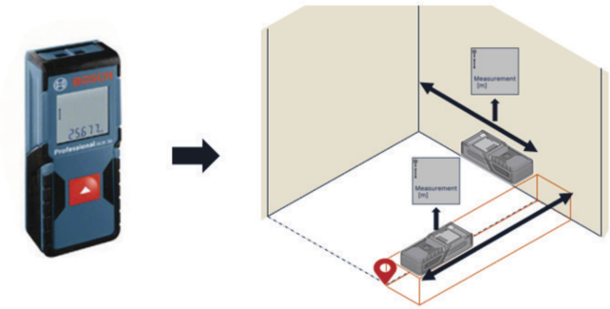

Figure 11. Illustration of how the digital laser rangefinder is used.

The physical equipment, both the AMR and the rack system, was evaluated with position changes with ten new locations in the workshop. These ten locations were not the same for the AMR and the rack system. For each position the floor was marked with the center point of the physical equipment (Figure 12). Then from the updated virtual environment, the coordinates of the equipment were read and calculations of differences between the positions in the virtual environment were compared with the measured distance from the digital laser rangefinder in x direction and y direction.

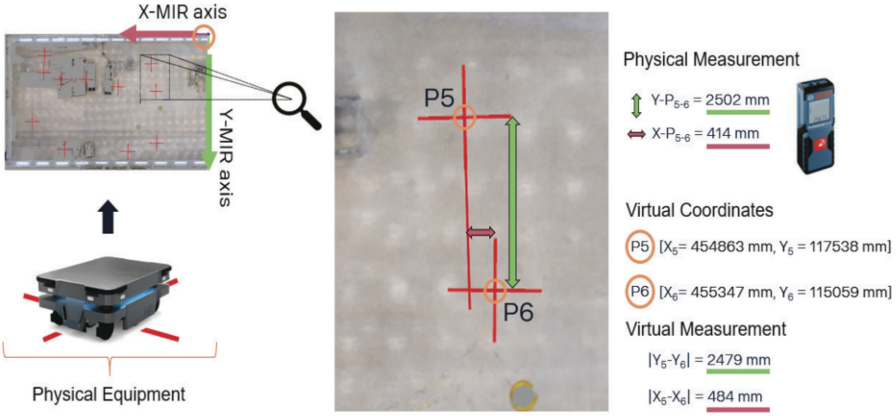

Figure 12. The physical equipment exemplified by point five (P5) and point six (P6), where its center point is marked on the floor. Then measurements are made and compared with virtual changes.

3. Results

The demonstrator presents an opportunity to understand how a digital twin could work in the future. The connection between the physical equipment and sensors via Node-RED and the virtual environment of IPS works. The incoming data from the H&D Wireless sensors and the AMR (with inbuilt sensors) are distributed via Node-RED and are automatically read by IPS, which updates the spatial position of the corresponding virtual description of the equipment in the virtual environment of IPS (Figure 13). Even though it is a manual step to setup the MQTT broker of Node-RED and set the subscription to the correct objects in the virtual environment, it presents a way of not having to manually measure and edit the virtual environment. The connection and thereby the update of the positions allows an objective approach to positioning the virtual equipment since it is a value sent by the physical equipment rather than measured manually, which would involve subjectivity.

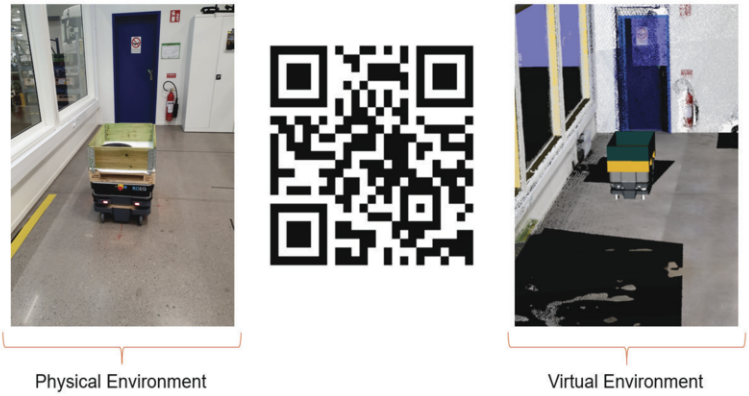

Figure 13. The QR code links to a video that demonstrates the real-time updates of the virtual environment based on changes in the physical environment.

In Table 1 the resulting values for the ten observed points per equipment are listed. The results are based on the absolute value distance for each difference between physical measurements and virtual measurements.

Table 1. Results of measurements

Equipment	Direction	Mean (average) [mm]	Standard deviation [mm]	Max deviation [mm]
AMR with inbuilt sensors	x	21	19	70
	y	31	17	74
Rack system H&D Wireless sensors	x	591	493	1870
	y	514	309	1116

4. Discussion

Many conference papers, journal papers, previously have highlighted the need for digital twins in the automotive industry and with the industry 4.0 concept, there are scarce ones evaluating the actual outcome of such ideas. This paper is one of the first to present and describe one way of evaluating a digital twin concept where the spatial position is sent from the physical environment to a corresponding virtual environment.

4.1. Consideration of Results

The lifecycle of a factory setup can often be described as a planning phase, an implementation phase, a verification phase, and a running phase. It usually begins with a virtual description so that planning can be done for how the factory setup should be installed and executed. This is done with models and simulations and analyses of the factory setup a factory layout. In the coming phases, investment in the actual physical equipment is made and the equipment is installed. Many companies then proceed with operation acceptance tests (OAT) to conduct operational readiness assessment of the production system. Part of that is to make sure the virtual environment is up to date so that future virtual activities such as virtual commissioning, optimizations, simulations, and offline programming of equipment can be performed.

Setting up a data exchange between the spatial position of the physical equipment and its corresponding virtual twin enables an automated approach to keep an up-to-date virtual factory setup. One intended usage would be to evaluate the planned position of the virtual environment, update the environment, and rerun optimizations on actual factory setups (Figure 14). To compare the planned factory setup with the actually implemented one is vital, since several activities are often performed in the planning phase, such as virtual robot programming and testing the process to be. If there are differences from the realized factory, the virtual environment needs to be updated so that analyses are done on the correct setup.

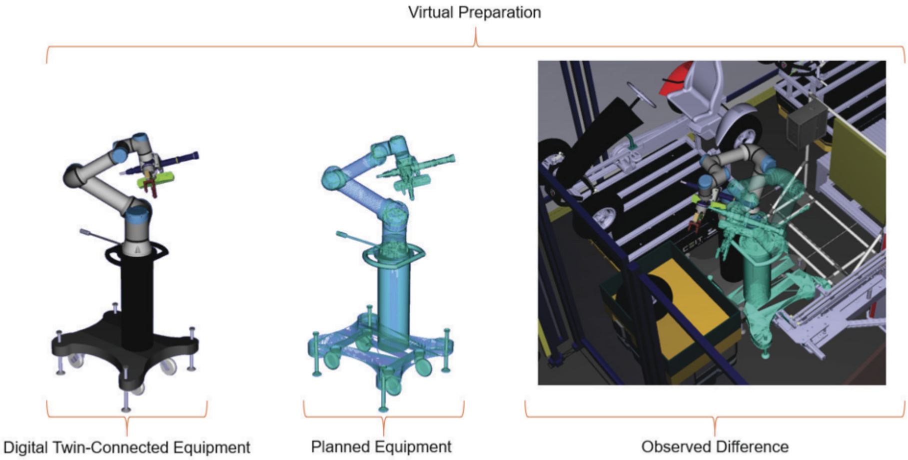

Figure 14. Illustration of usage to evaluate and observe difference between planned position of equipment and the digital twin position of the equipment.

To realize a digital twin solution, the virtual model needs to be described in such a way that it shares commonalities with its corresponding physical twin. One important aspect of this is the definition of the object's origin (Figure 5). If the spatial position is to be updating the virtual environment, the origin definitions on the object level need to match.

When evaluating the result of the data sent by the sensors and the associated updates of the virtual environment, the observation shows that the AMR has an accuracy in centimeters, while the rack system with the H&D Wireless sensors has an accuracy in meters. It can be questioned whether this accuracy is sufficient. In some cases such levels of accuracy might be good enough, but in other cases, for example in a robot cell, the accuracy might rather need to be in millimeters in accordance with reachability tests and clash analyses, and simulations of such equipment need to be done with a virtual environment with high accuracy. We see a need for more development and research to increase the accuracy but also to better understand how accuracy needs depend on application.

In summary, today's manual work to keep virtual environments up to date is cumbersome, and this demonstrator presents a way to create a connection between reality and a virtual environment, where the virtual environment is automatically updated based on incoming real-world data. Even with the current accuracy of the demonstrator it still offers the possibility to track changes observed in reality, which should trigger the need to understand and react on changes so that updates of the virtual environment are performed.

5. Conclusion and Future Work

5.1. Conclusion

To have an up-to-date virtual factory setup should enable digital trust and possibilities to optimize actual physical factories. When successfully realized, a digital twin solution can facilitate analyses of all kinds of data from reality, and when having data mapped correctly to the corresponding virtual model, one can use the data to simulate and optimize the virtual environment and then use it as a base to implement and improve reality. This is a step towards Industry 4.0, i.e., to be able to reuse information from reality in virtual upstream preparation activities and make use of data collections [6].

The virtual environment offers the capabilities to simulate and analyse, but it can only simulate the content that is present and accessible in the virtual environment, therefore the interoperation of the analyses and simulations should consider how up-to-date the virtual environment is. To have the spatial positions sent from the physical equipment to the virtual environment requires higher precision so that the virtual environment is as accurate as needed and the trust in the correctness of the virtual environment is unquestioned. When this is achieved, it should be possible to minimize manual work to keep the factory layout up to date and an up-to-date virtual environment should also then be available to more preparators in the company.

5.2. Future Research

Another technique currently in use to update the virtual environment of the factory setup is 3D point cloud scans. One could probably combine the 3D scans with sensors connected to physical equipment to achieve up-to-date virtual environments. The need for better and more accurate sensors is seen in this demonstrator. When such need exists the expectation is to connect more equipment to the virtual environment so that the, manual work needed to keep the virtual environment up to date can be minimized.

There are of course more datasets and information than just the spatial position of the physical equipment that are useful for a virtual environment and such information exchange in-between should also be included in the digital twin concept, e.g., sensor status such as open, closed fixtures and other signals. The benefit of having an up-to date virtual environment is that one is then able to simulate analyse and improve on more realistic and accurate datasets. Then one could imagine virtual reality visits to hazardous or sensitive factory environments in a virtual secure way to present safe ways to conduct studies of running production systems. Or indeed study things that otherwise would be hard or impossible to study in the real world. However, the sensors and position data need to have higher maturity and accuracy. The information received from the position of the physical equipment requires higher precision if the virtual environment should be updated automatically, since the virtual environment is a base for decisions and simulations of the process and factory setup. When precision expectations are met, a digital twin concept can be realized, meaning an up-to-date virtual environment automatically updated for virtual commissioning and optimization of production processes.

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