Digital and Physical Testbed for Production Logistics Operations

Jannicke Baalsrud Hauge, Masoud Zafarzadeh, Yongkuk Jeong, Yi Li, Wajid Ali Khilji, Magnus Wiktorsson

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Jannicke Baalsrud Hauge [1,2] , Masoud Zafarzadeh[1] , Yongkuk Jeong[1] , Yi Li[3] , Wajid Ali Khilji[1], Magnus Wiktorsson [1]

[1] KTH Royal Institute of Technology, Södertälje, Sweden
[2]Bremer Insitut fur Produktion und Logistik GmbH (BIBA), Bremen, Germany
[3] Fraunhofer-Chalmers Centre for Industrial Mathematics, Gothenburg, Sweden
jmbh@kth.se

Abstract. Digitalisation and automation of existing processes are key factors for competitive industry, but still logistics operations are often dominated by manual work. A shift towards higher degree of automation within existing infrastructure is often challenged by high cost and complex processes, thus a return-on-investment is hardly achievable within decent time. The experience has shown that it is hard to assess all restrictions and interactions between new and old components before any new equipment or infrastructure is implemented and put into operation. This paper presents and discusses if the usage of digital twins representing and simulating a physical part can support the related assessing and decision-making processes. In this context, this paper presents a production logistics test-bed includes physical devices, an IoT-infrastructure and simulation software for innovation as well as operational management purposes.

Keywords: Technology assessment, Cyber-physical system, Production logistics.

1 Technology assessment challenge

The cost of logistics is often high, but with minimal value-added contribution [1,2]. Consequently, stakeholders are looking into how to use technology to offer the same or better services at a lower cost [3,4,5].

This trend encounter several challenges, which concerns more the implementation of different components in an existing operative environment than the technical development [6, 7]. A key challenges is related to assessing how different new components will interact with the existing systems - i.e. a typically challenge when dealing with technology introduction in complex system [5]. The usage of test-beds can contribute to overcoming these challenges [8]. However, it will not sufficiently contribute to understand the interactions of new components in an industrial operative environment, since there are several context related challenges such as physical limitations. For example, a challenge is related to the decentralised decision-making process carried out by the autonomous robots (like automated guided vehicles, or smart cargo) [3, 1, 9]. The usage of digital twins can help in overcoming this challenge, since it can visualise the differences between the optimal path based on algorithms and the optimal path based on the inbuilt decision-system in the AGV.

The focus of this article is to discuss how digital twins can contribute to support the decision-making process of selecting the right components for a specific task both related to the degree of automation and the digitalisation of the operations. The rest of the article first describes the requirements on a digital twin used for decision-making; secondly how the manipulation of the digital twin can be used for a better understanding of the system and components interactions, before the test-bed we are using is described in more detailed. Finally, we describe how the different components are integrated and interacting and as well as the first results. The last section discusses the main challenges and the next steps.

2 Digital twin preconditions for production logistics' activities planning

Technology introduction has a large impact on the organisation of operational processes both at managerial and operative level [9]. Therefore, it is not sufficient to only pay attention to the technical aspects, but also required to predict their outcomes and based on that, make right decisions. According to [10] digital twins can support planning as well as prediction of the working processes. Regarding the definition of digital twin, we build it upon the definition by Tao et al. [9] p.3566 as well as the characteristics of digital twin as described in [9] in respect to a) real-time reflection b) interaction and convergence and c) self-evolution. As described in the introduction, a main challenge of introducing concepts like IoT, CPS, and Industrie4.0 etc. in existing environments is the assessment of how the technology will affect the whole organisation and interact with existing solutions. According to [11, 12, 13] digital twins that can be manipulated can support the decision-making process. Regarding the assessment of autonomous and decentralized decision-making, which is required in cyber-physical systems [14,15] it is hard to model these with the right interactions with other system components and with the right routing (decided upon by the autonomous object) [3, 10]. However based on experiences on importing sensor data from a lab-environment into the virtual environment, comparing the routes and interaction with the first simulations, and then modify and manipulate these data in the digital twin (by using game mechanics), a better system understanding can be achieved [16].

Digital twin can mirror or simulate complex scenarios very close to the reality [9, 15, 16, 17]. Besides providing an opportunity to be used as a learning and awareness-increasing tool in which operators, or management can use virtual reality (VR) tools to experience the real working conditions with high precision [18], the digital twin can support the introduction of new technologies and installations within the existing physical environment [18, 19]. In this case, we simulate the working processes and observe the material movements, machines, robots etc. and their interactions [20]. One of the Swedish test-beds focuses on production logistics, i.e. it focuses on the material and information handling within the production system, with strong and integrated interfaces to supply chain management. This physical test-bed should allow testing of a) man to material technologies b) robot to material c) material to man and d) material to robot. Furthermore, in order to realise the latter, it should explore the usage of Real time locating system (RTLS) and the interaction and operation of different AGVs. It should be set up to meet the industrial need for improved demand assessment, dynamic and more efficient milk-runs, shortened cycle times, reduced bullwhip effects, highly transparent and integrated supply chains as well as improvements in production planning, real-time information flows, end-to-end supply chain transparency and general improvements in flexibility [21]. By the four pillars of technology support, real-time information, interoperability and decentralized decisions core technology areas needed should include real-time data acquisition, organization, and management; digital twin representation; data analytics for logistics applications; and digital twin-based shop-floor management and control [17].

3 The physical and digital test-bed

3.1 Physical environment

The focus of the first set-up is on connecting equipment and RTLS, since these are a prerequisite for being able to realise a transparent and efficient material flow from one warehouse to a production site as visualised in Fig. 1. The initial demonstration scenario is to kit three different parts in two different kits by introducing a UR (collaborative robot), an AGV, a Kinect vision system, and a RTLS. The AGV transport the parts from storage position to the UR robot station, which performs the kiting with the help of the vision system. The kitted parts will be transported by the AGV to the assembly station at the end.

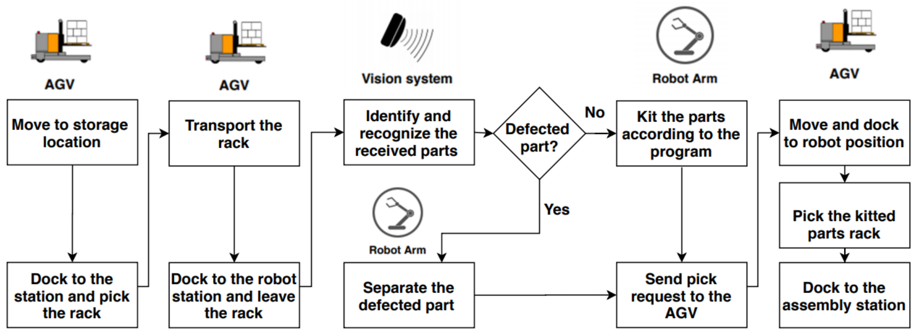

Fig. 1. Material flow process within the testbed

In order to investigate the problems mentioned in section 2, the physical objects and the digital twin are integrated in a single system, which components communicate via a data streaming bus. This system interconnects all components to make use of digital twin of the real-world scenario. As a first step, communication between each component was realised. A data streaming bus, which will hold and serve messages wherever needed was chosen for this purpose. Secondly, there is an application layer, which is required in order to write business logic or calculations. In addition, data storage and digital twin ought to be connected through the application layer. Fig. 2. represents the system architecture for the production logistics digital twin.

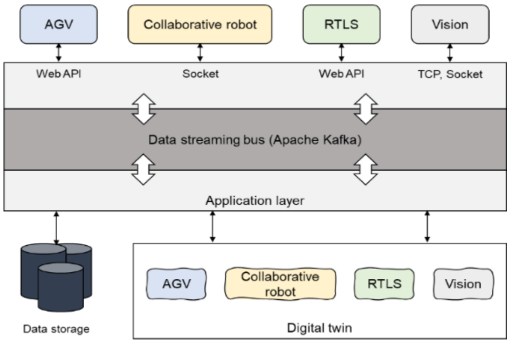

Fig. 2. Production logistics digital twin system architecture

3.2 Digital environment building the IoT solution

In the digital environment, replica components of the physical environment are defined. Each replicated component has to go through the data streaming bus and application layer to send and receive information from the physical environment since the operating systems, data formats, and communication methods are different by each component. Next describes communication between the components in more details: a) The AGV communicates via web API to share location data, and various parameters such as battery status, speed, and orientation of the AGV. b) The collaborative robot communicates over a Transmission Control Protocol (TCP) socket connection to share different types of data such as trajectories. Here, the robot is treated as a server and connected via a TCP client application. c) The RTLS system uses API to retrieve location data of these various objects. d) The vision system is currently built by using Microsoft Xbox Kinect and working via a C# program with the help of OpenCV wrapper, called EMGU. Coordinated captured by Kinect will be send to a middle-ware that translates them into the collaborative robot coordinates. e) To visualise the digital twin, Unity is used. Along with some complex prefabs like AGV and collaborative robot, delivered by the supplier or modelled using IPS. Each controller is responsible for fetching data or controlling the machine. f) Data storage is used for the long-term data solution for data analytics, or data mining aiming to replay a particular scenario. The next section describes the different possibilities we have for the models in the digital twin, as well as outlines what we currently mainly look at.

The digital environment does not only mirror the physical environment in the test-bed, but also allow 'manipulation' to allow experimentation with different technologies and equipment prior to the decision in a virtual world.

3.3 Applications for workstation design

As described above, it is needed to know what granularity our models should have, depends on what we intend to use them for. For the purpose of the test-bed and the given requirements, we need different granularities for different manipulations. Therefore, three examples in this spectrum of applications are presented. a) engineering of workstations, b) layout planning and c) collaborative robotics. This will cover all the levels we need in the test-bed on long term and gives an overview of the different levels of required granularities. In order to realise the three different cases, specific modelling tool is used: a detailed analysis of robotic workstation design and AGV route planning has been carried out through IPS simulation tool shown in Fig. 3. The UR robot trajectories during the kitting process is simulated to calculate the required space to place kitting boxes, loading rack, and AGV docking position. Besides, the required distances for safe operation is calculated here. The AGV movement within the testbed area is simulated based on IPS route planning algorithm, which is the optimal path. The simulated path can be compared with actual path taken by the AGV to compare the deviations and root cause analysis.

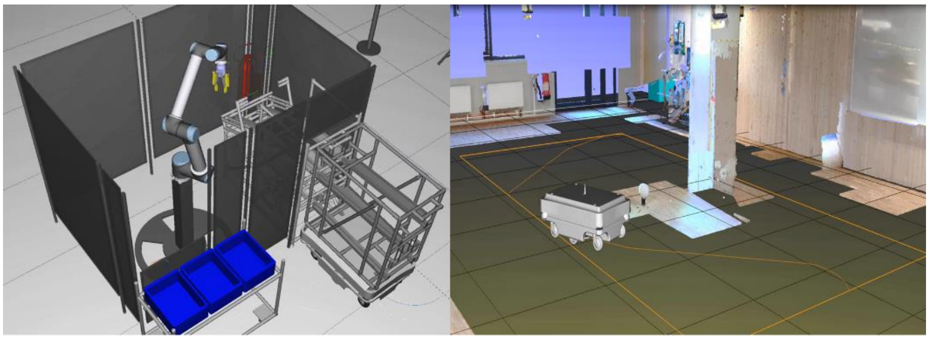

Fig. 3. Using IPS simulation tool to engineer workstation design and AGV route planning within the testbed environment

3.4 Applications for logistics operations analysis

The digital twin is used both with pure simulation data as well as with data from what we already have in operation to figure out the integration and interaction of AGV and picking robot investigating how the AGV is doing its mission scheduling and how this can be improved. Interaction and interference with existing systems as well as to decide upon the right new object (like the type of AGV) is a challenge as described earlier. Secondly, another challenge is that there is limited information about the algorithm the AGVs are using for calculating their path. In this case, we have however full control over the algorithm the digital twin of the AGV (modelled using IPS), which is the optimised algorithm. Comparing the results of the digital twin optimised algorithm and the physical movements of the AGV can give valuable information on the behaviour and thus help in the assessment of the suitability for implementation in different environments. Furthermore, the integration of the physical data in the digital twin allows a better visualisation that can be used for: a) Detailed investigation of the exact movements of the AGV or collaborative robot (as shown in fig. 4). b) Using a re-play function as well as combining different experiments in one single digital twin scenario helps to understand the variation in movements as well as to recognise patterns (i.e. continuously occurring deviations between real movements and optimised calculated paths). c) To explore an environment, which might have no or limited access (either using VR, AR or a 3D computer model on the PC). This can be used for teaching purposes to explain the interaction of the different components as well as for letting the students try out simple actions in a safe environment. Fig. 4 illustrates this possibility. The picture to the left shows the digital model of the lab environment. The viewer can use a camera to move around and experience the room. Besides the detail of the models- here the path of the AGV- is visualised. The image to the right shows the movement of the physical AGV (data imported in the Unity model via the communication bus).

The digital twin has the capability to start the different physical operations via the digital twin interface. This opens up the possibility for carrying out experiments in risk areas. In this case, except few individuals, most of the personnel do not have the right access to operate the physical equipment on site, can perform experiments through digital twin. This increases the possibilities to utilise expensive lab equipment to a higher degree.

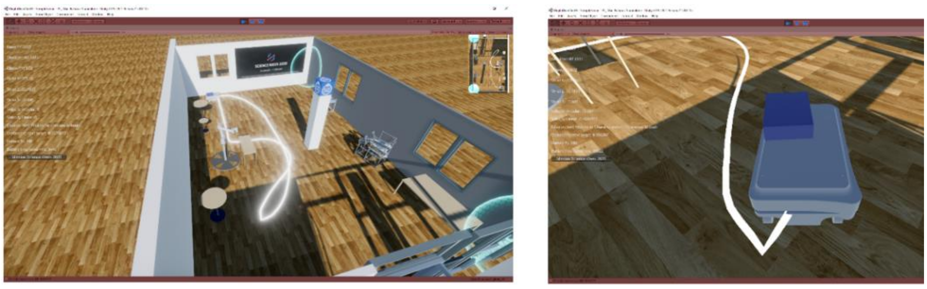

Fig. 4. Tracking AGV in real time within the digital twin

The mixed-reality environment, which we have described here, is in its prototypical implementation phase and the results are preliminary, but promising. During the last semester, the lab used as part of a master course for production logistics. Here a group of students carried out experiments studying the exact movements of the AGV in the physical lab. At that time, it was not possible to import and store the data in the digital twin for visualisation, but the collected data will now be imported and compared with the ideal (optimised) movements. Secondly, the first tests of using the digital twin for educational purposes have been successfully tried out in different labs. We have therefore now integrated our digital –physical twin environment for educational purposes in a digitalisation course. The remote control scenario is so far working well as long as it is operated within the network.

In the next step, it will also be possible to run and manipulate the model from outside. This will allow us to connect different test-beds to one single digital test-bed in order to look at larger challenges. The simulated optimized route in the digital twin will be compared to the actual chosen route by AGV in the physical environment. Besides, quality control checkpoints needs to be located as well as to investigate how to embed this into the material flow process.

4 Discussion and conclusion

The focus of this article is to discuss how digital twins can be used for technology assessment. . The digital twin has been used to analyse workstation design and AGV route planning with a focus on understanding how the granularity in the modelling used in the digital twin affect the transferability of the results achieved with the digital twin technology assessment to a physical world. By using a testbed environment, it has been possible to compare the technology assessment in the digital twin with a technology assessment of the physical environment and based on this draw conclusion about the need of granularity differences in the modelling. Main conclusion is that the granularity of the model is one of the key limiting factors for using a digital twin for technology assessment of real-world/physical logistical operations. . In this case, picking operation is simulated to analyse required space, cycle time, and safety. Compare to a manual system, a fully automated system is less flexible as human has much higher level of intelligence, but it has drawbacks such as mistakes, fatigue and less availability, however looking into the degree of granularity for the models, the experiments shows that this can be fairly low as long as we are only interested in cycle time and costs, but needs to be high for safety and medium for space usage For AGV route planning, the results showed how the AGV might behave in the physical environment compare to IPS simulated model. For these first experiments, a low granularity was needed, the required space, routes, possible hinders and safety concerns could be sufficiently well analysed. The collaboration with UR robot is another issue, which we could analyse by using digital twin and where we have to conclude that a high granularity is required.

In general, the primary results of how digital twin can be used for technology assessment in production logistics are promising. However, more tests and investigations are required to be able to be more explicit.

Acknowledgment

The present work was carried out partly within the project DIGILOG (Produktion 2030, Vinnova) and UniLog (Central Baltic program, grant no. CB743). This presentation does not represent the opinion of the European Community or Vinnova, and the European Community and Vinnova are not responsible for any use that might be made of its content.

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