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A Cloud-Based Research and Learning Factory for Industrial Production

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Abstract

The Digital Factory Vorarlberg is the youngest Research Center of Vorarlberg University of Applied Sciences. In the lab of the research center a research and learning factory has been established for educating students and employees of industrial partners. We devised learning scenarios and developed courses addressing a wide variety of topics related to Industry 4.0 and showcase best practice scenarios for various topics of digitalization. In addition, novel methods and technologies for digital production, cloud-based manufacturing, data analytics, IT- and OT-security or digital twins are being developed. A centralized SCADA (Supervisory Control and Data Acquisition)-System is the core data hub for the factory. As an alternative to on premise manufacturing, orders can be pushed into a cloud-based manufacturing platform, which has been developed at the Digital Factory. In this paper, we present the basic concept of the Digital Factory Vorarlberg, some of the newly developed topics as well as learning scenarios for students and industry staff.

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Keywords: Cloud-based research; Learning Factory; Digital Factory

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1. Background and Related Work

Learning factories have been a topic of great interest in the last couple of years. Abele et al. [1] give an overview of the current state of the art and outline their didactic foundations. They compare existing approaches and discuss their advantages as well as limitations. Using learning factories can be highly beneficial to train employees. Similarly, Banea et al. [2] identify learning factories as a key factor in preparing personnel for industry 4.0 processes. They show that learning factories prove effective for developing theoretical and practical knowledge for new employees as well as experienced ones. Prinz et al. [3] present a variety of learning modules, with specific learning targets and scenarios, for the smart factory in Industrie 4.0. They propose that these modules may be used to prepare, for example, students for the new job profile of employees in Industrie 4.0. In [4] Nardello et al. present a learning factory where they implemented a platform for developing technologies to satisfy manufacturing requirements and to demonstrate their value in a production environment. Erol et al. [5] propose a scenario-based learning factory developed at Austria's Industry 4.0 Pilot Factory. The multitude of new technologies in the digitization of manufacturing processes proves to be difficult to handle. Hence, they utilize scenarios for a problem-oriented learning of future production engineering. Tisch et al. [6] present a systematic approach for the competency-oriented development of learning factories. They integrate the conceptual design levels ‘learning factory’, ‘teaching module’ and ‘learning situation’. However, learning factories may also be addressing specific aspects of manufacturing processes. In [7] Abele et al. demonstrate how learning environments can be used to create awareness among employees when it comes to energy efficiency.

2. The Implementation of Digital Factory Vorarlberg

The Digital Factory is a showcase factory for the digitization in the manufacturing industry. Its implementation addresses a variety of topics related to Industry 4.0 with a strong emphasis on single-piece production.

2.1. Mechanical setup

The manufacturing cell of the Digital Factory Vorarlberg is designed to fabricate simple products in an automated, digitally controlled setup for mass production of customized single-piece items. The factory comprises only a minimum core of logistics and fabrication processes, which are required for development and demonstration of digital fabrication. Processes and stations have been chosen and designed to be exemplary and simple with the exclusive focus on the development of digital systems and processes. Development or optimization of the materials or processing related aspects of manufacturing are not purpose of the factory. Therefore, initial training requirements for students and personnel from non-manufacturing domains (e.g., computer scientists, etc.) is kept to a minimum and operation of the manufacturing facility can be guaranteed past the initial funding stages with little or no dedicated shop-floor personnel. However, to allow training and development of digital processes at industrial levels, all machines, systems and controllers are professional products, which are typically used in relevant industries.

Currently, the factory comprises five different stations (storage, transport, fabrication, assembly, manual operations). In a smart storage area, raw materials and prefabricated parts are stored in bins as unsorted bulk goods. For each manufacturing order, the required items are automatically collected by a bin picking robot which hands the items over to a transport robot (Servus Robotics) connecting the central storage area and all stations together. Intermediate storage areas at each station allow processing of orders in a completely decoupled and randomized fashion at each fabrication step. Generation of parts with different, customized shapes is accomplished by a small CNC mill (EMCO Concept Mill 55) with an industrial CNC controller (Heidenhain 640). A CAM system (Hypermill) is available to generate the required NC-files according to customer specifications. For parts assembly, a station comprising two collaborative robots (Kuka iiwa) is included in the fully programmable workflow. In addition to their collaborative capabilities, the robots are used to measure assembly forces for process control. Finally, a manual station is available for inspection and all remaining fabrication steps.

2.2. The digital controls system

A centralized, industrial SCADA-System (*zenon*) is the core data and control hub for the factory. All machines, stations and controllers are connected via this system (see Fig. 1). Machine Controllers are connected through drivers via standard protocols (e.g., OPC/UA) or customized drivers have been developed (e.g., DNC). Data is homogeneously collected by the SCADA system and stored in an external database (*crate.io*) which can be accessed by a dedicated data analytics server. Touchscreen based dashboards and HMI control panels are available through zenon and can easily be customized. A simple MES (Manufacturing Execution System), *MES_VL,* and a webshop have been developed to manage product configurations, manufacturing plans and order execution. In this webshop the customer can customize a product, e.g., a custom design of the wing of a fidget spinner, and a design checker will test the specifications and the geometry for manufacturability. If a design is being submitted for manufacturing, a CAD file and the necessary manufacturing plan are generated. The resulting CAD file is submitted to a CAM system to generate the required machining programs. In case of simple items, like the wing of the fidget spinner, this can be done completely automatically. In case of more complex geometries, manual input might be required (see Section 3). After all CAM-files and the manufacturing sequence have been generated the manufacturing order is submitted to the MES for automatic processing.

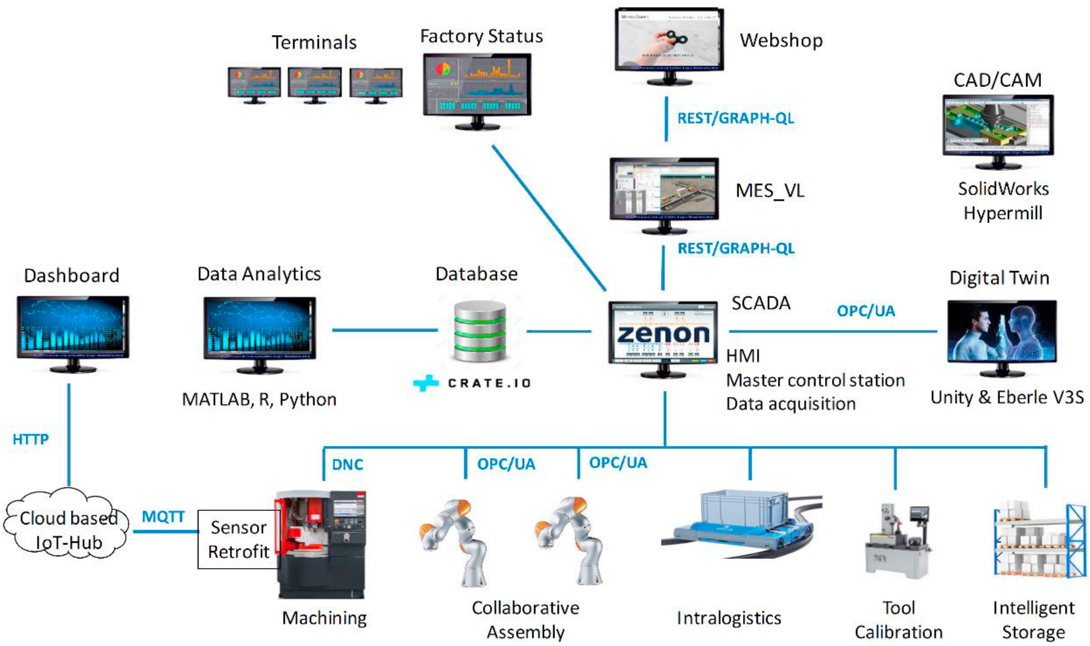

Fig. 1. Digital System of the Digital Factory Vorarlberg.

To complement on-site data analysis a cloud based showcase has been implemented. Sensor retrofitting and data analytics utilizing a cloud-based IoT-Hub can be demonstrated. In addition to an autonomous, on-site operation, the factory can be connected to a cloud based manufacturing system, which has been developed at FH Vorarlberg.

3. A Cloud-Based Manufacturing Platform

Nowadays, production processes are not limited by a single physical factory anymore, but rather encompass production steps performed in distributed facilities. Providing the means for supervisory systems and a standardized information exchange between factories is a key task in modern production. Building upon the implementation of the Digital Factory we develop a cloud-based manufacturing platform.

Cloud computing paradigms and their technologies are enabling factors for connecting distributed services and lay the foundation for combining distributed factories in cloud based manufacturing platforms [8]. Compared to traditional manufacturing this is a new paradigm [9] with specific characteristics and requirements. Additionally, new applications and business opportunities arise [10]. At the Digital Factory Vorarlberg, we develop and implement a Cloud Manufacturing (CMfg) platform, based on these paradigms. Essentially, our platform employs a microservice architecture [11] with services implemented in Java using Docker and Kubernetes [12]. This platform not only enables us to gain expertise in related research areas, but also to connect with local manufacturing companies.

Our platform comprises the entire production stack, including the low level machine devices on the shop floor and upper level enterprise information systems. A *Web application*, built in Angular, serves as an interface for consumers and providers to interact with the cloud platform. Here, providers, e.g., factories providing services, can register or consumers, i.e., customers, can order products. For constructing a product assortment of available products we use techniques first introduced in software product lines [13]. The gathered information, e.g., orders, is processed by services in the core of the platform and involved parties, e.g., machines on the *shop floor*, are informed. Using this approach we can provide a complete customizable, single-piece production. An overview of the platform is shown in Fig. 2 (a).

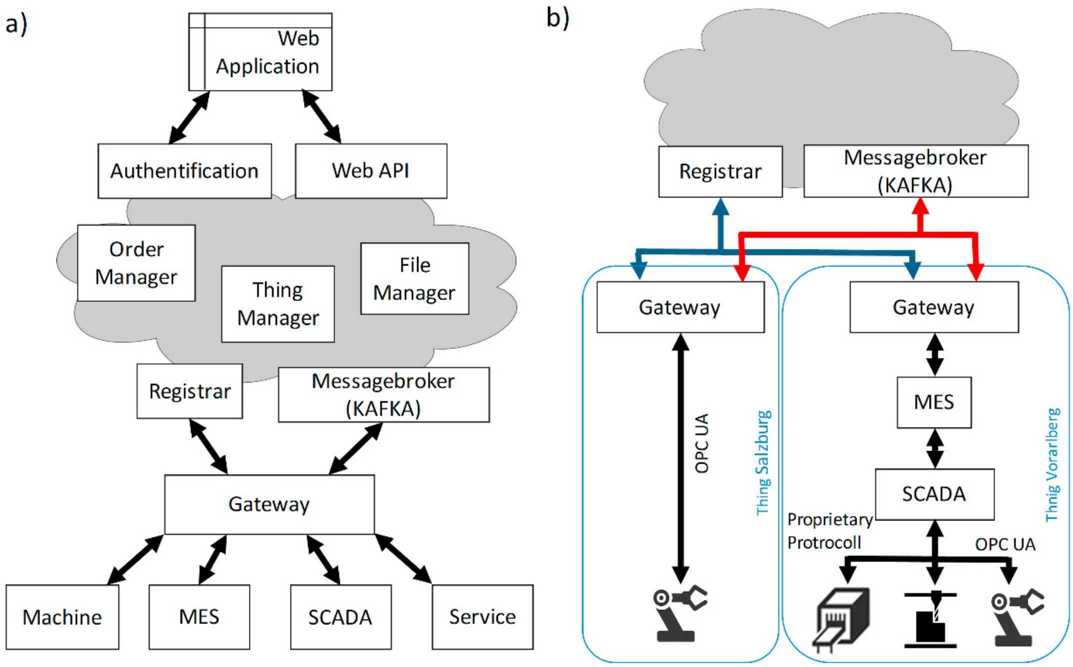

Fig. 2. (a) Overview of Cloud Manufacturing Platform; (b) Cloud Platform connecting two manufacturing sites.

For connecting external services to the core of our platform we use a *gateway* with an interface definition (API) and message oriented communication. The connected services can be complex systems, such as SCADA or MES, as well as single services of, for example, a milling machine. One of the key features of our gateway concept is that it contains a plug-in system. This enables integrating various protocols by providing a wrapper implementation using our gateway API. For example, Kuka iiwa robots, which are communicating via OPC-UA [14], are connected to our cloud platform using Eclipse Milo. Technically speaking, the communication uses Apache Kafka as a broker for message exchange. Fig. 2 (b) illustrates the concept of our gateway approach.

The core of the platform contains a semantic knowledge base given in OWL [15], which incorporates all information necessary for manufacturing processes. This includes connected services and their abilities [16] as well as information about products and their life cycles [17], making it the central hub for factories and customers.

We provide services that perform specific tasks based on the information in the knowledge base. For example, we developed an *Order Manager,* which collects orders, and a broker service that optimizes work plans and dynamically distributes orders from the *Order Manager* to registered services, i.e., solves a constraint satisfaction problem [18]. The resulting process plan may involve manufacturing steps in distributed factories, but for the customer it is a single operation. In addition, we also facilitate the possibility for participants to provide custom services for other participants. These services may be consumed based on different policies, e.g., against payment, which essentially makes this an App-Store for manufacturing services.

Both, the interfaces for higher, e.g., Web application, and lower, e.g., shop floor, tiers are flexible and highly extensible. We provide the means for developing new applications and allowing them to interact with the cloud platform by facilitating a REST API. Since information about provided services is vital for the operation of the cloud platform and, even more so, for the involved parties, a security concept is mandatory. Therefore we encrypt all communication between services and the cloud platform. For the Web application interface we use well established technologies and principles from web development, like OAuth2 and REST.

Utilizing this platform may lead to new business opportunities, which are not yet possible with traditional manufacturing paradigms. For example, it is conceivable that not all steps during processing an order can be fully automated. Generally speaking, an automatic transformation from CAD to CAM is not possible in all cases. If such a case occurs, this transformation has to be performed manually by experts, i.e., it is outsourced. Our platform makes it possible to register a service that does exactly that. A participant providing such a manual service is informed, e.g., in the Web application, and a task is assigned. After completion of the task the result is sent to the cloud platform and the manufacturing process continues with the next step.

4. Learning Scenarios and First Results

Utilizing the implementation of the Digital Factory enables teaching students as well as employees of industry partners in a wide variety of topics. To accomplish this we formulated learning scenarios that address current state-of-the-art issues in Industry 4.0 and use the Digital Factory to implement them.

One of these scenarios addresses IT- and OT-security topics and is intended for employees with basic training in IT-Security. We prepared a three-day course specifically addressing security issues that arise in Industry 4.0 and to raise awareness. In this course we not only discuss new emerging trends, e.g., data encryption on edge devices, but also demonstrate them using the Digital Factory, e.g., encryption methods on retro-fitted CNC sensor data. In collaboration with one of our research partners we demonstrate a new and modern approach to intrusion detection. The network traffic and log files created during operation of the Digital Factory allow us to demonstrate the necessity of combining information from data sources on multiple levels of abstraction for a coherent security concept. We plan to expand on this scenario and build a fully-fledged Cyber Range. Other learning scenarios include statistical analytics of data gathered from machines. In this course we perform an explorative analysis on datasets generated in the Digital Factory, e.g., movement information of the Kuka iiwa robots, by applying basic functional data analytic methods. We specifically address employees without any prior knowledge in statistics and show how tools such as R or NumPy in Python can be used to get an overview of large datasets.

However, we are not only addressing staff in the industry, but also students of various branches of studies. There are courses starting in the third semester leading up to the possibility of a master thesis. In one of the courses we demonstrate modern IoT solutions using the retro-fitted CNC machine. Using real data of physical machines makes it easier for students to establish an understanding for the topics since they have immediate feedback when an operation changes. In a five day course we teach students in how to use a SCADA-System and demonstrate this utilizing the

Digital Factory. For such courses we also invite staff from industry to present topics of a modern production plant. Here the Digital Factory helps us to bridge the gap between staff employed in the industry and students starting out.

We have received positive feedback from employees in industry and students. Many students stated that the courses prepared them well for their internships and that having real physical machines makes the topics more tangible. From the first iteration of courses we also learned that the topics are easier subsumable if they address a single specific area.

5. Summary and Outlook

At FH Vorarlberg, a research and learning factory with full industrial capabilities with little resource requirements has been developed and implemented. Development of digital production systems at various levels can be trained and a variety of state-of-the-art showcases can be demonstrated. In addition the factory is utilized to develop novel paradigms and systems, such as a cloud-based manufacturing system, service oriented manufacturing, data analytics methods or IT- and OT-security procedures. Further work will focus on the integration of professional MES and ERP systems, development of guidance systems for human machine interaction the development of machine learning methods for digital twins or the further advancement of broker systems, optimization of workflow and order management. Regarding the cloud-based manufacturing system we plan to integrate parts of external factories of industry partners, to prepare and train their personnel concerning demands of digitized production.

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