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FutureFit: a strategy for getting a production asset to an industry 4.0 component – a human-centered approach

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Abstract

Industry 4.0 and digitalization enable a badge size one production and individualized products in a feasible way. Especially the modularization of production components, like Cyber-Physical Production Modules (CPPM), has the potential to make the production environment more flexible. The concept of CPPM has been successfully implemented in the SmartFactory KL. In contrast, existing machines in factories often have a large lifespan and because of different vendors there are no standardized interfaces and functions. The question arises how existing production assets can be upgraded to fit in the industry 4.0 setup, making it more accessible especially for the workers in the production environment. The need to upgrade the existing machines and not excluding the operators is derived in the state of the art. A special focus addresses the specification of the so-called industry 4.0 (I4.0) component and the information supply on the shopfloor. An I4.0 component consists of a production asset with its Asset Administration Shell (AAS), realizing a standardized industry 4.0 communication. After deriving requirements from the state of the art section, the need to connect the human worker with the production assets on the shopfloor via the AAS is shown. Leading to a human-centered system structure for the human machine interaction. Furthermore, we propose the FutureFit strategy to transform a current production asset towards an I4.0 component. This serves as extension to the retrofit of equipment which is usually performed only once and not in a continuous way. Both parts together highlight the essential specifications of the AAS as the information and communication interface between human and machine. Together they provide a generic concept for the FutureFit approach in order to take a legacy production asset and upgrade it to an I4.0 component.

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1. Introduction

In our modern society, diverse megatrends like globalization cause a shift in the way manufacturers develop and produce their products. This is due to the fact that they are facing continuously changing customer demands. Instead of a low priced and standardized product, the customer seeks to order a customized, unique product with the aim to have it as soon as possible in badge size one. This implies shorter time to market and development cycle time. These changing requirements reveal the need for a more flexible way to produce goods and therefore a production environment with a higher flexibility needs to be developed [1]. In particular, the manufacturing equipment itself needs to change and reach a certain degree of flexibility to handle individual customer demands without causing economic shortfall, including the control systems of machines [2]. While changing customer demands influence the way companies produce, the question arises how the human worker will fit into this future factory scenario. From the past it is clearly visible that regardless of any technological changes in the production environment, the human worker remains and represents the only constant part in the system. Earlier attempts to exclude the human from the production environment revealed their integral importance, which was proven by the computer integrated manufacturing (CIM) era [3]. Hence instead of removing the human factor from the production area, we need to ensure that production workers will be able to handle and interact with the new production equipment.

The SmartFactory KL represents an implementation of a more flexible production environment through the modularization approach [4]. In this scenario, a production line is a Cyber-Physical Production System (CPPS), consisting of multiple Cyber-Physical Production Modules (CPPM) where each of these modules has a predefined set of manufacturing functions in order to realize a certain product. Within these CPPM we can identify smart and modular components, also called Cyber-Physical Systems (CPS). Components of the lower levels can be flexibly aggregated to higher level components. Due to their standardized interfaces, these components can be acquired from different vendors as well. This approach has proven to fit the objective to create a flexible and customer-oriented production environment if a company intends to develop and build a new production line (greenfield) [5].

In contrast to that, competitive companies' real-world problems are not solved by building a new production line from ground up. New machinery and equipment imply large financial investments plus additional costs for exchanging existing with new machines which causes production outages. From a financial point of view, companies will not completely replace their equipment, especially since nowadays production equipment like machines have a large lifespan of up to 50 years [6]. This implies that there is a need to gradually migrate the production environment towards a more flexible production in order to cope with limited investment budgets. Especially Small and Medium sized Enterprises (SME) need to be able to migrate their production without losing their competitiveness [7]. The necessity to transform the production environment due to changing customer demands, reveals the crucial role of the human worker in the production. The need to gradually migrate the current production to stay competitive leads to major challenges for companies.

2. State of the art

In order to deal with this challenge, this section takes a closer look at the way we see production components in the future (section 2.1), the changing role of the human in the production (section 2.2) with a focus on SME (section 2.3) and the retrofit concept (brownfield) of a production environment (section 2.4).

2.1. Industry 4.0 component

In the context of Industry 4.0 and the fact that production components need to be able to communicate with each other, we need to identify important characteristics and criteria. In nowadays discussion about intelligent components we can define the main parts of an industry 4.0 component as follows: a physical asset which is combined with an asset administration shell [8,9]. The software part is able to communicate and therefore integrates the asset as a service participant into the I4.0 network. This type is also called industry 4.0 software component because it uses more than only active and passive communication [8]. Identification, communication, semantics, virtual description, industry 4.0 services and states, standardized functions, security and safety aspects represent the main criteria an industry 4.0 component needs to fulfil [8,9].

The necessary requirement for the unique identification process of assets and asset administration shells is being realized through a unique identifier. The same precondition applies for data, standard functions and services. A unique identification is necessary to guarantee a common basis for communication between components. [8,9] The architecture of an industry 4.0 component is service-oriented, which implies that proper communication between components is an essential part for successful implementation. Communication supports data exchange and allocation of the required information. Therefore, the guarantee of a proper data transmission between assets is an integral criterion. This communication relies on a standardized vocabulary in form of data, functions and syntax. Hence a common semantics scheme needs to be implemented [8,9]. The virtual description is the composition of information such as semantics, product designs etc. This specification is the basis for a digital twin [8,9].

In the factory of the future components, systems and machines will be able to detect each other's current position, tasks and the next production steps in real time [8,9]. Furthermore industry 4.0 components will bargain about this kind of data, information and functions. Accordingly, these assets require a unique description with an identifier that represents the specific aspects. Industry 4.0 components need to be interoperable to work in every situation at every location and all the time from different suppliers [8,9]. The integration effort for the end user will be highly reduced if interfaces for communication are standardized and interoperable. Also functions need to be standardized to guarantee a higher degree of flexibility.

Besides the previously mentioned criteria the security and safety concept represent an important part of the industry 4.0 component. In the future development of new industry 4.0 assets, security needs to be a definite characteristic including a measurable quality [8,9]. Since we already highlighted that future assets need to communicate, transfer data and information, have standardized functions and use common semantics, there is a further need for security and safety aspects. Necessary functions of a security system are authentication processes, user and role management. Furthermore, inherent security capabilities will be digitally available. Safety, privacy, resilience and reliability will stand for further characteristics of the security area [8,9].

Summarizing this section, we identified many detailed and specific criteria and requirements for industry 4.0 components. Though the focus lies solely on technical aspects. Especially the identification, communication and common semantics between assets, products or machines are highlighted [8,9]. Thus, it is not considered to include the human as part of the criteria an industry 4.0 component needs to fulfil. The communication and identification as well as semantics deliver interfaces for human abilities that should not be omitted. Fulfilling all the above-mentioned criteria is a very ambitious goal to achieve, especially for companies with limited resources. It will be a highly challenging task to combine them with human aspects. The following section will focus on this area and suggest a strategy to fit the human and its specific characteristics into the architecture of the industry 4.0 component.

2.2. Information supply for the human in the production

Regarding the human role in production, previous work has shown that there is a need to support the human on the shopfloor, especially in a modular, decentralized production environment where the worker needs to be able to interact with the machine data in a flexible way [7]. From a technical perspective, the information supply of the production equipment can be realized (e.g. via the AAS), but the question arises how this information supply needs to be shaped.

In this context, [10] promote standardized semantic information models as a necessary requirement in industry 4.0 environments. Further, open machine interfaces are needed to guarantee information access [11,12]. In a decentralized production environment, which represents a complex network of different participants with different requirements, a production worker needs the ability to access information location-independent with a mobile device of free choice [13]. Machine interface as well as the used mobile device need to operate platform-independent to ensure a vendor-independent interoperability between production assets in an industry 4.0 environment [14,15].

From a data driven point of view, a consistent data handling chain can be seen as a guideline which comes with technical and functional adaptability, generalization, robustness, real-time capability, semantic interoperability, intelligent choice of analysis and visualization tools, flexibility and expandability [16]. Regarding the delivered information for the human worker, [17] propose a context-sensitive information supply which includes a model for the user profile, the working task, customizable user profiles, model of the production environment, links between working task and useful information as well as the possibility to search for specific information if necessary. Interacting with information becomes increasingly necessary, especially if unavailable information is instantly required and needs to be subscribed to.

2.3. Small and medium sized enterprises

The concept of the I4.0 component (section 2.1) and the requirements regarding information supply on the shopfloor (section 2.2) might be achievable for large industrial companies and research facilities. However, companies with equipment and machinery which is not state of the art still rely on their human workers on the shopfloor, making them key assets in the production area who must be supported in their daily work [7]. Due to the changes in the way customers order products and a therefore more flexible production, possibilities to support the human worker increase as well [18]. Because of digitalization and the I4.0 component, the possibility arises to connect human workers with machines via the AAS. Linking human workers and machines on the shopfloor is one option if superior IT-systems are not available. But still the question remains how the AAS can be linked to the human worker in order to realize a flexible interaction with the machine data.

2.4. The retrofit concept

Since the upcoming of the industry 4.0 terminology and the trend towards digitalisation in the production environment, approaches to upgrade legacy systems according to new requirements have emerged. Even before the word industry 4.0 was increasingly featured in the literature, the need to address the changes in customer demands was highlighted. [19] present an approach using web services deploying a service-oriented architecture to enable a field level communication with superior applications e.g. a manufacturing execution system. [20] define retrofit as a process that extends a current system with new functions, which were not available when the machine was produced. [21] show a concept how a production system can be integrated into an industry 4.0 environment by using a gateway approach. This gateway enables the production asset to change into a CPPS which interacts with e.g. monitoring applications. [22] provide an approach where an embedded system is retrofitted to a legacy machine in order to send the machine condition data to a cloud data center where it is forwarded to a frontend for the user. [23] show the possibility for a cost-efficient retrofit of manufacture equipment by installing communication and control modules on existing equipment and show their implementation phases. [24] present a retrofit approach that integrates a CNC-machine with its functional requirements, design parameters, data model and system architecture in order to realize a customer-oriented system. [25] describe seven steps for the implementation of the AAS as an enabler for a production asset to be integrated in the industry 4.0 environment with a focus on data integration with OPC UA. [26] present a technical report from an industrial retrofitting project where a gateway was used to create a communication infrastructure between a punching machine on the shopfloor and the companies' Enterprise Resource Planning (ERP) system.

Concluding our findings, we can identify that most approaches are only conducted once with a specific purpose. However, reaching the goal of an I4.0 component, a continuous approach with a successive expansion of a production asset's abilities is needed.

3. The FutureFit concept

This section presents the future fit concept with a focus on the human-centered approach for the future production environment.

3.1. Human-centered AAS

As identified in section 2.1, the I4.0 component has the ability to solve issues between different components in the production of the future but is therefore very complex, which makes the proposed criteria hard to achieve. In addition, the I4.0 component focuses on the interaction between (technical) components. So far, there is no solution for a flexible interaction with the human worker (see Section 2.1). The AAS needs to be extended to support the human worker in the future by using the I4.0 component approach. First implementations of the AAS in a real production environment have shown that the realization is possible, but the focus points on functions and submodels which support the production process itself and not the people on the shopfloor [27]. As a basis for a human-centered approach between human worker and AAS, the system structure in [7] is used and extended to a human-centered smart factory approach. From the state of the art, we can identify the following requirements regarding a human-AAS-interaction:

R1: AAS needs to be able to offer semantically described information in a uniform structure.

R2: AAS needs to be able to use a vendor-independent communication protocol (e.g. OPC UA) to communicate.

R3: AAS and CPPM are connected via exactly one information interface.

R4: AAS offers a user interface so that the human worker (user) is able to connect with it.

R5: Information between user and AAS can be exchanged in a bidirectional way. The user holds a mobile device to connect to the AAS.

R6: The AAS needs to offer the semantically described information in a human readable way, plus offering different types of interaction for the data exchange between user and AAS.

R7: Each user needs to be able to choose individual information, thus they need to be saved in a user profile.

R8: AAS must be able to describe the possible interaction patterns as well as the requirements and needs of the heterogeneous actors in the implementation of the interaction.

Regarding these requirements, we can identify that the essential parts for a human-centered AAS are as follows:

- a user interface which offers the possibility for the human worker to interact with the AAS via mobile device.
- a physical interface to the CPPM in order to collect the CPPM data.
- An interaction manager which offers the semantically described information with different types of interaction. The interaction manager is the connection between the physical interface of the CPPM and the user interface.

The current interaction manager which is defined within the AAS describes interaction protocols for automated negotiation between I4.0 components and decision algorithms to automatically reach an agreement between the interacting parts [28,29]. Therefore, the functionalities of the interaction manager have to be expanded according to the findings above to be used for a human-AAS-interaction. The findings are used to update the system structure in [7] and summarized in figure 1a.

3.2. The FutureFit Approach

Due to the holistic approach of the I4.0 component, it is hard to identify real-life production assets that can be classified as a complete I4.0 component. As mentioned above, the I4.0 component criteria are hard to fulfil while companies are in the middle of the digitization process. In addition to that, project budgets are limited to stay competitive. That's why companies need an approach to bring their current production assets towards an I4.0 component. Furthermore, most of the current production assets are not yet optimized regarding human machine interaction. Therefore, an implementation of the AAS as part of the I4.0 component and interface between humans and machines is currently considered as not realistic.

In this paper, the approach is to realize a flexible user interface for the human worker on the shopfloor in order to flexibly interact with whichever production asset necessary. Since the current work regarding the AAS focuses on automatic interaction between I4.0 components, another possibility would be represented by translating the human worker into an I4.0 component. Since this approach aims at automating human activities and confines the overall flexibility, we will not consider this topic any further in this paper. As identified in section 2.4, the concept of retrofit lacks a certain continuity in most approaches. With regards of the I4.0 and its AAS, the retrofit concept has to be expanded to a FutureFit concept. FutureFit is the gradual process of continuous enhancement of production assets towards the realization of an I4.0 component. In contrast, retrofit is a singular enhancement of a production asset with e.g. a specific use case such as the realization of data analytics. The general concept is shown in figure 1b.

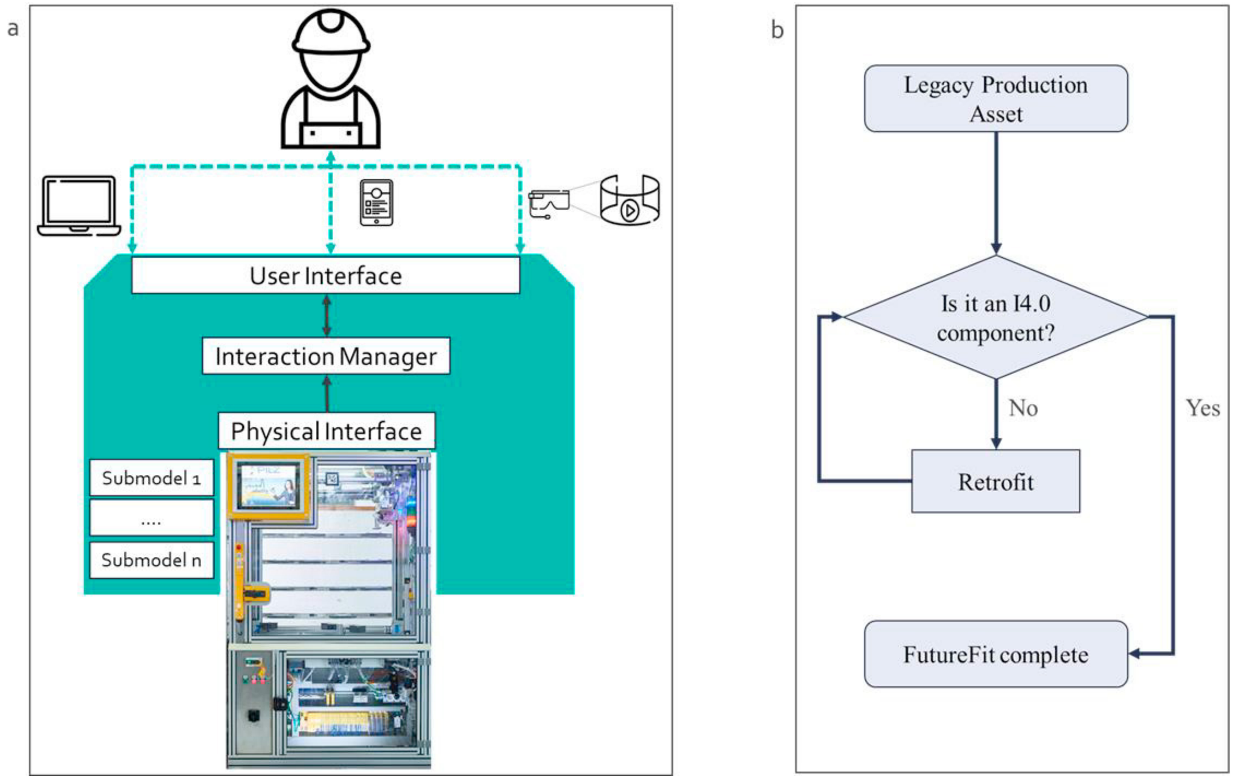

Fig. 1: (a) Necessities for a human-centered AAS interaction; (b) General concept of the FutureFit approach.

In a generic way, companies need to improve their production assets step by step to realize an I4.0 component. The question arises how far from the I4.0 component is the current production asset? At which point in time does a company know that it reached its goal? In order to answer these questions, the I4.0 component criteria need to be looked at in detail and subcriteria need to be defined. This area will be focus of future research.

As highlighted in section 3.1, our objective is not limited to the realization of I4.0 components according to the current classification but enables a realization of a human-centered I4.0 component in a modular production environment. In contrast, this paper excludes the manual assembly processes for the human worker. Approaches regarding manual assembly can be found in [30,31] for further reading.

4. Conclusion and Outlook

Concluding our findings, we can see that the idea of an I4.0 component can solve a wide range of problems that are occurring in the production environment. However, due to the holistic approach, it is difficult for companies to grasp which kind of requirements need to be fulfilled in their specific case. Furthermore, the I4.0 component and the AAS are not yet ready to answer questions regarding a flexible human-machine interaction in modular production environments, especially in companies where human workers on the shopfloor build the backbone of the company. In addition to that, a successive approach for upgrading existing production assets towards an I4.0 component is necessary. In this paper, we introduce a human-centered approach for the connection between the human worker and the AAS by deriving requirements for the AAS. Moreover, a system structure for a human-centered AAS interaction is presented. Additionally, we define the term FutureFit as a gradual retrofit approach towards an I4.0 component.

In future research, we intend to take a closer look at the system structure and the individual system components that need to be described in detail. In addition to that, the interfaces between the system components need to be defined in order to be able to implement this approach in a real-life system. Regarding the FutureFit approach, the I4.0 component criteria need to be specified with sub-criteria. This step is necessary to evaluate the status of a legacy system and to show the missing steps towards an I4.0 component. From the perspective that a production is a network of heterogeneous participants, a detailed method for modelling the interactions between these different participants is missing.

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