How to design a smart factory?

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Abstract

The enabling technologies of today creates a lot of opportunities. Hence, with all the different choices the complexity of different hardware and software increases. Furthermore, the communication between all the system needs a structure in order to make the whole system more flexible, proactive and productive factory. The aim of this paper is to demonstrate how a smart factory can be designed in terms of communication and interoperability between systems. To be able to demonstrate this a drone factory has been built in order to show a smart factory, from in-house logistics to end-on-line quality check. This paper uses the pathway framework to describe the development of the smart drone factory.

Keywords[1]

Interoperability, drone factory, CPPS

1. Introduction

Industry 4.0 have brought a multitude of enabling technologies [1]that individually can transform business processes and enhance performance through greater automation and control capabilities. These new technologies are believed to have a huge impact on future productivity for the manufacturing industry [2]. The three main characteristics of Cyber-physical-production-system (CPPS): intelligence, connectedness, and responsiveness [3] are all in line with the requirements that mass personalization puts on manufacturing and assembly systems. However, by interconnecting these technologies, new realms of interoperability emerge that present fundamentally new ways by which manufacturing can be conducted [4]. Hence, with a lot of technologies and a lot of communication needed, the complexity of the system increases. In order to make a flexible, proactive and productive system a strategy for implementation is needed. Furthermore, the system needs to be designed for the users, which means that the user perspective and information support system is important when designing the system [5]. Decentralization is an important design principle for Industry 4.0 [6] and should be demonstratable. Furthermore, modularization is vital if the flexibility of adding hardware and software shall be maintained [7](Huemer et. al, 2016). In order to create a strategy for digitalization and smart factory, digital maturity needs to be analyzed in order to understand the current state of the company and where they want to be in terms of digitalization and autonomy of decisions and communication. The pathway framework was developed to conceptualize and map the ways by which new technologies are used in business settings. The framework encompasses a means to map the value of digitalization in business environments. Within each of the pathways in the pathway framework, there are five milestones/levels that signify digitalization progress. This paper focuses on the autonomous smart factories' pathway, illustrated in figure 1.

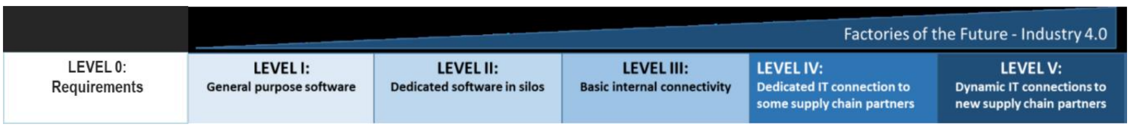

Figure 1: The milestones of the Autonomous smart factories' pathway

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This paper aims to describe the design process of the drone factory into an autonomous smart factory. Additionally, past, ongoing and planned implementations are mapped and analyzed by means of the pathway framework.

2. Designing a smart factory

This section will describe the design process towards a smart factory. In 2019 there was a start to design a drone factory as a testbed in order to apply and demonstrate the enabling technologies of industry4.0 [8].An aim with the factory was to show different levels of interoperability and different levels of the ISA-95 model (so called automation pyramid).A small supply chain was developed and a first product was developed, illustrated in figure 2.

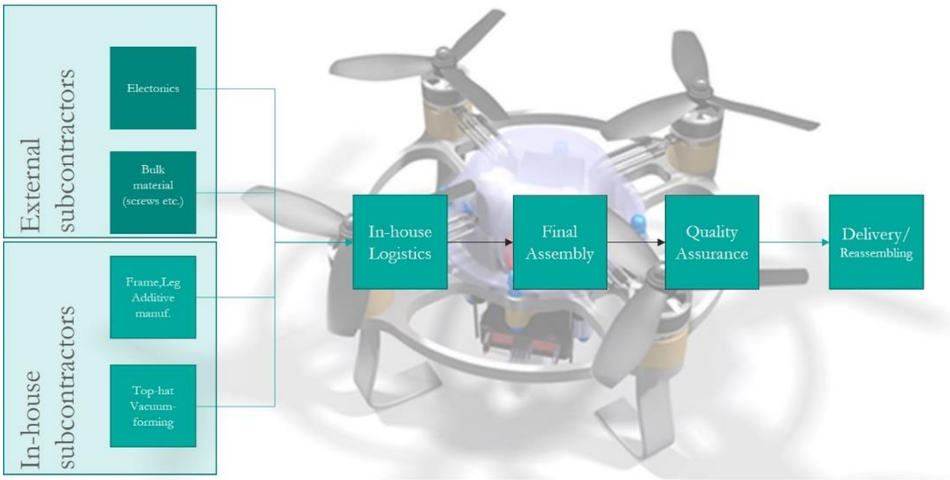

Figure 2: Supply chain and first drone in the drone factory

Since the drone factory is a green-field factory a strategy was needed in order to define the factory on a higher level in terms of factory boundaries and product specifications. The strategy started as requirements for the system, the requirements is presented as Level 0. The design process has been an interactive process between the levels. To be able to implement everything to reach real time optimization (Level 5) and to achieve all the requirements, twenty-five different implementations, or subcategories (SB) needed to be implemented. This shows the complexity of an implementation and design of a smart factory. The subcategories will be presented in the sections below.

2.1. Level O: Requirements

The aim of Level 0 is to create high-level requirements for the system to be able to demonstrate a smart factory. The vision of the drone factory is to demonstrate a fully functional production system that incorporates important principles of Industry 4.0 in the context of final assembly and inhouse logistics. A key characteristic of Industry 4.0 systems is *decentralized* decision-making [9, 10], which means that the common hierarchical layout of shop floor IT needs to change. To achieve this there are three aspects of systems integration that needs to be solved: vertical networking, horizontal integration, and end-to-end engineering [11]. Vertical networking, or vertical integration, aims to flatten the automation pyramid and reduce the number of steps between decision and system control. Horizontal integration means to improve information sharing between vertical organizations, which adds an organizational aspect to the automation pyramid. If systems integration is the goal, then interoperability is the means to achieve it. Interoperability can be described as the ability for one entity to perform operations for another. This interoperation can apply to two or more pieces of software, processes, systems, business units, etc. [12]. To maintain flexibility, interoperable systems do not fully integrate entities with hard coupled connections. Instead, a more federated approach is preferred where communication is managed more dynamically [13]. Because there are so many aspects of system integration in a future heterogenic IT environment, interoperability has become a research priority for Industry 4.0 [14], this is also one of the most important aims for the drone factory.

2.2. Level 1: General purpose software (Spreadsheets, text editors and paperwork)

Since the drone factory is a green-field factory, analog information in terms of paper instructions or spreadsheets for planning or scheduling did never exists. However, paper-based instructions and "spread-sheet planning" is very common in industry today, both in SMEs and OEMs and when it came it saved a lot of money going from push towards pull systems when starting using planning tools[15]. Hence, for industry 4.0 a more digital thread and digital twin is needed. Results show that an increase level of digitalization can result in a more effective, efficient and less stressful environment for both operators, team leaders and production managers [16].The social aspect within cyber-physical systems will be more vital to be able to simulate and visualize in the future [17].

2.3. Level 2: Use of dedicated software in silos

Two different silo implementations were done in Level 2; one in the in-house logistics area and one in the final assembly area.

In-house logistics: Implementing a Warehouse manufacturing system (WMS). The WMS (ELSE) keep track of the components' locations in the material façade and was first used for manual kitting of the components. Dedicated software for presenting the picking order of the component were also introduced (Binar, Vuzix and Ubimax).

Final Assembly: A digital representation of the components and the product was made using dedicated software i.e. CAD (Creo), PLM (Windchill) and ERP (IFS) systems. The CAD and the PLM software was chosen due to the interoperability between the systems, since both systems are distributed by the same company (PTC) it was easier to use them for integration and to create EBOMs and MBOMs.

2.4. Level 3: Use of Connected IIoT and OTs

The third level is to connect the dedicated systems with overall platforms such as IIoT platforms and OTs. In order to try the system-of-systems theories, two different IIoT platforms are implemented. In the *In-house logistics area*, Mindsphere from siemens, are implemented to communicate with the WMS system and the ERP system. In the *final assembly area,* the IIoT platform Thingworx from PTC is implemented and integrated with the CAD and PLM systems in order to present digital instructions and a digital thread of the assembly system. Thingworx is also used for orchestration and is implemented as a "MES light"- system. A PLC controls the conveyor and manages all necessary sensors (RFID readers and proximity sensors) and actuators to send palettes on and off. Each workstation has its own smaller conveyor, adjustable height controller, and a RFID reader also controlled by a PLC. A direct connection between the PLC on each workstation and the main conveyor PLC can be established using TCP sockets, which allows a high flexibility. The conveyor and workstations work as an isolated digital system (a system in the system). A future challenge is to connect the IIoT platforms' information

2.5. Level 4: Use of offline optimisation (of resources)

In order to become a truly autonomous factory, the information and knowledge sharing between humans needs to be taken into consideration[18] and be integrated as a system of systems and organizational interoperability. Today, a lot of tacit knowledge is used for assembly tasks and optimisation of systems. Also, competence matrixes used for resource planning and re-skilling/up-skilling of employees are also med offline or as dedicated software in silos (in level 2). Furthermore, resource and function allocations will be needed when Human-Robot teams are increasing and are implemented at the manufacturing industry shop-floor, this is one of the main challenges in industry of the future [19].

2.6. Level 5: Use of online (real-time) optimisation (of resources)

In order to reach the last level in the autonomous pathway there will demand a seamless integration between a virtual (cyber) and a physical system. One main challenge with CPPS are to model them, but foremost to maintain them and to have the fully up to date. The 5C architecture can be used in order to construct a CPPS from the initial data acquisition, to analytics, to the final value creation [20] but new ways of visualization and optimizing the CPPS is needed. The first and most important step is to create high-fidelity virtual models to realistically reproduce the geometries, physical properties, behaviors, and rules of the physical world [21] this also includes the cognitive level as mentioned in the 5C architecture. Another challenge is the seamless, real-time interaction between the physical and virtual environment. Today's technology is still not mature enough to achieve this in a safe and optimal way.

3. Discussion and Conclusion

This paper has presented the implementation process of the drone factory and mapped this process with respect to the Autonomous & Smart Factories pathway of the Pathway framework. The drone factory is a green-field factory in a lab environment which does not need to deal with latency of systems and other organizational issues. Different technical and structural implementations can vary very much in time and cost for an industry which is not clear from looking at the framework.

The aim with the drone factory was to be able to demonstrate how digital technologies can support activities in production systems and to show the complexity in designing a smart factory. Methods and pathways are vital in order to structure the implementation of a smart and seamless CPPS

As discussed in level 5, there are still a lot of challenges left in order to get a fully autonomous factory including modelling and optimizing all resources and including global digital supply chains.

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