The Smart Production Laboratory: A Learning Factory for Industry 4.0 Concepts

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Abstract. The manufacturing industry is moving "digital" and the changes required are numerous and extensive. In general, there is a lack of understanding of how new technologies are beneficial to the manufacturing industry. This transformation, also known as the 4th industrial revolution or Industry 4.0, created the need of a research platform that could enable practitioners and academia collaboration on new technologies. Aalborg University developed a Learning Factory that is a facility equipped with machines, materials and tools established to support research projects. This paper presents Aalborg University's "small Industry 4.0 factory" and its contribution to Industry 4.0 research by creating a platform for developing technologies to satisfy manufacturing requirements and by demonstrating their value in a production environment. The Leaning Factory is contributing to research by enabling the development of manufacturing technology. At the same time, it is providing practitioners with a platform for solving industrial problems.

Keywords: Smart Production, Industry 4.0, Digital Manufacturing, Laboratory, Demonstrator, Learning Factory

1 Introduction

Experts say that "we are at the tipping point of the fourth industrial revolution" [1]. The first step of this revolution involves the introduction of several technologies in the manufacturing industry – big-data, augmented reality, 3D printing, collaborative robots, and so on. The application of these technologies in production is drastically changing manufacturing bringing it into a new era, digital manufacturing. Industry 4.0 (I4.0) is opening a great amount of new opportunities that companies also in Denmark are actively trying to achieve [1].

Transitioning towards I4.0 involves a number of challenges. Surveys and interviews with Danish manufacturers "show that lack of knowledge, capabilities, and funding constitute the main barriers to further Industry 4.0 adoption" [1]. The first point on the agenda for manufacturing companies, is to understand the technologies, their application in the industry and the related benefits [1].

To address these challenges Aalborg University built a Learning Factory (LF), a facility equipped with machines, materials and tools established to support research projects [2]. This paper presents how the LF contributes to the I4.0 field. Danish manufacturers needed a research platform for understanding emerging technologies and experiment with them and assess their benefits. To address these needs Aalborg University developed a "small Industry 4.0 factory" resembling a real production environment to develop relevant technologies and integrating these technologies with existing ones. This LF (in the following is called also Smart Production Lab) includes transporting and processing modules and different kinds of robots (all implemented as Cyber Physical Systems). Design science methodology was used to design the LF that addresses research and industrial challenges.

The LF acts as a platform that enables close collaboration between students, researchers and practitioners. Currently, several PhDs and research projects are working at the LF.

Finally, the Smart Production Lab enables the creation of new knowledge and attracted so much attention from the industry that formal strategic collaborations with major organizations and SMEs are about to be finalized. For example, students and practitioners collaborated to improve production equipment maintenance service by developing a remote real-time monitoring solution and demonstrating its benefits.

2 Methodology

In August 2016 Aalborg University decided to develop a LF in smart manufacturing. Applying the design science approach [3], Aalborg University designed the Smart Production Lab to address needs from the industry and research concerning automation, robotics, and production methods. Manufacturing companies were lacking knowledge and capabilities related to I4.0. The university main goal was to develop the necessary equipment to operate as an I4.0 factory. The descriptive evaluation [3] of the artifact is based on the completion of research projects related to I4.0. A student research project will be presented to demonstrate the LF utility for I4.0 research.

3 Design of the artifact

3.1 Goals

Aalborg University is active in the I4.0 area with a Smart Production research program, that includes the above mentioned LF, to tackle two fundamental problems. First, due to the fact that most of new technologies have not been developed specifically for the manufacturing industry, research and development is required to adapt and integrate them in the production environment to address the industry's needs. Second, the changes required to adopt I4.0 involve the introduction of numerous new concepts. Demonstrator laboratories are required to fully understand the new opportunities enabled by I4.0 and the related benefits [1].

3.2 Smart Production Lab description

The Smart Production Lab at Aalborg University is a fully automated small production line integrating and demonstrating various I4.0 concepts and technologies. This LF acts as a platform to enable collaborative projects between students, researchers and companies. An overview of the Smart Production Lab is shown in figure 1. Its main components are:

- FESTOs CP factory [4], a small modular and expandable factory integrating many relevant I4.0 technologies composed of several standard FESTO-CP-factory transportation modules (linear conveyor belts) and one branch module. These modules have electrical, pneumatic and mechanical interfaces and can be easily moved since they are on wheels.
- Process modules, like part dispenser, drilling module, inspection module, and assembly module, are mounted on the transportation modules. Process modules are the ones performing the actions on the products and they can be mounted and unmounted from the transportation modules. Our process modules are either from FESTO or were developed in research projects.
- Robots integrated with the production line, like the dedicated robot (KUKA) assembly cell, developed by FESTO as part of CP Factory, the mobile robots (MiR) and collaborative robots (UR-robots). The latter two can also be combined (see figure 1) for example to automate the packaging of the finished parts.
  The standalone robot cell (SCARA robot from Adept) performs various tasks, like production of subcomponents for the FESTOs CP factory.

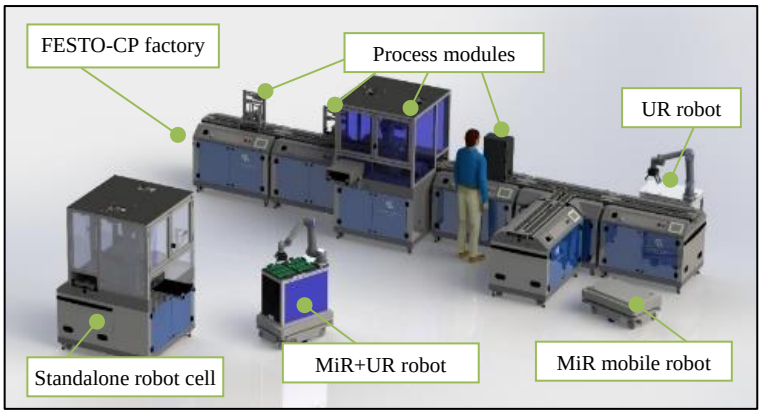

Fig. 1. Overview of the Smart Production Lab

3.3 Users

To address the two problems previously stated (see section 3.1), the LF involves researchers and students from different fields of studies (production engineering, electrical engineering, computer science and management), as well as practitioners from end-user companies, technology vendors and system integrators.

4 Significance to research

The Smart Production Lab supports research in two ways. First by enabling six PhDs and research assistant projects in several fields: in the Designing production systems field, with "Compliant robotic motion" and "Integrated virtual factory models for Smart Production" projects; in the Proactive supply chains field, with "Prescriptive Big-Data analytics" and "Resource optimization of Cyber-Physical systems"; and in the Sustainable value chains field, with "Operations development" and "Smart system integration" projects. Second by providing a platform for bachelor and master students for their semester projects related to I4.0.

5 Significance to practice

One of the best contributions to the manufacturing industry is the project with a Danish manufacturer of production equipment that required remote real-time monitoring of their equipment when used by their clients (other manufacturing companies) for two reasons: improve their maintenance service and start the journey towards Equipment-as-a-Service (EaaS) business model.

One master degree student collaborated for a year with the company to investigate IoT-based remote monitoring system, an I4.0 concept. In this project, the student jointly developed with the company an interactive dashboard to visualize data from different equipment from the LF. The real-time value of sensors in the process modules was communicated to the Programmable Logic Controller (PLC) in the transportation modules on which the process modules are mounted. Using the Open Platform Communication Unified Architecture (OPC-UA) protocol, the PLC sent the data to the gateway application. From the gateway, the data were transmitted to the cloud solution using the Advanced Message Queuing Protocol (AMQP). Finally, data were stored in a cloud database and visualized using Microsoft Power BI dashboard. The ability to visualize in real-time equipment data (e.g. errors, productivity, out of range values) makes possible for the company to drastically improve their maintenance service. Through the use of analytic tools on the cloud database this project set the basis for preventive and proactive maintenance services. In addition, this project provided the technical knowledge required to enable EaaS business model.

6 Discussion

The goal of the Smart Production Lab was to enable research related to Industry 4.0. In detail, research and development of technologies to fit the manufacturing industry needs, and apply in a production environment new concepts and technologies to demonstrate their industrial value.

Starting with the first objective, the LF enabled multi-disciplinary projects. We have been successful in initiating a number of Industry 4.0 projects (>10) involving more than 50 students and researchers from various departments at Aalborg University (e.g.

from mechanical engineering, robotics, computer science, electronics, business). Students have used the LF to formalize requirement specifications, to test their contribution and to integrate their result in a larger context. In addition, breaking into new grounds of manufacturing, the LF enabled the co-creation of new knowledge through a close collaboration between students, researchers and practitioners from various sectors.

Referring to the second goal, the LF brought value to the industry. There has been a great industrial interest in the Smart Production Lab. Between August 2016 and January 2017, more than 150 companies have visited the LF, and the many projects engaging companies were completed. This shows that our demonstrations for practitioners attract interest and bring value to the industry.

The LF open-door strategy and the great research community around it are leading to formal strategic collaborations with selected companies in order to continue to research and develop the application of new concepts and technologies in manufacturing and to create demonstrators. To best fit the production needs we have successfully engagement with SME system integrators and technology providers. However, involving SME end-users has been difficult. Some of the SMEs users don't think that they are I4.0 ready and would rather work on projects closer to Industry 3.0. The challenge of developing I4.0 competences in SME's is highly relevant to society, and this will be one of the focal areas for progress.

Finally, the Smart Production Lab being an instantiation of a LF could lead to the generation of new insights for this emerging concept. Future research activities will also focus on this aspect.

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Material. You can visit the Learning Factory website for more information at http://www.smartproduction.aau.dk/

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