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Platform for Industrial Internet and Digital Twin Focused Education, Research, and Innovation: Ilmatar the Overhead Crane

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***Abstract*—The paper presents first experiences on an overhead crane platform targeted for university education, research, and innovation purposes. The main contributions feature a description of projects from the first year after the inauguration of the crane platform. To provide a basic perception on the potential of the platform, the paper presents the basic technical properties as well as opportunities and challenges of the crane platform. Digital Twin concept has been selected as a focus of the research activities on the platform. Hence, the paper reviews status of the term Digital Twin. Results describe experience-based observations on how university should manage an education, research, and innovation platform while collaborating with industry partners.**

Keywords—Digitalization, Internet of Things, Cyber-Physical Systems, mechatronics, mechanical engineering, laboratory.

I. INTRODUCTION

Digitalization and Industrial Internet of Things (IIoT) are changing the skillset required from engineers to design competitive products. In addition to the physical characteristics, industrial products include a growing amount of digital value. Various digital features, such as round-the-clock connectivity, artificial intelligence, and system level optimization, are becoming essential parts of a product. To answer the need for multidisciplinary expertise, Aalto Industrial Internet Campus (AIIC) was founded. As a proof of interest in the initiative, industry has donated an overhead crane and the supporting software to the university. The crane environment acts as a platform for education, research and innovation implemented together with industry.

The crane platform was installed in a laboratory focused on mechatronics education. The relation of Internet of Things (IoT) and mechatronics has been considered by Bradley et al. [1]. The conclusions suggest that parties dealing with mechatronic systems must review their ways of working due to the recent advancements in IoT. These parties include educators, researchers, and industry employees. Furthermore, as described by Verner et al. [2], the Digital Twin paradigm is influencing the way practical learning exercises are implemented.

The high-level aim of the crane platform is to promote the adoption of Industrial Internet technologies. Particularly, the work on the platform develops overhead cranes towards further automation and IIoT compatibility. Any successful research results will be included in commercial products and services by the industrial partners, which narrows the gap between research and implementation. The platform also contributes to the goal of smart cities, as cranes are part of buildings and logistics.

The paper uses each of the terms IoT, IIoT and Industrial Internet, even though the terms have only minor differences in meaning. The paper characterizes IoT as public domain, while IIoT and Industrial Internet are managed by the industry. The paper assumes that in the future these concepts will seamlessly communicate with each other.

II. TECHNICAL OVERVIEW OF THE PLATFORM

The heart of the platform is the overhead crane shown in Fig 1. The crane was installed and accepted for use at AIIC premises on November 1st, 2016. It was named Ilmatar at a launch event of the crane platform on January 18th, 2017. The crane is equipped with the latest technology, as available from the vendor, including several smart features[1] and a remote monitoring service[2] with Industrial Internet connectivity. The smart features include for example sway control, target

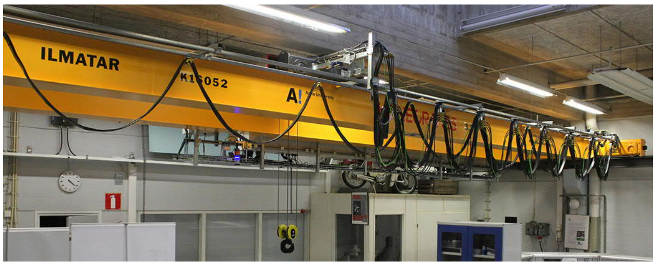

Fig. 1. Ilmatar the overhead crane.

[1] http://www.konecranes.com/sites/default/files/download/konecranes_brochure_smart_features_en_2015.pdf

[2] http://www.konecranes.com/sites/default/files/download/remote_service_en_brochure_aug2017_konecranes_0.pdf

positioning, and shock load prevention. Due to the advanced features, the crane is referred as a smart crane.

A. *Physical characteristics of the crane*

The basic functional properties of the crane are presented in Table I. The physical crane can be divided into three subsystems: hoist, trolley, and bridge, that also represent the three dimensions of crane movement.

B. *Software characteristics of the crane*

The main software characteristics from education, research, and innovation point of view are presented in Table II. Each software serves a certain purpose in the platform environment. The location of implementation and responsible manager for each software are also presented in the table.

C. *Connectivity solutions of the crane*

The connectivity solutions of the crane platform are under continuous development. Due to the mobile nature of the crane, no wired connection has been implemented between the crane and outside world. Currently, the crane features several WiFi routers for different purposes and an LTE modem for a mobile connection. The LTE modem connects to a NetLeap 4G network provided by Nokia Networks for research and development purposes at Aalto University. The NetLeap network provides an environment that is more controlled than public networks, and it has been used for research for example by Lin et al. [3]. Projected connectivity improvements of the platform include acquisition of one or more low power wireless network solutions, such as LoRaWAN or NB-IoT.

III. Digital Twin

Shafto et al. introduced the term Digital Twin in NASA 2010 technology roadmap [4]. However, the basic principles of the concept have been presented earlier, for example by Grieves in 2002 on his university lecture slides [5] and by Främling et al. in 2003 [6]. Terms used for similar or partially overlapping concepts include digital counterpart [7], virtual twin [8], virtual object [9], product agent [10], and avatar [11]. While certain technology fields commonly use some of these terms, they have not caught wider public attention.

In recent years, several academic papers have been published [7], [12], [13] and at least two book chapters [5], [14] have been written on Digital Twin. Furthermore, several corporations, for example GE[3], Siemens[4] , and PTC[5] , have adopted the term Digital Twin. A research and advisory company Gartner has also included Digital Twin in the top 10 strategic technology trends of both 2017[6] and 2018[7].

TABLE I. Hardware of the Crane

Subsystem	*Feature*	*Value*
Hoist	Lifting height	3.0 m (6.0 m [a])
	Lifting motor power	4.5 KW
	Lifting speed	8.00 m/min stepless
	Lifting capacity	3 200 kg
Trolley	Movement range	9.0 m
	Motor power	1.5 KW
	Movement speed	20.0 m/min stepless
Bridge	Movement range	19.8 m
	Movement speed	32 m/min stepless

a. Total rope height, only usable in limited areas.

TABLE II. Software of the Crane

Software	*Purpose*	*Location*	*Manager*
PLC software	Handles crane sensor and control data	Crane	Vendor 1
OPC UA server	Provides external access to the crane data	Crane	Vendor 1
UI server	Provides external access to web UI	Crane	Vendor 1
Remote monitoring system	Provides external access for monitoring	Crane, vendor 1 cloud	Vendor 1
IoT operating system	Provides customizable IoT and analytics capabilities	Crane, laboratory[b], vendor 2 cloud	Vendor 2
PLM software	Handles crane design data	University computers and servers	Vendor 3, university
Remote controlling software	Enables external control of the crane	Laboratory[b]	University

b. Separate equipment located at the laboratory.

However, even though the term Digital Twin has been widely adopted, definition of the technology behind the term remains vague. To make the issue even more complicated, one can even claim that Digital Twin has been used as a marketing term to boost one's own operations. This has made the overall definition of Digital Twin even more obscure.

The era of digitalization has enabled commoditization of Cyber-Physical Systems (CPS). Currently, the physical part of a CPS can be quite exactly defined, but the cyber part is vague. To address this issue, Schroeder et al. [12] have presented that the cyber part can be represented by the Digital Twin. While one can argue that Digital Twin may not be the most suitable term for this definition, the IoT and IIoT concepts clearly need a widely adopted term for the cyber part of CPS. For this purpose, Digital Twin seems to be the most promising as it has already reached public attention.

3 https://www.ge.com/digital/sites/default/files/The-Digital-Twin_Compressing-Time-to-Value-for-Digital-Industrial-Companies.pdf

4 https://www.siemens.com/content/dam/internet/siemens-com/customer-magazine/old-mam-assets/print-archiv/advance/adv152-en-screen.pdf

5 https://www.ptc.com/en/digital-engineering/digital-twin

6 https://www.gartner.com/smarterwithgartner/gartners-top-10-technology-trends-2017/

7 https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2018/

As a conclusion, a compact definition of Digital Twin can be structured as follows: Digital Twin is the cyber part of a Cyber-Physical System.

IV. Education, Research, and Innovation Platform

The purpose of the crane and the information systems related to it is to provide a common platform for activities of students, researchers, and industry employees. The aim is to bring together personnel from multiple disciplines, primarily from mechanical engineering, computer science, and telecommunications. These are the key players that will enable execution of functioning Industrial Internet equipment in machine industry. The ideal outcome of the platform is to bring education and research activities together, creating innovations that support the industry.

A. Opportunities of the Platform

By pursuing the previously defined goals of the platform, the participating stakeholders can reach multiple benefits, as described in the following paragraphs. Working with relevant challenges can also lead to acceleration of local and global economies and the work towards adoption of IoT promotes general wellbeing.

Students learn to use up-to-date hardware and software in order to tackle the latest challenges in the industry. Working with real-world challenges can help students adjust their study paths correctly regarding their future career ambitions. Learning is also typically more efficient when doing concrete exercises. The actual education activities can vary from student projects implemented in small groups [15], such as described in Use Case 2, to building a whole course assignment around the crane, such as described in Use Case 4.

The university researchers can use the latest hardware and software of the platform to perform novel research more conveniently. This can be achieved, as the researchers do not have to deal with legacy system problems that are solved in the latest versions. Instead, the researchers can dedicate their efforts on issues that are relevant to their research topic.

The industry receives skillful labor force from the students that have been educated to use state-of-the-art technology. University collaboration also offers great innovation capacity for developing industrial products. Industry and university can study relevant topics in joint projects that use the platform as a common research environment. Industry receives the latest theoretical knowledge thanks to the collaboration.

B. Challenges of the Platform

Some extra time and effort must be spent to maintain and support the complex platform, as well as for the management work. These investments, however, are believed to pay back in the long run. Education using the platform may require more working hours for planning and executing the teaching activities than traditional classroom teaching. However, the real-world problems fascinate students.

In the research work, the short-term and long-term objectives have to be matched together. The issue is tackled by mutually dividing tasks so that companies focus on practical work and universities address the more fundamental questions of technology development.

Mutual goals between the collaborators must exist for the platform to function effectively. This must be considered each time a new collaborator joins, and at regular time intervals with existing stakeholders. Nevertheless, it can be argued that striving for mutual goals results in better outcomes from a wider perspective.

V. Use Cases: First Projects

Since the installation of the crane in late 2016, the crane has been used for one doctoral student research project, one master student course project and one master’s thesis project. Additionally, the crane served as a reference platform for the exercises of an undergraduate course.

A. Use Case 1: High accuracy lifting innovation

In the high accuracy lifting innovation project, the crane is used to perform an automated high accuracy lifting procedure, targeting to enhance a particular assembly phase in Finnish industry. The targeted assembly procedure features fitting a stator of an electric motor to the frame of the motor. The fitting requires positioning accuracy of less than 1 mm and the lifted component weighs more than the maximum capacity of the Ilmatar crane. Hence, a reduced scale prototype was constructed to enable development at Aalto campus. To reach 1 mm positioning accuracy, additional sensors were added as a separate unit to the frame.

The research work is still ongoing, but important work for the platform has already been made. OPC UA has been identified as a convenient communication protocol to access the crane usage data and for controlling the crane. A method for ensuring security, even though quality of code is not confirmed, has been introduced. This enables continuous testing of the code in the real environment. An object library was written for easy access to the crane data via Python programming language. The library enables rapid implementation of controlling the crane in upcoming projects.

B. Use Case 2: User identification

A course project implemented by a group of master students studied potential identification methods of crane users. For this project, the crane platform provided an easily accessible in situ environment for the students to innovate. However, full potential of the crane platform was not utilized, as the identification system was not implemented to the actual crane platform due to resource limitations of the student project and the readiness level of the platform. The project acted as a valuable lesson for the platform administrators, emphasizing the importance of appropriate guidance in student projects. Nevertheless, a prototype of a GSM identification system was introduced and can be used in future projects.

C. Use Case 3: Mixed reality

An ongoing master's thesis project is implementing mixed reality (MR) based visualization and control of the crane. Furthermore, the Digital Twin concept is utilized to enhance universal connectivity between the crane and other devices, foremost the MR device Microsoft HoloLens in this use case. The Digital Twin is supposed to maintain a small database of the crane position and relay information to the MR device. The Digital Twin also forwards control signals from the MR device to the crane. The thesis project provides valuable hands-on experience on implementing selected segments of a Digital Twin in a real environment and application.

D. Use Case 4: Product design course

An undergraduate course on product design methodology used the crane platform as a learning environment. The course teaches more than 150 students every year on how to approach an engineering design challenge in a systematic way. The course includes a series of exercises targeting a real-world design task. Additionally, a visiting company representative provided a concrete link to industry for the students.

The task was to design a crane accessory that could be used to fulfil a specific lift task automatically. The students received an introduction to the properties and potential IIoT use cases of the crane, which was accessible also for the rest of the course. The course exercises included performing the following tasks: background study, requirement list, abstraction, function structure, solution sets for subfunctions and concept selection. The selected concepts were finally presented with the aid of mock-up prototypes for other students, course staff, and a company representative in a gala. Feedback from the students state that the availability of a concrete environment and industrial relevance supported their learning.

VI. Conclusion

The presented use cases have provided valuable experience how a platform targeted for education, research, and innovation purposes should be managed. It has become apparent that the platform evolves with its projects. The research project described in Use Case 1 has enabled external control of the crane, which would not have been implemented otherwise due to the amount of work required. The possibility of external control has broadened the potential scope of future projects. For example, Use Case 3 builds directly on the introduced control capability. The crane platform has also served as an educational environment for a group project work based course described in Use Case 2 and for a large course described in Use Case 4.

The Digital Twin concept has been selected as the focus area of the research executed at the platform. A brief review on the term was presented to provide an opening for the research. The basic concept of a data linking oriented Digital Twin was also presented in Use Case 3.

The crane platform has achieved its goal so far by inspiring the initiation of multiple projects. The platform has provided an environment for natural collaboration between university and industry with mutual goals. As a conclusion, the Ilmatar crane has enabled a flying start on the way towards realization of Industrial Internet of Things.

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