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Active Learning based Laboratory towards Engineering Education 4.0

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***Abstract*—Universities have a relevant and essential key role to ensure knowledge and development of competencies in the current fourth industrial revolution called Industry 4.0. The Industry 4.0 includes different digital technologies that allow the convergence between the information technology and the operation technology towards smarter factories. Under such new framework, multiple initiatives are being carried out worldwide to respond the requirements of such evolution and, particularly, from the engineering education point of view. In this regard, it is introduced in this paper the initiative that is being promoted at the Technical University of Catalonia, Spain, called Industry 4.0 Technologies Laboratory, I4Tech Lab. First, some of the main aspects considered in the definition of the so called engineering education 4.0 are discussed. Next, the proposed laboratory architecture, objectives as well as considered technologies are presented. Finally, specific focus is done over the proposed academic method supported by an active learning approach.**

Keywords—engineering education 4.0, active learning, industry 4.0, academic laboratory, digital technologies

I. INTRODUCTION

Industrial engineering means the knowledge for the promotion of research, invention, development and innovation towards the technological evolution through the design and operation of its industrial processes. In this regard, its study as a field of knowledge is directly related to the beginning of the first industrial revolution, contributing since then to the development of one of the pillars activities in the progress of modern societies. Each industrial revolution has been characterized by one paradigm shift in the technological vision of industries. Thus, steam power and machine tools characterised the first industrial revolution; the electricity and mass production were the basis of the second industrial revolution; and electronics and computers were support of the third industrial revolution.

Now, the fourth industrial revolution called Industry 4.0, is built up from the consideration of the internet of things and the cyberphysical systems as key enabling technologies for convergence between Information Technology (IT) and Operation Technology (OT). The term Industry 4.0 was originally established by the German Federal Ministry of Education and Research in Germany in 2011 to promote smart factories in the industrial sector [1]. Starting from such framework, the worldwide productive sector is evolving towards the digitalization of industrial processes. Specifically, by means of new technologies such as artificial intelligence, augmented reality, edge computing and cloud data analytics among others [1]. Through such technologies, the fourth industrial revolution will impact on the efficiency and productivity from the business side, while from the product side it will impact on value extraction from data towards usage-based design and mass customization [2]. However, the adoption of such Industry 4.0 framework will result in the transformation of lower qualified positions through advanced automation and digitalization skills requirements [3]. In this regard, the foreseen professional scenario demands a significant transformation in the workforce skills, organizational structures, leadership mechanisms and even corporate culture.

Indeed, the new industry 4.0 era is inevitably linked to cross-functional professional positions mixing different knowledge and skills on the basis of IT and OT convergence. In this regard, the universities and their engineering departments have a crucial role in the training of qualified professionals to fulfil this need. Universities' mission comprise three main objectives: first, the training of professionals capable of deal with technological, social, politics and economic challenges, with ethics and responsibility, second, the leadership in the advance of knowledge through scientific research, and third, the transfer of knowledge and experience towards society to improve the quality of life [2]. It is in this regard that the university plays a relevant and essential role to ensure knowledge and development of competencies of current students and future professionals that will drive this fourth industrial revolution [3]. The engineering education which generates the engineers for Industry 4.0 is referred as Engineering Education 4.0 (EE 4.0) and aims to meet the aforementioned demands under a multidisciplinary engineering integration.

In this regard different academic and research initiatives are being carried out by different universities around the world as response of such formative demand. One representative example is the collaborative initiative carried out by the Aachen, Ruhr and Dortmund universities in Germany. The so called ELLI project aims to promote interdisciplinary competencies and the definition of a roadmap for teachers and students in engineering education 4.0 [4]. The University of Naples Federico II, Italy, is also considering, as part of students' academic curricula, their participation in the Fabrication Laboratories, where an academic environment based on adaptive manufacturing and internet of things allows young engineers to have more chances to gain high-technology know-how about recent innovation trends from a multidisciplinary point of view [5]. Likewise, an important initiative is being leaded by the Institute of Information Engineering, Automation and Mathematics in Bratislava, Slovakia, by deploying the concept of Laboratory of Things [6]. It is supported by a laboratory network of experimental devices and processes from the field of automatic control, where students and educators can use unified service-oriented architectures to build their own control applications.

Other approaches, including not only academic but also industrial focus, are being also carried out. For instance, the Aalborg University promotes a small Industry 4.0 factory as platform for developing technologies to satisfy manufacturing requirements and by demonstrating their value in a production environment [7]. The so called Leaning Factory is contributing to formation and research by enabling the development of manufacturing technology and, at the same time, providing a platform for the assessment of industrial solutions. Aligned with this same concept, the University of Auckland in New Zealand, and the Swinburne University in Australia manages the Industry 4.0 Smart Manufacturing Systems laboratory and the Testlab, respectively, to established a research showcase environment focused on key technologies related with the Industry 4.0 and assisting local industries getting a better understanding of technologies' benefits.

Indeed, all these initiatives reveal the importance of experiment based learning approaches within university environments in order to become the student as an active participant of the learning procedure. This fact drives the promotion of such active learning based industry 4.0 laboratories, which lead to efficient learning and effective usage of the available technologies. Active learning setups in engineering education proven to be a significant improvement over the classical teaching approaches [8]. This active learning approach is particularly beneficial specially, considering the need of a multidisciplinary technologies curricula required by the Industry 4.0 [9].

In order to address such new challenges under the EE 4.0 framework, the Technical University of Catalonia, Spain, (Universitat Politècnica de Catalunya, UPC), is building up the Industry 4.0 Technologies Laboratory, I4Tech. The I4Tech laboratory is equipped with machines, controllers and tools emulating an industrial manufacturing cell to support Industry 4.0 academic and research activities. In this regard, this paper presents the I4Tech laboratory as new tool being developed under the Industry 4.0 framework in order to adapt teaching to the new EE 4.0 through an active learning approach.

This paper is organized as follows, section II describes some of the main aspects considered in the definition of the engineering education 4.0 and considered during the design of the I4Tech laboratory. Section III describes the laboratory architecture, objectives as well as considered technologies. Section IV presents a brief description of the academic method proposed, supported by the active learning approach, to be used over the I4Tech laboratory as part of the engineering education 4.0. Section V concludes this paper including future research and development lines over the I4Tech laboratory initiative and the active learning method.

II. Engineering Education 4.0

It has been accepted by multiple educative institutions that multidisciplinary and creativity represent two of the main capabilities to be intensified in higher education engineering programs. Future industrial engineering works are characterized by an increase of interconnection, flexibility and innovative technologies management [10]. In this regard, although there is no consensus about the meaning of 'competency', this is considered a multidimensional term combining skills, attributes and behaviours measured from the assessment of a successful realization of a job. Thus, within the framework of a new curriculum for the Engineer 4.0, a set of general competencies have been identified as result of different studies [11]: *(i)* virtual collaboration, *(ii)* resilience, *(iii)* social intelligence, *(iv)* novel and adaptive thinking, *(v)* load cognition management, *(vi)* sense making, *(vii)* new media literacy, *(viii)* design mind set, *(ix)* transdisciplinary approach and *(x)* computational skills. According to such related studies, all these competencies should be evaluated over the topics identified as need of the Industry 4.0. The identification of such topics results in the definition of four main modules which comprise knowledge blocks identified as substantial part of the Engineer 4.0 formation [10-12]:

1) *Module 1:* Industrial automation and control, including advanced control technology and human machine interfaces, embedded controllers, cyber physical systems as well as advanced robotics concepts.
2) *Module 2:* Production, management and business principles, including from monitoring to maintenance strategies, quality control and energy efficiency.
3) *Module 3:* Advanced manufacturing including enterprise resource planning and manufacturing execution systems, data analytics and key performance indicators, as well as flexible – additive manufacturing.
4) *Module 4:* Information and communication technologies, including open communication, cloud, big data and cybersecurity concepts as blockchain technology.

Indeed, the confluence among these four modules of knowledge represent the convergence of operation and information technologies based on systems engineering, which will allow adding value to the factories of the future. In fact, it has been identified that employers demand students with problem-solving skills. In this regard, students need to understand how to deal with such variety of technology from an innovative and critical thinking approach, thus, being required specific academic methods to teach students from a holistic thinking point of view [13].

Although the Engineer 4.0 will develop specific knowledge about related technologies, the capability to focusing on the whole represents one of the main required skills and, at the same time, one of the most challenging considering the new multi-technological industrial environment. Dealing with such consideration, five transverse axes are revealed as key aspects in regard with the expected qualification of engineers in the industry 4.0 framework [14]: *(i)* a comprehensive integration and information transparency of systems and processes, *(ii)* an increased automation of production systems, *(iii)* a self-management and decision-making by systems, *(iv)* a digital communication and interactive management and *(v)* a flexible use of available engineers.

Thus, the new industrial era will be supported by such five transverse axes of qualifications for which competences in the aforementioned four modules of knowledge are required in order to deal with the new industry 4.0 cross-functional roles resulting from the information and operation technology convergence. This relation between qualifications and competences depicted in Figure 1 represents the basis of the proposed initiative.

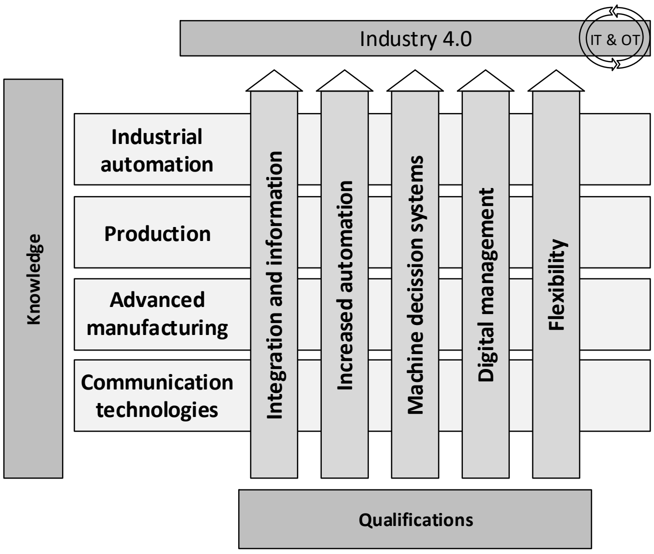

Figure 1. Qualifications and competences identified as demands of the Engineer 4.0 curriculum.

Therefore, from such point of view, academic methods should be updated in order to promote broader skills and job-specific capabilities, which will allow current students to face their future professional positions in an Industry 4.0 framework. Indeed, although the contents of the required Engineer 4.0 curricula is being clarified, the education approach is also being a field of scientific discussion. Some experts define a vision for the future of engineering education in a wider scope by means of three main purposes [15]:

- Responses the needs of industry 4.0, where man and machine collaborate to enable new possibilities,
- Harnesses the potential of digital technologies, open sourced and globally-connected world, and
- Establishes a blueprint for the future of learning - lifelong learning - from childhood schooling to continuous learning in the workplace.

Based on these general guidelines, and considering the specific Industry 4.0 context and challenges, new pedagogical practices in higher education are then proposed, mainly, focused on the transformation of the engineering curriculum by means of [10]: *(i)* implementation of new learning strategies in the direction of active and experiential learning, and, *(ii)* consideration of a transformation framework integrating the latest industry trends with academic content, physical infrastructure and engineering practices.

Thus, aligned with such analysis of the Engineer 4.0 curriculum contents, and the new challenges to be faced for a proper arrangement of the Engineering Education 4.0, higher education institutions are promoting multiple initiatives as the one presented next.

III. I4Tech Laboratory

As it has been aforementioned, Industry 4.0 represents the transformation process of the industrial sector towards smart factories based on the integration of technological innovations to offer greater interoperability, transparency in information and decentralized decisions. Among the main driving technologies focused on the industrial digitalization stand out the Flexible Automation (FA), the Industrial Internet of Things (IIoT), the Cyber-Physical Systems (CPS), and the Augmented Reality (AR).

Indeed, smart factories of the future will offer the ability to re-task the production lines based on productivity, logistics or manufacturing information leading to the flexible automation of industrial cells. Under this context, the digitalization of the industrial processes represents an enabling aspect that requires the integration of equipment and machinery with the industrial internet of things. This fact leads to the deployment of connected devices able to identify each other with computing and communication capabilities to turn them into intelligent objects with informative and self-decision making purposes. Thus, the huge increase of data requires its transformation into added value information, for which cloud storage and computing capabilities are required. This remote data management allow a decentralized data processing based on the intelligent analysis of the information. In fact, it is under this structure that the cyber physical system are enabled as a link between the data generated by the physical devices highly interconnected with the machinery, and the cyber systems of supervision and control for high decision level. Such technology deployment implies the accessing of multiple services towards more efficient and competitive factories. In fact, real-time data from IIoT devices results, after cyber physical systems analysis, in decisions over the flexible automation based plants. Is under this framework that augmented reality capabilities over the manufacturing lines constitute a new approach of interaction with the factory. In that way, personnel has immediate and updated information about decision and assistance at plant level through mobile terminals.

Therefore, the design of the I4Tech Laboratory is based on the combination of the expected flexibility and digitalization of the industrial automation 4.0, with the expected holistic technological skills of the users. This approach tries to build up an enhanced interaction environment between human intelligence and cognitive abilities of artificial intelligence based systems. Thus, the calculations and precision fall on the machine side while strategic decision-making and infrastructure management are assumed by the human side. This relation ensures a dynamic and effective human-machine collaborative environment in a clear jump forward towards the Engineering Education 4.0.

In order to summarize the scope of the I4Tech Laboratory, the considered technologies and specific areas of application are depicted in Figure 2.

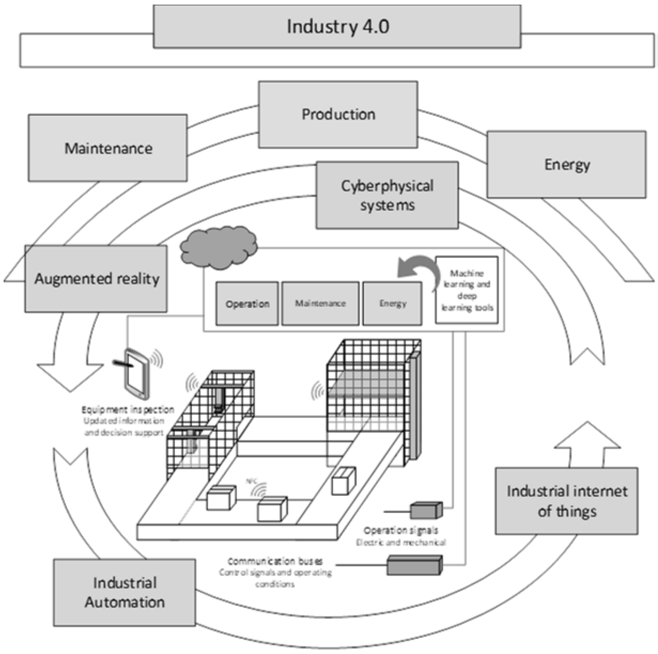

Figure 2. I4Tech Laboratory technologies and their interrelation.

A. *Industrial cell*

In particular, the initiative promoted by the UPC is reassembling an actual industrial manufacturing environment to deploy relevant technologies and integrate these with existing ones. In this regard, the I4Tech Lab aims to act as a platform for a close collaboration among students while facing a multidisciplinary industrial challenge. Hence, the laboratory represents the digital transformation of an industrial process organised around an automation cell through the implementation of an Industry 4.0 architecture. Aligned with the aforementioned technologies, the laboratory includes the technologies related with the automation, communications, analytics and visualization, which allow to perform supervision, modelling, prediction, optimization and decision support tasks related to the entire life cycle of the product and the manufacturing line management and control.

The I4Tech Lab has a flexible automated production cell managed by programmable logic controllers (PLC). The cell has industrial field buses that allow a distributed control system. The cell is based on a set of conveyor belts in order to manage the displacement of industrial trays over which different types of products can be transported (e.g. boxes, metallic pieces, etc.). Some views of the laboratory industrial cell are shown in Figure 3.

The conveyor belts which compose the industrial cells are arranged in such a way that there are four main work stations. The central area of the industrial cell is responsible of moving the trays circularly, and the four stations of the working areas are connected to the central zone to request and return trays emulating different manufacturing processes. These work zones offer different manufacturing possibilities such as the weighing of the trays or even the accumulation through a vertical elevator to store and supply trays to the belt. Also, there are two pneumatic manipulators to transport trays among different working spaces.

Figure 3. Views of the I4Tech Lab industrial cell.

From the operation point of view, an important part of the installation is the industrial communication systems, which allows the distributed control of the industrial cell. For this reason, the cell incorporates different field buses used in the industry such as AS-i, Profibus and CAN, as well as a control and supervision bus through an Ethernet network. The different stations are controlled by PLCs from Schneider Electric equipped with digital input and output modules. Also, an Altivar frequency converter is connected to the Profibus network to allow the regulation of the conveyors' speed. The industrial cell has also a Schneider Magelis touch screen with TCP / IP connectivity for complete supervision and control.

B. *Industry 4.0 technologies*

As it has been aforementioned, the laboratory is focused on four main digital technologies related with the Industry 4.0 [16], that is: the Flexible Automation (FA), the Industrial Internet of Things (IIoT), the Cyber-Physical Systems (CPS), and the Augmented Reality (AR). These technologies are deployed over the laboratory architecture by means the integration and connectivity among different elements such as PLCs, smart devices, mobile terminals (i.e. tablets), edge boxes, servers, data bases, dashboards platforms as well as cloud computers as depicted in Figure 4.

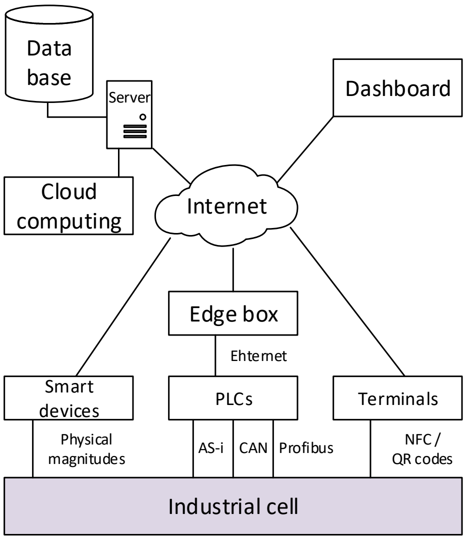

Figure 4. I4Tech Laboratory architecture.

1) Flexible automation: The entire industrial cell is envisaged to be managed by the Schneider Electric SoMachine software. The SoMachine environment is a professional and original equipment manufacturer software solution that allow development, configuration and control tasks in a single environment including logic, motor control, human-machine interface and related network automation functions of the entire industrial cell. The set of available PLCs allow the programming of multiple control loops defining different industrial cell operations. In this regard, the management of the distributed control is routed trough a Schneider Electric Magelis Edge box to link the industrial cell with upper decission levels. Specifically, the Edge box is provided by the Node-Red programming tool as a graphical and simple connecting tool to easily design the data communication flows between OT and IT.

2) Industrial internet of things: Considering data as core of the Industry 4.0, the smart devices for measurement and processing represents the key elements for and industrial cell supervision. This technology is responsible of gathering high volumes of data about its industrial environment and then uses embedded intelligence to obtain useful information for operation and management, including the sharing of information with other systems and devices via communication networks. Such IIoT devices take a wide variety of forms and perform a wide variety of functions. The I4Tech Lab is equipped with a set of IIoT devices supported by Arduino and Raspberry Pi hardwares. Each device is connected to different set of sensors, including vibration, current, voltage, pressure, speed or temperature among others. Each device includes embedded processing from basic digital processing to advanced machine learning algorithms. Also, the connectivity of such devices has been considered to cover multiple communication technologies, including servers connectivity, wireless protocols, and mesh networks among devices.

3) Augmented reality: The laboratory is envisaged to be equipped with the Schneider Electric EcoStruxure Augmented Operator Advisor, which will provide access to real-time information at different points of the industrial cell. The customization of the application allows students to design and implement its own operational functionalities enabling the superimposition of current data and virtual objects onto a power cabinet, machine or product. The applications cover a wide range of objectives dealing with: *(i)* downtime reductio (e.g. electrical cabinets' doors can be opened virtually), *(ii)* speed up operation and maintenance (e.g. information can be found faster with immediate access in the field to real-time data, user manuals, instructions or diagrams), and *(iii)* human errors reduction (e.g. step-by-step guidance can be used to complete maintenance procedures).

4) Cyber physical systems: The manipulation and processing of information by means of statistics tools, data mining, machine learning or deep learning represents a requirement to enable decision support systems real-time connected to machines, processes and personnel. In this regard, the I4Tech Lab includes the necessary hardware and software architecture to design and develop artificial intelligent based software modules. The application of pattern recognition techniques, expert systems, artificial neural networks, fuzzy systems and hybrid artificial intelligence techniques allows data-based modelling approaches to obtain a digital model of the industrial cell. Such models are analyzed to solve, within certain limits, unforeseen problems on the basis of even incomplete and imprecise information or even the recognition of previously identified incidences for industrial cell management and operations.

IV. ACADEMIC METHOD

Under the I4Tech Lab environment it is intended that the student team covers the automation and digitalization of an industrial process through the horizontal and vertical interconnection of hardware and software elements. Thus, leading to the development of functionalities and services including flexible automation, IIoT devices, development of CPS based on artificial intelligence, and interfaces and augmented reality for the promotion of an enhanced connectivity environment where the human-machine collaboration takes place.

In this regard, the proposed contents for the promotion of the Engineer 4.0 program at undergraduate and graduate levels consist of the design of a challenging environment, where the students are involved in a complete industrial process as a real learning framework. This approach considers a combination of active learning techniques, like problem based learning and problem oriented learning, where the education process is connected with the experimental resolution of the proposed tasks. Thus, the students experience the participation in a collaborative laboratory, where a multidisciplinary project over an actual industrial cell takes place.

Figure 5 depicts the envisaged strategy of the proposed academic method under an Engineering Education 4.0 framework through an active learning based laboratory. The model is inspired on different international proposals and studies [10].

Figure 5. Five stage teaching-learning model.

In a first stage, a set of face to face sessions takes place to introduce the laboratory architecture, technologies, objectives and procedures. Thus, the global objective proposed to the students is the design and development of information supported services related with the management and supervision of production, maintenance and energy aspects of the industrial cell.

In a second stage the students begin the problem resolution by accessing available information and formative material related with each considered technology, that is, FA, IIoT, CPS and AR. All students deal with a set of partially solved problems related with each of the four corresponding technologies as practical training.

In a third stage, the students are distributed in four different groups, each one focused on one of the considered technologies. For each station and technology, the input and output information as well as details about expected functionalities are specified. In this stage, the students organize themselves to discuss, define and check their solutions over safe environments for code simulation and debugging. This stage finalizes with the validation of the integrated solution at station level after teacher supervision.

In a fourth stage, the connectivity among stations is faced. The students' teams, each one specialized in one considered technology by this time, face a common problem from a multidisciplinary approach. A set of additional aspects about the expected services related with the management and supervision of production, maintenance and energy are defined in this stage in order to focus the exercises to specific functionalities. This stage finalizes with the experimentation of the solution over the industrial cell.

Finally, in a fifth stage, the assessment of the acquired competencies are assessed. All students are evaluated by means of a test exam including questions about the studied technologies, functionalities, services and industrial cell operation.

V. Conclusion

The industrial sector is undergoing a significant transformation under the Industry 4.0 framework due to the increase of digitalization in companies. Such new professional environment requires a greater collaboration among personnel with different fields of specialization. In consequence, this transformation in the industry requires initiatives to respond to the professional demand from the higher education universities. Thus, a multidisciplinary knowledge is required to be promoted in the academic contexts in order to strength the teaching-learning process towards the Engineering Education 4.0. In this regard, an initiative carried out at the Technical University of Catalonia, Spain, is presented. The Industry 4.0 Technologies Laboratory, I4Tech, represents an experimental learning environment where an active learning approach is being developed to adapt teaching to the new engineering education requirements. The laboratory provides a teaching environment where students can learn the principles of a set of the most novel digital technologies in the industrial sector at the same time that interact with the industrial cell from a collaborative approach. The challenges includes individual and team approaches on the basis of problem based learning, where the laboratory act as industrial environment to discuss, practice and learn.

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