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NEW CHALLENGES IN EDUCATION: TEACHING FUTURE ENGINEERS FOR THE INDUSTRIAL INTERNET OF THE THINGS AND INDUSTRY 4.0

Abstract:

A major topic that can dictate the success of the Industrial Internet of the Things (IIoT) is obviously related with the new challenges that arise in engineering education. New skills and knowledge are required for future engineers that must incorporate a broader range of abilities and qualifications. Students' social attitudes and collaborative working in multidisciplinary teams must also be properly addressed and stimulated during graduation. In this context, scientific and technological competences must be complemented with computing, communication, and even social, sustainability, social impact and behavioral science knowledges. The typical engineering knowledge core of math, physics and chemistry, must be substantially expanded. Students' curricula must be arranged according to these new required competences and skills and must emphasize students' attitudes, as well as communication capabilities.

This paper underlines some teaching strategies that can be considered to maximize the skills and the capabilities of future engineers for the Industrial Internet of the Things and Industry 4.0, including lifelong learning that must be a continuous activity of any engineering graduate.

Keywords:

education; engineering; IIoT; Industry 4.0

JEL Classification: I23, I29, A00

1. Introduction

A topic that deserves a special attention is obviously related with IIoT learning through the utilization of open-ended systems that will allow for technology familiarization, innovation and research. The demand of industrial employers upon the education framework will rise to levels not seen before and since this demand is a global demand there is no guarantees that the education system of the different countries is ready to answer in an effective way [1-4].

The traditional education in STEM (Science, Technology, Engineering and Maths) [5-6] must be replanned and carefully rethought according to the new aptitudes that are required in the future IIoT jobs. A new vision of engineer education must empower future engineers to succeed in an increasingly complex, changing, technological IIoT world. A solid knowledge base in STEM areas is required to deal with the multidisciplinary issues associated with IIoT and Industry 4.0.

The main reasons that justify this focusing in STEM skills, include, among others, the following topics: globalization and knowledge-based economy; current jobs are disappearing due to automatization; new jobs are being created based on the vertiginous technical advances; the way students learn is changing and is very different from the past and STEM occupations are growing and the associated wages are increasing. Moreover, according to US Bureau of Statistics [7-8], in the next 20 years 80% of jobs will require technical skills. Generically, STEM skills include the following aptitudes: creativity; inquiry skills; critical analysis; teamwork and collaboration in multidisciplinary teams; initiative; communication, written and oral; digital literacy and problem solving [9].

Innovation in ICT (Information and Communications Technology) is a major topic thar include: 5G mobile communications; robotics and AI (Artificial Intelligence) technology innovation; future networks; smart sensors and integrated circuits; Big Data and cloud computing; 3D/4D printing technology; autonomous systems; blockchain; quantum technology IoT/M2M (Internet of the Things/Machine-to-Machine) [10] communications.

Before focusing to the main topics of this paper, it is important to clarify the meaning of IIoT and Industry 4.0 in terms of working knowledge. The usage of these terms deserves a clarification since lot of time they are used incorrectly as synonymous and the right concepts and definitions are always important, particularly when teaching issues are under analysis. IIoT is associated with connecting devices on the plant floor, allowing for the development of cyber-physical systems and inter-device communication, enabling the new ways to generate, collect and analyze large quantity of data in industrial environments. By its turn, Industry 4.0 is a mix of digitalization, new technologies, and practical decisions focused on products' manufacturing flexibility, production yields, and large visibility inside every level of manufacturing. Its impact is essentially towards production processes and supply chain. Thus Industry 4.0 is a corporate philosophy that underlines digitalization, new technologies, lean initiatives, automation and materials, and is complemented by IIoT that provides the enabling technology to connect industrial devices, machines and people, and support predictive maintenance based on big data and analytics. This complementarity enables a globally competitive industrial network with positive results in terms of process visibility, production flexibility, efficiency, zero downtime and maximum OEE (Overall equipment effectiveness). Although there are different meanings associated with Industry 4.0 and IIoT, throughout this paper, for writing simplicity, they will be referred globally as IIoT&I4.0.

This paper is organized as follows: section 1 is the introduction; section 2 is dedicated to the main topics included in the IIoT; section 3 addresses the education building blocks for the IIoT; section 4 is dedicated to IIoT teaching issues related with the different education levels and in the last section, section 5, paper's conclusions are drawn.

2. Main characteristics and differences between M2M, IIoT and Industry 4.0

The main techniques and technologies that are nowadays applied in machine-to-machine (M2M) network applications are basically the same that will be applied in IIoT. In both cases, devices are used to capture data, such as physical measurements, that is transmitted over a wired, wireless or hybrid network, and processed by an application that runs remotely. However, even if it seems similar, the main and substantial difference between M2M technologies and IIoT, is related with the scale of integration. In IIoT the network integration enables that a huge quantity of data can be analyzed online, in distributed cloud storage systems, and that a large number of services are integrated to optimize process efficiency. Large amounts of data, from different equipment, running in the same or different manufacturing units (MU), can be processed together improving the overall performance and efficiency of a global production system. This capability can justify the implementation of IIoT due to the cost reductions and products' quality improvements that can be achieved. It is important to refer that advanced algorithms that are used to process the Big Data (Big Data Analytics) [11-12] can detect hidden correlations between data that can't be found by processing, locally, captured data for a single device, or from a group of devices, eventually working in different MU. In this scenario, diagnostic data from sensors, actuators and PLC (Programmable Logic Controller), as well as historical data trends of the different industrial variables, can provide the required data to establish a successful predictive maintenance, reducing maintenance costs, avoiding superfluous preventive maintenance tasks and costly unscheduled production shutdowns. Predictive analytics tools can be used to identify the precursors of unplanned adverse events, determine the most profitable way to handle aging and degrading of assets and to optimize the usage of maintenance resources [13-15]. In summary, it can be referred that IIoT promotes the integration of devices, systems and resources using, as much as possible, standard communications and protocols, to integrate companies' distributed systems and to increase the entire value chain of their business. Regarding IIoT protocols, even if the purpose is always standardization, it is obvious that the different real-time and security requirements in the MU floor and in the cloud are completely different. Thus, different protocols, more or less compatible with the OSI model, are implemented to provide the desired global interconnectivity between MU and services. Concerning transmission modes, an increased usage of Wireless and 5G technologies, to provide remote and centralized data visualization, and to support monitoring and maintenance activities, is obviously expected. IPv6 and network security are also two important topics that must be considered for the success of IIoT.

Regarding the Industry 4.0, it can be referred that IIoT is an enabling force for its implementation. Industry 4.0 is a blend of digitalization and new technologies focused to increase industrial process flexibility, reliability and efficiency, based on unprecedent visibility of every production equipment including the supply chain and, eventually consumers. The selection of IIoT technologies is a required condition, or step, to achieve the Industry 4.0 desiderate. This mean basically that IIoT is the enabling technology that connects devices, machines and people and Industry 4.0 implements the corporate philosophy based on digitalization and new technologies that includes lean initiatives and automation solutions in every MU.

The synergies that result from IIoT and Industry 4.0 gives a set of globally competitive results from which stands out a performance increase of visibility, flexibility, efficiency, zero downtime and maximum overall effectiveness of industrial equipment's.

3. Education building blocks

The six building blocks that can be considered for IIoT&I4.0 teaching process includes: industrial success skills; industrial equipment and technologies; smart sensors and smart devices; control systems; connectivity and networking; and inform -actionable data.

3.1 Industrial success skills

The students must have a basic understanding of the disciplines that sustain industrial success, namely: safety of the work place and work practices; an understanding of the basic equation and the basic industrial need to maximize efficiency and productivity; understanding of industrial seven deadly wastes that include overproduction, inventory, motion, defects, over-processing, waiting, and transport; familiarization with industrial standardized quality systems; the ability to troubleshoot industrial processes and equipment; and soft industrial skills including collaboration, problem solving, discipline and time management.

3. 2 Industrial equipment and technology

The students must understand the production and manufacturing equipment in order to perform a correct and wise analysis of the industrial process data. Otherwise, it would be impossible to extract the right information from the huge quantity of data this produced by IIoT devices.

Without the required equipment and technology knowledge it is not possible to transform data into information even if the best algorithm is used to process data. For understanding the basic manufacturing technologies, the students must have knowledge about different topics, including electricity, pneumatics, hydraulics, fastening, product finishing, materials and metrology.

3.3 Smart sensors and smart devices

Smart sensors and smart device are building blocks of the IIoT. Current transducers and actuators now include functions that go far beyond those of their classic counterparts, which in the vast majority of situations were limited to guaranteeing a system interface with the measurement or actuating system. These new transducers, which we will call intelligent, have ceased to be mere interfaces with the outside and have started to perform functions of increased complexity supported by the processing capacity of microprocessors, microcontrollers and/or digital signal processors (DSP).

Associated with this evolution, there is, of course, the need to integrate different areas of knowledge that are necessary for the implementation of intelligent transducers and actuators. For the huge quantity of I/O (Input-Output) devices, the students must understand how to embed data in the device and how to extract from it.

Figure 1 depicts the main capabilities that are typically associated with smart devices.

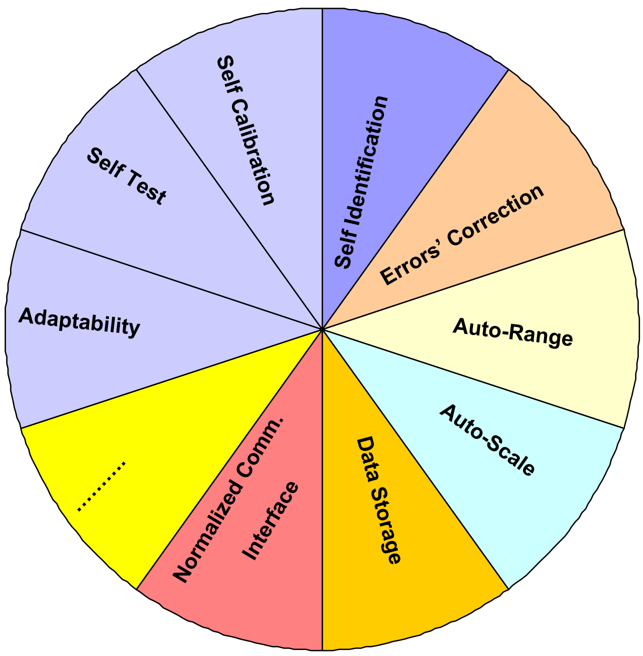

Figure 1. Main capabilities of smart devices.

3.4 Control Systems

The basic functions of the control systems starting from the PID (Proportional, Integral and derivative) actions must be well understood by the students. The control system functions and the DCS (Distributed Control Systems) supervising functions are a key element to control manufacturing processes and must assure real time capabilities to optimize systems' performance. The student knowledge must include competences in the following domains: PLC operation and programming; safety PLC operations and programming PLC; operator and HMI (Human Machine Interfaces); distributed I/O; electronic and variable frequency drives; motor and motion control; and power and control electronics, among others.

3.5 Connectivity and networking

Assuring data communication and networking is essential to extract embedded data form a distributed device in order to create higher level information about the overall processes. In the IIoT&I4.0 the fieldbuses [16] are a natural extension of the Internet and Intranet networks at the manufacturing floor level. The actual systems must lose their propriety nature and be transform in IP based systems and the graduated students, that operate those systems, must have dual competences in OT (Operational Technologies) and IT (Internet Technologies). This point is a critical point for the success of the IIoT&I4.0 because companies fear to lose their property, that means their place in a competitive business market. This is part of the perpetual fight between proprietary interests and standardization together with the problems of networking security that are hard to control in Internet based networks.

Regarding data security, a particular attention must be dedicated to IIoT systems. All security gaps must be closed and this is not an easy task when different interfaces and protocols are used, and particularly, when data is transmitted over the Internet. A major requirement is related with compatibility of protocols and applications that are used by all the partners that will be involved in IIoT. Without winning these challenges, IIoT can't be successful and the value-add that is envisaged with its implementation could be a mirage or, at least, be delayed in time.

3.6 Inform-Actionable data

IIoT devices delivers huge quantity of data. But, as previously referred, huge quantity of data in not synonymous of huge quantity of information. Advanced algorithms must be developed for each application and the quality of the results that can be achieved implies multidisciplinary work teams that must include, at least, process engineers, programmers and data scientists, to implement data analytics based on large amount of data that must be transformed in useful information aligned with the industrial efficiency goals, in terms of products' profit and quality.

Thus, a major concern about teaching for IIoT&I4.0 is related with students' competences related with data analysis and data action including engineering decision, particularly, whenever trade-offs can must be taken into account. Thus, students' competences must include practical knowledges of statistical series, including time series analysis, regression analysis, programming and familiarization with SQL (Structured Query Language) [17], SSAS SQL Server Analysis services) [18-19] and R programming [20]. It is also important to process data to build the right reports and data representations according the usefulness of data for a given objective and post-processing usage.

4. Challenges for engineering education

The challenges of engineering education much address the six education building blocks described in the previous section. As a matter of fact, new skills and knowledge will required for future engineers and the field of engineering must incorporate computing, programming, telecommunications and networking, not forgetting, life, social and behavioral sciences and the humanities, neither its well-established core oh math, physics, and chemistry.

Computing knowledge must also include besides programming, computer architecture, data mining, software design and data science. This knowledge is crucial and, nowadays, it is estimated thar these requirements already reach over 15 % of engineering occupations of the working market [21].

It is important to underline that universities and, particularly, polytechnical institutes, and, obviously, teachers, must be motivated to change their teaching methods. New pedagogical methods and inclusive teaching techniques must be acquired by the teaching staff.

The interdisciplinary requirements of IIoT&I4.0 demand also new pedagogical approaches to develop new skills for engineers that include active learning, entrepreneurial experience, service learning and lifelong learning.

4.1 Active learning and research-based techniques

Active learning includes teaching strategies that involves students in classroom activities and encourage reflection about scheduled and synchronized tasks. Students must interact to achieve a teaching goal by using collaborative tasks and problem-based learning]. In this pedagogical method the teacher acts more as a mentor than a master. In order to achieve this goal, the educational institutes must have integrated laboratories with easy access that must include equipment for rapid prototyping and support technicians to promote the development of technical and professional skills.

4.2 Entrepreneurial experience

Another important point is related with the need to develop oral and written skills and to develop skill to work in teams thar include people from different disciplines. Thus, it is important to design student curricula that incorporate fixed period for internship between academia and the professional world. The evaluation of these internships must be performed by a mixed evaluation jury that includes professors and engineering supervisors from the industry. In internship the students must promote their ability to organize, plan, manage projects or professional or technical activities; innovate in the face of solving unpredictable problems in the areas of action; making decisions in unpredictable work or study contexts; take responsibility for managing the professional development of individuals and groups; work independently and autonomously even in the context of team work; perform targeted research work, collect data, analyze and interpret results; and integrate knowledge, skills and competences.

4.3 Service learning

It is also to includes in the students' curricula opportunities to acquire real-world experiences and to develop community services. These opportunities can include international experiences (Erasmus type programs) and language proficiency, among others, in order to exercise students' intercultural aptitudes.

In this context, it is also important that students boost confidence in their professional skill participating in community tasks. Regarding curricula evaluation these activities must have a pre-defined number of credits to motivate students' participation, otherwise, a large number of students move away from the outside the discomfort zone living domain. Living-leaning (L/L) also promoting the students' participation in academic or extra or cocurricular is also advisable to enhance students' connections and interactions, develop motivation, and improve educational outcomes such as oral and written communication capabilities and analytical skills.

4.4 Lifelong learning

The multidisciplinary nature of IIoT&I4.0 together with the vertiginous speed of technological evolution makes the lifelong learning of engineers, particularly those graduated a few year ago, as an imperative demand for a successful implementation of IIoT&I4.0 [22-24].

In this context, it is important to refer that the Lifelong Learning Imperative (LLI) [25] project was initiated to assess current practices in lifelong learning for engineering professionals, reexamine the underlying assumptions behind those practices, and outline strategies for addressing unmet needs. The LLI project brought together leaders of U.S. industry, academia, government, and professional societies to assess the current state of lifelong learning of engineers; to examine the need for, and nature of, lifelong learning going forward; and to explore the responsibilities and potential actions for the primary stakeholders.

5. Conclusions

As conclusions it is important to refer that many educational institutions are still graduating students to be programmers or traditional engineers, focused in specific knowledge fields, rather than data scientists with engineering knowledge in a broad and complementary set of areas. Teaching must be focused on multidisciplinary topics, creative thinking, critical reasoning and trainability. Change teaching methods and promoting the development of students' creative initiatives is not an easy task and is a process that needs time to achieve the desired results. Basically, teacher-centered approaches must be replaced by student-centered approaches [26].

From the view point of financial issues, it is important that investors be patient because process improvements and profit returns don't come immediately. Besides the investment in sensors, actuators and equipment, including network devices and protocols, the desired results are not obtained after the first steps of IIoT&I4.0 implementation. Data tuning and the development of the right data analytics algorithms is not as obvious as it could seem. A large amount of data is not synonymous of a large amount of information, particularly in which concerns industrial data.

References

[1] MC Alves, "University-industry partnership for global education: Implementing and integrating an engineering international", 2015.

[2] American Society of Mechanical Engineers, "Creating a Culture for Scholarly and Systematic Innovation in Engineering Education (Phase I Report)", Washington, 2009.

[3] American Society of Mechanical Engineers, "Innovation with Impact: Creating a Culture for Scholarly and Systematic Innovation in Engineering Education", Washington, 2012.

[4] American Society of Mechanical Engineers, "Vision 2030 Creating the Future of Mechanical Engineering Education:Phase 1 Final Report", New York, 2011.

[5] National Science Board, "Revisiting the STEM Workforce: A Companion to Science and Engineering Indicators", Washington: National Science Foundation, 2015.

[6] L. Rosen, "The truth hurts: The STEM crisis is not a myth. Huffington Post", 2013. Available at www.huffingtonpost.com/linda-rosen/the-truth-hurts-the-stem-_b_3900575.html.

[7] P. Cappelli, "Skill Gaps, Skill Shortages and Skill Mismatches: Evidence for the US. NBER Working Paper No. 20382", Cambridge, MA: National Bureau of Economic Research.

[8] A.Carnevale, J. Strohl, M. Melton, "What's It Worth? The Economic", 2011.

[9] https://stem.getintoener gy.com/stem-skills-list/ and Western Australia Department of Education

[11] Phil Simon, "Too Big to Ignore: The Business Case for Big Data", Wiley and SAS Business Series, 2015

[12] Vincent Granville, "Developing Analytic Talent: Becoming a Data Scientist", 1st Edition Wiley and SAS Business Series, 2016

[10] Andriy Burkov, "Machine Learning Engineering Paperback", 2020

[13] Gartner Inc., "Using Advanced Analytics to Predict Equipment Failure", Available from https://www.gartner.com/doc/3065317/using-advanced-analytics-predict-equipment [Accessed Apr. 2018].

[14] SAS Institute Inc., "Channeling Streaming Data for Competitive Advantage", Available from https://www.sas.com/en_us/whitepapers/channeling-data-streams-107736.html [Accessed Apr. 2018].

[15] Forrester Research Inc., "The Forrester Wave: Big Data Streaming Analytics", Available from https://www.sap.com/documents/2016/06/92d1323c-797c-0010-82c7-eda71af511fa.html [Accessed Apr. 2018]

[16] Fieldbus Foundation, Tecnhical Overview FD-043, 1998.

[17] Alan Beaulieu, "Learning SQL: Generate, Manipulate, and Retrieve Data", 3rd Edition Kindle Edition, 2020.

[18] Antonio Badia, “SQL for Data Science: Data Cleaning, Wrangling and Analytics with Relational [19] Databases (Data-Centric Systems and Applications)”, 1st ed., Springer, 2020.

[20] Brett Lantz, “Machine Learning with R: Expert techniques for predictive modeling”, 3rd Edition, Packt, 2019.

[21] National Survey of College Graduates, https://nfs.gov/statistics/srvygrads.

[22] C.E. Brawner, R.M. Felder RM, R. Allen, “A survey of faculty teaching practices and involvement in faculty development activities”, Journal of Engineering Education, 91(4):393–396, 2002.

[23] S. Jiusto, D. DiBiasio, “Experiential learning environments: Do they prepare our students to be self-directed, life-long learners?”, Journal of Engineering Education 95(3):195–204, 2006.

[24] C.E. Brawner, R.M. Felder, R. Allen, R. Brent, “A survey of faculty teaching practices and involvement in faculty development activities”, Journal of Engineering Education, 91(4):393–396, 2002.

[25] National Academy of Engineering, “Lifelong Learning Imperative in Engineering: Sustaining American Competitiveness in the 21st Century, Proceedings, 2012.

[26] Максим Писаревський, “Education in Finland: schools without walls, learning with no marks”, Available from https://innovationhouse.org.ua/en/statti/obrazovanye-v-fynlyandyy-shkoly-bez-sten-ucheba-bez-otsenok/ [online], 2017. Accessed Apr. 2018