ANALYSIS OF PROSPECTS AND OPPORTUNITIES OF CYBER-PHYSICAL SYSTEMS EDUCATION

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Abstract: The readiness for digital transformation of industry is highly dependent from the existence of enough ICT experts with profiles to industrial applications and cyber-physical systems as well as the widespread promotion and application of existing industry standards and practices in the domain of Industry 4.0. The raising of the digital readiness index for the industry requires the development of educational and scientific initiatives in order to create capacity for institutional and organizational acceptance of the requirements and prerequisites of Industry 4.0 as well the creation of pilot projects and demonstration installations for the purpose of visualizing and presenting good practices. This paper analyses prospects and opportunities of Cyber-physical system education in order to prepare well-trained and capable specialists for Industry 4.0. Some good practices in this area are outlined. Ideas for building the foundation of the training as well as the organization of the laboratory practice are presented.

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Introduction

Digitization offers impressive new opportunities to strengthen the position of European industry. The Industry 4.0 platform is an initiative of the German Federal Government to support German industry in the transition to digital production (Platform Industry 4.0; Kagermann, 2013). It is based on the full integration of 9 technologies: big data and analytics, autonomous robots, simulation, horizontal and vertical integration, industrial internet of things, cybersecurity, clouds, additive manufacturing and augmented reality. This can be achieved by using the concept, methods and tools of cyber-physical systems (CPS). One of the most complete definitions of CPS was given by Acatech (2011), where CPS are systems with embedded software (computers, as part of devices, industrial control systems, manufacturing systems, logistic processes and management processes), which: record physical data by means of sensors and influence physical processes using propulsion mechanisms; the data obtained is evaluated and retained by actively interacting with the physical and digital world; are connected to the global networks and to other CPSs through digital communication facilities (wireless and / or cable); using globally available data and services; specialized human-machine interfaces.

The fourth wave of technological advancement will bring benefits in four areas: productivity (productivity gains of 5 to 8 percent), revenue growth (additional revenue growth of about €30 billion a year for Germany), employment (6 percent increase in employment in Germany till 2025) and investment (€250 billion till 2025 of the German producers) (Gerbert, 2015). The speed and scope of technological changes coupled with the emergence of new technologies and trends makes the task of optimizing these benefits too complex and the industry has to face a number of challenges. One of these challenges is the educational field and training, which have to cope with the shortage of digital skills professionals and the emergence of new professions related to the ongoing technological change. Digitaleurope (2019) states that 52% of Europe's workforce needs to be reskilled by 2022. To remain competitive, by 2025, Europe must reskill 20% of its workforce and must initiate training for professions such as: data analysis scientists, specialists in artificial intelligence and machine learning, in big data analysis, in digital transformation, cyber security and more. The number of job created will increase from 1.8 in 2019 to 3.7 for one closed job, resulting in 58 million new jobs in 2025. All these findings clearly show that the reform of the education system and the way of reskilling are necessary. A strong emphasis in education must be on digital skills and technological innovation in all fields of education (Kaldashev, 2019). And again according to Digitaleurope (2019), it is necessary to increase computer literacy of the workforce in enterprises, and by 2025 this should be achieved by 30% of them. So far, such a rise in computer literacy is taking place in only 22.6% of businesses in Europe. It is crucial to increase the use of Big Data analytics, which should increase from 10.8% in 2019 to 30% in 2025. 87% are industries planning to introduce machine learning by 2022.

The assessment of the readiness of national economies to adopt and adapt the initiative Industry 4.0 and CPS by using three different methods, analyzed in Batchkova et al. (2018a) shows that the Human capital and especially the current and future labor force is one of the most important key indicators for

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the readiness, defined in World Economic Forum (2018) as “the ability to capitalize on future production opportunities, mitigate risks and challenges, and be resilient and agile in responding to unknown future shocks”. The main conclusion from these assessments is that it is urgent to tackle the digital skills shortage that will grow and ensure prosperity for future generations.

This paper analyses prospects and opportunities of Cyber-physical system education in order to prepare well-trained and capable specialists for Industry 4.0. After the introduction, the importance of CPS and their basic characteristics are discussed. Part 3 presents an analysis of state of the art CPS university education. Some good practices in this area are outlined. The last part of the paper gives some ideas for building the foundation of CPS education for different university degrees as well as the organization of laboratory practice based on the “teaching factory” paradigm. Finally in the paper are made some conclusions.

Importance and key features of cyber-physical systems

The main goal of the Industry 4.0 platform is to accelerate and enable the implementation of digital production with intelligent, digital networks and systems that allow significant self-control and self-management of production processes. Industry 4.0 pays attention to the functions of the created intelligent adaptive and predictive industrial systems. These systems must be self-optimizing, self-configurable and self-diagnosable, realizing cognitive information processing and intelligent networks in interaction with the environment (Batchkova, 2017).

In the introduction of this paper one detailed definition of CPS is cited, but there are other much shorter ones such as this suggested in Rajkumar et al. (2010), which defines CPS as physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core, or this of Lee (2008) defining CPS as systems for "integration of computational and physical processes". However, none of these definitions emphasize all the key features of CPS that make them an indispensable foundation of the Industry 4.0 platform.

CPSs have the chance to meet the challenges of modern enterprises, because they have some very important key features, which may be summarized as follows (DeCarolis et al. , 2016): adaptable to heterogeneous environments; capable of working in distributed networks; based on a modular open architecture; incorporate human interfaces (HW & SW based); be fault tolerant; capable of learning; fulfil stringent safety, security and private data protection regulations and ability to deal with incomplete data, data mining and data fusion, situation awareness.

In order to achieve the above mentioned features CPS need to follow chosen reference architecture, such as for example the reference architecture, suggested by CPS Public Working Group at NIST, and illustrated in Figure 1. It consists of 6 layers and even more transversals capabilities, each of which is included in each layer. In Batchkova et al. (2018b) this reference architecture is used in order to develop the functionality at the third layer, connected with the monitoring and control of CPS.

Figure 1: NIST Reference architecture of CPS

The Strategic Research Cooperation Plan (Hafner-Zimmermann et al., 2017) says that European industry needs to take advantage of the wider use of the CPS concept as one of the key technological opportunities. Science owes CPS and the lack of theoretical foundations and methods developed creates barriers that can impede the adoption, commercialization and success of new CPS applications (CPS summit, 2016).

The design, development, implementation and maintenance of cyber-physical systems require multidisciplinary knowledge, skills and competencies in various fundamental and applied fields. All these engineering activities are becoming more complex, and the optimization of time to market is becoming more significant. The current education system is unable to provide professionals to cope with these challenges. The growing interest and demand for engineers for cyber-physical systems requires educational reform and the creation of new curricula and courses for training of professionals with different educational degrees in this area.

State of the art in cyber-physical systems education

Discussions about opening a CPS undergraduate curriculum began back in 2006 at the Faculty of Electrical and Computer Science at Berkeley University (Seshia, 2018). They outline the basic contours of the Bachelor's degree in CPS, which is still developing today. In 2008, the first CPS Introduction to Embedded Systems course was piloted. Almost at the same time, in early 2007, the needs of CPS knowledge and competence engineers increased significantly, and CPS training for motivated students and employees in various forms of training became a high priority.

Initiatives related to the various forms of CPS training continuous in 2011 with the annual CPS Summer School. The training in cyber-physical systems started in 2013 with the introduction of a Bachelor's degree course in CPS Fundamentals at the Carnegie Mellon University (Loos et al., 2014), which introduces students to the basic concepts in the field of CPS and the verification methods in respect to their security. The CPS-Education Workshop is dedicated to the introduction of a CPS course in the Bachelor's degree and focuses mainly on the fact that students enrolled at this time do not have the basis to study this course. There is a need to train future scientists and practitioners to properly review CPS.

The U.S. National Science Foundation (NSF) initiated in 2016 a study on the need for CPS training and established a Committee to develop a 21st Century vision for education in the field (National Academies of Sciences, Engineering, and Medicine, 2016). The 21st Century Committee on Education for Cyber-Physical Systems agreed that (i). CPSs are evaluated as an engineering field with significant economic and social impacts, and (ii). The future workforce of CPS will include engineers trained in core fields (such as electrical and computer engineering, mechanical and industrial engineering and computer science), engineers targeting specialized application engineering, CPS engineers focused on cyber technology and physical systems that working in the physical world, as well as a workforce that undergoes additional training courses on CPS. Efforts should be made to integrate CPS training into the engineering and computer science curricula of the bachelor's degree, complemented by initiatives to expand the skills of the existing workforce through continuing education and master's programs. Based on the analysis of the need for CPS training, the Committee divides the required knowledge into three main groups: core, cross-domain and domain specific and defines six key bases for the CPS curriculum: (1) Basic computing concepts; (2) Computing for the physical world; (3) Discrete and continuous mathematics; (4) Cross-cutting application of sensing, actuation, control, communication, and computing; (5) Modeling of heterogeneous and dynamic systems integrating control, computing, and communication; (6) CPS system development, especially for safety-critical, high confidence, and resilient systems.

During the period 2014 - 2019, many publications on CPS education appeared. Most of these are within the framework of organized Workshops on Embedded and Cyber-physical Systems Education (WESE'14 ÷ WESE'19) and the Workshops on Cyber Physical Systems. The presented papers discuss the educational aspects of embedded systems and CPS, the evolution of engineering education and analyze the skills and capabilities which are required for the CPS engineers. For example Taha et al. (2014) analyzed the first course on CPS and Grimheden et al. (2014) explained the educational needs and discussed the existing state of the art in CPS education, defining the core CPS competences. Some of the proposed researches are in the frame of European research projects from the domain of CPS, such as the CyPhERS project for creation of CPS roadmap and agenda for Europe (Törnngren et al., 2015),

CPSE-Labs fostering an open network of design centres and establishing a marketplace for CPS engineering assets (CPSE-Labs, 2020), ARTEMIS-IA defining the most important challenges for 2030 for Embedded and Cyber-Physical Systems (ARTEMIS-IA, 2013) and more.

Lieu Tran et al. (2019) have conducted comparative analysis of secondary data for CPS curricula and courses operating worldwide. A total of 63 curricula / courses have been analyzed, with 57 of them being conducted face-to-face and 6 of them online. The distribution of the curricula is presented in Figure 2, where the educational degrees are represented on the ordinate axis and the number of developed curricula/courses is presented serially according continents by the abscissa. From Figure 2 it is clear that master's and PhD degrees are predominant. The Bachelor's Degree Program in CPS is relatively poorly covered. Probably the reason is that the future undergraduate students are not familiar with both the term CPS and the job opportunities in the CPS field. However, they can be attracted from curricula and courses that include more attractive CPS topics such as: robotics, the Internet of Things (IoT), smart cities and the industrial Internet. The leader in the undergraduate education on CPS is Australia. It is noteworthy that courses in Introduction to Embedded Systems are still predominant in training. Europe is the leader with 31 curricula / courses and is well ahead of the United States (17), followed by Asia with six.

Figure 2: CPS education based on the research and Lieu Tran et al (2019)

Source: Author

Analysis of the prospects and opportunities for CPS education

The fourth industrial revolution will not only lead to an increase in the level of automation and job losses caused by the disappearance of some professions, but also to the emergence of new professions and new jobs. The main problem is not the loss of jobs, but the completion of new jobs that require specialists with sufficiently high digital and interdisciplinary qualifications. There is a need to tackle the shortage of specialists with digital skills and interdisciplinary education in a timely manner to meet the challenges of the Fourth Industrial Revolution.

The CPS field is interdisciplinary and uses knowledge and topics from various professional fields, such as computer science, electrical engineering, electronics, automation, software engineering and other engineering disciplines. For this reason, it is extremely important how to integrate this diverse knowledge into one whole - the field of CPS. An important prerequisite for the choice of disciplines is the accumulated experience in the field of CPS research, as well as the existing curricula and disciplines at the respective university. However, it is necessary to select topics from each area and to find and present the intersections between them.

In preparing the syllabus, a balance must be struck between the general and specific orientation of the disciplines, the depth and breadth of the acquired knowledge and skills, and between the theory and practice presented. Curriculum development should be based on a thorough analysis of existing

curricula, focusing on courses that cover both cyber and physical aspects of systems. These are the following groups of courses:

- Courses that address the principles of integration of cyber and the physical aspects of the system, such as: communication and networking, real-time work, distributed and embedded systems, physical properties of hardware and environment, and human interaction;
- Courses that underpin CPS, such as: (1) basic computing concepts, (2) calculations for the physical world, (3) discrete and continuous mathematics, (4) cross-cutting applications, (5) modeling and (6) system development.
- Courses covering the system features of CPS, such as: security, interoperability, reliability, safety, etc.

As a consequence of the analysis of CPS education, an exemplary scenario for its successful introduction into the university can be proposed, which includes the following steps: (1) Involvement of the CPS field in university / department research activities; (2) Starting the development of labs, test beds, or teaching factory for CPS; (3) Enrichment of current engineering courses with new CPS topics; (4) Creation of courses related to CPS research topics; (5) Creation of new master's degree in CPS; (6) Development of new courses for CPS engineering undergraduate degree; (7) Creation of new undergraduate degree in CPS.

In this scenario, some essential steps and requirements for some of them are hidden. First, it is the search for a balance between the theory and practice taught. As noted in one of the steps, it is necessary to proceed as soon as possible to build laboratory stands (virtual, real), pilot installations, platforms. A strong point in CPS training is the creation and use of teaching factories that connect the university and industry in a bidirectional way, complementing students' knowledge and skills with industry knowledge and skills, enhancing their competence. Very important and actual for the CPS education is the use of private-public cooperation and establishment of open source initiatives for creation and sharing of educational platforms for CPS, which facilitate testing and experimentation of new technologies and make possible the interdisciplinary learning, including technology kits for CPS labs, "open labs", "hacker spaces" and "maker spaces". Another important point is the ability to create and run CPS courses to increase the knowledge and competence of employees, which can be organized and conducted in a very flexible and proactive manner, on a lifelong learning basis.

Conclusion

The next generation of CPS will need a workforce with the right education, skills and competencies. This cannot be achieved with the funds of the old university education system; reform is needed. The focus of this reform is on providing interdisciplinary knowledge and skills to future CPS professionals as the need for developers with sufficient interdisciplinary education increases with the proliferation and refinement of cyber-physical systems.

In order to be successful in a project for the introduction of CPS education, a number of peculiarities of the field must be taken into account. It is not enough to create CPS curricula simply by combining course materials from existing courses, It is necessary to look for topics that highlight the interaction between cyber and physical parts of the systems, providing such a level of proactive education that offers a stable foundation for lifelong learning, using various forms of further learning and responding to social and economic needs. Since the CPS curriculum includes many new courses, it may be difficult to find qualified and competent teachers for a number of disciplines. It is required to improve teaching methods and techniques, as well as to create new ones. All stakeholders should be involved in the design and discussion of the curricula and courses.

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