Industry 4.0 and the Challenges Faced by STEM Education

Peter I. Yakimov[1], Katya K. Asparuhova[1], Tsvetana G. Grigorova[2] and Daniela A. Shehova[3]
[1]Department of Electronics, Faculty of Electronic Engineering and Technologies
Technical University of Sofia
8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
[1]{pij, k_asparuhova}@tu-sofia.bg
[2]Department of Electronics, Faculty of Electronics and Automation
Technical University of Sofia, Plovdiv branch, Bulgaria
[2]c_gr@tu-plovdiv.bg
[3]University of Plovdiv Paisii Hilendarski, Bulgaria
[3]dani_shehova@abv.bg

Abstract – **The paper surveys the main factors supporting the implementation of the paradigm Industry 4.0. Their basic characteristics which represent challenges in front of the STEM education are considered. Some tasks faced by the industrial automation engineers are taken into account. A possible correspondence between the required skills and the taught subjects is presented.**

Keywords – **automation; education; Industry 4.0; STEM.**

I. Introduction

The higher education in the STEM (science, technology, engineering, mathematics) field is facing some tremendous challenges in the recent years which will force its transformation in order to respond to the requirements of the modern industry.

In 2000 five important factors which would influence the higher education were predicted: the growth of the information dependence of the economy, the demographic status of the population, the new technologies penetration, the expansion of the private educational institutions, and the widening of the cooperation between the scientific centers [1]. Less than 20 years later much of the prognostic has occurred which is evident from the following trends: individualization of the higher education, shifting the focus of the higher education from teaching to learning, having in mind competence-based education (priority of skills versus degrees).

Nowadays the globalization of the world's economy has brought a severe competition to the manufacturing enterprises from counterparts all over the world. The pressure concerns the production prices, functionalities, quality and time to market. The higher environmental standards also force the manufacturers to improve the processes because of their responsibility to the humanity [2]. In the same time consumers have become more variegated and demanding which leads to transformation of the mass production to mass customization [3]. The mentioned above challenges have driven the manufacturing industry to introduce new technologies in order to be competitive and to respond to users' demands. The management of the modern enterprises needs big amounts of various data in order to set all producing lines to work effectively in terms of time, energy consumption and safety. Although the term Big Data is associated mostly with meteorology, complex physical simulations, biology and environment, in the recent years it is linked with the huge volumes of data in different fields of the industry. It happens along with the implementation of concepts like Industrial Internet of Things, Connected Enterprise, Smart Factory and Industry 4.0.

The Industry 4.0 paradigm is also recognizable with the performing of higher order functions like preventive diagnostics, industrial communications and functional safety. For Industry 4.0 to reach the next level is needed the production lines to become more flexible. For this purpose artificial intelligence based algorithms can dynamically optimize the entire enterprise.

A new global forecast on the market for artificial intelligence (AI) in manufacturing predicts nearly a 40% compound annual growth rate during the period from 2019 to 2027, reaching $27 billion by the end of the forecast period. There is no doubt that the key technology for incorporation of AI into manufacturing is the growing deployment of the Industrial Internet of Things (IIoT). The interaction of the mentioned modern paradigms can be represented like a live organism where IIoT collecting data and interfacing sensors and actuators is the body, and the AI is the brain. They exist as a complete and inseparable complex.

The goal of the presented work is to analyze the trends in the modern manufacturing industry and to point the particular learning subjects and approaches which might improve the knowledge and the skills of the graduate engineers.

The paper is organized as follows: in section 2 are outlined the recent trends in the manufacturing industry and the modern technologies which have been introducing into it. The possible subjects which can enable the start of successful career in the field of industrial automation are discussed in section 3. The conclusions and the future work are presented in the last section.

II. Industry 4.0 Development Cornerstones

The aim of every manufacturer is the constant production growth. To ensure this a permanent increase of the

978-1-7281-7426-6/20/$31.00 ©2020 IEEE

technology effectiveness is needed. It is not possible with the direct participation of the people in the production process. Hence automation approaches and tools are searched in order to improve the effectiveness and quality of the fabrication. Customers are demanding individual products on prices as for mass production. This requires manufacturing of small series with higher productivity. In other words the future enterprises have to be adaptive, flexible, efficient and user friendly. The production process will be accompanied with self-diagnosis and self-testing which will lead to self-regulation. The goal is the autonomous enterprise.

The term Industry 4.0 originates from Germany and describes the introduction of Internet technologies in the industrial automation domain to create smart products and to provide smart services [4].

The key factors to implement this paradigm are Industrial cyberphysical systems, artificial intelligence, edge computing, industrial Internet of Things, sensor networks, mechatronics, robotics and etc.

A. Industrial cyberphysical systems

Industrial cyberphysical systems (ICPSs) are basic subject of research in the Industry 4.0 era. Particularly ICPS are the link between the digital and physical realities. This link generally is performed by sensors embedded in physical devices and networking technologies as well which are intended for collection the data from them. Thus their study focuses the research worldwide. The design and deployment of ICPSs have a significant theoretical and practical importance because of the following statements - the improvement of the performance and the safety of industrial systems can be achieved by developing specific information infrastructure models, application of approaches for monitoring and control, leading to controllability maintaining in the presence of external disturbances and unexpected faults.

ICPS are fundamental in technological aspect. They embrace the vertical and horizontal connectivity, integration and communications of the manufacturing components, subsystems and automation systems.

The research into ICPSs control is spread over various fields - smart grids, power electronic systems, vehicles, robotics, process control systems and etc. [5].

B. Artificial intelligence

The direct participation of people in the modern production process will spoil the quality of many products and will delay the operations. The using of artificial intelligence (AI) and a variety of automation instruments have let many manufacturers to benefit from the obvious advantages. Automation speeds up the operations which are often thought as essential for the quality of the production. An example for the advantages of the AI over the human's capabilities in the manufacturing is machine vision, which can be used on the production line to spot microscopic defects too small to be noticed by human eye. In the same time the operation will be performed significantly faster.

AI and automation will be involved in Quality assurance (QA) and control (QC), giving engineers more time for creative work.

Industrial automation and artificial intelligence particularly have enabled various trends and practices to be implemented, and lots of them to become already a norm.

In terms of hardware AI moves from industrial PCs and servers into embedded devices. Industrial applications benefit from embedded AI.

AI-based algorithms will also support productivity raise in the enterprises due to the possibility of dynamic optimization of the complex production cycle and the energy consumption.

AI and machine learning provide the possibility to process the big data collected by the sensor networks, rapidly developed with the expansion of IoT-based devices [6], [7].

Intelligent control strategies can be represented with the interaction between artificial intelligence, cyberphysical systems and Big Data. The CPSs deliver the information from the field devices, the big data contains the information and the knowledge, and the AI provides the intelligent learning tools [5].

C. Industrial edge computing

The term industrial edge computing describes a distributed platform integrating communication, computation, and storage resources which are intended to perform real-time applications which can be accessible directly from the cloud [8]. The term edge computing nodes (ECNs) is used in the industrial edge computing terminology. This group includes smart devices, smart gateways, smart systems and smart local clouds.

The 5-level reference architecture model known as ISA-95 can be mapped to industrial cloud and edge computing. The lower levels from ISA-95 (sensors/actuators, PLC/DCS and SCADA/HMI) which have high real-time requirements are covered by the edge computing which provides intelligent services at the device level [9]. Higher levels form ISA-95 (manufacturing execution system and enterprise resource planning) which have low real-time constraints but need huge computer resources can be placed in the industrial cloud.

The industrial edge computing reference architecture model can be divided into three layers. The top layer contains industrial cloud platforms which offer different applications concerning design, manufacturing, management and maintenance. The industrial edge gateway is on the middle layer and performs functions for deploying algorithms, balancing computing, networking and data storage, and data acquisition management from all ECNs. The control layer is placed down and contains distributed ECNs which interface the real world performing real-time control, data acquisition and human-machine interface. With another words the edge computing adds computing resources closer to the field devices [10]. To ensure flexibility the configuration on this layer can be dynamically updated by using the possibilities for online programming.

Although the edge computing is applicable in nearly all domains, with the appearance of Industry 4.0 and the Industrial Internet of Things, together with industrial clouds it contributes to the industry transformation towards massive customization and service-based production [11].

D. Industrial Internet of Things

The term IoT is being used to describe appliances with capabilities for connection to the Internet. Nowadays it has become so widely used that it seems almost everything must be connected to the Internet to be valuable. Generally, the term IoT represents all variety of network-enabled gauges that is a part everyday living – smart health, smart transportation, smart homes, smart cities and etc.

The integration of IoT concept in industrial applications for real-time processing of data from integrated networked sensors and actuators aiming maximal adaptation of the activities to the markets dynamics and demands specifications has let industry to have its own subset of the IoT, reasonably called IIoT — the Industrial Internet of Things. The devices intended for industrial applications quite differ from those for home automation. They have to be robust and durable to ensure that data is properly collected, even in the harsh environments that are often found in industrial sites.

This paradigm will trigger the deployment of millions cloud oriented services related to continuous monitoring of the electromechanical and power devices aiming in early detection and real-time diagnosis of possible damages of the equipment and the production.

The information collected from various smart measuring devices might support the improving of the effectiveness of the manufacturing systems in which the smart equipment is introduced. The control of Big Data in the process automation is an effective approach to identify a potential for industrial processes optimization. Industrial Big Data are organically associated with IIoT. It is one of the main sources of Big Data.

The distributed nature of IIoT requires possibilities for distant firmware updating. Thus the development of hardware and software tools for remote programming over Internet is considered as a perspective approach [12].

E. Sensor networks

The condition monitoring is an instrument of a significant importance for the ubiquitous deployment of the paradigm Industry 4.0 which needs a collection of massive amounts of data in order to improve the efficiency of the enterprise. Available on the industrial clouds this data will help the maintaining personnel to monitor the current status of the production process and equipment.

In this aspect the smart sensors are fundamental in fields like mechatronics, robotics, autonomous enterprises and etc. They are also applicable in various areas like healthcare, smart cities, smart homes [13].

Nowadays the industrial monitoring is spread over huge areas and the sensor networks have to be developed in order to cover the warehouses, logistics, transport and the equipment.

Wired networks are applicable with stationary devices. Their disadvantage is the higher cost because of the higher costs of the copper and the installation activities. With the introduction of portable apparatus the usage of wireless communications rises [14].

F. Mechatronics

Mechatronics is an interdisciplinary field which personifies the synergy of the mechanical power and the precise electronic control, e.g. the involving of hydraulics and pneumatics in accurate positioning systems. The result of this synergy is found in the smart sensors and actuators, the fundament of the model Industry 4.0. Mechatronics is growing up very rapidly illustrating the integration in the production machines the advantages of the embedded control. The recent trends in the servo drives comprise the embedded motion control and fast communications interfaces. New motor types and motion control techniques are intended to support Industry 4.0 paradigm implementation. Various motor control applications for factory and process automation intended for energy saving are developed aiming in lowering the costs and improving the effectiveness of the enterprises.

Precise motion control, smart sensors and actuators, and reliable communications outline the important role of mechatronics as one of the cornerstones for establishing the manufacturing of the future.

G. Robotics

Industrial robots widen more and more their participation in the production. They are used in almost all fields - from food industry to automotive. Obviously the robots surpass humans in terms like accuracy and speed. In addition they preserve them from doing dangerous and hard activities in harmful environments. Also robots can be used 24/7. The collaborative robots which augment human abilities are known as cobots. Artificial intelligence can be introduced to them to contribute for realizing flexible production lines. The most common operations where the robots are used can be classified as follows: assembly, picking and packing, material removal, welding, painting and etc. An advantage of using robots is the possibility for reprogramming which easily will set a new pattern for the operation.

III. STEM Education Transformation

The faculties in the STEM field have to transform their curricula and the organization of the teaching process in order to respond to the requirements of the modern industry. In this aspect they have to provide students not only with theoretical knowledge but to give them practical skills as well. In the same time the teaching material has to be presented in attractive way. It is well known that the STEM education is difficult for the students and also it is considered as boring.

New technologies need more and more skillful engineers. There is a misinterpretation that the implementation of the model Industry 4.0 will close many jobs. But the truth is that the ubiquitous automation of the industry will reduce the people involved in the risky, hard and harmful operations, which will be performed by advanced equipment after the implementation of artificial intelligence. The new industry is to be developed by experts in the fields of AI, mechatronics, robotics, edge computing and the other factors mentioned above. Still there is a lack of software engineers, PLC programmers, and embedded designers. The rapid progress in these areas will force the prequalification of engineers from another branches. Furthermore the industrial automation engineers have to keep on qualifying in order to follow the state-of-the-art.

In accordance with the main features of the Industry 4.0 model there is a need for qualification in some important fields. A possible correspondence between the areas of required knowledge and practical skills and taught topics is presented in Table 1.

TABLE 1.

Required knowledge and skills	**Educational topics**
Signal conditioning	Analog electronics (scaling amplifiers, filters)
Sensors and actuators	Data converters
Data processing	Embedded systems
Field devices control	PLC programming, SCADA, HMI
Mechatronics and robotics	Motion control, computer vision
IIoT	Industrial network protocols (Ethernet, Profinet, Ethercat)
Communications	Internet protocols (cable and wireless)
Cloud computing	Internet programming

To attract the students' attention new forms of interaction like project oriented learning and learning by doing have to be introduced in the educational process. The students have to be involved in teams work in order to obtain skills for cooperation.

A sustainable trend in the Faculty of Electronic Engineering and Technologies at the Technical University of Sofia in the recent years has become the joint students work in embedded systems field after the start of an introductory course based on Arduino and Raspberry Pi. Exercising with these user friendly platforms and the application of the learning by doing approach the students overcome the initial stress from the new subject and more than half of the diploma projects afterwards are based on them.

IV. CONCLUSION

The paper surveys the basic factors driving the implementation of the model Industry 4.0. Their characteristics from the point of view of the engineering education in the field of industrial automation are considered. A possible correspondence between the required knowledge and practical skill for a successful career in this area and the relevant educational topics is proposed. The learning by doing approach is useful for competence-based education. It attracts students and gives them sustainable practical skills.

ACKNOWLEDGMENT

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

[1] Levine, A. „The remaking of the American university," *Innov. Higher Education*. 25, 2000, pp. 253–267.

[2] C. Yang, W. Shen and X. Wang, „The Internet of Things in manufacturing: Key issues and potential applications," in *IEEE Systems, Man, and Cybernetics Magazine*, vol. 4, no. 1, pp. 6-15, Jan. 2018, doi: 10.1109/MSMC.2017.2702391.

[3] Xun Ye and Seung Ho Hong, "Toward Industry 4.0 components," *IEEE Ind. Electron. Mag*., vol. 13, No. 1, 2019, pp. 13-25.

[4] M. Wollschlaeger, T. Sauter, J. Jasperneite, "The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0," *IEEE Ind. Electron. Mag*., vol. 11, No. 1, 2017, pp. 17-27, doi: 10.1109/MIE.2017.2649104.

[5] Shen Yin, Juan J. Rodriguez-Andina, and Yuchen Jiang, "Real-time monitoring and control of industrial cyberphysical systems: With integrated plant-wide monitoring and control framework," *IEEE Ind. Electron. Mag*., vol. 13, No. 4, 2019, pp. 38-47, doi: 10.1109/MIE.2019.2938025.

[6] M. Jaffe. (2014). IoT won't work without artificial intelligence. *WIRED*. [Online]. Available: https://www.wired.com/insights/2014/11/iot-wont-work-without-artificial-intelligence/

[7] E. Sappin. (2017, June 28). How AI and IoT must work together. *VentureBeat*. [Online]. Available: https://venturebeat.com/2017/06/28/how-ai-and-iot-must-work-together/

[8] Wenbin Dai, Hiroaki Nishi, Valeriy Vyatkin, Victor Huang, Yang Shi, and Xinping Guan, "Industrial edge computing: Enabling embedded intelligence," *IEEE Ind. Electron. Mag*., vol. 13, No. 4, 2019, pp. 48-56, doi: 10.1109/MIE.2019.2943283.

[9] W. Shi, J. Kao, Q. Zhang, Y. Li, and L. Xa, "Edge computing: Vision and challenges," *IEEE Internet Things J*., vol. 13, No. 5, 2019, pp. 637-646, 2016.

[10] J. Jasperneite, T. Sauter, M. Wollschlaeger, "Why We Need Automation Models: Handling Complexity in Industry 4.0 and the Internet of Things," *IEEE Ind. Electron. Mag*., vol. 14, No. 1, 2020, pp. 29-40, doi: 10.1109/MIE.2019.2947119.

[11] A. Pereira and F. Romero, "A review of the meanings and the implications of the Industry 4.0 concept," *IProc. Manuf.*, vol. 13, pp. 1206-1214, 2017, doi: 10.1016/j.promfg.2017.09.032.

[12] L. Bogdanov and R. Ivanov, "Flash Programming Low Power Microcontrollers over the Internet," *2019 IEEE XXVIII International Scientific Conference Electronics (ET)*, Sozopol, Bulgaria, 2019, pp. 1-4, doi: 10.1109/ET.2019.8878542.

[13] M. Shopov, I. Kakanakova, N. Kakanakov and B. Mateev, "An mHealth application for female fertility assistance," *2019 4th International Conference on Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, 2019, pp. 1-5, doi: 10.23919/SpliTech.2019.8783086.

[14] Liqun Hou and Neil W. Bergmann, "Novel industrial wireless sensor networks for machine condition monitoring and fault diagnosis," *IEEE Transactions on Instrumentation and Measurement*, vol. 61, No. 10, 2012, pp. 2787-2798, doi: 10.1109/TIM.2012.2200817.