ADVANCES IN CYBER-PHYSICAL SYSTEMS

Vol. 4, No. 1, 2019

MASTER OF COMPUTER ENGINEERING PROGRAM WITH A SPECIALIZATION IN CYBER-PHYSICAL SYSTEMS

Anatoliy Melnyk, Alexey Botchkaryov

Lviv Polytechnic National University, 12, Bandera Str, Lviv, 79013, Ukraine.
Authors' e-mail*: aomelnyk@lp.edu.ua, alb@lp.edu.ua*

Submitted on 01.05.2019

***Abstract*: The problem of designing a master of computer engineering program with a specialization in cyber-physical systems has been considered. The concept of cyber-physical systems has been analyzed from the perspective of generalization and formalization for educational purposes. The need for designing a master program in cyber-physical systems has been justified. Program competencies and learning outcomes have been defined. The structure of the master of computer engineering program with a specialization in cyber-physical systems and the corresponding structural-logical scheme of master's training have been regarded.**

Index ***Terms*: computer engineering, cyber-physical systems, master program**

I. INTRODUCTION

In the paper, the problem of designing a specialized master program in Cyber-physical systems (CPS) based on the specialty "Computer engineering" is considered. The long-term experience of the staff of the Department of Computer Engineering of Lviv Polytechnic National University in the research and development of cyber-physical systems and their main components became the basis for the development of a specialized master program in Cyber-physical systems and corresponding teaching materials. In 2015–2017, the department successfully completed a research project "Integration of methods and means of measurement, automation, processing and protection of information based on cyber-physical systems". The scientific and practical results of the project became a resource for the implementation of the specialized master program at the level of advanced modern achievements in the field of CPS. Involving students of the basic specialty "Computer Engineering" to the scientific work within the project allowed us to form the methodological foundations for teaching the disciplines of specialized master program in CPS and revealed the high interest of students in this program. The issue of creating the master program was raised and discussed at the scientific seminar "Cyber-physical systems: achievements and challenges" (Lviv Polytechnic National University, Lviv, 2015–2017). The developed draft master program was approved by the Scientific and Methodological Commission of the specialty 123 "Computer Engineering". The draft master program was discussed and approved at a meeting of the Academic Council of the Institute of Computer Technologies, Automation and Metrology of Lviv Polytechnic National University. On the recommendation of the scientific and methodological council of the university, the work program was reviewed and approved at a meeting of the Academic Council of Lviv Polytechnic National University. In 2018, the Department of Computer Engineering began to train students in the master's program "Cyber-physical systems" on the basis of the specialty "Computer engineering".

II. THE CONCEPT OF CYBER-PHYSICAL SYSTEMS

A cyber-physical system is a combination of physical processes and cybernetic tools [1-4], which provide for the organization of measurement and computational processes, protected storage and exchange of measurement and service information, and the organization and implementation of effects on physical processes. The integration of these components within one system allows to obtain qualitatively new results that can be used to create a wide range of fundamentally new scientific, technical and service tools [5–9]. The potential effect of the creation and use of cyber-physical systems can be compared in scale and influence with the effect of the creation of the Internet. The idea underlying the concept of the CPS is to try to radically expand a person's ability to interact with the physical processes of the surrounding world through more sophisticated, more autonomous and more "smart" cybernetic tools.

The interaction of the CPS with the environment (Fig. 1) occurs simultaneously in two spaces: 1) cybernetic (cyberspace), which refers to artificial cybernetic tools in their entirety and diversity, and 2) the physical space (environment) in which the physical objects are located and the corresponding physical processes of their interaction take place. The input of the CPS is 1) input data d_x from the set of all possible variants for input data D_x and commands c_x from the set of commands C_x, 2) the current state of physical processes s_p from the set of states S_p. At the output of the CPS, we obtain 1) the output data d_y from the set of all possible variants of the output data D_y, 2) the control actions a_p from the set of control actions A_p. Thus, the interaction of the CPS with its environment can be represented as a tuple $<D_x, C_x, D_y, S_p, A_p, T_d, T_p>$, where $T_p:(D_x,C_x)\times S_p \rightarrow D_y$ is

an operator that transforms input data, commands and states of physical processes into output data, and $T_d:(D_x,C_x)\times S_p \rightarrow A_p$ is an operator that transforms the input data, commands and states of physical processes into control actions. The type of operators (T_d, T_p) is defined by the structure and parameters of the CPS, which in turn are chosen in such a way as to maximize the given utility function

$$u = F_{CPS}(x_1, x_2, \ldots, x_m),$$

where x_1, x_2, …, x_m are the CPS parameters (including structural ones).

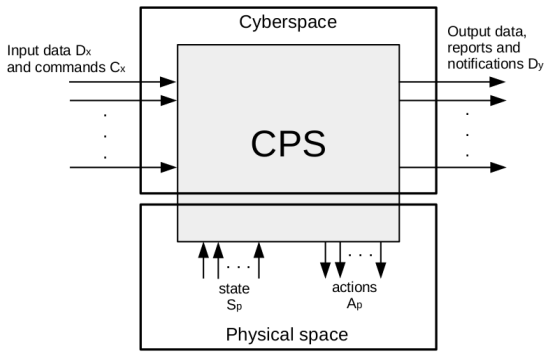

Fig. 1. The interaction of CPS with the environment

In [1], a multilevel platform of cyber-physical systems was proposed, on the five levels of which the following components were placed: means of interaction with the physical world, means of information collection and delivery, means of information processing, means of decision-making, and personal services. In [2, 3], the principles of integration of these levels are proposed.

III. THE REASONS TO DESIGN A MASTER PROGRAM IN CPS

The development of modern economics requires the introduction of computer technology in all spheres of human existence and activity, as well as the integration of the physical world and information systems. It is expected that the rapid development of computer technology in the near future will ensure the interaction of users with all processes of the physical world that are significant for them.

This interaction is carried out through cyber-physical systems, which have a wide and long-term range of applications, which include aerospace equipment, reliable medical devices and systems, production, transportation control, environmental control, control over critical infrastructure (electricity, irrigation networks, communication systems), automation of industrial production of data collection, automated process control, energy consumption and recovery, the next generation power systems, civil infrastructure, etc.

Along with the continuous development of science and technology, further development of the potential of cyber-physical systems is expected in such areas as industrial production (in particular, nanoscale), medical facilities (in particular robotic surgery), transportation (in particular collision avoidance), means for dangerous or inaccessible environments (search and rescue), firefighting and in-depth reconnaissance, air traffic control, energy efficiency (in particular, buildings with zero consumption m of energy).

It is expected that cyber-physical systems will bring great socio-economic benefits. Therefore, many developed industrial countries, including the United States and the countries of the European Union, have already paid attention to the study of cyber-physical systems and provided them with huge investments. In particular, the European Union countries are investing tens of billions of euros in research and development of embedded intelligence and cyber-physical systems under the Horizon 2020 program. China introduced research in cyber-physical systems in the Plan for Scientific and Technical Research of the Twelfth Five Year Plan as a major information technology project. Masters in the “Cyber-physical systems” are taught in many leading universities of the world [10-12].

The emergence of cyber-physical systems became a natural stage in the development of computer, information and telecommunication technologies. The main areas of previous years, on the basis of which the concept of cyber-physical systems was formed, are areas that are within the scientific interests of the Department of Computer Engineering and are presented in a number of subjects of the master program in “Computer Engineering” (such as embedded computer systems, computer networks, intelligent systems, means of cryptographic protection of information, high-performance computer systems). As a result of research in the framework of the project “Integration of methods and means of measurement, automation, processing and protection of information on the basis of cyber-physical systems”, new scientific knowledge and scientific results in the creation of cyber-physical systems have been obtained, scientific and pedagogical personnel have been trained in this area, and a number of new academic subjects have been created. At present, about 50 percent of bachelor’s and master's qualifying works in the Department of Computer Engineering are carried out within the real needs of the IT industry enterprises in Lviv and belong to the sphere of cyber-physical systems.

The fact that cyber-physical systems are increasingly covering various aspects of social and economic life, have a powerful influence on the development of society and contribute to the rapid development of computer technologies, as well as other scientific and engineering areas, indicates the need to open the specialized master program in Cyber-physical systems. Training graduates in this master program will allow our country to reach the leading position in the world in key areas of scientific, industrial and social development.

Despite the large number of graduates (about 200 people) at the Department of Computer Engineering masters traditionally studied in several specializations, which facilitated their employment. Before the

introduction of new curricula, these were specializations in the following areas: “Computer systems for medical and technical diagnostics”, “Computer tools for signal and image processing”, “Administration of computer networks”, “High-performance computer systems”, “Embedded computer systems”. Cyber-physical systems were formed, including the basis of the above directions, that is, CPS are their successors. Thus, for the opening of the specialized master program in CPS at the Department a significant part of the necessary methodological support has already been accumulated, there is the necessary basic laboratory equipment and the trained qualified personnel is available.

IV. PROGRAM COMPETENCIES AND LEARNING OUTCOMES

The main objective of the proposed master program is to provide theoretical knowledge and to develop practical skills sufficient to successfully perform professional duties in the framework of the CPS on the basis of the specialty Computer Engineering. A prerequisite for training in this program is the bachelor's degree in the specialty 123 “Computer Engineering”.

The master program provides the student with the following special (professional) competencies (in addition to the competences common to masters of all specializations of the specialty 123 “Computer Engineering”):

1) the ability to design and develop cyber-physical systems of all levels of complexity, conduct the selection of the element base in accordance with the requirements and conditions of operation, the ability to design embedded computer systems;

2) the ability to apply methods for determining the technical characteristics and the reliability of cyber-physical systems equipment using computational tools and specialized programs;

3) the ability to choose CAD tools for modeling cyber-physical systems, the ability to analyze the system under study in order to obtain a preliminary assessment of the expected simulation results, the ability to develop simulation algorithms and related software, the ability to debug models and analyze simulation results;

4) the ability to develop proposals for the main directions of the project of research and development of cyber-physical systems, using the requirements of state standards and relevant regulatory documents, the ability to substantiate the technical and economic decisions to ensure that the project complies with the terms of reference, patent clearance and competitiveness;

5) ability to manage project work in the field of cyber-physical systems, the ability to coordinate the work of structural units in carrying out production tasks, be able to draw up work schedules and schedules for monitoring work performed, and be able to conduct production meetings;

6) the ability to conduct operational control over the functioning of the equipment of cyber-physical systems and its modes of operation, the ability to use the technical documentation of the embedded computer systems, the ability to analyze the operation of embedded computer devices;

7) the ability to organize work on the maintenance, operation and repair of cyber-physical systems, the ability to make schedules of preventive maintenance;

8) the ability to carry out a functional analysis of the structure of a specific cyber-physical system, the ability to analyze the causes of failures in cyber-physical systems using appropriate diagnostic methods, the skills to eliminate the identified failures;

9) the ability to justify the introduction of new cyber-physical systems or their elements, the ability to conduct tests and commissioning of new hardware and software of cyber-physical systems;

10) the ability to carry out preventive maintenance based on the introduction of modern methods of operating the hardware and software of cyber-physical systems, the ability to ensure a failure-free functioning of the equipment of cyber-physical systems;

11) the ability to formulate the tasks of research of cyber-physical systems, the ability to perform an analytical review of the area under study using Internet resources, possession of the skills of collective research work using Internet technologies;

12) ability to create mathematical models for the study of cyber-physical systems using computational tools based on the accepted assumptions;

13) the ability to design experiments for researching a cyber-physical system under development, the ability to analyze research results from the point of view of comparative analysis of the developed system with analogs;

14) proficiency in cyber-physical systems modeling using specialized software and high level programming languages;

15) the ability to conduct laboratory workshops in special disciplines, to teach special courses, to participate in the development of teaching and methodical support, as well as to conduct research work on the creation, analysis and study of the operational characteristics of modern cyber-physical systems.

As a result of training students in the proposed master program they will acquire the following knowledge and skills:

– knowledge of the principles of programming, modern programming languages, basic data structures;

– knowledge of the theoretical (logical and arithmetic) fundamentals of building modern computers and the ability to use them in solving professional problems;

– knowledge of computer architecture, be able to apply them in the process of construction and operation;

– knowledge of the circuitry of modern computers;

– knowledge of the features of system programming, knowledge of methods and tools for developing system software;

– knowledge of the features of building system software, as well as general principles of organization and operation of operating systems;

– knowledge of computer-aided design, the ability to use modern computer tools for structural, functional, and technological design of embedded computer systems;

– knowledge of general methodological principles for constructing modern cyber-physical systems with various organizations to ensure high-performance information processing;

– knowledge of the principles, methods and means of design, construction and maintenance of modern computer networks of various types and purposes;

– training in software development for computer systems with parallel or distributed architecture, knowledge of the means of modern languages and libraries of parallel programming;

– knowledge of modern theories of database organization, methods and technologies for their development and use;

– knowledge of organizational, technical, algorithmic and other methods and means of protecting information in cyber-physical systems, in accordance with legislation and standards, with modern cryptosystems; the ability to use them in the process of professional activity;

– knowledge of modern technologies and development tools for complex software systems (software engineering), the ability to apply them at all stages of the development life cycle;

– knowledge of the methods and technologies of research and design of cyber-physical systems, the ability to research, design, develop and maintain complex cyber-physical systems, the ability to develop and use embedded computer tools;

– ability to solve problems in the field of research and design of cyber-physical systems based on knowledge of modern architectures of embedded computer systems, network technologies, parallel computing technologies, hardware and software virtualization technologies, signal and image processing methods, artificial intelligence methods and information protection methods;

– ability to manage the implementation of design work in the field of research and design of cyber-physical systems; the ability to ensure the efficiency, performance and proper technical condition of software and hardware of cyber-physical systems;

– the ability to receive, analyze, synthesize and use information to solve problems of research and design of cyber-physical systems, using global information resources, as well as scientific, regulatory reference and special literature;

– skills in conducting research in the development and improvement of cyber-physical systems;

– the ability to professionally formulate new tasks of research and design of cyber-physical systems, to produce and make decisions about their solution based on system analysis and professional-specific knowledge and practical skills;

– the ability to define the goals of innovation in the field of research and design of cyber-physical systems and to look for ways to achieve them based on the knowledge and skills of research;

– ability to assess the competitiveness and economic efficiency of the developed solutions and technologies for research and design of cyber-physical systems.

V. THE STRUCTURE OF THE MASTER PROGRAM

In order to better prepare masters in CPS, the corresponding professional orientation of students begins in the last years of the bachelor's degree program in Computer Engineering. In particular, the block of special CPS subjects is included in the bachelor's degree program. This block contains the following subjects: “Computer systems modeling”, “Peripherals, interfaces and drivers in cyber-physical systems”, “Cross-platform programming tools”, “Testing and diagnostics of cyber-physical systems”, “Automated design of computer and cyber-physical systems”, “Architecture of cyber-physical systems”, “System software of cyber-physical systems”, “Software technologies for cyber-physical systems”, “Physical processes modeling”, “Software for microprocessor-based systems”, “Digital signal processing”, “Technologies of measurement and control”.

The total amount of the proposed master program in CPS is 90 ECTS credits (1.5-year study). The structure of the program provides for the distribution of academic subjects into two training cycles: general and professional (Table 1). For the general training cycle, 6 credits were allocated (7 % of the study load). 84 credits were allocated to the professional training cycle (93% of the study load). In addition, the subjects are divided into a mandatory component (60.5 credits) and a selective component (29.5 credits). Subjects of a selective component are chosen by students independently. The main subjects of the mandatory component of the professional training cycle are “Research and design of computer systems and networks”, “Research and design of software systems”, “Network information technologies”, “Artificial intelligence technologies in computer and cyber-physical systems”, “Design of information security tools in computer systems and networks”. The main subjects of the selective component of the professional training cycle are “Designing computer tools for signal and image processing”, “Research and design of embedded computer systems”, “Technologies of machine learning in cyber-physical systems”, “Designing tools for mobile and cloud computing in cyber-physical systems”, “Design of data processing tools in cyber-physical systems”, “Research and design of network tools of cyber-physical systems”, “Designing components for the Internet of things”.

Table 1

The structure of the master program in CPS (cycle of professional training)

Master program components	ECTS credits
Mandatory components of the specialty	
Research and design of computer systems and networks	6
Research and design of software systems	5
Network information technologies	4
Artificial intelligence technologies in computer and cyber-physical systems	3
Design of information security tools in computer systems and networks	4
Research and design of computer systems and networks — course project	3
Research and design of software systems — coursework	2
Network information technologies — coursework	2
In total:	29
Selected blocks of components	
Selected components of block 01:	
Designing computer tools for signal and image processing	5
Designing computer tools for signal and image processing — coursework	2
Research and design of embedded computer systems	4
Technologies of machine learning in cyber-physical systems	3
Designing tools for mobile and cloud computing in cyber-physical systems	3
Areas of research and development in cyber-physical systems	4.5
Selected components of block 02:	
Design of data processing tools in cyber-physical systems	5
Design of data processing tools in cyber-physical systems — coursework	2
Research and design of network tools of cyber-physical systems	4
Decision-making technologies in cyber-physical systems	3
Designing components for the Internet of things	3
Basics of research and innovations in the field of cyber-physical systems	4.5
In total:	21.5

The relationship and dependencies between the subjects of the proposed master program are shown on the structural-logical scheme of master's training in CPS (Fig. 2).

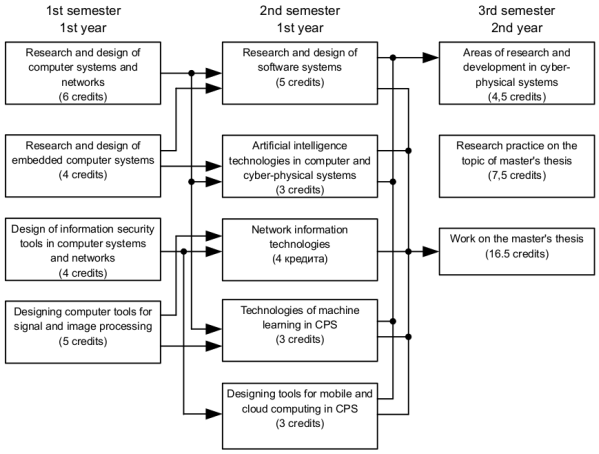

Fig. 2. The structural-logical scheme of master's training in cps

VI. CONCLUSION

The problem of designing a master of computer engineering program with a specialization in cyber-physical systems was considered in this paper.

The concept of cyber-physical systems was analyzed from the perspective of generalization and formalization for educational purposes.

The need for designing a master of computer engineering program with a specialization in cyber-physical systems was justified.

Program competencies and learning outcomes were defined.

The structure of the master of computer engineering program with a specialization in cyber-physical systems and the corresponding structural-logical scheme of master's training were proposed.

REFERENCES

[1] Melnyk A., Cyber-physical systems: problems of creation and directions of development, Transactions on Computer systems and networks, Lviv Polytechnic National University Press, No. 806, 2014. – pp.154–161 (in Ukrainian)

[2] Melnyk A. Cyber-Physical Systems Multilayer Platform and Research Framework / Advances in cyber-physical systems. – 2016. – Vol. 1, Num. 1. – C. 1–6.

[3] Melnyk A., Integration of the levels of the cyber-physical system, Transactions on Computer systems and networks, Lviv Polytechnic National University Press, No. 830, 2015. – pp.61–67 (in Ukrainian)

[4] Rajeev Alur, Principles of Cyber-Physical Systems, The MIT Press, 2015. – 464 p.

[5] Siddhartha Kumar Khaitan and James D. McCalley, Design Techniques and Applications of CyberPhysical Systems: A Survey, IEEE Systems Journal, Volume: 9, Issue: 2, June 2015. – pp. 350–365.

[6] Jay Lee, Behrad Bagheri, Hung-An Kao, A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters, Volume 3, 2015. – pp. 18–23.

[7] Cyber-Physical Systems: A Computational Perspective, Chapman and Hall/CRC, 2015. – 644 p.
[8] Cyber Physical Systems. Design, Modeling, and Evaluation, Proceedings of the 5th International Workshop, CyPhy 2015, Amsterdam, The Netherlands, October 8, 2015. – 147 p.
[9] Edward A. Lee, The Past, Present and Future of Cyber-Physical Systems: A Focus on Models, Sensors, 2015, 15(3). – pp. 4837–4869.
[10] Jon Wade, Roberta Cohen, Mark Blackburn, Eirik Hole, and Nicholas Bowen, (2015) Systems Engineering of Cyber-Physical Systems Education Program. In Proceedings of the WESE'15: Workshop on Embedded and Cyber-Physical Systems Education (WESE'15), ACM, New York, NY, USA.
[11] Taha, Walid & Zeng, Yingfu & Duracz, Adam & Fei, Xu & Atkinson, Kevin & Brauner, Paul & Cartwright, Robert & Philippsen, Roland. (2017). Developing a first course on cyber-physical systems. ACM SIGBED Review. 14. 44–52.
[12] J. A. Stankovic, J. W. Sturges and J. Eisenberg, "A 21st Century Cyber-Physical Systems Education," in Computer, vol. 50, no. 12, pp. 82–85, December 2017.

Anatoliy O. Melnyk is a Head of Computer Engineering Department at Lviv Polytechnic National University since 1994. He graduated from Lviv Polytechnic Institute with the Engineer Degree in Computer Engineering in 1978. In 1985 he obtained his Ph.D in Computer Systems from Moscow Power Engineering Institute. In 1992, he received his D.Sc. degree from the Institute of Modeling Problems in Power Engineering of the National Academy of Science of Ukraine. He was recognized for his outstanding contributions to high-performance computer systems design as a Fellow Scientific Researcher in 1988. He became a Professor of Computer Engineering in 1996. Since 1982 to 1994 he has been a Head of Department of Signal Processing Systems at Lviv Radio Engineering Research Institute. Since 1994 to 2008 he has been Scientific Director of the Institute of Measurement and Computer Technique at Lviv Polytechnic National University. Since 1999 to 2009 he has been a Dean of the Department of Computer and Information Technologies at the Institute of Business and Perspective Technologies, Lviv, Ukraine. He has served since 2000 as President and CEO of Intron ltd. He has also been a professor at Kielce University of Technology, University of Information Technology and Management, Rzeszow, a visiting professor at University of Bielsko-Biala. Currently, he is a professor at the Department of Artificial Intelligence of John Paul II Catholic University of Lublin.

Alexey Botchkaryov was born in 1975 in Lviv, Ukraine. He received the B.S. and the M.S. degrees in computer engineering from Lviv Polytechnic Natioinal University in 1996 and 1998. He has been doing scientific and research work since 1994. His work resulted in 79 publications and master thesis. Currently, he is a Senior Lecturer at the Computer Engineering Department and a Research Assistant with the Intelligent Systems Laboratory, Lviv Polytechnic National University. His research interests include intelligent data collection technologies and multi-agent systems.