Műszaki Tudományos Közlemények vol. 20. (2024) 36–41.
DOI: Hungarian: https://doi.org/10.33895/mtk-2024.20.07
English: https://doi.org/10.33894/mtk-2024.20.07

LABOR DEVELOPMENTS AND METHODS FOR SUPPORTING EDUCATION IN THE CYBER-PHYSICAL AND INTELLIGENT ROBOT SYSTEMS LABORATORY

Abdullah MASUK,[1] Szabolcs Sándor DIÓS,[2] Tamás DINYA,[3] Attila SZÁNTÓ,[4] Géza HUSI[5]

[1] *Debrecen University, Vehicles Engineering Department, Debrecen, Hungary, masuk@eng.unideb.hu*
[2] *Debrecen University, Mechatronics Department, Debrecen, Hungary, dios.szabolcs@eng.unideb.hu*
[3] *Debrecen University, Faculty of Engineering, Debrecen, Hungary, tamasdinya@gmail.com*
[4] *Debrecen University, Doctoral School of Informatics, Debrecen, Hungary, szanto.attila@eng.unideb.hu*
[5] *Debrecen University, Vehicles Engineering Department, Debrecen, Hungary, husigeza@eng.unideb.hu*

Abstract

This study investigates the education and laboratory market trends in the Cyber-Physical and Intelligent Robot Systems Laboratory and presents the previous works. The laboratory utilizes augmented reality, virtual reality, and simulation technologies to offer immersive learning experiences. The program emphasizes industry-aligned projects to prepare students and researchers for Industry 4.0. The curriculum teaches collaborative problem-solving and human-robot interaction. The lab trains flexible automation professionals for industry. The integration of technology and pedagogy empowers students to apply CPS and IRS concepts effectively. The laboratory is instrumental in advancing the educational landscape in these domains and is at the forefront of preparing students for the evolving challenges of automation technologies.

Keywords*: Cyber-Physical Systems, Intelligent Robot Systems, Laboratory Developments, Robotics Education.*

1. Introduction

The integration of Cyber-Physical Systems (CPS) and Intelligent Robot Systems (IRS) has revolutionized automation technologies, necessitating a bridge between theoretical knowledge and practical proficiency (Fig. 1).

CPS and IRS Laboratory is a pioneer in this field, utilizing advanced technologies and pedagogical methodologies to provide immersive experiences in real-world applications.

Augmented reality (AR) and virtual reality (VR) platforms, combined with sophisticated simulation environments, enhance students' understanding of CPS and IRS. The laboratory's curriculum is designed to align with Industry 4.0 demands, emphasizing hands-on projects that mirror real-world challenges.

Beyond technical skills, the laboratory emphasizes collaborative problem-solving and human-robot interaction studies, fostering holistic skill sets. Through workshops, seminars, and strategic industry partnerships, students and researchers receive a comprehensive knowledge that transcends conventional boundaries. This holistic approach ensures that graduates emerge as adaptable, industry-ready professionals capable of leading advancements in automation

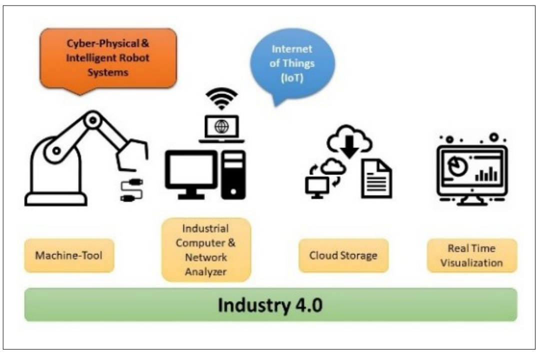

Fig. 1. *Implementation of Cyber-Physical with an intelligent robot system.*

technologies. The laboratory's role in shaping the educational landscape of robotics engineers and researchers is significant, as it combines experiential learning, state-of-the-art technologies, and dynamic industry integration.

2. Cyber-Physical Systems (CPS)

Cyber-Physical systems are control systems that span across devices and networks, such as cars, airplanes, and the national power grid. Building large-scale CPS requires understanding network limitations, particularly the Internet, and determining which parts of a real-time, closed-loop system can be implemented on Internet protocol networks. Real-time computing, focusing on meeting periodic deadlines, has been a priority in computer systems research since the 1960s and 1970s [1]. Fig.2 demonstrates a connected graph of further key literatures used for review.

The research center aims to optimize existing technologies and prevent accidents by monitoring ongoing research projects [2]. The study conducted by the faculty of engineering at Debrecen University in 2020 explores the significance of robots in the 21st century, particularly in the context of the Industrial Revolution 4.0. The research emphasizes the role of robots in controlling and analyzing systems through Human-Machine Interfaces (HMI) or wireless network connections. The study highlights how robots can enhance the efficiency of processing and production units by working continuously and autonomously. The project specifically focuses on using a mobile robot equipped with Microsoft's Xbox Kinect depth sensor to map the Cyber-Physical System Lab in 3D. The mapping process is facilitated by the ROS OS software installed on a Linux machine. The mobile robot utilizes Simultaneous Localization and Mapping (SLAM) to estimate its location while mapping the environment. The main objective of the study is to develop a mobile robot that can autonomously map the 3D environment of the lab and analyze different objects within the industry [3].

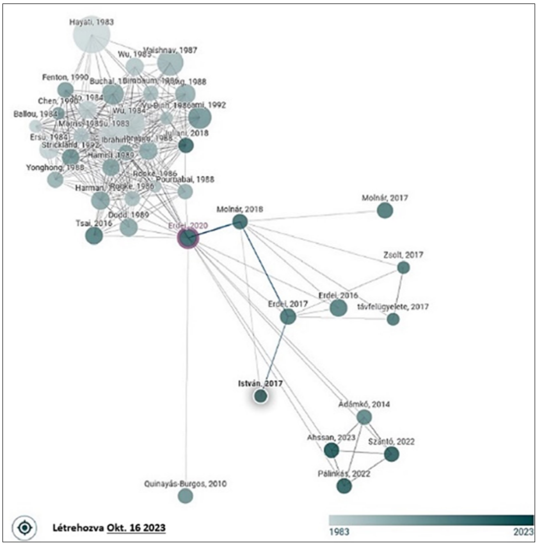

Fig. 2. *Publications related to the lab.*

CPSs are distributed systems that combine computation and physical processes, offering features such as energy control, secure control, transmission and management, control technique, system resource allocation and model-based software design. They require high automation and advanced feedback control technologies, and reliability and security are crucial. Energy supply is a significant challenge for CPSs due to supply and demand issues. The research program aims to integrate physical and cyber design, distinguishing CPSs from desktop computing, embedded real-time systems, and wireless sensor networks [4, 5].

2.1. Intelligent Robot Systems (IRS)

In a recent study related by the lab (2020), the issue of singularities in an industrial welder robot, specifically the KUKA KR5, was examined. Singularities can have a negative impact on the robot's performance and therefore need to be carefully addressed in the design of assembly lines (Table 1).

Table 1. *KUKA KR5 robot position* [10]

Name	Value	Unit
Tool/Base		
-	#NONE	Tool
-	#NONE	Base
Position		
X	396.160	mm
Y	40.593	mm
Z	1255.304	mm
Orientation		
A	4.30	deg
B	26.93	deg
C	10.59	deg

To address this issue, the researchers developed an original measuring system that indirectly measures the robot's movements. This system consists of a control system, robot arm, laser, accelerometer and angular speed sensor [6]. While previous research has been conducted on this problem, further investigation is still required [7].

Other lab related research, (2016) addressed the data processing and force control of a 6-DOF industrial robot, which has ramifications for the automation and manufacturing industries. The study develops a building mechatronics research center monitoring system to improve security and detect suspicious activity. To accurately monitor and report security occurrences, high-resolution TCP-IP cameras in the surveillance system can provide clear images [8].

Several other researchers (2019) discuss the upgrades made to the robotics lab at the University of Debrecen, including the conversion of the KUKA KR5's cube holder, the addition of a linear drive powered system, and the simulation of a manufacturing process in the robot cell. The process in automatic mode follows a sequential method, making it easy to read and modify the existing program.

CodeSys modeling and simulation were done, with options for manual and automatic execution. Linear drives were used in conjunction with the KUKA KR-5 robot (Fig. 3.) robot to move cubes in a specific way [9].

Future industrial simulations can analyze robot manipulator behavior to determine integration into production lines and parts needing upgrades or replacements. These simulations can also test pneumatic and electric gripper movements [11]. The KUKA KR5 industrial welding robot could be expanded by 3D printing new parts. Successful integration and programming of the KUKA KR5 have been successful, but there are limitations in sending the welding cell program to the robot arm due to the controller and operating system [12].

2.2. Augmented Reality (AR) & Virtual Reality (VR) Technology

Augmented Reality (AR) technology can enhance visualization, simulation, programming, maintenance, training, and monitoring of industrial situations. The use of AR in educational settings can provide a more immersive and engaging learning experience, particularly in the field of robotics. The integration of 3D CAD design of robot arms into an AR environment can help students understand the operation and functionality of industrial robots without the need for expensive physical machines [10] (Fig. 4). In addition, the system possesses the capability to encrypt commands intended for robots, so enabling a secure means of communication and control [13].

In a recent study (2022) the authors explore the application of digitalization technologies, such as virtual reality (VR), augmented reality (AR), and digital twin, in the industry for educational and production purposes. One notable application of digitalization is the creation of digital replicas of laboratories, like the Cyber-Physical and Intelligent Robotics Laboratory (Fig. 5). These virtual

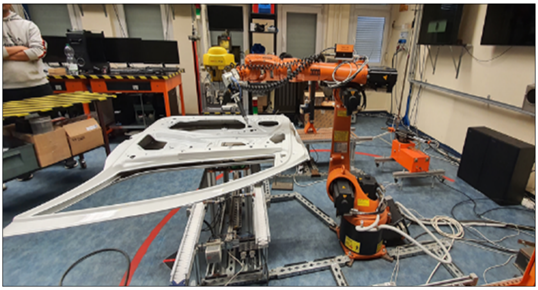

Fig. 3. *KUKA KR5 robot.* [10]

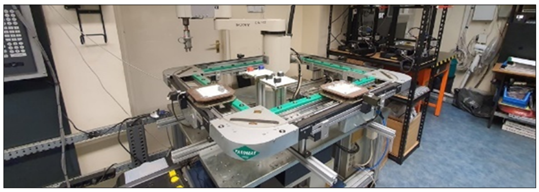

Fig. 4. *Sony SRX-611 Lab robotic arm.*

Fig. 5. *Fanuc Spider Robot.*

labs provide professionals with the opportunity for virtual training, allowing them to practice informally with minimal risk of physical damage [14].

2.3. CPS & IRS Algorithm

Comparable to social networks, the cyber level of CPS enables interconnection between machine health analytics via a machine-cyber interface.

Tracking changes in machine status, deriving knowledge from historical data, and advancing outputs to the subsequent level all require algorithms [15]. In 2022, the lab members, using data synthesis designed a 3D model of the robot unit and its elements and products to generate any number of pictures with any number of elements and high-resolution images in virtual frames.

Blender was used to simulate virtual sceneries utilizing varied textures, geometries, lighting effects, and camera viewpoints. Ray Tracing Precision, OptiX temporal denoising, and Optimal compact BVH were added. Denoising was crucial since it allowed faster image production and produced a cleaner image after rendering [16].

To be able to print 3D models for the lab, in 2016 utilized an open-source Arduino platform to construct a delta tripod-based autonomous fused deposition modeling (FDM) 3D printer (Fig. 6).

This technology enables rapid prototyping, which reduces the time and expense of development. Motors with a maximum current per phase of 1.3 A and a reference voltage determined by a particular formula are utilized by the printer. The print is produced at a pace of 50mm/s, with a 0.2 mm layer thickness, 30 % fill factor, and movement resolution determined by formulas [17].

2.4. AI-Ecosystem

The Industry 4.0 AI-ecosystem, places an importance on machine-to-machine interactions and data technologies. It underscores the risk that smart manufacturing systems are susceptible to cyber threats and stresses the necessity for industry readiness by highlighting the significance of data quality in AI algorithms for dependable outcomes [18].

Dursun et al. (2020) explore the use of the YOLO algorithm (Fig. 7) for traffic sign recognition in autonomous vehicles at level 2 stage [19]. The algorithm, known for its real-time capabilities and object detection accuracy, is crucial for the development of autonomous vehicles [20] (Table 2).

Cyber-Physical systems (CPS) refer to control systems that encompass a wide range of interconnected objects and networks, including but not limited to automobiles, aircraft, antenna and radar [21].

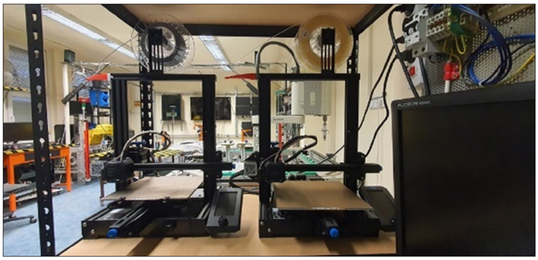

Fig. 6. *3D printer.*

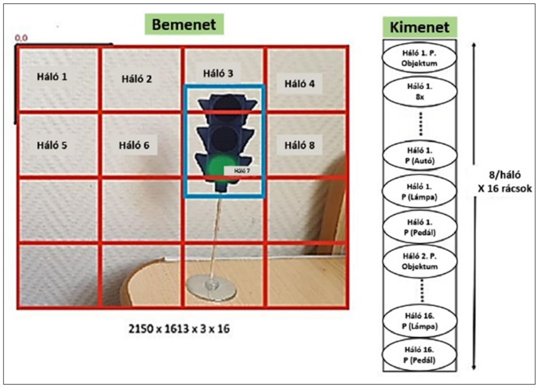

Fig. 7. *YOLO input-output algorithm.* [19]

Table 2. *Sample Output YOLO algorithm* [19]

Grid 7	
P.Object	1
Bx	0.8
By	0.9
Bw	1.5
Bh	1.2
P.Light	1
P.Pedestrain	0
P.Car	0

*P.Object: 0 for all other grids.

The faculty of engineering at the University of Debrecen, has successfully designed and implemented a cutting-edge surveillance and security system for the 'Intelligent facility'. This advanced system serves the purpose of monitoring ongoing research projects and safeguarding the overall safety of the facility. [22]

The Cyber-Physical and Intelligent Robot Systems Laboratory offers immersive learning experiences using augmented reality, virtual reality, and simulation technologies. It prepares students for Industry 4.0 demands through industry-aligned projects and a curriculum that fosters collaborative problem-solving and human-robot interaction studies. The laboratory integrates technology and pedagogy, empowering students to apply CPS and IRS concepts effectively. It plays a crucial role in advancing automation education and preparing students for evolving challenges.

3. Conclusions

The Cyber-Physical & Intelligent Robot Systems Laboratory aims to prepare students and young researchers for Industry 4.0 with AI by providing immersive learning experiences using augmented reality, virtual reality, and simulation technologies. It focuses on collaborative problem-solving and human-robot interaction studies, with the goal of nurturing adaptable and industry-ready professionals for careers in automation technologies.

Cyber-Physical Systems (CPS) demand the use of automation, advanced control technologies, reliability, and security measures. The unique feature of Cyber-Physical Systems (CPSs) lies in the incorporation of both physical and cyber design elements. In industrial settings, Augmented Reality (AR) provides a range of functionalities including effective networks, secure communication, visualization, modeling, programming, maintenance, training, and monitoring.

This research could be helpful in the vehicle topics that we have previously addressed at the university, such as lightweight aircraft and antenna design **[23, 24]**. It can also support the design of virtual vehicle models **[25]** or the virtual testing of engine characteristics **[26]**.

References

[1] W. Wolf: *Cyber-Physical Systems*. Computer (Long. Beach. Calif)., 42/3. (2009) 88–89. https://doi.org/10.1109/MC.2009.81

[2] T. I. Erdei, N. C. Obinna, Z. Molnar, G. Husi, *Surveillance and Security System in the Building Mechatronics Research Center*. In 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC), IEEE, Jun. 2017, 509–512. https://doi.org/10.1109/ICE.2017.8279928.

[3] Rohit Singh Chauhan, T. I. Erdei, Géza Husi: *ROS OS-based 3D Mapping of Cyber-Physical System Lab by the Depth Sensor*. Recent Innov. Mechatronics, 7/1. 2020. https://doi.org/10.17667/riim.2020.1/5

[4] J. Shi, J. Wan, H. Yan, H. Suo: *A Survey of Cyber-Physical Systems*. In 2011 International Conference on Wireless Communications and Signal Processing (WCSP), IEEE, Nov. 2011, 1–6. https://doi.org/10.1109/WCSP.2011.6096958

[5] A. Masuk, O. M. Kende, A. Husam, I. Balajti: *Cyber-Physical System Aspects of Microstrip Patch Antenna of Radar Sensor Application*. In 23rd International Radar Symposium (IRS), IEEE, Sep. 2022, 378–383. https://doi.org/10.23919/IRS54158.2022.9904974.

[6] T. I. Erdei, G. Husi: *Singularity Measurement in the Cyber-Physical and Intelligent Robot Systems Laboratory*. Int. Rev. Appl. Sci. Eng., 11/2. (2020) 82–87. https://doi.org/10.1556/1848.2020.20001.

[7] G. Á. Sziki, A. Szántó, J. Kiss, G. Juhász, É. Ádámkó: *Measurement System for the Experimental Study and Testing of Electric Motors at the Faculty of Engineering, University of Debrecen*. Applied Science, 12/19. (2022) 10095. https://doi.org/10.3390/app121910095.

[8] T. I. Erdei, Z. Molnár, G. Husi: *Selecting Equipment and Supplies for Self–Replicating 3D Printer*. Acta Technica Corviniensis, IX/1. (2016) https://www.researchgate.net/publication/296696614_Selecting_Equipment_and_Supplies_for_Self-Replicating_3D_Printer

[9] T. Pajkos, T. I. Erdei, G. Husi: *CodeSys Modeling of an Industrial Cell, and Linear Drive Control with PLC & ATmega2560 Microcontrollers for Testing and Improvement Purposes*. IOP Conference Series: Materials Science and Engineering, 568/1. (2019) 012061. https://doi.org/10.1088/1757-899X/568/1/012061.

[10] T. Istvan Erdei, R. Krako, N. David Peter, G. Husi: *3D CAD Design of KUKA Robot Arm & Integration into AR Environment to Educational Purposes*. In: IEEE 20th International Power Electronics and Motion Control Conference (PEMC), IEEE, Sep. 2022, 590–596. https://doi.org/10.1109/PEMC51159.2022.9962864.

[11] A. Szántó, S. Hajdu, G. Á. Sziki: *Dynamic Simulation of a Prototype Race Car Driven by Series Wound DC Motor in Matlab- Simulink*. Acta Polytech. Hungarica, 17/4. (2020) 103–122. https://doi.org/10.12700/APH.17.4.2020.4.6.

[12] T. I. Erdei, N. C. Obinna, Z. Molnár, T. Gönczi, G. Husi: *Industrial KUKA Robot Manipulator in Simulation Environment and Position Read-back*. In: 1st International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS 2016), 2016. https://www.researchgate.net/publication/311970929_Industrial_KUKA_Robot_Manipulator_in_Simulation_Environment_and_Position_Read-back

[13] T. I. Erdei, Z. Molnár, N. C. Obinna, G. Husi: *A Novel Design of an Augmented Reality Based Navigation System & its Industrial Applications*. ACTA IMEKO, 7/1. (2018)57. https://doi.org/10.21014/acta_imeko.v7i1.528.

[14] T. I. Erdei, R. Krakó, G. Husi: *Design of a Digital Twin Training Centre for an Industrial Robot Arm*. Appl. Sci., 12/17. (2022) 8862. https://doi.org/10.3390/app12178862.

[15] J. Lee, B. Bagheri, H.-A. A. Kao: *A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Systems*. Manuf. Lett., 3. (2015) 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001.

[16] T. P. Kapusi, T. I. Erdei, G. Husi, A. Hajdu,: *Application of Deep Learning in the Deployment of an Industrial SCARA Machine for Real-Time Object Detection*. Robotics, 11/4. (2022) 69. https://doi.org/10.3390/robotics11040069.

[17] T. Templom, T. István Erdei, Z. Molnár, E. Shaw, G. Husi: *Designing a Delta Tripod Based Robot Fused Deposition Modelling 3 Dimensional Printer Using an Open-Source Arduino Development Platform*. MATEC Web Conf., 184. (2018) 02013. https://doi.org/10.1051/matecconf/201818402013.

[18] J. Lee, H. Davari, J. Singh, V. Pandhare: *Industrial Artificial Intelligence for Industry 4.0-Based Manufacturing Systems*. Manuf. Lett., 18. (2018) 20–23 https://doi.org/10.1016/j.mfglet.2018.09.002.

[19] Szántó A., Ádámkó É., Juhász G., Sziki G. Á.: *Simultaneous Measurement of the Moment of Inertia and Braking Torque of Electric Motors Applying Additional Inertia*. Measurement, 204. (2022) 112135.

[20] C. Dursun, T. I. Erdei, G. Husi: *Artificial Intelligence Applications in Autonomous Vehicles: Training Algorithm for Traffic Signs Recognition*. IOP Conf. Ser. Mater. Sci. Eng., 898/1. (2020) 012035. https://doi.org/10.1088/1757-899X/898/1/012035.

[21] A. Masuk I. Balajti: *Mechatronics Engineering Aspects of VHF band Antenna Design of Industry 4.0 Applications*. In 23rd International Radar Symposium (IRS), IEEE, Sep. 2022, 77–82. https://doi.org/10.23919/IRS54158.2022.9905051.

[22] Szántó A., Kiss J., Mankovits T., Szíki G. Á.: *Dynamic Test Measurements and Simulation on a Series Wound DC Motor*. Applied Sciences, 11/10. (2021) 4542.

[23] A. Masuk, H. Géza: *Aero Graphene in Modern Aircraft & UAV*. Recent Innov. Mechatronics, 9/1. (2022) https://doi.org/https://doi.org/10.17667/riim.2022.1/4.

[24] A. Masuk H. Géza: *Uses of Aero Graphene and CNT in Modern Aircraft*. 2023, 020029. https://doi.org/10.1063/5.0181354.

[25] A. Szántó, É. Ádámkó, G. Juhász, G. Á. Sziki: *Simultaneous Measurement of the Moment of Inertia and Braking Torque of Electric Motors Applying Additional Inertia*. Measurement, 204, (2022) 112135. https://doi.org/10.1016/j.measurement.2022.112135.

[26] A. Szántó, J. Kiss, T. Mankovits, G. Á. Szíki: *Dynamic Test Measurements and Simulation on a Series Wound DC Motor*. Applied Sciences, 11/10. (2021) 4542. https://doi.org/10.3390/app11104542.