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FEATURES OF USING A TEAM PROJECT BASED TEACHING METHOD TO IMPROVE ENGINEERING STUDENTS' UNDERSTANDING OF ELEMENTS OF CYBER-PHYSICAL SYSTEMS

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Abstract. This article describes a teaching method that was used to teach second-year mechatronics and robotics majority students the elements of cyber-physical systems. A line following robot was used for the teaching. This course was designed 48 academic hours. As a result, the students noted that after building the robot in teams, their attitude towards cyber-physical systems changed, and they became motivated to carry out larger projects related to cyber-physical systems.

Keywords. ETUT, Cyber-physical Systems, Teaching Method, Line following robot.

Introduction

Oguz Han Engineering and Technology University of Turkmenistan (ETUT) was opened in 2016 and is one of the youngest universities in the country. Despite its youth, our university, which is one of the leading universities in the country, is a reporter of the THE (Times Higher Education) [1], member of CDIO [2], UI Green-Metric [3], and a number of other international organisations [4, 5]. ETUT trains engineering technologists and technicians at Bachelor's degree. The aim of the ETUT's teaching staff is to prepare a competitive specialist in their field.

At the Oguz Han Engineering and Technology University of Turkmenistan students receive a quality education in English and Japanese in accordance with international educational standards in the majorities automation and control, mechatronics and robotics, electronics and nanoelectronics, biomedical electronics, physics of modern technologies, technical means of data protection, technologies of digital economy, digital infrastructure and cybersecurity, mobile and network engineering, innovative economics and etc [6].

One of the main tasks of the academic staff of the Department of Cyber-Physical Systems at the ETUT is to provide the students of this department with a broad modern understanding of cyber-physical systems (CPS). CPS are one of the main directions of the intelligent industry that is planned to be organised in the country in the coming years.

A smart manufacturing is an industrial system that integrates modern information and communication technologies with the production environment to ensure real-time management of energy, productivity and costs in the production process at the machine, factory or enterprise level. In other words, the smart manufacturing is the production of the future, combining the imaginary and physical worlds through CPS. The capabilities of devices and sensors to transfer information between each other make it possible to build an intelligent network throughout the entire production chain [7, 8]. In order to achieve the above, there is a need for highly qualified specialists who are will be able to model CPS platforms and their production, create software using different programming languages for the interaction of modern sensors and con-

trol systems with each other, in short, engineers who can deal with CPS.

For this reason, the academic staff of the Department of CPS are striving to train personnel who will work in this new industrial sector, which will make a great contribution to the development of the country, according to modern requirements and to achieve a continuous improvement of their skills. This article describes the characteristics of the method that uses a programmable line following robot to improve the understanding of elements of CPS by undergraduate students of the Department of CPS.

Literature review

To date, several researchers have conducted research into teaching methods for students with components of cyber-physical systems.

V. Gadepally et al. using the existing project "Autonomous Driving in Mixed Environments" explain to students the structure and working principle of CPS. In this paper, based on the "Autonomous Driving in Mixed Environments" project, students are invited to develop algorithms for the cyber-physical system, "Roomba, overcoming competition", and the results of this method are analysed through a project competition. The aim of this event is to give students the opportunity to study the elements of CPS by working independently on existing scientific projects [9].

N. Ueter et al. In their work, they teach computer science and computer engineering students the components of CPS by building an unmanned vehicle using the project-based learning method. Project-based learning is a comprehensive programme in which students start with projects in one subject area while developing their skills in other subjects. In this article, the basic concepts of cyber-physical systems are explained to the students and the results demonstrated by the students are discussed and evaluated at the end of the project. In this methodology, students are given the opportunity to apply their theoretical knowledge, complete a project and test their work in real life to improve their cognitive skills. This method also aims to improve students' ability to work in groups on complex projects [10].

The work of S.A. Nelke et al. is also based on the use of Project-based learning methodology in teaching students the components of CPS. But the difference in their



methodology is that it is aimed at teaching undergraduate students in Industrial Engineering and Technology Management, who practically have no knowledge about the components of CPS, about courses in electricity and programming. The authors solved this problem by teaching students about the Internet of Things, one of the key components of CPS. This is because technological business engineers, who are the profession of the future, will be able to work with electrical engineers and programmers, and gaining an understanding of their work, will enable them to properly manage multifaceted projects [11].

S. Ghosh et al. use the “CPS testbed”, which specialises in developing a simple way to teach students the elements of cyber-physical systems. This testbed allows students to design, run and analyse control algorithms in various CPS [12].

As can be seen from the teaching methods above, each institution uses different methods to teach students the components of CPS. This article describes our teaching methodology used to teach the components of cyberphysical systems to 2nd year students of Mechatronics and Robotics at the Faculty of Cyberphysical Systems.

Methodology

Teaching students about the components of cyber-physical systems starts with explaining to them what the term “Cyberphysical Systems” means. To do this, we use Google Scholar to analyze various literature and use the most cited articles. Using several articles and writing definitions in notebooks, we discuss all these definitions together with the students. While discussing the definitions of the term CPS, we also come across a number of other terms related to CPS, and again analyse the relevant literature sources in order to understand them. This methodology allows students to better understand cyberphysical systems. In order to consolidate what has been learnt in this lesson, in the next lesson we give the students cards with the names of the terms and explore the students’ concepts. If the student has not improved, more time is given and the previous activities are repeated. As an example of the definition of “Cyberphysical Systems”, consider the following definitions.

E.A. Lee: “*A cyber-physical system (CPS) is an orchestration of computers and physical systems. Embedded computers monitor and control physical processes, usually with feedback loops, where physical processes affect computations and vice versa*” [13].

V. Gunes et al.: “*Cyber-Physical Systems (CPSs) are complex, multi-disciplinary, physically-aware next generation engineered systems that integrate embedded computing technology (cyber part) into the physical phenomena by using transformative research approaches. This integration mainly includes observation, communication, and control aspects of the physical systems from the multi-disciplinary perspective*” [14].

R. Alguliyev et al.: “*Cyber-Physical Systems (CPS) is a system that can effectively integrate cyber and physical components using the modern sensor, computing and network technologies*” [15].

A. Humayed et al.: “*CPS are composed of various components in many ways. There are different hardware*

components such as sensors, actuators, and embedded systems. There are also different collections of software products, proprietary and commercial, for control and monitoring” [16].

M.N.O. Sadiku et al.: “*A CPS has three main components: (1) a physical system, (2) networking and communication element, (3) a distributed cyber system. CPSs are designed with a set of distributed hardware, software, and network components which are embedded in physical systems and environments. The software plays the most important role; it includes all software programs for processing, filtering, and storing information. CPSs interact with the physical system through networks*” [17].

As we can see, in the definitions provided to understand the meaning of the term CPS, we find several other terms such as integrated systems, physical system, sensors, computing structure, actuators, high precision network. These new terms are also discussed throughout the course. Of course, many of these new terms have been explained in previous lessons. If these terms have not been considered before this lesson, then these new terms are also being supplemented. Once the students have learnt these terms, it remains to familiarise them with the places where they are used in the design of cyber-physical systems and the functions they perform, by seeing and “touching” the devices that make up cyber-physical systems in real life. To do this, we use the “Project based learning” method mentioned above, i.e. we choose a specific project. Students are introduced to the function that each element in the system performs individually.

Given the importance of group learning, we divide the group into sub-groups of 5 to increase efficiency by comparing the tasks undertaken by the sub-groups. This creates a habit of working as a team and encourages the development of specific engineering skills, such as the ability to publicly explain new ideas and knowledge to team members.

Results and Discussions

In this section we will discuss project selection, selection of components for real-time project execution, project execution and analysis of the results obtained as a result of project execution. The “Line following robot” project was chosen for the “Project based learning”. The “Line following robot” consists of hardware and software and is a prime simple example of a CPS.

Line Following Robot is an autonomous robot which is able to follow a colored line that is drawn on the surface. As we can see from the definition, our robot must be able to follow a given line, i.e. it must be able to feel the line and receive information about it, for which we use an IR sensor. The next step is to process the data received from the sensor using the Arduino Uno platform and develop an algorithm for the program to send commands to control the DC motors and communicate with the wireless remote control. We use Motor Driver to control the movement and direction of the DC motors. We added the HC-06 Bluetooth module to this project to control the robot remotely in case of some technical problems.

This project allows students to interact in real time with sensors, actuators, data processing tools,

programming and many others that are components of cyberphysical systems. Students are provided with all necessary equipment and components for the implementation of the project. The main goal of this project is to give students the opportunity to select the components of cyberphysical systems and develop a autonomous robot in the team that can move along the black line, controlled wirelessly (Bluetooth) if necessary, and to compare the performance of the teams with each other.

The robot consists of the components listed in table 1.

Table 1 – Components of the Line following robot

№	Components
1	Rolling chassis with wheels
2	Arduino Uno
3	Motor Driver L298N
4	IR sensors
5	Connecting wires
6	DC motors
7	Bluetooth module HC-06
8	Rechargeable batteries
9	Battery box
10	Arduino software

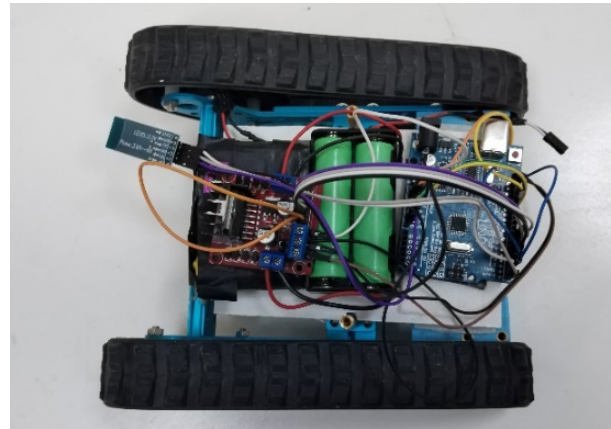
The sub-group consisted of 2nd year students from the Mechatronics and Robotics majority. These students had previously taken courses such as Scientific fundamentals of innovative technologies, Physics, Mathematics, Mathematical statistics and probability theory, Programming and Engineering Graphics in different semesters. As the Line following robot is controlled by the Arduino Uno platform, team members should be familiar with the Arduino programming language, as well as courses such as Digital signal processing, Fundamentals of mechatronics, Fundamentals of robotics, Control systems. But the most important thing is not that they can fully understand these courses. The focus was on the students' motivation and skills. Although the students had previously learnt the basic concepts in these courses, they did not complete the real project by 'touching' all the components. And this time they did a real project.

Sub-groups were formed taking into account the skills and abilities of the students. This is a common situation in engineering teams. The students are given a total of 48 hours to complete this project (16 hours of practical lessons and 32 hours of additional lessons). The 16 hours of practical lessons are carried out according to a timetable drawn up by the teachers, and the 32 hours of extra lessons are carried out after the main lessons according to the timetable drawn up by the sub-groups themselves and agreed with the teacher.

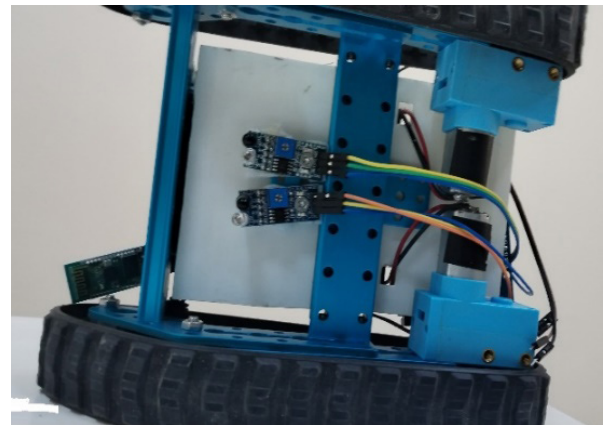
The project consisted of 4 phases. These are: choosing components and studying their purpose and working principles; building the robot, putting all the components in their places; developing and uploading a code algorithm for Arduino Uno; testing the ready-to-use Line following robot experimentally. After each phase, the sub-groups presented their work. In the presentation, they presented a list of the literature used to complete this

phase and what they learned from the relevant literature to complete this phase of the project.

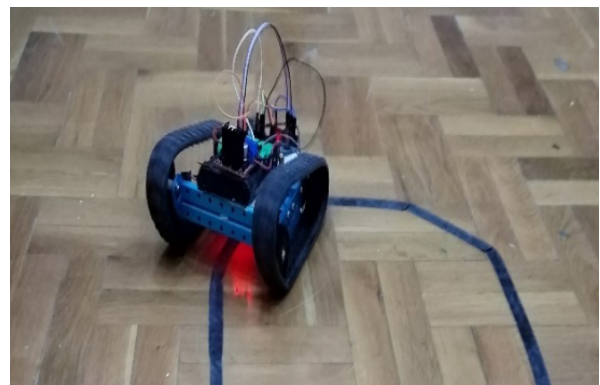
Once the line-following robot has been built from components, it is connected to a power supply (figure 1).



a) View from above



b) View from bottom



c) line following robot in process

Figure 1. Ready-to-use line following robot

After the allotted 48 hours, all teams tested their completed projects on the track with lines. Some of the problems encountered with the prosthetics were discussed with other groups and teachers. Several competitions were organised to compare the projects with each other.

When the students were asked for their opinion in order to determine the effectiveness of the teaching methodology used, they noted that for the first time they had mastered the skills of teamwork, explaining their ideas to each other, typical for engineers, and that they



realized that what they had learned in the classroom could be applied in real life.

Conclusion

In this article has been described the teaching method where we have used to teach second year mechatronics and robotics majority students the elements of cyber-physical systems using a line following robot. Our aim is to give students the opportunity to learn how to work in a team and put it into practice. The students were given the basic information about cyber-physical systems and the opportunity to get to know each of the components that make up the cyber-physical system separately in real life. During the 48-hour placement, the sub-groups worked as a team to build a line-following robot. In order to determine the results of the teaching method, the students were asked about the results. Students noted that after building the line following robot, their attitude towards cyber-physical systems changed and they became motivated to carry out larger projects related to cyber-physical systems. As a result of what they have learned in this course, we expect students to successfully complete course projects in their 3rd year and diploma projects in their final 4th year.

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ОСОБЕННОСТИ ИСПОЛЬЗОВАНИЯ МЕТОДА ОБУЧЕНИЯ НА ОСНОВЕ КОМАНДНЫХ ПРОЕКТОВ ДЛЯ УЛУЧШЕНИЯ ПОНИМАНИЯ СТУДЕНТАМИ ИНЖЕНЕРНЫХ СПЕЦИАЛЬНОСТЕЙ ЭЛЕМЕНТОВ КИБЕРФИЗИЧЕСКИХ СИСТЕМ

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Аннотация. В этой статье описывается метод обучения, который использовался для обучения студентов второго курса мехатроники и робототехники элементам киберфизических систем. Для обучения использовался робот, следующий за линией. Этот курс был рассчитан на 48 академических часов. В результате студенты отметили, что после создания робота в командах их отношение к киберфизическим системам изменилось, и у них появилась мотивация выполнять более масштабные проекты, связанные с киберфизическими системами.

Ключевые слова. ИТУТ, киберфизические системы, метод обучения, робот движущийся по линии.