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DEVELOPMENT OF AN IOT BASED 3D PRINTED MOBILE ROBOT PLATFORM FOR TRAINING OF MECHATRONICS ENGINEERING STUDENTS

[1] János Simon, [2]László Gogolák

[1] Department of Mechatronics and Automation, Faculty of Engineering, University of Szeged, Moszkvai krt.9. 6725 Szeged, Hungary,
[2] Department of Mechatronics and Automation, Faculty of Engineering, University of Szeged, Moszkvai krt.9. 6725 Szeged, Hungary,
e-mail: simon@mk.u-szeged.hu

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ABSTRACT

The advent of the Internet of Things (IoT) has opened up new opportunities in education, particularly in the field of mobile robotics. Mobile robotics is a fast-growing field, and with the increasing demand for skilled robotics engineers, it is essential to provide students with hands-on experience in designing and developing robots. In this regard, an IoT-based 3D printed mobile robot platform has been developed for students training. STEM (Science, Technology, Engineering, and Mathematics) education has been gaining attention as a means to improve science and engineering education. STEM education aims to foster critical thinking, problem-solving skills, creativity, and innovation among students. It involves an educational policy that aims to develop the next generation of skilled professionals by integrating the fields of Science, Technology, Engineering and Mathematics. The goal of this approach is to provide students in mechatronics, who are assigned to the robotics lab during their studies, an up to date knowledge and experience in research and development activities. Thus, this paper aims to provide education that focuses on the acquisition and application of engineering knowledge, including control engineering, mechanical engineering, electrical and electronic engineering, information engineering, among others, with the main focus on mobile robot research.

Keywords: 3D print, STEM, IoT, Multi-robot systems

1. INTRODUCTION

The rapid advancements in technology have significantly impacted the field of robotics, and as a result, there is an increasing demand for skilled robotics engineers. It is, therefore, essential to provide students with hands-on experience in designing and developing robots. STEM represents an interdisciplinary approach to education that integrates these four disciplines into a cohesive learning paradigm. STEM education aims to foster critical thinking, problem-solving skills, creativity, and innovation among students. By emphasizing real-world applications and hands-on learning experiences, STEM education prepares students for future careers in fields such as engineering, computer science and mechatronics. However, robotics education can be challenging due to the high cost of equipment and the complexity of the subject matter. To address these challenges, an IoT-based 3D printed mobile robot platform has been developed for students training. The platform is designed to be easy to use, cost-effective, and customizable, making it an ideal tool for teaching robotics to students [1]. The platform utilizes four different microcontrollers, namely, the ESP32, ESP8266, Raspberry Pi, and PIC 18x, to provide flexibility in programming and control. Each microcontroller has its unique features, and students can choose the one that best suits their needs. The use of microcontrollers provides a practical approach to teaching programming and control, making it an excellent platform for mechatronics students. The platform is 3D printed, making it easy to manufacture and assemble [2]. The design is modular, allowing students to customize the robot according to their requirements. The robot's chassis, wheels, and sensors can be easily replaced or modified, making it an excellent tool for students to experiment with different designs and configurations. The robot platform is equipped with a variety of sensors, including ultrasonic sensors, line-

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following sensors, and infrared sensors. The sensors enable the robot to detect obstacles, follow lines, and detect objects. Students can program the robot to perform various tasks, such as navigating a maze, following a line, or avoiding obstacles. The platform is also equipped with Wi-Fi and Bluetooth modules, allowing students to control the robot remotely using a smartphone or tablet. This feature enables students to experiment with wireless communication and control, providing them with essential skills in the field of IoT. The development of the IoT-based 3D printed mobile robot platform has been successful in providing students with a practical approach to learning robotics [3]. The platform's modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels. The platform is cost-effective, easy to manufacture and assemble, and customizable, making it an excellent tool for schools and universities with limited resources. In conclusion, the development of an IoT-based 3D printed mobile robot platform has opened up new opportunities in robotics education as depicted in fig 1. The platform provides students with a practical approach to learning programming, control, and wireless communication. The modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels [4]. With the increasing demand for skilled robotics engineers, providing students with hands-on experience in designing and developing robots is essential, and the IoT-based 3D printed mobile robot platform provides an excellent platform for achieving this goal.

2. MATERIALS AND METHODS

This section outlines the proposed tools aimed at mechatronic engineering students to reconstruct core learning elements using basic concepts based on active learning. Unlike educational robotics, the tools aim to develop students' skills and abilities to generate innovative solutions to industrial automation problems and facilitate their integration into the job market. The core of the educational strategy lies in the promotion of analytical thinking, achieved through the implementation of elements of STEM. [5]. To ensure logical development in each student guide, a purpose or objective must be presented first, followed by a question that guides the problem or issue, and information gathering from facts, data, evidence, or experiences. Inferences and conclusions can then be drawn, and assumptions and beliefs can be justified with solid evidence. Concepts such as ideas, theories, laws, principles, or hypotheses are used to make sense of the gathered information, and a point of view or perspective is taken into account.

2.1. Hardware components

The hardware requirements for the development of an IoT-based 3D printed mobile robot platform for students training would depend on the specific features and capabilities of the platform. However, there are some general hardware requirements that would be essential for building such a platform:

- Microcontroller: The platform would require a microcontroller to control the robot's movements and sensors. The ESP32, ESP8266, Raspberry Pi, and PIC 18x microcontrollers are all suitable options for this purpose.
- Sensors: The platform would require a variety of sensors to detect the robot's surroundings and enable it to perform tasks. Sensors such as ultrasonic sensors, line-following sensors, and infrared sensors are commonly used in mobile robot platforms [6].
- Motors: The platform would require motors to drive the wheels and enable the robot to move. DC motors or servo motors are commonly used for this purpose.
- Power source: The platform would require a power source to run the microcontroller, sensors, and motors. A rechargeable battery or a power supply would be suitable options.
- Wi-Fi/Bluetooth module: The platform would require a Wi-Fi or Bluetooth module to enable wireless communication and control. The Raspberry Pi 4, ESP32 and ESP8266 microcontrollers have built-in Wi-Fi and Bluetooth capabilities, while the PIC 18x microcontrollers require additional modules.

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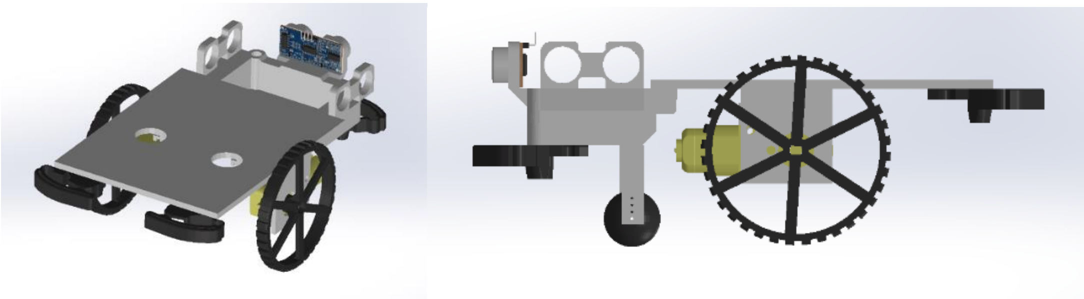

Figure 1. 3D model of the developed mobile robot platform. (Perspective view)

Overall, the hardware requirements for the development of an IoT-based 3D printed mobile robot platform for students training are relatively simple and affordable. The platform can be built using readily available components, and the use of 3D printing technology makes it easy to customize the robot's design and components.

2.2. Software components

The software environment for the development of an IoT-based 3D printed mobile robot platform for students training would depend on the microcontroller used in the platform. Each microcontroller has its own software development environment, but some general software requirements include an Integrated Development Environment (IDE) which is a software application that provides a programming environment for writing, debugging, and testing code [7]. Depending on the microcontroller used, the appropriate IDE should be selected. For example, the Arduino IDE is commonly used for programming the ESP32 and ESP8266 microcontrollers, while the Raspberry Pi can be programmed using Python or other programming languages. The firmware is the software that runs on the microcontroller and controls the robot's movements and sensors. The firmware should be programmed in the appropriate programming language for the microcontroller used, such as C or Python. Libraries are collections of pre-written code that can be used to perform specific tasks, such as controlling motors or sensors. The appropriate libraries should be selected for the microcontroller used. Simulation software can be used to simulate the robot's movements and test the firmware before uploading it to the robot. This can be useful in identifying errors and optimizing the firmware. Communication software can be used to establish wireless communication between the robot and a smartphone or tablet. The appropriate communication software should be selected depending on the microcontroller used. CAD (Computer-Aided Design) software can be used to design the robot's chassis, wheels, and other components before 3D printing them. This can be useful in customizing the robot's design and components. The software environment for the development of an IoT-based 3D printed mobile robot platform for students training should be easy to use and accessible to students of all levels. The software should be free or low-cost, and the appropriate software should be selected depending on the microcontroller used in the platform [8]. Additionally, simulation software and CAD software can be useful in optimizing the robot's design and performance.

3. DISCUSSION

An IoT-based 3D printed mobile robot platform for students can be used for a wide variety of tasks and exercises that can help students develop their skills in robotics, programming, and electronics. Here are some examples of tasks and exercises that can be solved using such a platform:

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- Line-following: The robot can be programmed to follow a line on the ground using line-following sensors. This task can help students develop their skills in programming and sensor integration.
- Obstacle avoidance: The robot can be programmed to avoid obstacles using ultrasonic or infrared sensors. This task can help students develop their skills in programming and sensor integration.
- Remote control: The robot can be controlled remotely using a smartphone or tablet via Wi-Fi or Bluetooth. This task can help students develop their skills in wireless communication and programming.
- Autonomous navigation: The robot can be programmed to navigate a maze or follow a specific path using a combination of sensors and algorithms [9]. This task can help students develop their skills in algorithm development and programming.
- Robotic arm control: The robot can be equipped with a robotic arm that can be controlled using servos and sensors. This task can help students develop their skills in robotics and electronics.
- Object detection and recognition: The robot can be programmed to detect and recognize objects using cameras and machine learning algorithms [10]. This task can help students develop their skills in image processing and machine learning.
- Swarm robotics: Multiple robots can be programmed to work together to perform a task, such as navigating a maze or carrying objects [11]. This task can help students develop their skills in collaboration and teamwork.
- Environmental monitoring: The robot can be equipped with sensors to monitor environmental factors such as temperature, humidity, and air quality [12]. This task can help students develop their skills in sensor integration and data analysis.
- Home automation: The robot can be programmed to control home appliances such as lights and fans using Wi-Fi or Bluetooth. This task can help students develop their skills in IoT and home automation.

Using, an IoT-based 3D printed mobile robot platform can provide students with a hands-on learning experience in robotics, programming, and electronics [13]. The tasks and exercises listed above are just a few examples of what can be achieved using such a platform, and the possibilities are virtually endless. Figure 2 presents the 3D printed and assembled mobile robot platform.

Figure 2. 3D printed and assembled mobile robot platform.

The decision to incorporate a mobile robot into the curriculum is driven by the significance of this type of robot setup in the context of Industry 4.0 [14]. The main objective of utilizing this mobile robot (depicted

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in Fig. 2) is to familiarize students with the mathematical model, control inputs, sensors, and actuators, with the aim of equipping them to tackle Industry 4.0-related challenges, such as devising a new configuration to address a particular issue in the industry, for example, streamlining the packaging process of an e-commerce enterprise [15].

4. ELEMENTS OF THE SYSTEM

4.1. Central processing unit

Raspberry Pi 4, ESP32, ESP8266 microcontrollers, and PIC 18x microcontrollers can all be used as the central processing unit of an IoT-based 3D printed mobile robot platform. Each microcontroller has its own strengths and weaknesses, and the appropriate one to use would depend on the specific requirements of the robot and the tasks it needs to perform. The Raspberry Pi 4 is a powerful single-board computer that can run a full-fledged operating system such as Linux [16]. It has a quad-core ARM Cortex-A72 CPU, up to 8GB of RAM, and a wide range of connectivity options such as Wi-Fi, Bluetooth, Ethernet, and USB. The Raspberry Pi 4 is well-suited for tasks that require a lot of processing power and connectivity, such as image processing and IoT applications. The ESP32 is a low-cost, low-power microcontroller that is designed for IoT applications. It has a dual-core Tensilica LX6 CPU, up to 520KB of RAM, and built-in Wi-Fi and Bluetooth connectivity. The ESP32 is well-suited for tasks that require wireless connectivity, such as remote control and IoT applications. The ESP8266 is a low-cost, low-power microcontroller that is similar to the ESP32 but has less processing power and memory. It has a single-core Tensilica L106 CPU, up to 80KB of RAM, and built-in Wi-Fi connectivity. The ESP8266 is well-suited for simple tasks that require wireless connectivity, such as data logging and remote sensing. The PIC 18x microcontrollers are a family of 8-bit microcontrollers that are designed for low-power, low-cost applications. They have a range of processing power and memory options, and can be programmed using the C language. The PIC 18x microcontrollers are well-suited for simple tasks that require low power consumption, such as sensor reading and control [17].

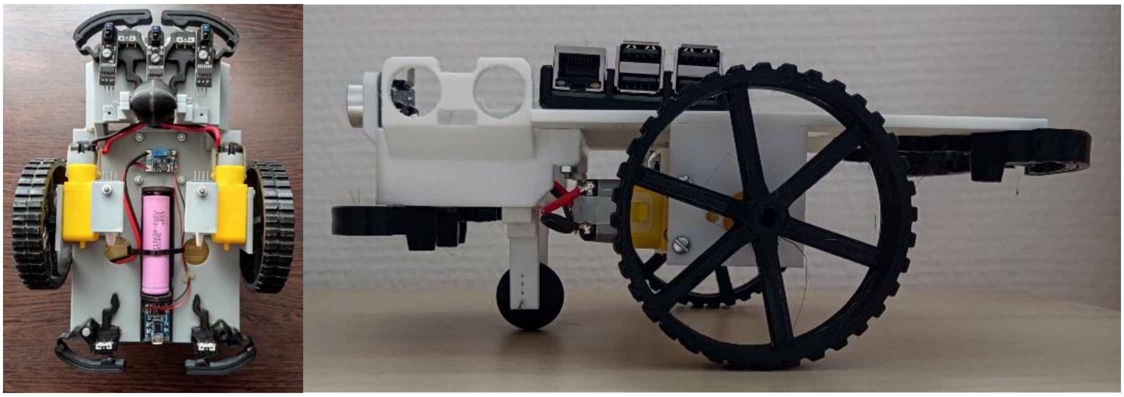

Figure 3. 3D printed and assembled mobile robot platform bottom and side view.

In many cases, Raspberry Pi 4, ESP32, ESP8266 microcontrollers, and PIC 18x microcontrollers can all be used as the central processing unit of an IoT-based 3D printed mobile robot platform. The appropriate one to use would depend on the specific requirements of the robot and the tasks it needs to perform.

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4.2. Sensors

Each sensor has its own unique capabilities and can be used for different purposes. Bumpers are simple sensors that detect physical contact with objects. They are often used to detect collisions and prevent the robot from damaging itself or its surroundings [18]. The HC-SR04 sonar sensor uses ultrasonic sound waves to measure distances. It is often used to detect obstacles and map the environment around the robot. The TCRT5000 IR sensor is a reflective sensor that detects the presence of objects by reflecting an infrared beam off them. It is often used for line following and obstacle detection. The FC-03 optical encoder module measures the rotation of a wheel or shaft. It is often used for measuring distance traveled and controlling the speed of the robot as can be seen in fig 3. The BME280 is a sensor that measures temperature, pressure, and humidity. It is often used for environmental monitoring and weather forecasting. The OV2640 camera module is a low-cost camera that can capture still images and video. It is often used for vision-based tasks such as object detection and recognition. The list of used sensors are given in table 1.

Table 1. Mobile robot sensor types

Type	Description
Bumpers	4x Digital switches
HC-SR04	3x Sonar sensor (min. 1)
TCRT5000	3x IR sensor
FC-03	2x Optical Encoder Module
BME280	1x Temperature, humidity sensor
OV2640	1x Camera Module

Bumpers, HC-SR04 sonar, TCRT5000 IR Sensor, FC-03 Optical Encoder Module, BME280, and OV2640 Camera Module are all useful sensors for an IoT-based 3D printed mobile robot platform. The appropriate sensors to use would depend on the specific requirements of the robot and the tasks it needs to perform.

4.3. Actuators

Two TT Micro DC geared motor with encoder is used as a main actuator of the robot platform. It is a motor with a 120:1 gearbox and an encoder disc with 20 slots and 24mm outer diameter along with encoder slit sensor module for detecting the number of counts moved by the wheel. The encoder slit sensor module is responsible for detecting these counts and relaying the information back to the control system of the robot. This information is crucial in determining the position and speed of the robot, allowing for accurate and efficient movement. With this setup, the robot platform is able to achieve smooth and precise motion, making it suitable for a variety of applications. The parameters of the motor are given in table 2.

Table 2. Actuator specifications

Parameter	Value
Gear ratio:	120:1
No-load speed @ 6V:	160 rpm
No-load speed @ 3V:	60 rpm
No-load current @ 6V:	0.17A
No-load current @ 3V:	0.14A
Max Stall current:	2.8A
Max Stall torque:	0.8kgf.cm

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Rated torque:	0.2kgf.cm
Encoder operating voltage:	4.5~7.5V
Motor operating voltage:	3~7.5V (Rated voltage 6V)
Operating ambient temperature:	-10~+60℃
Weight:	50g

4.4. Power supply

The TP4056 Li-Ion battery charger module was used with a 2600mAh rechargeable Li-ion battery cell - 18650 - 3.6V battery to power the mobile robot. This module is made for charging rechargeable lithium batteries using the constant-current/constant-voltage (CC/CV) charging method. In addition to safely charging a lithium battery the module also provides necessary protection required by lithium batteries. The 2600mAh capacity of the battery provides a sufficient power supply for the mobile robot, allowing it to operate for an extended period without needing to recharge the battery frequently. The 18650 form factor is also convenient, as it is widely available and easy to replace if necessary.
An MT3608 DC/DC Boost converter was used to step up the voltage level from the battery to the required 6V. This converter is efficient and can provide a stable output voltage, which is essential for the proper operation of the robot's components. The specifications of mobile robots can vary widely depending on their intended application, so I will provide a comparison based on some common parameters:

- Size and Weight: The newly developed 3D printed mobile robot is likely to be smaller and lighter than many commercially available systems, as it is designed for student training and likely does not require heavy-duty components.
- Sensors: The newly developed robot may have a similar range of sensors to commercially available systems, such as bumpers, sonar, IR sensors, encoders, and cameras. However, the specific sensors used and their accuracy and precision may vary.
- Power Supply: The use of a 2600mAh rechargeable Li-ion battery cell and a TP4056 Li-Ion battery charger module with an MT3608 DC/DC boost converter provides a reliable and safe power supply for the robot. However, some commercially available systems may have more powerful batteries or alternative power sources such as solar panels.
- Processing Power: The use of a Raspberry Pi 4, ESP32, ESP8266, or PIC 18x microcontroller as the central processing element provides a decent amount of processing power, but it may not be as powerful as some commercially available systems. For example, some high-end robots may have dedicated processors and GPUs for advanced computation.
- Connectivity: The use of IoT technologies such as Wi-Fi and Bluetooth for connectivity is a modern and convenient feature of the newly developed robot. However, some commercially available systems may have additional connectivity options such as cellular networks or satellite communication.
- Control Interface: The newly developed robot likely has a user-friendly control interface that is designed for student training purposes. Commercially available systems may have more complex control interfaces for advanced users.

A newly developed 3D printed mobile robot may have some limitations compared to commercially available systems, particularly in terms of processing power and connectivity options. However, it is likely to be a cost-effective and user-friendly option for students and hobbyists who are interested in learning about robotics.

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5. TESTING AND RESULTS

The mobile robot physical dimensions are (LxWxH) 204x150x160mm witch servers as an excellent platform for educational purposes. The methodology is implemented with the involvement of nine mechatronics students from the University of Szeged and Óbuda University (as shown in Fig. 4 an 5) and is based on the theories of forward and inverse kinematics as well as SLAM.

Figure 4. Students working with 3D printed and assembled mobile robot platform.

After applying the educational methodology, 85% of the students confirmed that what they had learned in class was sufficient to solve the exercise. Additionally, 95% of them found the concepts, techniques, and tools used significant for their future goals. All students preferred the teaching and learning process using the developed mobile robot. The use of developed mobile robot allowed the students to have a better grasp of the theoretical concepts and their practical applications, providing them with greater confidence when interacting with a real mobile robot.

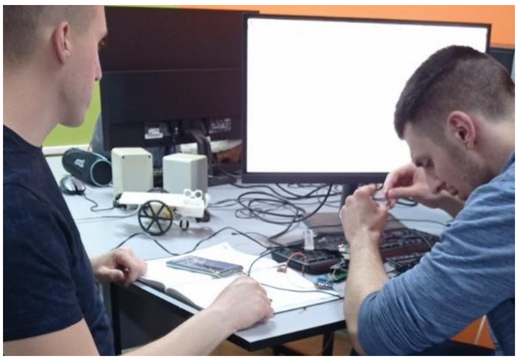

Figure 5. Students working with 3D printed and assembled mobile robot platform.

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Furthermore, the process enabled them to improve their skills in designing robots, which will prove useful in their future endeavors. The Dabble Android application is utilized to remotely control a mobile robot that is based on the ESP32 microcontroller, using Bluetooth technology. Figure 6 depicts the remote controller of the mobile robot using an android phone or tablet.

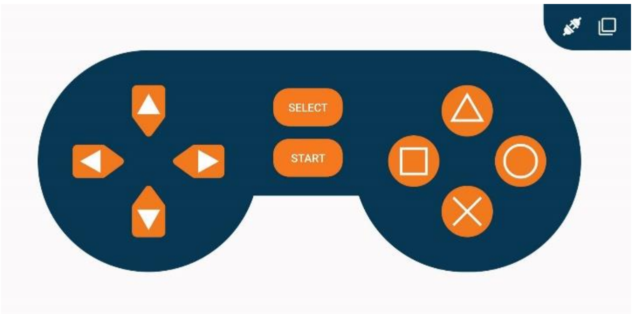

Figure 6. Using Dabble android application to control an esp32 based mobile robot via Bluetooth.

Dabble is an Android application that allows for easy control of an ESP32-based mobile robot via Bluetooth. The application provides a user-friendly interface with various controls, such as joysticks, buttons, sliders, and switches, that enable users to operate the robot remotely. By utilizing the Bluetooth technology, the user can connect to the ESP32 and control the robot from a distance of up to 10 meters. One of the main advantages of using Dabble is that it simplifies the process of controlling the robot, as it eliminates the need for complex coding and programming. The user can simply drag and drop the controls they want to use and customize them to their desired functionality. Figure 7 depicts one of the developed controller module based on the ESP32.

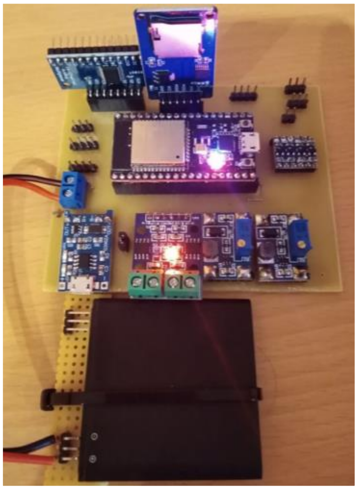

Figure 7. Developed ESP32 board for the mobile robot.

Moreover, Dabble provides a feature to log sensor data which helps the user to monitor and analyze the performance of the robot. Another advantage of using Dabble is its compatibility with different platforms and devices. It can be used with various ESP32-based robots that have Bluetooth connectivity, and can be accessed from any Android smartphone or tablet.

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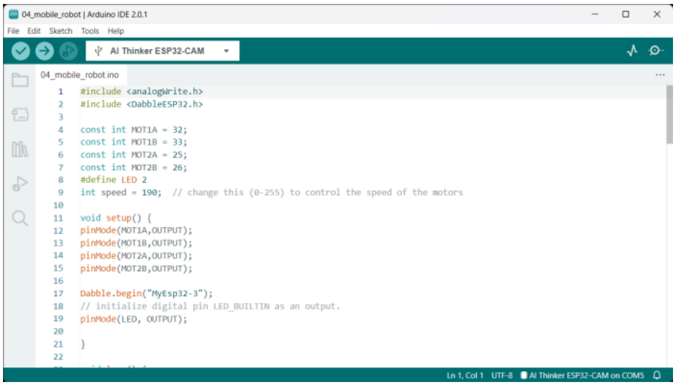

Figure 8. Arduino IDE for ESP32 board.

The Arduino IDE is an integrated development environment used for programming Arduino boards (fig 8). However, it can also be used for programming other microcontroller boards like the ESP32 and ESP8266. Swarm robotics is a field of robotics that focuses on the study of decentralized systems consisting of large numbers of relatively simple robots or agents that are able to coordinate and work together to achieve a common goal (see fig 9). The robots in a swarm are typically capable of sensing and reacting to their environment, communicating with one another, and making decisions based on local information.

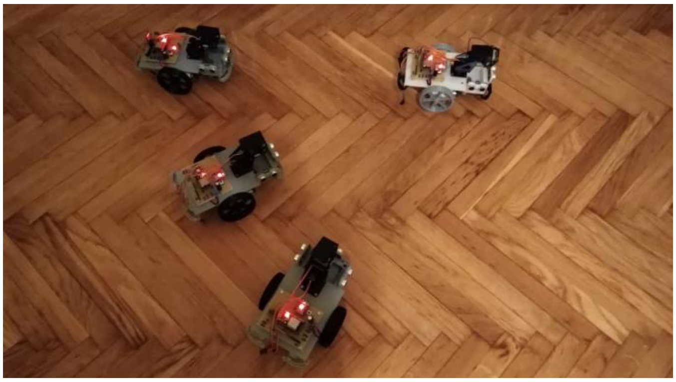

Figure 9. Swarm robotics with the developed platform.

Swarm robotics has applications in a wide range of fields, including search and rescue, environmental monitoring, agriculture, and manufacturing. Examples of swarm robotics systems include swarms of Automated Guided Vehicles (AGVs) used for surveillance and swarms of autonomous vehicles used for transportation. Swarm robotics research is focused on developing algorithms and techniques for coordinating large numbers of robots, as well as understanding the emergent behavior that can arise from interactions between individual robots in a swarm. Some of the key challenges in swarm robotics include developing effective communication and coordination mechanisms, dealing with uncertainty and partial information, and ensuring robustness and fault tolerance in the face of individual robot failures.

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4. CONCLUSIONS

In conclusion, the development of an IoT-based 3D printed mobile robot platform has opened up new opportunities in robotics education. The platform provides students with a practical approach to learning programming, control, and wireless communication. The modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels. With the increasing demand for skilled robotics engineers, providing students with hands-on experience in designing and developing robots is essential, and the IoT-based 3D printed mobile robot platform provides an excellent platform for achieving this goal. Considering the interdisciplinary nature of the curriculum and the emphasis on hands-on practice, educators view the proposed mobile robot-based teaching process as highly beneficial to students, resulting in increased satisfaction levels with the course and related disciplines. The current reference course is mechatronics engineering, but the mobile robot-based approach can be adapted to incorporate various processing units, such as thermoforming and non-traditional processing, to fulfill diverse subject requirements and enrich the mechatronics engineering training experience. Educators and teachers have provided the following feedback: (I) The mechatronics engineering training system meets the demands of contemporary engineering education, thanks to the appropriate selection of equipment and facilities, and the advanced planning of training workshops. (II) Enhancing communication between the teaching staff and students is critical in promoting comprehensive training gains. (III) Improvements to the engineering training curriculum are necessary to ensure proper execution of the education plan, high-quality courseware, and an effective teaching system. The future research directions and plans are:

- Investigating the scalability of the proposed system to accommodate larger datasets and more complex tasks, with a focus on optimizing performance and efficiency.
- Exploring the integration of additional sensors and perception modules to enhance the robot's ability to interact with its environment and adapt to changing conditions.
- Conducting longitudinal studies to evaluate the long-term effectiveness and impact of the educational robotics platform on students' learning outcomes and development of computational thinking skills.
- Collaborating with educators to develop and implement curriculum enhancements that leverage the educational robotics platform to address specific learning objectives and standards.
- Exploring the potential of incorporating machine learning and artificial intelligence techniques to enable the robot to autonomously adapt its behavior and decision-making based on observed data and feedback.
- Investigating the usability and accessibility of the educational robotics platform for diverse student populations, including those with special needs or varying levels of technological proficiency.
- Exploring interdisciplinary applications of the educational robotics platform beyond STEM subjects, such as incorporating elements of arts, humanities, and social sciences to foster creativity, critical thinking, and interdisciplinary problem-solving skills.
- Collaborating with industry partners to explore real-world applications of the educational robotics platform in fields such as manufacturing, healthcare, and environmental monitoring, with a focus on addressing pressing societal challenges and advancing technological innovation.

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