Learning Mobile Robotics: An Approach Based on a Classroom Competition

Laiany Brancalião[1,3](✉), Mariano Alvarez[1,4], João Coelho[1], Miguel Conde[3], Paulo Costa[4,5], and José Gonçalves[1,2]

[1] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
{laiany,marianoalvarez,joaocoelho,goncalves}@ipb.pt

[2] Laboratório para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal

[3] University of León, Campus de Vegazana, 24071 León, Spain
mcong@unileon.es

[4] Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal
paco@fe.up.pt

[5] INESC TEC - Institute for Systems and Computer Engineering, Technology and Science, Porto, Portugal

Abstract. Robotic competitions have been popularly applied in the educational context, proving to be an excellent method for fostering student engagement and interest in science, technology, engineering, and math (STEM). In this context, this paper presents the application of mobile robots in a classroom competition, in order to encourage students to enhance mobile robotics concepts learning in a dynamic and collaborative environment. The mobile robot prototyping is presented, and the methodology, including the Hardware-in-the-loop approach applied in the classrooms, is also described, together with the competition rules and challenges proposed for the students. The results indicated an improvement in students' motivation, teamwork, communication, and the development of technical skills, computational thinking, and problem-solving.

Keywords: Mobile robots · Educational robots · Robotic competitions · STEM

1 Introduction

Robotics have been present in various fields globally, such as industry, domestic services, agriculture, education, etc. This technology is implemented to provide a range of benefits, enhancing society's well-being. Consequently, the demand for qualified professionals in this area is steadily increasing [1,2].

Taking this into account, robotic competitions have been widely applied around the world to push state of the art in technological fields, motivate

R. Molina Carmona et al. (Eds.): TEEM 2024, LNET, pp. 648–658, 2025.
https://doi.org/10.1007/978-981-96-5658-5_64

researchers to develop innovative robotic solutions, and also inside the educational context as a tool to encourage students to learn in the STEM field, contributing to develop their technical skills, critical thinking, problem-solving, teamwork and also increase students interest in pursuing a career in technology [3,4].

Nowadays, a wide variety of robotic competitions exist across numerous fields, including soccer, autonomous driving, rescue, industrial tasks, domestic activities, etc. Some well-known examples of robotic competitions are FIRST LEGO League, which introduces young students to STEM concepts; RoboCup, which includes several categories like soccer, rescue, industrial and domestic service; DARPA Robotics Challenge, focused on ground vehicles; SAUC, dedicated to marine robotic vehicles [5,6]. According to [1], the participation of students from schools in such events offers many benefits for them since they can be involved in STEM activities, contributing to generating interest and motivation for the technological field.

Integrating robots in classrooms has emerged as a powerful tool for motivating and supporting students learning, creating fun activities, and arousing curiosity [7,8]. Researchers and educators have popularly applied this approach to assist the learning process, capture students' attention, and increase their interest and development of skills, which consequently generates academic success [8,9].

According to [7], Educational robotics (ER) is a term defined as a research area focused on improving the student's learning process through the implementation of activities that apply tools and technologies like robots. This concept has been attracting attention, mainly due to the availability of robotic platforms. Recently, there have been several robotic kits designed for education and are commercially available, such as Lego Mindstorms and Arduino Alvik [8,10]. However, the cost of these kits has increased exponentially, limiting the school's ability to obtain this type of tool. That way, the development of low-cost robotics kits allows more students to get in touch with this kind of technology [7].

Therefore, this work presents the prototyping and application of low-cost mobile robots inside a robotics classroom context, in which the students were also supported by SimTwo, an open-source simulator, applying a Hardware-in-the-loop approach. A robotic competition was implemented to create a dynamic environment, encourage teamwork, and develop technical skills, problem-solving, and critical thinking.

This paper is structured as follows. Section 2 presents the hardware of the mobile robots, and Sect. 3 shows the software architecture. The methodology applied in the classroom is presented in section 4, the Hardware-in-the-loop approach is described in 4.1, and also a description of the simulator used by students. Section 5 discusses the classroom robotic competition as well as the rules and challenges proposed for the students. The results obtained are discussed in section 6, followed by the conclusion and future work.

2 Mobile Robot Prototype: Hardware Description

This section describes the mobile robot prototype developed for the students, as shown in Figure 1. Four identical robots were provided for students to work in teams. The robot prototype has differential kinematics and was designed to be able to follow a line and avoid obstacles. The mechanical design, presented in Figure 2, was 3D-printed and included two wheels, a chassis to load the electronic components, and two additional parts for attaching sensors.

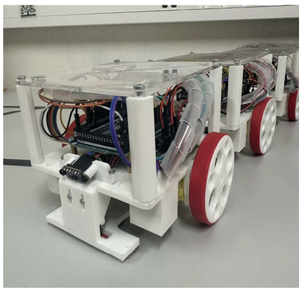


Fig. 1. Assembled mobile robots

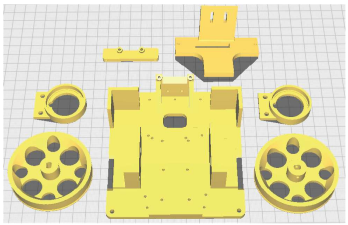


Fig. 2. Mechanical design

The hardware module consists of an Arduino Mega microcontroller responsible for data processing, two DC motors with built-in encoders for robot locomotion allowing a closed-loop speed control and odometry estimation, a FIT0450 drive board to control these motors, a QTR-8A line sensor that detects the line the robot should follow, a VL53L0X Time-of-Flight distance sensor that provides data for obstacle avoidance and two rechargeable 3.7V Lithium Ion batteries for system power. In order to prevent battery damage, the robot also features an auto-power-off function. Figure 3 illustrates the data flow between these components.

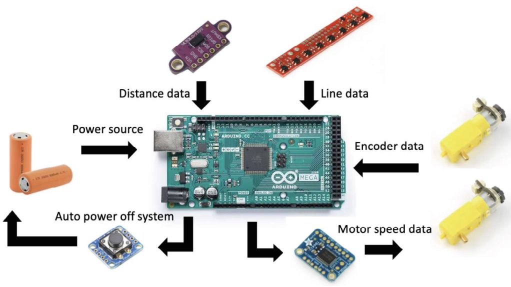


Fig. 3. Hardware components

3 Software Architecture

The software architecture is divided into two approaches. The first one is related to real robot programming, in which the actuation, data acquiring and processing is all performed inside the microcontroller, and the second one is focused on the programming applying Hardware-in-the-loop (HIL), in which it is not needed the real robot but just the microcontroller, because there is a simulator to acquire data from sensors and to perform the actuation in a virtual robot, being the processing still performed by the microcontroller.

Figure 4 presents a flowchart of the software architecture. The blue blocks represent the processes executed by the microcontroller, the green blocks represent the processes performed by the simulator in a computer, and the red blocks represent the process in which the students must develop.

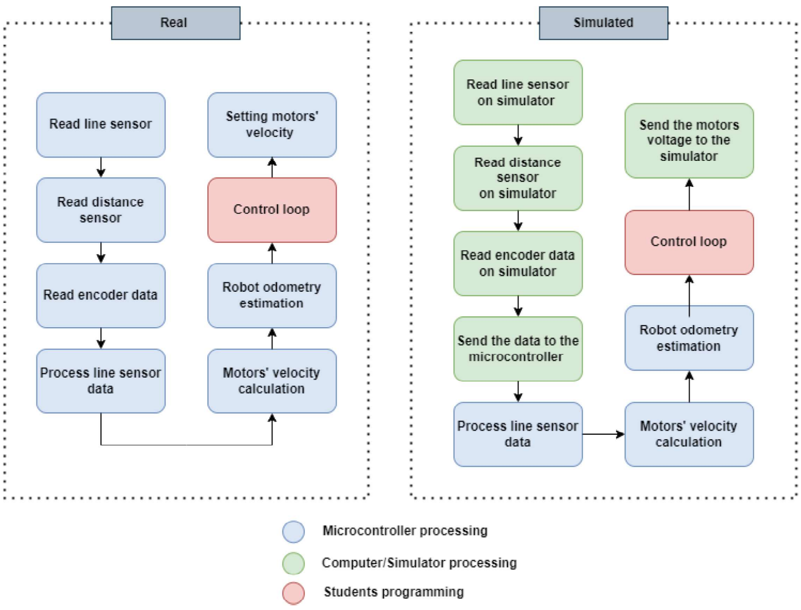


Fig. 4. Software architecture for real and simulated robot

In the approach of programming with the real robot, the data from the line sensor, distance sensor, and encoder are read. The processing of this information is executed, including the determination of the motors' velocity with encoder data, the estimation of robot odometry, calculation of line error with line sensor data, and then a control loop that includes a PID calculation to set motor's velocity. This part of the firmware, which is the core of the robot, must be created by the students.

In the second approach, the tasks are similar, except that some of them are performed by the simulator. The sensors' readings are acquired by the virtual sensors inside the simulator, and this information is sent to the microcontroller by serial communication to perform data processing and control execution. At the end of the process, the necessary voltage for the motors is sent from the microcontroller to the simulator, so that it acts on the virtual robot.

Therefore, only the necessary data is made available to students, a pre-processing is already done in a developed library, in order to become the programming easy to use for the students. Data such as line sensor error, line sensor values, distance value, robot odometry estimation (position x, y and θ) and motors setpoints velocities are provided for them. This way, students must know how to use this data to program the control loop for differential locomotion, with the goal of following a line and avoid obstacles.

4 Methodology

This section describes the HIL approach applied in the classroom. Students can access the mobile robots prototypes during the classes to perform tests. However, implementing the HIL approach allowed groups to test their algorithms even if no robot was available or another group was using it.

4.1 Hardware-in-the-loop Approach

The Hardware-in-the-loop approach, mentioned previously, provides a lot of advantages inside the educational context, and it was applied in the classroom methodology. Through this technique, students can test the controller algorithm in real hardware conditions without generating wear and tear on the robot and even in situations where equipment like robotic kits are limited at schools [11–16].

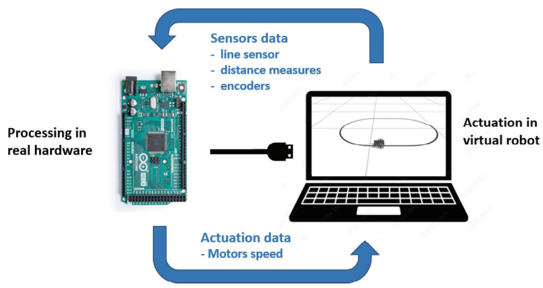
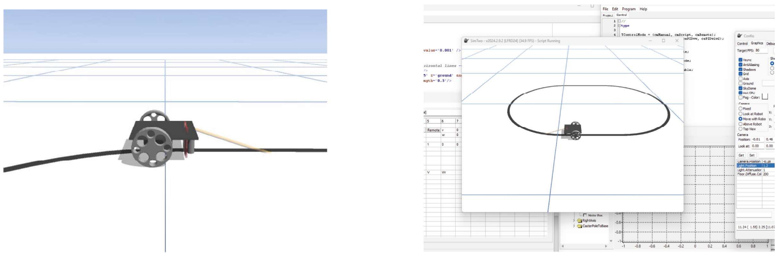


Fig. 5. Hardware-in-the-Loop approach

Figure 5 illustrates the HIL process, in which a simulator acquires data from virtual sensors, sends it to the microcontroller where all the processing is performed in the real hardware, and then, the processed data is sent back to the simulator that performs the actuation of a virtual robot in a realistic simulation environment. This way, students can develop and test several approaches for their algorithms before test it in the real robot.

SimTwo, an open-source realistic simulator for robotics, was applied in this work. In this software, it is possible to use several kinds of robots in which the physical characteristics, such as shape, mass, elasticity, resistance, inductance, inertia, and others, can be included inside the simulation environment, obtaining realistic simulations [17–19].

A virtual robot was developed with the real robot's exact dimensions, components, and characteristics, as presented in Fig. 6 a). A scenario with a trajectory to follow a line approximately 1.94m in length was also created in the SimTwo simulation environment, as shown in Fig. 6 b). Students had access to this simulator, including the robot and the scenario, but they could change the path if desired.



(a) Virtual robot (b) Scenario

Fig. 6. SimTwo simulation environment.

5 Classroom Mobile Robotic Competition Description

To motivate and encourage students to apply their theoretical knowledge to create a real solution, and also as a way to evaluate the students performance, it was proposed a classroom robotic competition, designed for a mobile robot to follow a line and avoid obstacles in the minimum possible time. The rules and challenges of this competition were based on an international robotic competition called Robotic Day, described in [20]. The path created is illustrated in Figure 7, composed of interruption, bifurcations, and obstacles through the trajectory, all with the same size and color.

The students could view and perform tests on the track before the competition. However, they did not know where the obstacles would be positioned in the path, because they were inserted minutes before the competition started. The challenges consisted of creating a control system from all the sensors reading, performing the robot's navigation and locomotion over the path, overtaking situations like bifurcations and interruptions, and avoiding obstacles successfully, without going too far off track.

Following the same idea as the international competition cited in [20], a device was also developed to accurately count the time of the robot's trajectory, emphasizing the importance of precision in the competition. Figure 8 shows the gantry, composed of a VL53L0X Time-of-Flight distance sensor to detect the robot's passage underneath, an Arduino Uno for processing, a LCD Display for showing the time score, and two rechargeable 3.7V Lithium Ion batteries for system power. The structure was developed by applying 3D printer technology.

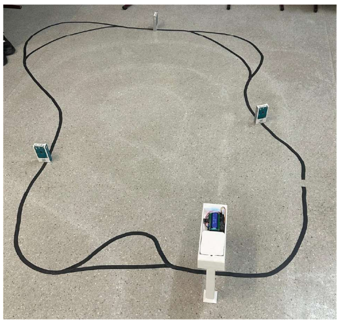


Fig. 7. Path created for the mobile robotic competition

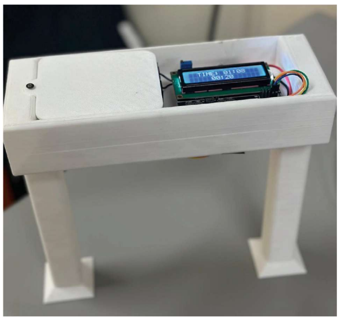


Fig. 8. Gantry developed for the time counting in the robot trajectory

Groups from three to four students were created, totaling nine teams. The competition was divided into several rounds, the first being qualifications, where the teams had three attempts to put the robot on the path. In the end, the best score time was chosen. The second phase was the eliminations, in which the teams competed against each other in pairs, and the best of the two went on to the next round, and the other is eliminated. Then, there were the semifinals, where four robots competed, with just two remaining for the final round. In the last phase, two teams compete against each other, and the team with the fastest time is the winner.

6 Results and Discussion

In this section, the results of the classroom robotic competition are presented. Table 1 shows the qualifications rounds, in which there are three enumerated times, followed by the final time, which is the best time of three. It is also presented the name of the nine teams and their respective times during each round, being "x" when the robot was not able to complete the path.

Almost all the teams went to the eliminations, except for team "Brazilians", in which the robot was unable to complete the track in 3 attempts. At the end of qualifications phase, the team "Made in Bahia" led the rank with the shortest time for the robot to follow the track.

Table 2 shows the eliminations, semifinal and final round. In the eliminations, the teams with the best scores played against the teams with the worst scores in pairs. In this stage, there were two attempts, and those who lost were already eliminated. However, the priority was to complete the track, enhancing that robustness in a robotic application is a key factor, even if a team had a shorter time but was unable to complete it in the other attempt, they were eliminated. The team that completed both rounds prevailed even with a longer time count. From this round, only four teams remained, being them "Rasca", "Charles Lecrash", "Made in Bahia" and "Team Mechanics".

In the semifinal, it remained the same method as the previous round. However, it was necessary to add another round for "Made in Bahia" against "Team Mechanics" because they were tied on whether to complete the track or not. Then, in the finals, team "Rasca" played against "Team Mechanics" in two rounds, the first one in one direction of the path and the other in an opposite direction. The winner was "Team Mechanics" for completing the track in both rounds, even though the time count was longer than the other team.

Table 1. Qualifications results of the mobile robotic competition

Team name	Qualifications			
	Time 1	Time 2	Time 3	Final time
ROR	x	00:49	x	00:49
Relâmpago Marquinhos	x	00:44	x	00:44
Rasca	00:51	00:46	x	00:46
Charles Lecrash	00:47	00:51	00:53	00:47
African group	00:56	x	x	00:56
Brazilians	x	x	x	00:00
Carletes	x	x	00:48	00:48
Made in Bahia	x	00:43	00:44	00:43
Team Mechanics	00:50	x	00:57	00:50

Taking into account the team's performance, it can be concluded that many groups had a good robot performance, creating a controller for the robot to be able to follow the line, cross the line challenges, and avoid obstacles. The teams implemented different algorithms and codes, proving that they could learn the knowledge acquired in theoretical classes and apply it in the competition.

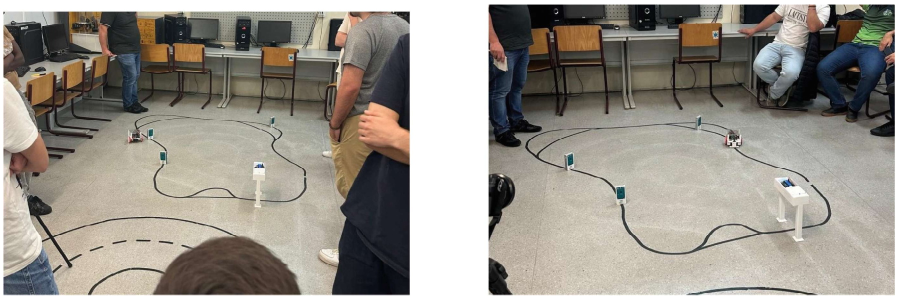
The teams applied different approaches to obstacle avoidance. For example, some groups programmed the robot to avoid obstacles smoothly, including the winning team, which was the best approach. Other groups applied a more straightforward method, turning the robot at an angle of 90 degrees to one side, then going 90 degrees to another side, moving in parallel to the obstacle, and then returning to the line in the same way. There was even a team that took

Table 2. Eliminations of the mobile robotic competition

Team name	Eliminations		Semifinal			Final	
ROR	00:58	00:51					
Relâmpago Marquinhos	00:47	x					
Rasca	00:54	00:51	00:52	00:50		x	00:53
Charles Lecrash	00:53	00:50	00:50	x			
African group	00:51	x					
Carletes	00:45	x					
Made in Bahia	00:45	x	00:47	x	x		
Team Mechanics	00:56	00:58	x	00:56	00:56	01:02	00:58

an even more straightforward approach, where the robot followed the shape of a triangle when going around the obstacle, with just two movements.

It was possible to observe the student's excitement with the competition, including their interest, dedication, and motivation to win and create a good solution. Figure 9 a) and 9 b) show some pictures taken during the robotic competition in the classroom. This competition generates many advantages for the students learning, such as practice teamwork, developing technical skills like computer programming, problem-solving, and introducing them to the interaction between theory in the classroom and practice in real-world situations.



(a) (b)

Fig. 9. Classroom mobile robotic competition

All files related to the mobile robots were made available to students of the robotics course of the Master's degree in Electrical Engineering and Mechanical Engineering, using the IPB Virtual platform. The files related to the mobile robots prototype are available online through the link: https://github.com/Laiany/Educational-Mobile-Robots-Prototype.git. After some improvements, based on the tests carried out, the firmware and software will be made available to a wider audience in the future.

7 Conclusion and Future Work

This paper presented the development and application of mobile robots in a robotic competition inside a classroom context. The competition was implemented to encourage and motivate students for this robotic class, applying their theoretical knowledge learned in a real solution.

The competition generated many advantages for students learning, such as computational thinking, problem-solving, teamwork, improvement of technical skills including computer programming, mechanics, and electronics, and also introducing them to the bridge between theory concepts and practice in real-world solutions.

The teams were able to develop a solution in which the robot follows a line and avoids obstacles, overcoming challenges like line interruption and bifurcation. The teams implemented different algorithms, controllers, and distinct obstacle avoidance approaches, proving that they learned the knowledge in theoretical classes and applied it in a real problem.

As future work, it is intended to continue implementing robotic competitions in upcoming disciplines due to the advantages generated for students learning. It is also planned to improve the competition approaches and the mobile robot prototypes, as well as its hardware and software.

Acknowledgment. The authors are grateful to the Foundation for Science and Technology (FCT, Portugal) for financial support through national funds FCT/MCTES (PIDDAC) to CeDRI (UIDB/05757/2020 and UIDP/05757/2020) and SusTEC (LA/P/0007/2021). Laiany Suganuma Brancaliao and Mariano Alvarez thank FCT for the PhD Grant 2023.01441.BD and 2023.01113.BDANA.

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