Robot at Factory Lite - A step-by-step educational approach to the robot assembly

Luiz E. Luiz[1,2], Leonardo Pilarski[1,2], Kaïs Baidi[1,2], João Braun[1,3,4,5], André Oliveira[2], José Lima[1,3,5], and Paulo Costa[3,4]

[1] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, Bragança, Portugal.
{a52482@alunos.,a52480@alunos.,a52611@alunos.,jbneto@,jllima@}ipb.pt
[2] Universidade Técnológia Federal do Paraná - UTFPR, Brazil
andreoliveira@utfpr.edu.br
[3] INESC Technology and Science, Porto, Portugal
[4] Faculty of Engineering of University of Porto, Portugal
paco@fe.up.pt
[5] Laboratório para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Portugal

Abstract. In a robotics scope, an excellent way to test and improve knowledge is through competitions. In other words, it is possible to follow the results in practice, compare them with the development of other teams and improve the current solutions. The Robot At Factory Lite proposal simulates an Industry 4.0 warehouse scenario, applying education through Science, Technology, Engineering, and Mathematics (STEM) methodology, where the participants have to work on a solution to overcome its challenges. Thus, this article presents an initial electromechanical proposal, which is the basis for developing robots for this competition. The presented main concepts aim to inform the possibilities of using the robot's parts and components. Thus, an idea can be sketched in the participants' minds, inspiring them to use their imagination and knowledge through the presentation of this model.

Keywords: Engineering Education · Mobile Robotics · Robotics competition · STEM · Automatic Guided Vehicle · Education 4.0

1 Introduction

The industry can be understood as a competition, where constant innovation is the key to success in keeping up with technological development. Competitions such as Robot at Factory Lite are a starting point for school or university students to awaken their interest in robotics and take the first steps toward the job market [1, 2]. Robotics competitions teach students, researchers, and engineers transferable and technical skills through competitive innovation in the Science, Technology, Engineering, and Mathematics (STEM) methodology. For instance, this competition simulates an Industry 4.0 warehouse challenge with objects logistics and transportation between sectors using autonomous robots. Thus, participants have to innovate and seek creative solutions to solve the problems imposed by competition and overcome their opponents [3].

The design and simulation environment is crucial for the beginning of the project, presenting an experimental vision before the assembly of any prototype. In terms of simulation, the robot's design does not present significant flaws due to the improvements made throughout the project duration and also because there is no interference of non-idealities of the physical world. However, when advancing to the real scenario, these imperfections begin to appear. Thus, this work presents the technical development and assembly of a prototype used in the Robot at Factory Lite competition based on the acquired and available knowledge since the beginning of the competition. The prototype seeks to use the ideals of Industry 4.0, with the introduction of Wi-Fi communication and encoders in the motors [4, 5]. New structural approaches are also presented, aiming to improve the robot's performance.

The article is presented as follows: after this introduction, the state of the art about robotics competitions is presented in Section 2. Then, in Section 3, the robot architecture's development is described, emphasizing its mechanical hardware assembly. Section 4 presents the results obtained. Finally, in Section 5, the conclusion about the work is highlighted, as well as possible future directions.

2 Related work

Competition is a resource applied in most areas, such as the nature of the evolution of the species and survival, animal reproduction, human sports, and others. It allows going further when the same objective needs to be accomplished and different competitors are playing. Using competitions in robotics is a way to push research and innovation in scientific, academic, and industrial areas. Thus, this section addresses the importance of robotics competitions and the Robot at Factory Lite competition rules.

2.1 Importance of robotics competitions

STEM education is a popular pedagogical approach for enhancing the students' creativity and problem-solving skills, increasing the interest in these areas [6]. Since robotics addresses multidisciplinary areas, it plays an essential role in the STEM concept.

Competitions also bring together multiple research groups working on the same problem. This fosters the exchange of ideas [7]. There are a huge number of robotic competitions around the world. One of the most competitive in the world is the RoboCup competition. According to [8], the ultimate goal of the RoboCup initiative is, by the mid of the 21st century, a team of fully autonomous humanoid robot soccer players shall win a soccer game complying with the official rule of the International Federation of Association Football (FIFA), against the winner of the most recent World Cup. Of course, there is a long way to there, and several robotic competitions have been appearing worldwide. More robotic competitions can be found in [9–12]. The leading robotic competitions are oriented toward strengthening the autonomous capacity of robots. This point allows the development of the computational thinking of students [13].

2.2 The competition rules

The Robot at Factory Lite competition rules are based on the Robot at Factory competition, with mechanical and hardware simplifications, following the main objectives of locating and being able to transport boxes between warehouses [14]. The method of recognizing the box type could be done through an Radio-Frequency Identification (RFID) reader until 2022, but after 2023 this method will no longer be available, with preference being given to consulting a server by Wi-Fi. As for navigation, the warehouse's floor is composed of black lines, on a white background, with a width of 30 mm to facilitate the robots' locomotion.

The competition consists of three rounds. Each team has 20 minutes per round. The first 10 minutes are to test the robot, and the last 10 minutes are to compete, with as many attempts allowed within that time. In each round, the best result is considered, i.e., the highest number of boxes correctly placed, with a tie-breaking criterion based on time.

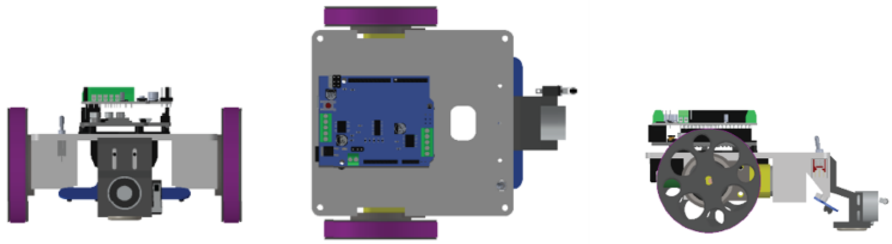
In the first round, the objective is to collect four boxes from the incoming warehouse and transport them to the outgoing warehouse. In the second round, there are two types of boxes, the one used in the first round, blue, and the other, green, that must be processed by a machine before being delivered to the outgoing warehouse. For the third round, in addition to the boxes presented above, there is a third type, red, that must be processed by two different machines before being delivered to the output warehouse. There is an additional rule for the second and third rounds: each attempt must be spaced at least one minute apart.

This section presents the technical aspects of the construction and operation of the robot. It is separated into subsections about mechanical assembly, electronics, and software programming and strategy.

3 Robot architecture & methodology

This latest version of the Robot at Factory Lite robot is the result of all the knowledge acquired and published, since the first edition of the competition, with an emphasis on the development done in the 2022 edition held in Santa Maria da Feira - Portugal. The mistakes and the possible solutions were noted. The principal modifications are related to the components' position, which will be discussed in this section.

The robot's structure must be compact, light and stable to facilitate its displacement on the track and perform the necessary tasks in an ideal time. In this case, the robot assembled has a length of 151 mm (Figure 1a), a width of 138 mm (Figure 1b) and a height 80 mm (Figure 1c).



(a) (b) (c)

Fig. 1: Views of the Robot: (a) Front View, (b) Top View, (c) Right Side View.

The components used to assemble the robot are disposed in Table 1 and Figure 2. The basic structural part of the robot is composed of two parts. The base (chassis) is the first, which serves as a connection platform for the other parts. The second is the three-part support, also used for the pad that acts as the third point of contact with the ground. These parts are labeled 1 and 7 in Figure 2, respectively. Attached to them are the hardware components responsible for power supply, movement, sensing, actuators, and control.

Table 1: Components of the Robot

Number	Component	Quantity	Description
1	Support Fix	1	3D printed piece
2	Motor with Encoder	2	Direct Current (DC) Motor 6 V 160RPM 120:1
3	Rigid ball bearings	2	SKF reference: 6002-2Z
4	Elastic band	2	Material: rubber
5	Bearing support	2	3D printed piece
6	Wheel	2	3D printed piece
7	Electromagnet support	1	3D printed piece
8	DC 5 V Electromagnet	1	-
9	Line sensor	1	5-ch Infrared detector ITR20001/T
10	Battery holder	1	-
11	Battery	2	18650 3.7 V lithium ion battery
12	Board holder	1	3D printed piece
13	Limit switch	1	-
14	Expansion board	1	TB6612 Motor Shield V2
15	Microcontroller	1	WEMOS D1 R32 ESP32
16	ON/OFF Switch	1	-
17	Foot pad	1	Material: Teflon

As shown in Figure 2, regarding the wheels, parts 2 to 6 are connected using screws and nuts, attached following the numerical order displayed in the picture.

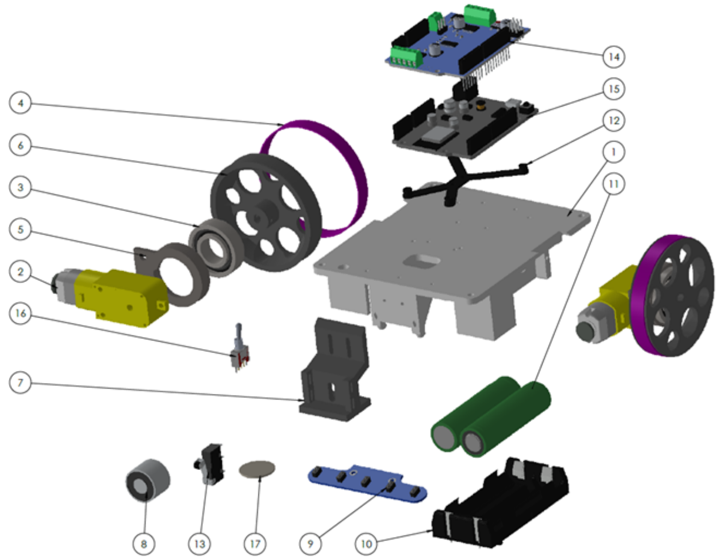


Fig. 2: Components of the robot

In addition, an extra screw is used to secure the connection with the wheels and the motor's axles. This gives translational mobility between the wheels and the surface through the rotation of the wheels. This was the first main change made in the latest version, the wheel connection. Previously, the connection was made directly between the wheel and the motor. However, in this version, bearings connect the motors to the wheels, as shown in Figure 3, increasing the robustness of the robot. This solution allows the entire wheel's surface to be always in contact with the track, with no possibility of slipping when accelerating or rotating. Moreover, the robot's centre of gravity is located near its wheel rotation axis, which increases the weight on it and consequently the friction between the wheel and the track, decreasing the occurrence of miss-spins.

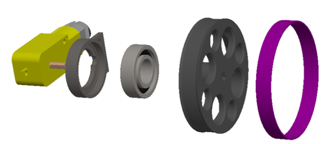


Fig. 3: Exploded view of the wheel connection.

Part 7, shown in Figure 4, besides serving as support for the infrared sensors and the electromagnet, part 17 from Figure 2, serve as a third support point for the robot. It has a self-adhesive material attached to the bottom of the support with a Teflon surface on the other side of the material, facing the floor, to decrease the friction with the track. The other parts are attached to the support using nuts and screws. This base is considered the second main modification. It has three different adjustments to increase the assembly accuracy. The first adjustment is the height of the third "wheel" of the robot, which can vary up to 10 mm. This adjustment, shown in Figure 4 with the number 1 arrow, allows the adaptation of the distance between the infrared sensor and the track lines. The second adjustment is the height of the limit switch, indicated by the number 2 arrow of the same figure, setting the contact between the switch and the box. The last one, indicated by the number 3 arrow, sets the height of the electromagnet to ensure contact with the metallic part of the box.

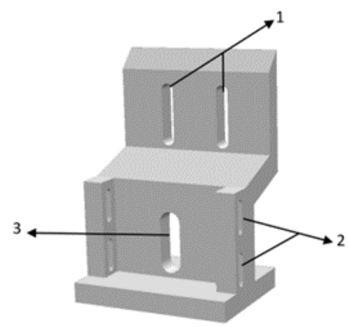


Fig. 4: Three-part support.

The other parts attached to the robot are the same as the old version [3], changing only their spatial location. Parts 10 and 11, from Figure 2, are coupled in the inferior part of the robot, responsible for the energy supply. The limit switch sensor, part 13, is attached to the three-part support by screws. Afterwards, the prototype boards, pieces 14 and 15, responsible for the control, are attached to the base by screws using part 12 as support. The latter avoids direct contact between the components and the base of the robot. Finally, a power switch, part 16, can be added to supply or interrupt power to the circuit.

3.1 Assembling Hardware

Electronic operation

- Power: The system is powered by two lithium batteries, each rated at 3.7 Volt. They are connected in series, supplying 7.4 Volt at their nominal voltage levels. The voltage supply powers the entire electronic system of the robot. The supply can be cut off with a power switch.

- Movement: The motion occurs through two parallel aligned wheels with a diameter of 67 mm, coupled to DC motors with encoders. Two H-bridges control the movement of the wheels. The robot can move in any direction on the track, moving forward or backwards, if both wheels move in the same direction and speed, or in curvy motions when the wheels have a different direction of motion or at least different speeds. This behaviour occurs due to the possibility of generating independent commands for each DC motor through the controller, as this robot has a differential-drive architecture. Moreover, closed-loop control for speed was implemented to increase the precision of movement and the robustness for perturbations.
- Sensor: Robot sensing comprises three sensors: the infrared sensor, the limit sensor switch and the encoders of the motors. The infrared sensor is the one responsible for guiding the robot through the track by identifying the reflection rate of the floor through the emission and reception of infrared light, allowing the robot to identify if it is over the black or the white track. The limit switch is responsible for identifying that the robot is in contact with the boxes, mainly to activate the electromagnet. Finally, the encoder provides feedback on the number of revolutions made by the wheels, providing another source of closed-loop control through odometry when the robot is out of the track.
- Actuator: The tool used for coupling the box is the electromagnet. When subjected to a current, this component produces a magnetic field capable of attracting metals, keeping them locked until the current ceases and, consequently, the magnetic field. Thus, performing the proposed task of grabbing the box for transportation.
- Control: The robot's operation is based on the programming of the ESP32 D1 R32 development board and the TB6612 Motor Shield V2 extension board. This union is the basis for interconnecting all the other components, distributing the energy from the batteries, receiving signals from the infrared sensors, limit switches and encoders, and sending signals to the motors and the electromagnet.

Electronic Schematics The electronic schematic diagram is shown in Figure 5, displaying all the electronic components used in the robot with the wiring between them. For the robot to perform its tasks, it must be able to detect the external environment, interpret the data and give orders to the actuators through the different conditions defined in the program.

At the initial stage, the robot needs to follow the line. In order to do this, information on the line sensor must be read. Its channels are connected to the microcontroller through analog inputs (GPIO_32, GPIO_36, GPIO_33, GPIO_34 and GPIO_39). These, in turn, are connected to 12 bits analogue-to-digital converters. Once the position of the robot in relation to the centre of the line is known (the organizers provide a developed function to calculate it), it will send orders to the motors connected to the driver to move. This command is sent from the microcontroller to the motor driver via I2C communication (GPIO_22 to CSL and GPIO_21 to SDA).

Moreover, when the contact sensor switch is activated, the robot is informed that it is in contact with the box. This information is transmitted to a digital pull-up input making the microcontroller send a command to activate the electromagnet to attach the box.

Using the two encoders allows the robot to estimate the speed of the wheels and perform odometry calculations. Moreover, a PID controller is also implemented and available to the teams.

The outputs of the encoders (OUT A_RIGHT, OUT B_RIGHT, OUT A_LEFT, and OUT B_LEFT) are connected to the digital interrupt input pins of the microcontroller (GPIO_5, GPIO_6, GPIO_4, and GPIO_3).

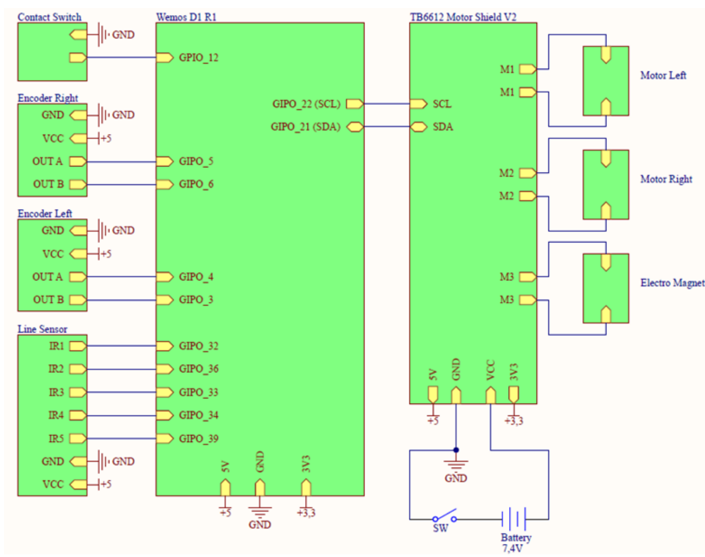


Fig. 5: Electrical Diagram of the robot.

Regarding the power supply, the battery is connected directly to the motor driver, and the energy is distributed to the actuators according to the commands of the microcontroller using PWM by the I2C bus. Also, this voltage passes through two step-down voltage converters (3.3 V and 5 V) to supply the microcontroller and the other sensors.

3.2 Software kit developments

Regarding the robot's programming, the organization provides a base code to create the software. This is available on the SimTwo GitHub in the file titled *control.cpp*[6]. The programming operates based on a state machine architecture.

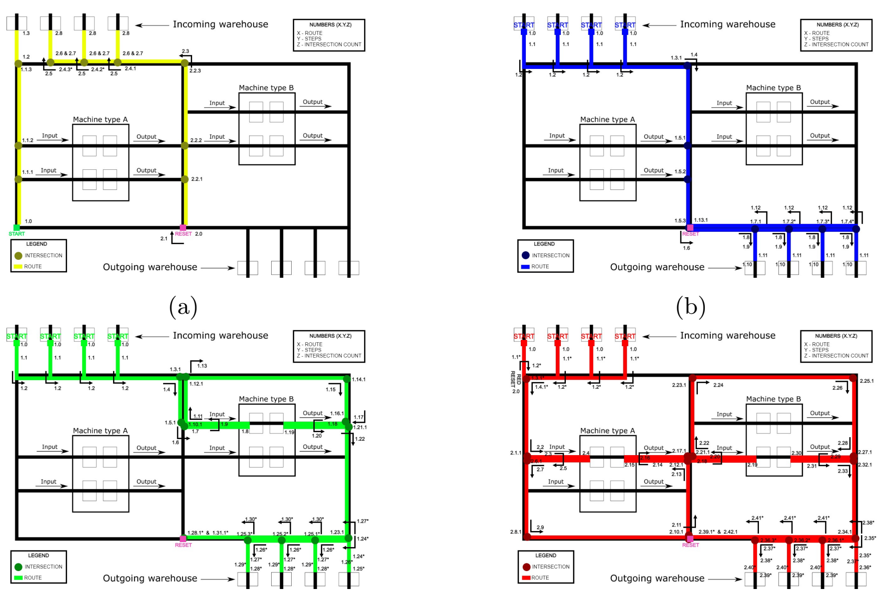
[6] https://github.com/P33a/SimTwo/blob/master/RobotFactoryLite2022/rafliteduinoHWLoopESP/src/control.cpp

Therefore, each participating group can develop its states from the base code to complete the objectives.

Two different functions can be used to command the robot to travel across the track, counting the intersections it has crossed, $followLineLeft$ and $followLine Right$. These functions are useful to prevent minor errors in the robot's angle from interfering with the final destination.

The developed code works in two different moments, the first being the robot catching a box and the second when the robot has a box and will deliver it. Because of that, it needs a reset position to change from one to the other. The selected position is the corner between the bottom line vertically and the centre line horizontally.

The boxes collection part has a common path for all of them, changing only the number of intersections that the robot must cross to enter each of the four positions of the boxes Figure 6a, whereas the delivery part has three subdivisions, each responsible for one route depending on the type of box the robot is carrying, for the blue box Figure 6b, for green Figure 6c and for red Figure 6d.



(a) (b) (c) (d)

Fig. 6: Route configuration (a) route to take the boxes, (b) Blue box route, (c) Green box route, (d) Red box route.

3.3 Hardware-in-the-loop Simulation

The competition organizers propose an official simulation environment in the SimTwo simulator. Simulators generally hide hardware limitations, such as memory and computational power, in contrast to embedded systems in mobile platforms that have such limitations. Thus, the Hardware-in-the-loop (HIL) approach is presented to force such limitations and get closer to real conditions, where a microcontroller is used to perform the control, navigation, and decision tasks while communicating with a simulated robot. As presented in Figure 7, the main objective of the HIL is to use the same microcontroller and code for simulation and the actual scenario, the only difference between the two cases is the form of communication, configured by the variable *UsingSimulator*. The simulator can be downloaded in [7].

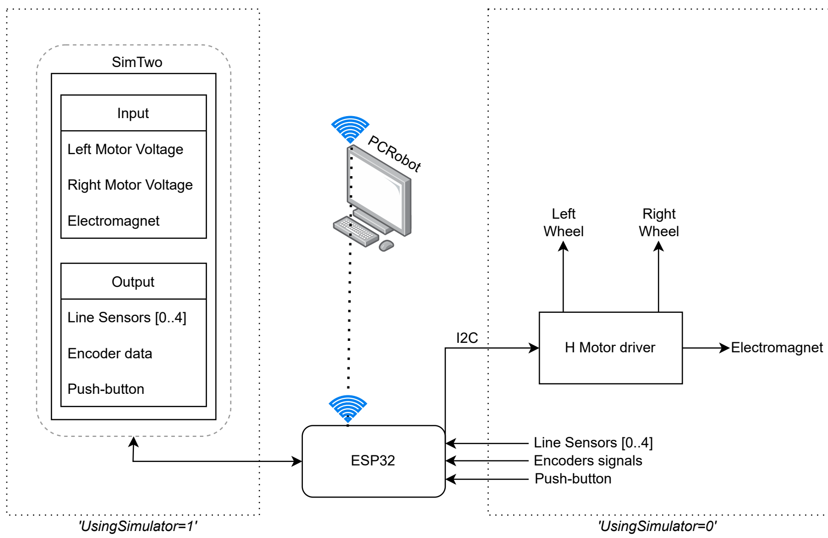


Fig. 7: Main architecture of the HIL. On the left side (*UsingSimulator*=1), the microcontroller uses a USB port to control the robot and receive sensor data from the simulation. On the right side (*UsingSimulator*=0), the microcontroller connects to the real hardware.

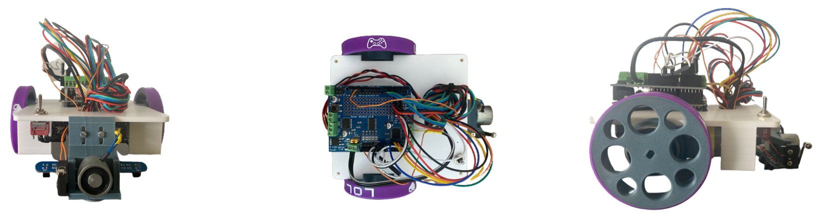
After programming the ESP32 D1 R1 microcontroller, the serial connection should be enabled in the SimTwo I/O config tab. Afterwards, the start condition should be triggered in the sheet window to run the simulation with HIL.

4 Results

The results obtained with this work can be summarized in the assembled real robot, as shown in Figure 8. Its new assembly, with the modifications based on the observations obtained in the participation in the last competition, made the

[7] https://github.com/P33a/SimTwo

robot more robust and better adaptable to different possible test conditions. The adjustment levels expanded the possibility of adaptation regarding the box pick-up, contact switch height, and the distance between the track and the infrared sensor. Finally, a better arrangement of the components related to the centre of mass provided more stability to the robot, especially for rotations.



(a) (b) (c)

Fig. 8: Views of the assembled robot (a) Front View, (b) Top View, (c) Right Side View.

5 Conclusion and future work

Robotic competitions are an excellent place to test projects and acquire knowledge based on their performance during the challenges and the approaches presented by other teams. In ideal design conditions, many thought-out approaches seem to solve the problems. However, in real testing conditions, non-idealities and external interferences appear. Thus, the best thought-out and tested projects have the best conditions to win by making changes and adapting.

This work presented the development of a robot model, bringing a broad approach concerning mechanical and electronic assembly. It inspires teams to construct and participate in robotics competitions with an emphasis on the Robot At Factory Lite Competition. Therefore, for future work, new tests, inquiries, and brainstorming sessions will be performed to assess the possibilities of improving the mobile platform.

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