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FLOOR - Forklift Laser OmnidirectiOnal Robot

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***Abstract*—The robot presented in this paper was developed with the main focus on participating in robotic competitions. Therefore, the subsystems here presented were developed taking into account performance criteria instead of simplicity. Nonetheless, this paper also presents background knowledge in some basic concepts regarding robot localization, navigation, color identification and control, all of which are key for a more competitive robot.**

***Index Terms*—robotic platform, robotic competition, sensors, actuators, localization, navigation**

I. Introduction

In recent years, mobile robots have been used in a variety of areas [1]. One of the main areas is autonomous transportation of materials on industrial environments.

Furthermore, these type of vehicles present some interesting challenges (eg. localization, navigation and safety), which can be presented in a didactic way, through robotic competitions.

In this paper, a robot designed to participate in the Robot@Factory competition, among others, will be presented. Nonetheless, each of these competitions present a subset of the above mentioned challenges. Additionally, this platform will also be used to help students in learning new concepts.

Throughout this paper, the developed platform will be presented, in the following sequence: in section II, the robot design considerations will be introduced; section III describes the design of the robot, including the mechanical, hardware and software designs. In section IV, the final prototype is presented, and in section V some of the possible applications for the robot are stated. Finally, section VI exhibits the conclusions and the future work.

II. Design Considerations

In this section, the design considerations derived from the competition restrictions that this robot will attend, will be listed.

A. Competitions

The presented robot was designed to participate on the Robot@Factory [2] competition, during the Portuguese Robotics Open [3]: an event that hosts a variety of competitions like the Robot@Factory, Middle Size League (MSL), Autonomous Driving, etc.

The Robot@Factory competition is inspired on the use of mobile robotics to operate on a factory shop floor (Figure 1).

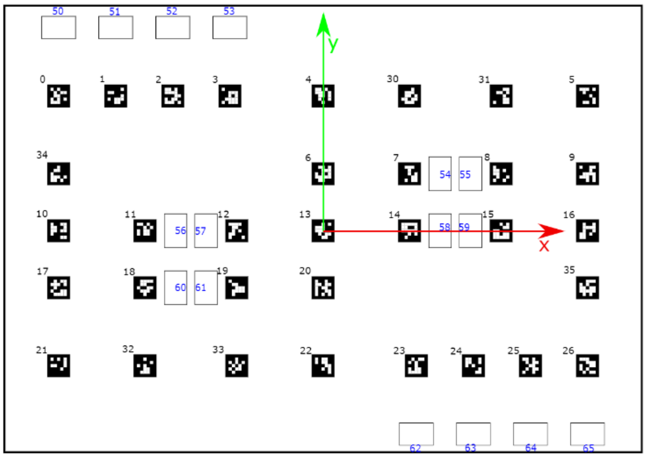

Fig. 1. Robot@Factory Shop Floor [4]

This competition simulates a factory floor where there are warehouses and machines. Through three rounds, with growing difficult, a robot (or more in the third round) should transport five boxes from one warehouse to another, taking into account where the boxes need to be processed (according to the color of the box), before they are dropped at the final warehouse.

Moreover, this robot design should also be modular enough so it can also prove advantageous on other competitions, like Bear Rescue, inserted in the Prague Robotic Day [5].

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B. Design Constraints

It is important to note that this platform was developed to mainly participate in the Robot@Factory competition. Given this, a set of specifications were then defined to fulfill the competition's rules. These and some more are listed below:

- The robot must fit into an area of 45 x 40 cm with a maximum height of 35 cm;
- The robot should be able to perform a fully autonomous mission, without any kind of communications to the outside the shop floor;
- The robot must have localization capabilities;
- The Processing Unit must fit into the robot, and must be as small as possible;
- The robot must be able to distinguish colors, to perform a Red-Green-Blue (RGB) evaluation;
- The robot should be able to pickup weights up to 0.5 kg;
- The robot must be modular, so it can be easily mounted and unmounted, for part replacement purposes;

III. Robot Design

In the next subsections, all the decisions that were taken in terms of mechanical, hardware and software designs are presented.

A. Mechanical

Since the robot must perform a fully autonomous mission, the material in which it must be built should be both rigid and cushion every casual impact. The vehicle was constructed using two similar bases (Figure 2), one lower to serve as a structure for the motors, camera, servo motors' structure and the processor unit. The other (upper base), to support the laser and the buttons/switches. The hardware was bolted on to the bases, except the external power supply.

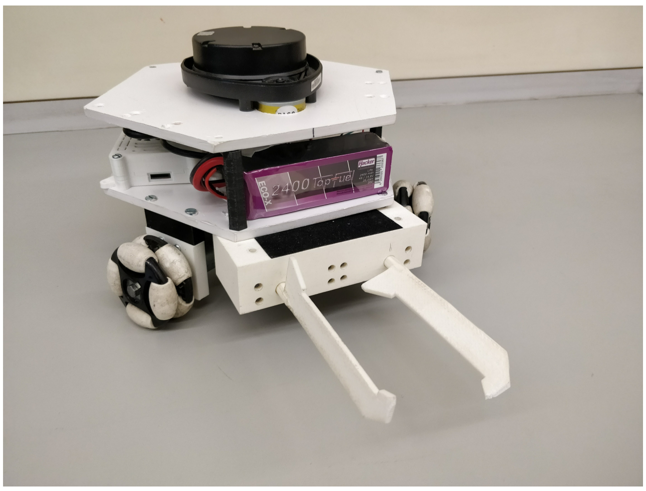

Fig. 2. Robot

1) Traction: Considering that the robot has to travel around the shop-floor and that the slots in which the boxes are supposed to be have different orientations, the omnidirectional traction was selected. The advantages of this type of traction is that the robot can move in every direction and rotate around its own axis, simultaneous, which allows to orientate to any direction, even while moving. This feature is very useful for time concerning criteria, when the vehicle encounter obstacles, or when the quickest trajectory involves curvatures, which is the case of this competition. The kind of omnidirectional traction that was chosen was the 3-wheeled one, since the 4-wheeled has some added mechanical particularities, like the need for an independent suspension system between wheels in the same axis. So, for this kind of traction, the kinematic of the vehicle must be calculated, as in [6], [7] and [8]. To be able to perform that calculation, Figure 3 was created, to define the body-frame (centered on the vehicle), the inertial-frame (world) and the direction of the speeds of each wheel.

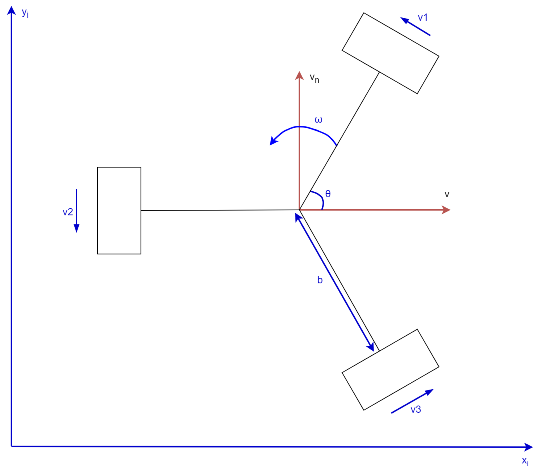

Fig. 3. 3-wheeled omnidirectional robot diagram

Knowing the respective frames, the system of equations used to calculate each wheel speed is presented in Equation (1):

$$\begin{bmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \end{bmatrix} = \begin{bmatrix} -sin(\theta(t)) & cos(\theta(t)) & b \\ 0 & -1 & b \\ sin(\theta(t)) & -cos(\theta(t)) & b \end{bmatrix} \cdot \begin{bmatrix} v(t) \\ v_n(t) \\ \omega(t) \end{bmatrix} \quad (1)$$

The circumference with the same center of the vehicle is divided, and each motor is placed with $\theta = \frac{2\pi}{3}$, so they can be all at the same distance from each other, which results in Equation (2):

$$\begin{bmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \end{bmatrix} = \begin{bmatrix} -sin(\frac{2\pi}{3}) & cos(\frac{2\pi}{3}) & b \\ 0 & -1 & b \\ sin(\frac{2\pi}{3}) & -cos(\frac{2\pi}{3}) & b \end{bmatrix} \cdot \begin{bmatrix} v(t) \\ v_n(t) \\ \omega(t) \end{bmatrix} \quad (2)$$

Considering that the algorithm assigns speeds $v,\ v_n$ and ω to the robot, Equation (2) is used to transform these into speed references $v_1,\ v_2$ and v_3, that are passed to the motor driver.

2) Forklift System: Since the robot described here is mainly to be used for the Robot@Factory competition [2], a forklift system was developed for picking up the boxes. It consists on two servo motors and a claw coupled to each other, as can be seen in the Figure 4.

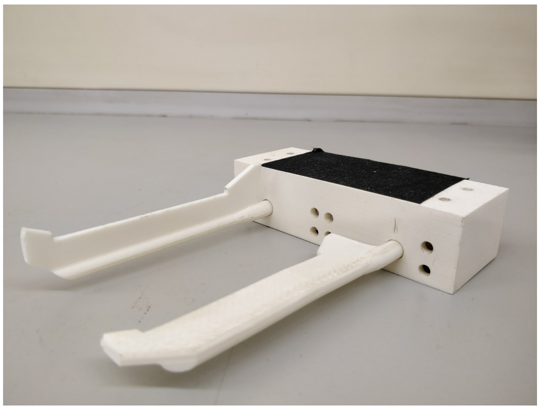

Fig. 4. Close-up of the forklift system

Furthermore, each claw has three pre-defined positions, these are unlock position - which is used when the robot travels without any box, loading/unloading - which is used for pickup/place a box in a designated area and lock position - which is used to secure the box when it is being carry by the robot.

B. Sensoring

In this subsection, the robot's sensoring unit will be presented. These endows the robot with localization and navigation capabilities. Moreover, the colour identification routine will also be presented.

1) Localization and Navigation: To perform the desired tasks, the robot needs to navigate in the shop floor using some kind of process, as analyzed by the authors of [9]. For this, one possibility is to navigate in the factory, following the white lines, which connects all the machines and warehouses. However, using this method the robot becomes restricted to paths which includes the white lines and thus leads to greater traveled distances.

Another way to navigate, is to use the localization of the robot. This method allows the robot to travel along any desired path on the shop floor, since it can localize itself. Therefore, the robot is free to travel along the smallest possible distances, which is an advantage comparing with the follow lines approach. To localize itself, the robot contains a map of the shop floor and then a laser collecting data together with the odometry equations to localize itself on the stored map (perfect match algorithm [10] - Figure 5).

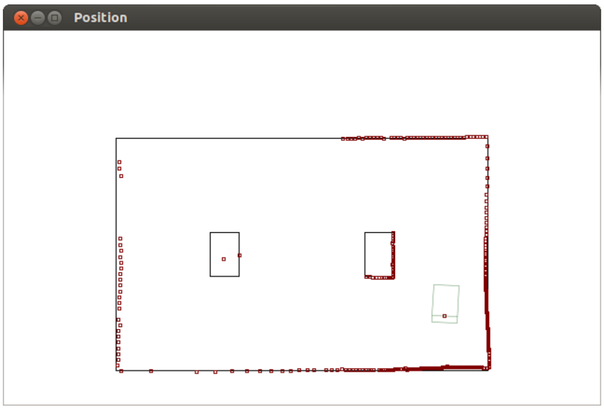

Fig. 5. Localization of the robot on the map

Since the shop floor is symmetric it is necessary to initialize the position of the vehicle to guarantee that the localization calculated by the robot is accurate.

2) Color Identification: As previously mentioned, the Robot@Factory competition [2] is divided in three rounds. Each of which are distinguished by the number of boxes of a certain color. Therefore, a subsystem was developed to acquire this unknowns and evaluate them.

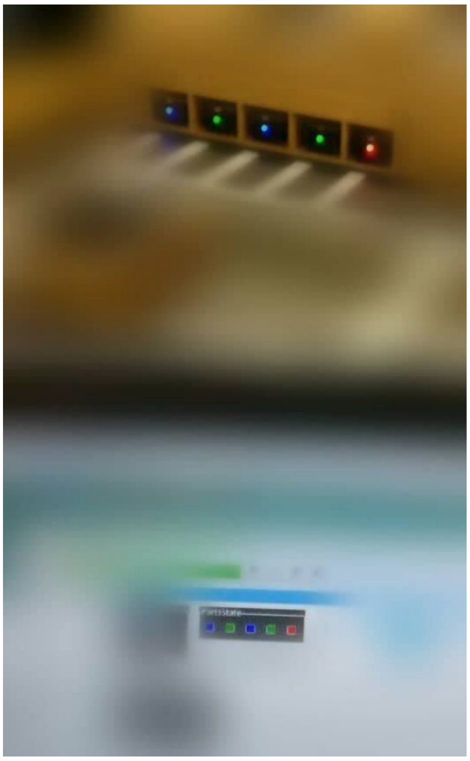

Fig. 6. Demonstration of the working system in a past competition

In the present work, this subsystem was built relying on a camera (Figure 7), since it brings additional benefits over a simple RGB sensor, for example the robot can identify all the box's colours from the start position.

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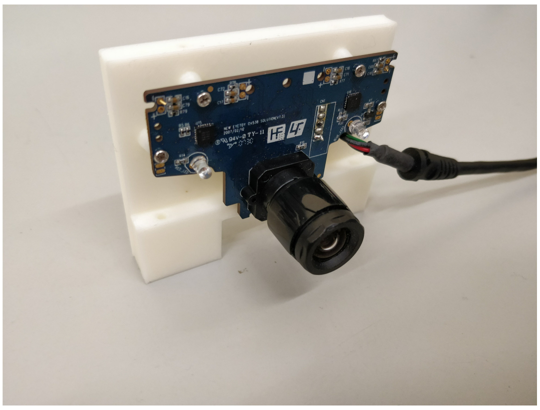

Fig. 7. Close-up of the camera support

Moreover, RGB values acquired with the camera's subsystem vary significantly with the daylight conditions. To oppose this, two additional modifications were made. The first one was the development of an online interface with this subsystem. This is intended to allow tuning of the acquisition parameters (eg. white balance), as performed in [11]. The other one, consist in defining the area on the acquired image, that is used for processing and thus colour identification. These, not only allow selecting the best area for color identification (area where the intensities of each RGB color can be better distinguished), but also reduce the image processing time needed, since only a small part of the acquired image is processed. The outputs of this process are illustrated in Figure 8.

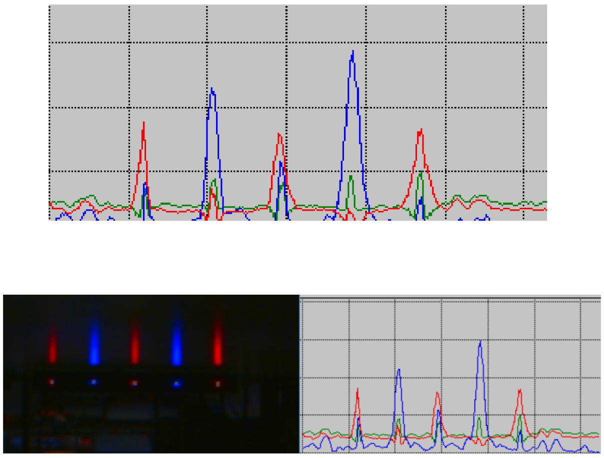

Fig. 8. RGB values of an acquisition taken with the camera subsystem

Lastly, after identifying the number of boxes of each colour, a state machine is built in order to plan the consecutive waypoints for the robot's route, that minimize the distance to be travelled, which allows completing the stage, as further explained in section III-D.

C. Electronic Hardware

Regarding the robot's electronic hardware, all the components were selected considering the design constraints previously enumerated in section II-B. For the robot's motion, omnidirectional wheels are used, due to imposition by the chosen traction scheme. Furthermore, the wheel's motors operate in nominal conditions at 12V. Moreover, encoders are also needed to allow feedback control of the motor's speeds. At the color identification level, the only requirements is that the used camera can acquired RGB images, to allow box color identification from a distance up to approximately 2 meters, which is the distance from the competition starting point to the loading warehouse. Concerning the laser unit, it needs tp provide a 360○ view, in order to accurately reject all encountered outliers and thus allowing for reliable localization of the robot in the shop floor.

As a processing unit, a Raspeberry Pi 3 was used since it fulfills all the performance and interface requirements (eg. number of USB ports needed). Lastly, the used power system consists in a 12V Lythium-Polymer battery to supply the robot's motors voltage demands and a 5V power bank to supply the remaining electronic components.

D. Software

The software architecture (Figure 9) has been developed to be modular, so it is possible to change some sub-part without having to rebuild all the structure. Nonetheless, there are some blocks of code that must remain untouchable, as the communication module, which provides the appropriate interface between the sub-modules. This strategy allows the programmers to improve the code without having to change the whole structure.

Furthermore, this architecture relies on sensors, actuators and a processing unit. The platform depend on these subsystems to locate itself in the space, sense its surroundings, perceive the colors of the boxes, move the robot with/without boxes and lift them.

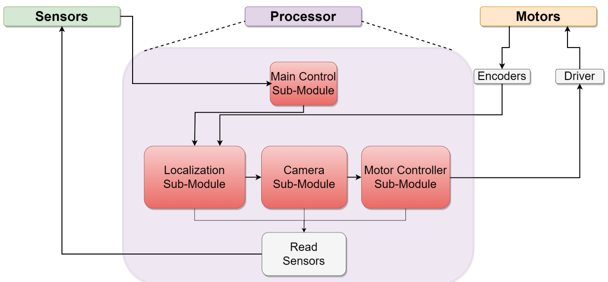

Fig. 9. Robot's System Architecture

In Figure 9, the green block has the sensoring part of the platform. This part consists in the data received from the camera and the laser. The orange block corresponds to the actuation part of the platform, which consists in the motors to move the robot as well as the servo motors that pick up the boxes. Finally, the purple block has the detailed processing unit part of the project. Inside this, the red blocks are the sub-modules that controls each sub-part of the robot. It is noteworthy that the modularity of the system makes it easily to

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be reconfigurable to host new blocks and/or expand the system capabilities.

IV. Prototype

The built robot is presented in Figure 10.

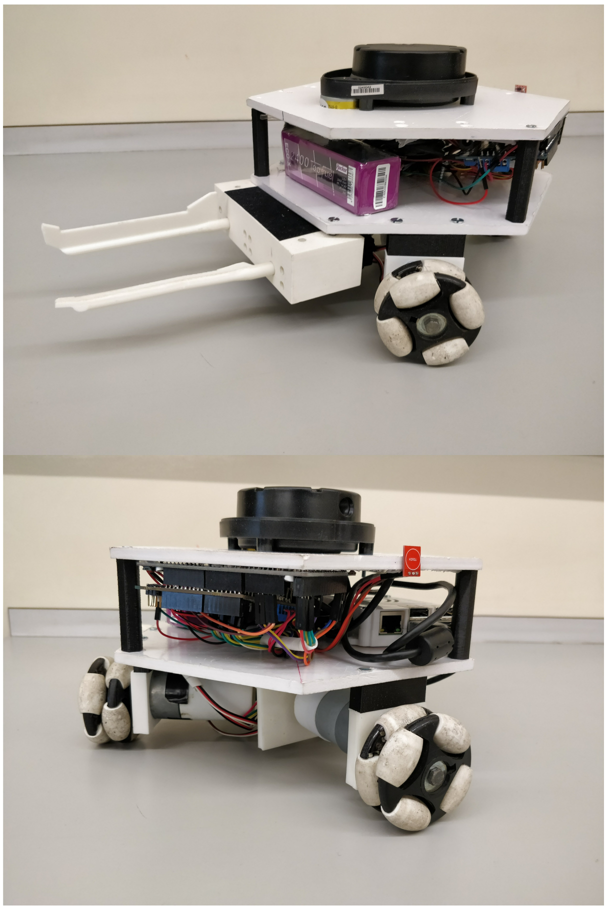

Fig. 10. Photos of the Real Robot Prototype

This robot was built using PVC boards of 6 mm in an hexagonal shape. The obtained prototype has the following characteristics (Table I):

TABLE I
Robot Characteristics

Radius	0.12 m
Height	0.18 m
Mass	2.5 kg

V. Applications

This robot is targeted to be used in robotic competitions. These events intent to present real world problems in a smaller scale, allowing the participants to develop a variety of solutions to a given problem in a competitive environment. These competitions provide an interesting opportunity to test different approaches and technologies that can be translated into real world applications. In particular, the Robot@Factory competition represents a real world application where the use of mobile robotics is applied to automatize a factory shop floor, which is related with one of the main applications of mobile robots. Therefore, the know-how acquired during the development of the robot for this competition can be used to improve existing robots developed for use in the industry. Moreover, this robot can also be used in other competitions, like the bear rescue competition, where the robot must find and rescue a bear inside of a playing field, since it is easy to adapt this vehicle to other tasks. For this example, it would only be necessary to change the forklift system to one that can capture the bear.

Furthermore, this robot can also be used as an educational robot, to teach mobile robotics concepts to students. This robot allows introduction of concepts like odometry calculation, localization using a laser, navigation, actuation, image acquisition and analysis, etc. Lastly, this robot can also be used to promote mobile robotics and encourage interest in the field. Therefore, this robot is an interesting vehicle to use in demonstrations like "Semana Profissão Engenheiro" [12] and "Universidade Júnior" [13], which are the divulgation programs from Faculty of Engineering of University of Porto for high school students.

VI. Conclusions and Future Work

In this paper, it was presented the development of a robot to be used in robotic competitions and as an educational platform. Therefore, this robot was developed to fit the competition's design constraints and to present concepts related with the field of mobile robotics, in order to illustrate real world problems using a hands-on approach. The developed robot was designed to provide a versatile platform that can be easily adapted and that uses different technologies to solve the proposed challenges. Moreover, this robot introduces mobile robotics concepts like laser based localization, navigation and odometry proving to be a valuable tool to teach new concepts to engineering students. This robot also can be used as a testing platform to new approaches that aim to solve similar problems as the ones presented in the different competitions. As future work, it is planed to develop a new robot based on this design, to use on the Robot@Factory competition, for cooperation purposes between two of these robots. This will allow completing the rounds in a more efficient/quicker way. It is also planned to optimize the software and redesign the software interfaces to achieve better results and improve the user interface of the vehicle.

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