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DESIGN AND DEVELOPMENT OF A WHEELED ROBOT SOCCER TEAM

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Abstract. *Mobile robot competitions offer several categories, including the Very Small Size, in which each team is consisted of three cubic robots with a maximum edge dimension of 7.5 cm. The aim of this paper is to present the design and development of the new robot that will be used for the next competitions. The development of the robot is part of a multidisciplinary project that includes mechanics, electronics and computing. In the mechanical project, the geometry of the carcass, the dispositions of the motors and wheels, the weight, the torque and speed were dimensioned and specified. The embedded electronics consists of a microcontroller, magnetic encoders, transceiver and rechargeable battery. The computational project is responsible for processing the data sent by the vision system and control signals based on the strategy of the game. A CAD software was utilized to design the robot. The speed with and without load, the strength and the closed-loop robot speed control system were tested.*

Keywords: *robot soccer, Very Small Size, encoder, embedded system*

1. INTRODUCTION

Robot competitions bring together every year hundreds of researchers who compete in order to find out which one is able to best meet a particular goal. There are several types of categories and competing robots such as the biped (Sungkono et al., 2016) and mobile robots (Green and Plumb, 2011). Robot competitions are already widespread around the world and among them there is the IEEE Very Small Size category (Celso et al., 2016). According to the rules of this category (CBRobótica, 2009), each team consists of three robots with a maximum dimension of a cube with an edge of 7.5 cm, that compete on a field similar to a soccer one, but measuring 150 cm by 130 cm. Each match lasts 10 minutes, divided into 2 halves of 5 minutes each and a 10 minutes long interval between them, the ball used is an orange golf ball with 4.27cm in diameter weighing 46g.

In the IEEE Very Small Size category (VSS) all the management of the robot is done by a computer that processes the image of the field with the robots of both teams and the ball, through a video camera placed above the field, and controls the robots according to a predefined strategy (Oliveira and Araujo, 2015). The computer processes all the information coming from the images of the field and sends control signals via bluetooth to each robot. The robots receive the signal and it is processed by a microcontroller, causing them to move according to the planned strategy. The main goal is similar to conventional soccer, to get a ball into the opponent's goal.

Currently, the POTI soccer team of robots work in the laboratory of Robotics and Dedicated Systems of the Department of Computing Engineering and Automation of the Federal University of Rio Grande do Norte (DCA - UFRN). The team holds the largest number of national titles in its first twelve years of existence. This paper will present the development and construction of the prototype that will be used in the following competitions.

2. ARCHITECTURE OF THE ROBOT SOCCER SYSTEM

The robot architecture of the Poti team consists of a few modules: robot, vision, location, strategy, control and transmission. The connection between them allows the gameplay of the robots. Fig. 1 shows the modules used in the robots soccer system. Next, the architecture modules of robot soccer will be described.

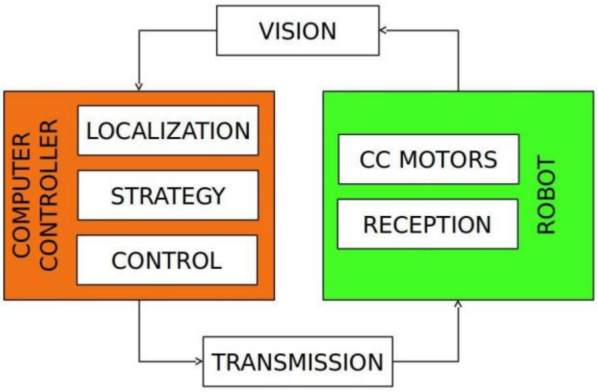

Figure 1. Robot Soccer System Architecture.

2.1 Robot

The mechanical design developed in CAD software was made with the maximum dimensions allowed by the competition rules. The IEEE VSS does not establish a maximum or minimum weight, but based on previous projects it was noticed that a very light robot impairs the control of its movement, as the robot ended up reducing the friction of the contact between the tire and the field in the collisions, making the robot not to reach the location indicated by the strategy code. Thus, instead of the structures manufactured by means of rapid prototyping, previously used by the team (Oliveira and Araujo, 2015), it was decided to manufacture the structure in acrylic made in modules, in order to increase the mass of the robot and facilitate the assembly of its components. Besides that, the structure was designed with an internal space to fit two axial electric motors with reduction box and encoders plus a rounded design to facilitate the conduction of the ball. Fig. 2 shows all the components that form the robot of the Poti team.

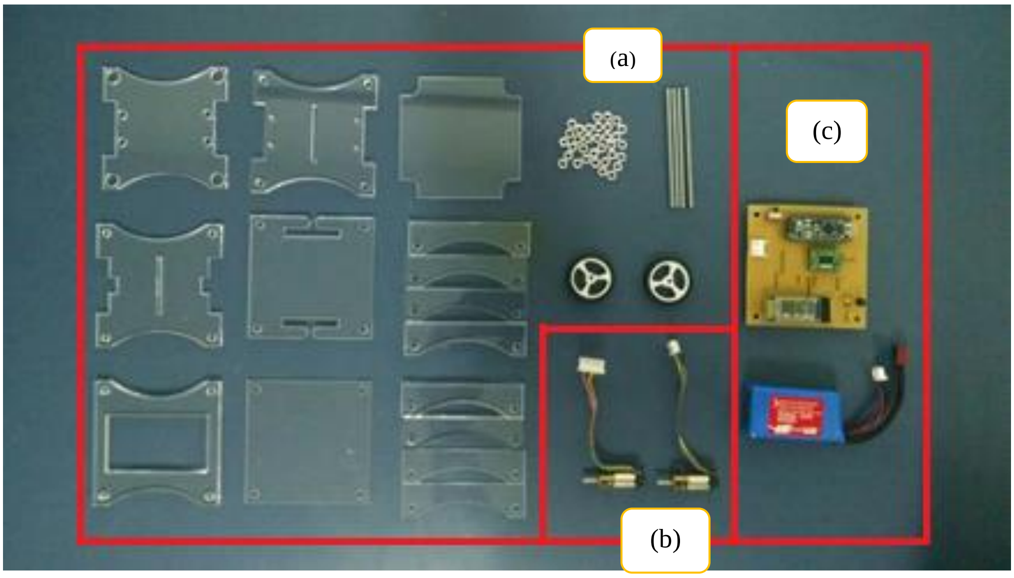

Figure 2. Components of the Poti robot.

The robot building can be divided in three parts as shown in Fig. 2: (a) mechanics, (b) electromechanical and (c) electric. The mechanical part consists of 15 modules made of acrylic to form the structure of the robot, four threaded rods with a diameter of 3 mm and 75 mm in length, thirty two nuts for fixing and two wheels of 32 mm. The electromechanical part basically consists of the motors and the electrical part is formed by the battery and the printed circuit board. Tab. 1 shows the masses of each part of the robot, as well as the total mass.

Table 1. Mass of each part of the robot.

	Mass (g)
Mechanics	270
Electromechanical	25
Electric	110
Total	405

The robot was developed with two wheels that are triggered by an electric micromotor. Each wheel is fixed in an electric motor and are aligned in the axial direction of the motor with the center of the structure. A high-power and carbon brushes (HPCB) CC motor was used, with a 30:1 reduction gearbox to increase torque and decrease rotation (Jusoh, 2011), with dual-shaft for coupling the encoder and capable of producing a no-load speed of 1000 RPM with 6V voltage. Fig. 3 shows a comparison between the prototype made in CAD Software and the actual built robot.

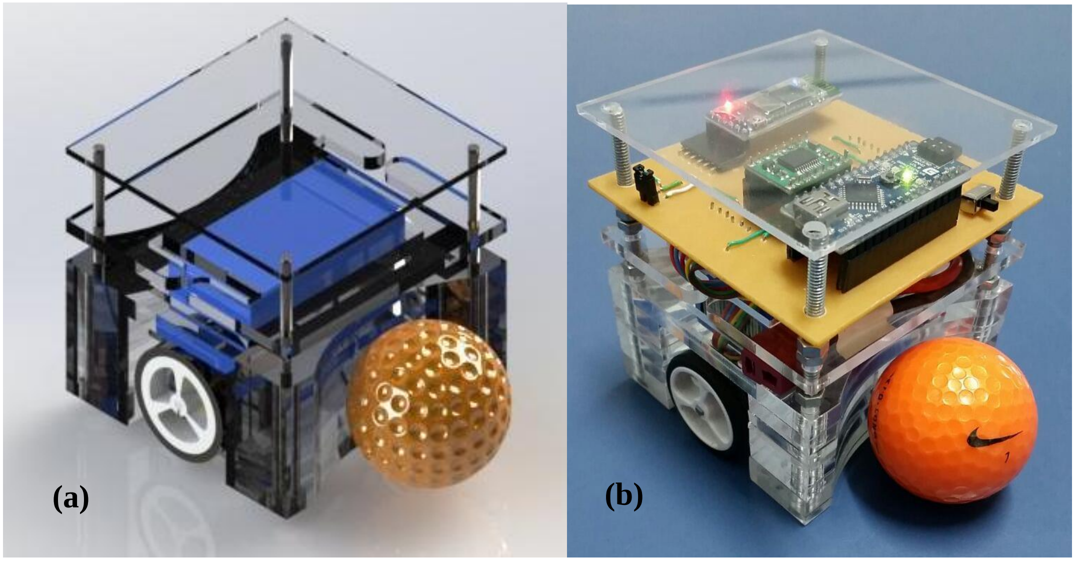

Figure 3. (a) Prototype modeled in CAD Software and (b) real robot.

2.2 Vision and Location

After the viewing module has taken pictures of the field of the match, using a camera with a USB 2.0 bus, the localization module uses the images to get the coordinates of all the robots, of both your team and the opposing team and the ball.

During this process, the program must locate the colored regions that represent the robots, being them labeled and having its position calculated based on the central region of the labels. Once the positions and color labels have been defined, the next step involves identifying the robots and the ball. Then, each of the three team robots is individuated. The calibration and image processing techniques used will be described below.

A. Calibration

Before each match, it is necessary to perform the system calibration. One of the steps is to set the thresholds of the color space components that define each of the colors used in the game. Each pixel has its RGB components transformed into HPG components (Hue, Puriry and Grayness), a color space developed by the UFRN robotics group that performs well when you want to segment color regions consisted of gray backgrounds. The colors to be identified are defined using HPG component thresholds and used to define whether a particular pixel belongs to the given color during program execution.

Then, the coordinates of the pixels relative to the noticeable points of the field are defined. As the actual position of these points is known, we can calculate a homography matrix that is used to transform a coordinate of a pixel of an image into a coordinate of the field that the given pixel represents. The coordinates of the pixels relative to the noticeable points are also used to determine the parameters used in the radial distortion correction function.

The calibration should be performed immediately before of the game, because variations in ambient lighting and possible field or camera support structure changes alter previously calibrated values, and using outdated values affects the system performance.

B. Image Processing

When a new image is received, the location system scans for blue, yellow, or orange pixels, which are the mandatory colors of both teams and the ball. Since objects have a minimum size in known pixels, the search is done only in a few pixels, with each *x* rows and *y* columns.

When a pixel of one of the main colors is found, all neighboring pixels of the same color are searched, using an optimized version of the Seedfill algorithm. A mean of the coordinates of the pixels found is then calculated in order to define the center of the region. In the case of a blue or yellow region, a nearby scan is performed to locate color regions corresponding to the auxiliary labels. If a pixel belonging to an auxiliary label color is found, the Seedfill runs starting from this pixel and the center of the new region is calculated. The center of the robot is calculated from the mean formed by the centers of the main and auxiliary region, while its orientation is calculated by the angle formed by the centers of these labels.

Once the center of the region corresponding to the ball and the centers of the robots are calculated, this information expressed in units of pixels is converted to meters by means of the radial distortion correction and the transformation through the previously calculated homography matrix.

2.3 Strategy

The strategy part aims to define a reference to where the robot should move based on its current position, the position of the opponents and the position of the ball (Silva, 2010). It is based on the attribution of predefined roles to the robots and on actions that each one can take. The roles available are Goalkeeper, Forwarder and Defender.

The robot defined as a goalkeeper should be close to the goal, oriented with the field line, and trying to orient himself with the position *y* of the predicted position of the ball. The attacking robot will try to line up with the ball and kick or drive the ball depending on the situation, always seeking to score a goal. The defending robot should remain mostly on the defensive field, trying to advance the balls that go to the defensive field and avoiding as much as possible to approach the striker on order to not collide with him and undermine the team's performance. The defending robot positions itself in the defensive area, waiting for a chance to become an attacker. If this happens, there is a role shift.

Other more specific actions were implemented in terms of penalty kicks, fouls, free-kicks and goal kicks. These actions basically reposition players on the field in one of the above functions, and are soon replaced by one of the default actions when the game is restarted.

2.4 Control

Using the references generated by the strategy module, the control calculates the voltages to be sent to the CC motors. The strategy used is based on an adoption of classical controlling techniques (Vieira, 2003; Vieira, 2004).

In summary, the adopted approach is formed by the separation of the position control in two independent controllers: an angular controller and a linear controller. The angular controller is concerned with pointing the robot to the desired reference, while the linear controller aims to position it along the line that coincides with its current reference at the R point closest to the desired reference (Vieira, 2003; Vieira, 2004).

2.5 Transmission

The transmission module consists of a Bluetooth HC-05 Transceiver, in slave mode, with a frequency of 2.4 GHz and a speed of 2 Mbps - 3 Mbps running at 3.6 V ~ 6 V for reception on each robot. It receives Bluetooth data from a computer configured in master mode to transfer the information that should be sent to the robots.

Through the computer, 3 bytes packets are sent to each robot every 30 milliseconds, on which the first byte contains a code responsible for identifying the transmitter, so that the robots confirm this code and execute the movements. The other two bytes are then divided for each motor. In each byte, the first bit refers to the direction of the motor and the remaining seven refer to the speed. That way, we can have up to 127 different speeds.

3. EXPERIMENTAL PROCEDURE

The experiments were divided in tests of linear speed (with and without load) and strength, always performing seven measurements, for statistical reasons, and using the mean as a base. Robot speed and strength tests were performed by varying the motor voltage at about 1.5V, 3V, 4.5V, 6V and 7.5V for each test.

3.1 Loaded speed test

In the linear speed with load test, the robot remained on the field and an equal tension was provided on the two wheels, allowing it to perform a straight line motion. These tests were filmed with a camera placed above the field. With the help of a video editing software, it was possible to obtain the time the robot took to cover 0.75 m, which is equivalent to half of the soccer field of the IEEE VSS category. To calculate the average linear speed with load, the distance was divided by the time spent and based on the mean.

3.2 No-load speed test

On the other hand, in the realization of the test of linear speed without load, a tachometer was used to measure the angular speed of the wheels of the robot having it not touching the ground. Fig. 4 shows the measurement of the angular speed by means of the tachometer, the values of this rotation (in RPM) when multiplied by the perimeter of the robot wheel (of radius 32 mm) results in the robot’s linear speed without load.

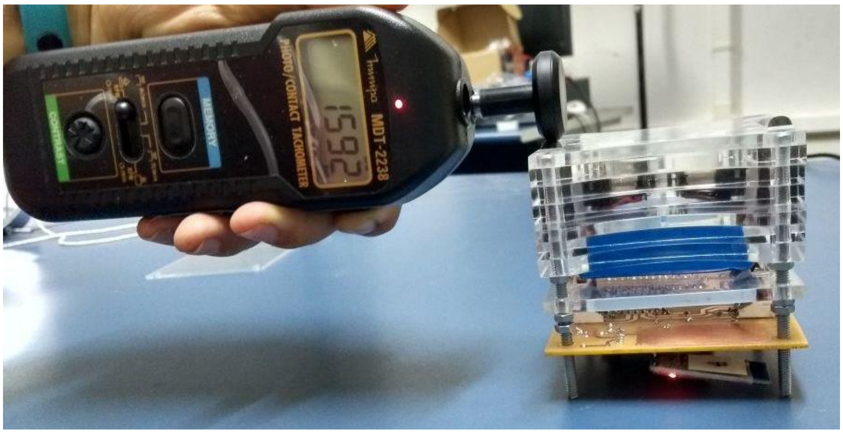

Figure 4. Rotation measurement with tachometer.

3.3 Strength test

For the strength experiment, the robot tractioned a cable attached to a load cell as shown in Fig. 5. Thereby, the higher the tension of the wheels of the motors, greater the tensile strength the robot exerted on the cable that consequently also trailed the load cell.

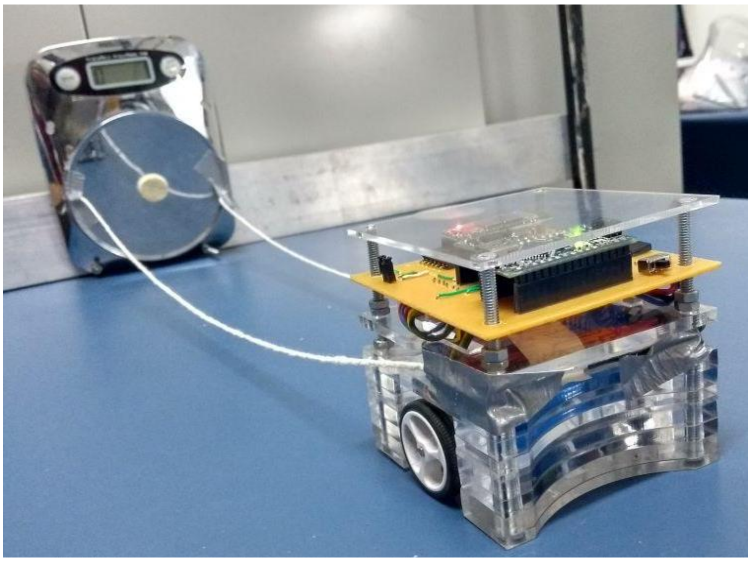

Figure 5. Strength test with load cell.

4. RESULTS AND DISCUSSION

In this section we present the results of the experiments described above. Tab. 2 shows the result of the average linear speed with load of the robot for various voltages in the wheel triggering motors. Based on this table, a chart (shown in Fig. 6) has been plotted in order to show the variation of the average speed with load as a function of the voltage of the motors.

Table 2. Data load speed.

Voltage (V)	Average Speed (m/s)
1,5	0,286
3	0,541
4,5	0,770
6	0,906
7,5	0,959

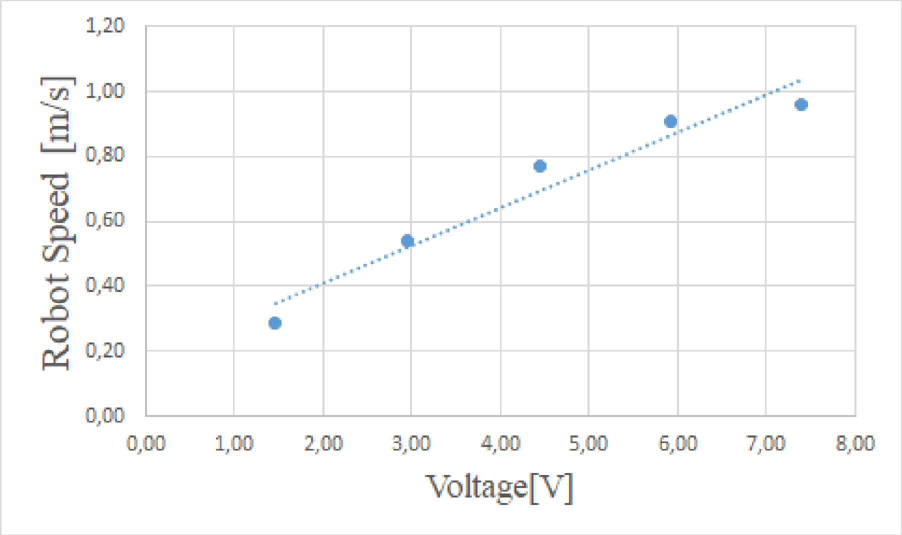

Figure 6. Speed chart with load as a function of the motor voltages

The average linear maximum speed with load presented values higher than 2% in comparison to previous projects of the Poti team (Cavalcanti et al., 2014; Oliveira and Araujo, 2015). However, the most prominent ones are the speeds for smaller voltages, since for the voltage of about 1.5 V the speed had an increase of 186% when compared to the higher speed of the team's old robots.

Tab. 3 shows the result of the average robot’s linear speed without load measured in revolutions per minute and in meters per second for varied voltages in the wheel triggering motors. Based on this table, it was possible to show in Fig. 7 the variation of the average speed with load as a function of the motor’s voltage.

Table 3. Data no load speed.

Voltage (V)	Average Speed (RPM)	Average Speed (m/s)
1,5	180	0,302
3	476	0,796
4,5	714	1,196
6	992	1,662
7,5	1322	2,213

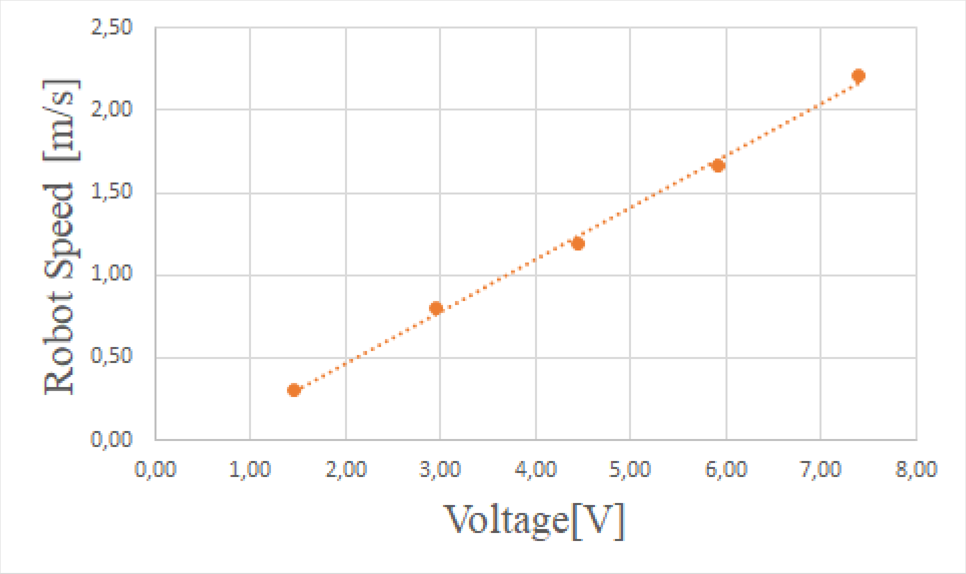

Figure 7. Speed chart without load as a function of the motor voltages

Finally, Tab. 4 shows the result of the average strength of the robot for the varied voltage in the wheel triggering motors. Based on Tab. 4, a chart showing the force variation of the robot as a function of the motor voltage was plotted in Fig. 8.

Table 4. Strength data.

Voltage (V)	Force (N)
1,5	1,20
3	1,54
4,5	1,77
6	1,87
7,5	1,93

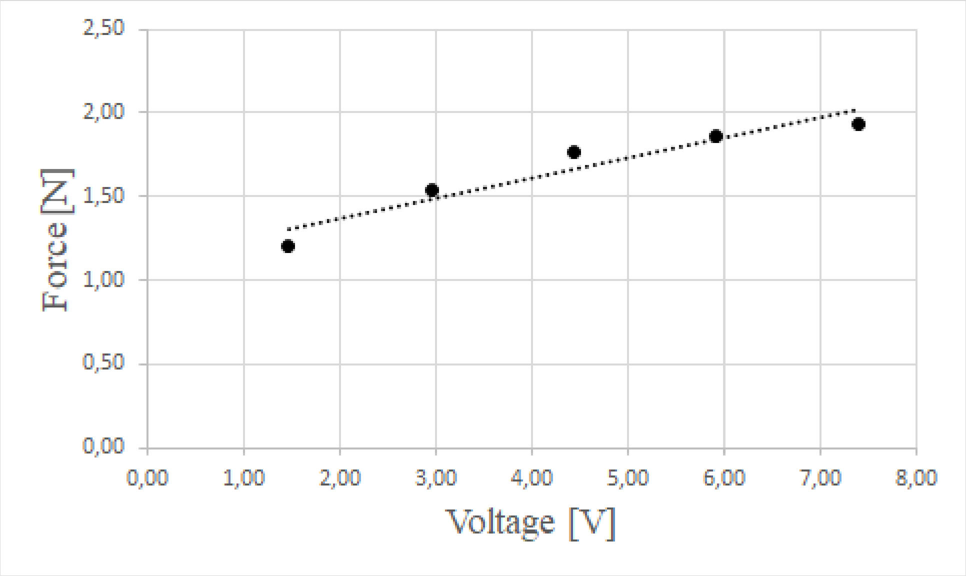

Figure 8. Chart of the force as a function of the motor voltages

On previous robots of the Poti team, Cavalcante et al. (2014), showed that the force of the robot with a voltage of about 3V did not exceed 0.8N, while the voltage of 7.5V reached close to 2 N. Oliveira and Araujo (2015), showed that the stronger robot reached a force of 0.85 N with a voltage of 3 V, and with its maximum voltage, it reached 1.95 N. As we can see, the lowest voltage used in the 1.5 V tests generated higher forces than previous robots of the Poti team and the maximum voltage was practically the same.

Due to the high torque of the motors, the test for the voltage of 7.5 V had slips between the wheel and the contact surface, which led to a small variation for the tests of the last two voltages.

5. CONCLUSIONS

The paper presented the description of a designed mobile robot with wheels, which has an embedded microelectronics with artificial intelligence, belonging to the IEEE Very Small Size category of the Poti team. With the development project of the first prototype, it became possible to carry out measurements of strength and speed. Therefore, based on the measured values, it is possible to have a previous knowledge of the competing robot's application.

Even the robot being heavier than the previous versions, it kept the maximum compatible speed. Besides that, in general, for smaller voltages the robot has demonstrated higher speeds and strength than the older versions. The speeds with the measured load and the tensile force are compatible with the technical specifications necessary to be successful in the competition.

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