DEVELOPMENT OF A RULES-BASED FUZZY ALGORITHM FOR DEVIATION OF OBSTACLES

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ABSTRACT
The objective of this project is to introduce the study of the Fuzzy logic, presenting the development of a navigation system in MATLAB software and its implementation in an autonomous mobile vehicle. The application proposal aims to integrate an Automated Guided Vehicles gifted a navigation system elaborated from Set Theory Fuzzy, in any kind of plan environment with obstacles at random points, so that it is able to identify any obstacles present in the environment in which is inserted and through the developed programming language C based on Fuzzy logic implemented in a ARDUINO MEGA2560 plate, calculating the deviation and executing necessary to avoid a collision with any obstacle encountered in the environment. At the end of deployment tests were conducted to obtain the robot responses and compared with the simulation software, according to the possibilities of reading of the sensors. The responses were satisfactory, following the same trend behavior of the simulations of the Fuzzy controller.

Keywords: Fuzzy Logic, Mobile robot, Autonomous navigation, Artificial Intelligence.

1. INTRODUCTION
One of the characteristics of human thinking is dealing with frequent situations that involve factors such as uncertainty, ambiguity or lack of information for its resolution, for example, where it is necessary to use skills such as experiences, knowledge, intuition and even common sense to manipulate such situations. According to Pasternak (2015), Khatchatourian & Treter (2010) and Reis, Dayr & Pati (2000), Artificial Intelligence (AI) is a computer system performing as a substitute for intelligent functions of human beings
This technology involves using methods based on the intelligent behavior of humans and other animals to solve complex problems, representing characteristics that are associated with intelligence in human behavior and the ways in which nature adapts to imbalances (COPPIN 2010).

The Fuzzy Logic, one of the techniques of AI, transforms the verbal, imprecise or qualitative expressions into numerical values and has wide application in modeling of several systems (Khatchatourian & Treter 2010; Zadeh 1990; Shaw & Simões 1999). This system is known as nebulous or diffuse logic and, as stated by Gomide & Gudwin (1994) and Faria & Romero (2002), has been elaborated in order to solve the problems of imprecision Mathematics, supporting the modes of reasoning that are close to the human, but not exact.
Cox (1994) affirm that while the Boolean Logic proposes that these values be true or false, Fuzzy Logic proposes that this is a matter of degree, making possible the use of approximation and even the inference of something that is necessary.
There is a large number of research on the selection problem within a fixed number of alternatives targeted to specific applications.
Lacevic & Velagic (2011) developed a fuzzy logic based position controller whose membership functions are tuned by genetic algorithm. The main goal is to ensure successful velocity and position trajectories tracking between the mobile robot and the virtual reference cart. Simulation results indicate good performance of position tracking while at the same time a substantial reduction of the control torques is achieved.
Shayestegan et al. (2013) demonstrated a hybrid control methodology for mobile robot navigation of a two-wheeled non-holonomic mobile robot by using fuzzy logic controller (FLC) incorporated with a switching command strategy (SCS). Yoo, Kim & Jeong (2012) proposes a fuzzy integral-based gaze control architecture incorporated with the modified-univector field-based navigation for humanoid robots. Using the partial evaluation values and the degree of consideration for criteria, fuzzy integral is applied to each candidate gaze direction for global evaluation.
Omrane, Masmoudi & Masmoudi (2016) designed and implemented a trajectory tracking controller using fuzzy logic for mobile robot to navigate in indoor environments. Simulation results show the

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performances of the intelligent navigation algorithms in terms of simulation times and travelled path.

Within this context, this paper propose to develop a Automatic Guided Vehicle (AGV) controlled by Fuzzy Logic, able to move in a known flat environment, providing it with a navigation system that identifies random obstacles in its route so that it is able to calculate and execute the deviations that are necessary to avoid its collision. The parameters of the system were elaborated in MatLab software, based on the proposal of a Fuzzy controller based on the literature.

2. EXPERIMENTAL

2.1. Materials

The robot developed in the study must move forward always and make the necessary deviation to avoid its collision when an obstacle is detected by one of the three ultrasonic sensors arranged at 90º in the front part of the prototype. Its deviation must attend to the rule base created to execute the inference strategically in the Fuzzy controller.

According to Corradini & Orlando (1997) and Yang, Li & Huang (2016), for the decision making of the robot it is necessary that it can detect the positions of the obstacles where the necessary deviations must be made to avoid their collision. In view of the required data and the imposed application, it was decided to use three ultrasonic sensors (S1; S2; S3), model HC-SR04, arranged at 90º, with a range of 2cm to 4m, an effect angle of 15º and a 5V supply in direct current. This sensors easily calculate the distance from the obstacle in relation to the emitter and present good accuracy.

Two motors DC PM Gear Motor, model 37JB6K/3530, were used to drive the two wheels used in the robot. In order to allow the connectivity of the respective motors with a microcontroller to control them, the electronic circuit H-bridge was used, being able to provide the current or voltage necessary for the operation of the motors and also provides an easier way for the possibility of changing the direction of rotation of the motor, only the polarity of the terminals being necessary. The model used in the project was the L298N, which presents in its structure two H-bridges, controlled via the Arduino platform and the C language program, which allows controlling the direction and speed of the motors through the pulse width modulation in the Pulse Width Modulation (PWM) of the board.

The Figure 1 allows to visualize the final mechanical structure of the mobile robot developed, emphasizing the need of the application of two motor wheels and a free wheel to maintain the stability of its structure in relation to the surface.

The Figure 2 presents a diagram of the mobile robot with the detail of the hardware used.

Figure 1: Mechanical structure of the robot.

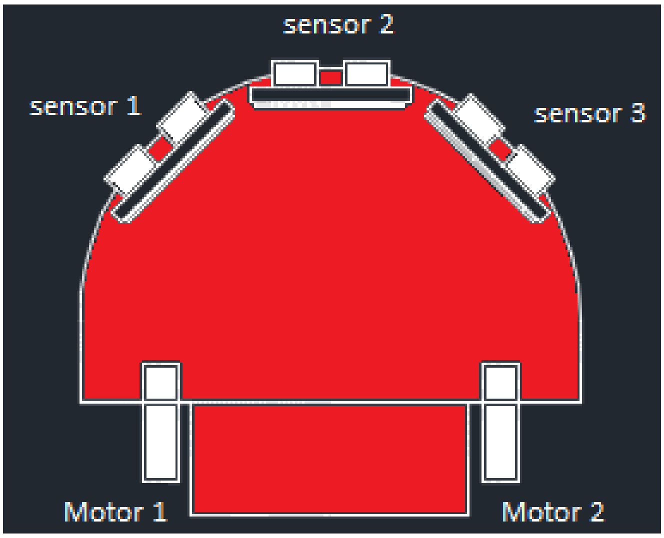

Figure 2: Diagram of the mobile robot hardware.

2.2. Methods

The Fuzzy Logic is a simple system of modeling by allowing its application through linguistic variables and their answers obtained in a short processing time, adapting to the real time application needful. Its application can be done in numerous areas such as industrial, medical and domestic services, replacing jobs that require dexterity, safety and precision (Gomide and Gudwin 1994; Carvalho, Yamakami and Bonfim 2013; Corradini and Orlando 1997).

The basic purpose of a Fuzzy control is to model actions based on expert knowledge, rather than modeling the process itself. According to Takagi & Sugeno (1985), even with the different methods found, controllers can be grouped into two large groups:

- Mandani controller: based on the Fuzzy Implication Functions in Composition Operators for the Fuzzy Output Definition of the Controller;

- Sugeno controller: simplification of the Mamdani controller, dispense with the definition of implication functions and operators for inference.

The Mandani controller the quantitative values into qualitative ones (Fuzzy) and then, in other values also qualitative through inference, after the Defuzzifier is used for the final quantitative response. These controllers are easy to model because they are based on intuition and are good when a rough control is acceptable, and for thinner systems the Sugeno controller presents superior performance, but with a mathematical modeling through the functions of the input language variables (Takagi and Sugeno 1985).
For the implementation of the study an Arduino MEGA 2560 board was used, due to its specifications that successfully meet the needs of the project.
For the virtual evaluation and modeling of the proposed solutions, MatLab was used to construct the Fuzzy controller of the robot navigation system, with the help of the Fuzzy Logic Toolbox.
The system developed for the navigation control was created in such a way that the robot was able to detect the obstacles present in its trajectory, to judge the conditions of the environment around and make decisions through the performance of the engines.
In the Fuzzy system, developed through MatLab, according to Figure 3, three input variables (S1; S2; S3) were determined, relative to the input values of the left, center and right ultrasonic sensors, respectively, located on the front of the robot And two output variables (Left Wheel; Right Wheel) referring to the PWM values that will be assigned, respectively, to the left and right motors.

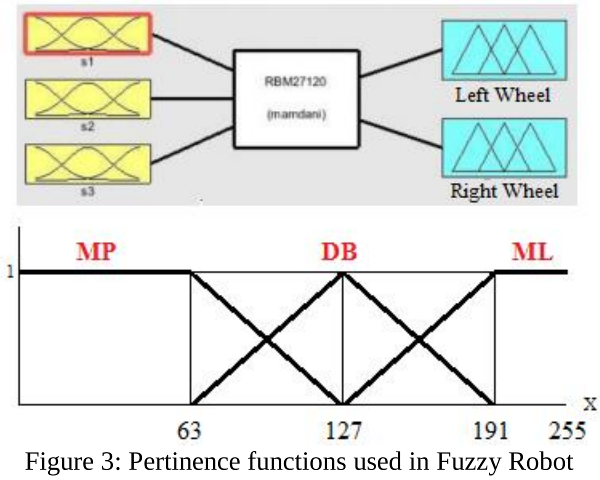

Figure 3: Pertinence functions used in Fuzzy Robot System.

Three inputs of data were used in this study, each one originated by an ultrasonic sensor considering the distance of the sensor to some object. For each input, three pertinence functions were assigned, according to the distance range: MP (Very Close); DB (Good Distance); and ML (Very Far).
Considering the quantities of pertinence functions present in the controller were assigned 27 rules, referring to the possibilities of combining the variables of each entry.
To define the rules, the positions of the sensors and the situations in which the robot can be submitted has been considered, in order to avoid its collision with any obstacle present in the operating environment.
The speed control actions of the robot has been established, working with the PWM values for the two motors, such as: VP (Positive Velocity); V0 (Average Speed) and VN (Negative Speed).
By using the inference method asked for the system, the following reading values were obtained from the sensors to define the pertinence functions: reading values less than 63 considered as Very Close Distance (MP), higher than 191 considered as Very Far Distance (ML) and from 63 to 191 as Good Distance (DB) considering the pertinence degrees of each linguistic value superior to 0.5 to be stored for use in the inference. The robot will move forward when the obstacle is too far away or when it picks up an obstacle on the side sensors (DB or MP) and the control unit is reading an obstacle too far (ML). If there is an obstacle ahead, the robot should deflect to the side where the sensor identifies the longest distance to it. When the two side's sensors are the same and have no distance ML, it has been established that the curve is made to the left.
Defuzzificador present in the robot navigation system is responsible for converting the fuzzy controller outputs inferred into traditional values, which in this case will be the outputs with the PWM value that will give the desired motions to the motors. The centroid method was chosen as the method for Defuzzification of the controller, where the final output value of the system is given by the position of the centroid of the generated geometry in the output Fuzzy sets from the input inference (Simonsen 2011).
In summary, the first stage is responsible for the communication of the robot with the environment, where it is made the reading and storage of the digital values measured by the ultrasonic sensors, these data are converted to the Fuzzy set of the system (0 to 255) and inserted in the fuzzifiers of the controller where they are transformed into linguistic variables according to the coding performed in degrees of pertinence. Each Fuzzifier has three outputs for each of the pertinence functions. The coded values are evaluated according to the defined rules, in this step the pertinence functions (MP; DB; ML) are stored, according to the inference method, of each sensor to choose the rule to be followed, resulting in a Language value of output (VN, V0; VP). In Defuzzification these values are, again, converted into the range 0 to 255 and sent to the PWM outputs of the board defined in the programming, corresponding to the speed that each motor must act.
Figure 4 shows the diagram of the electrical scheme used for the development of the project, with the connections used for sensor communication, H bridge, DC motors and the Arduino ATmega2560 board.

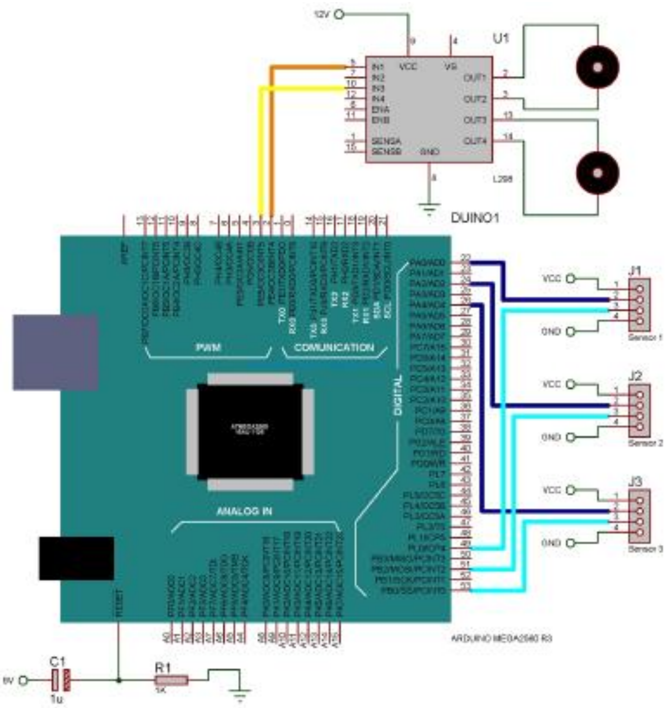

Figure 4: Electrical scheme of the project.

3. RESULTS AND DISCUSSION

Below are presented the results obtained by individually analyzing an input and an output.

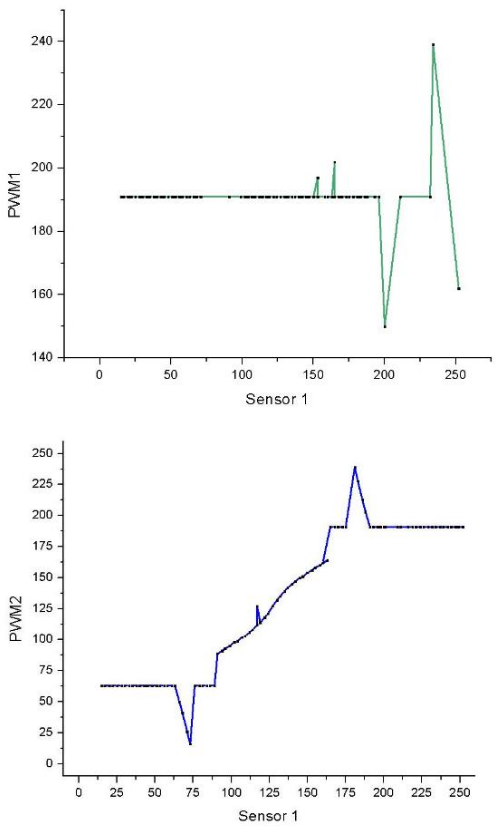

Figure 5: Sensor 1 input (PWM1) and output (PWM2) values.

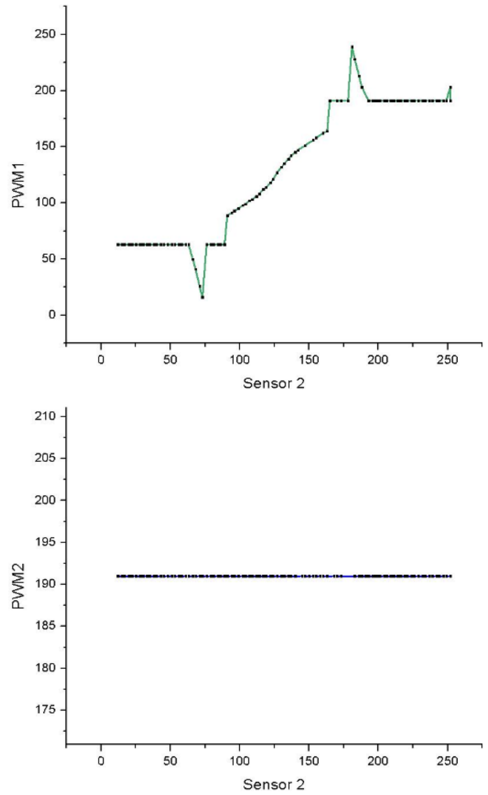

Figure 6: Sensor 2 input (PWM1) and output (PWM2) values.

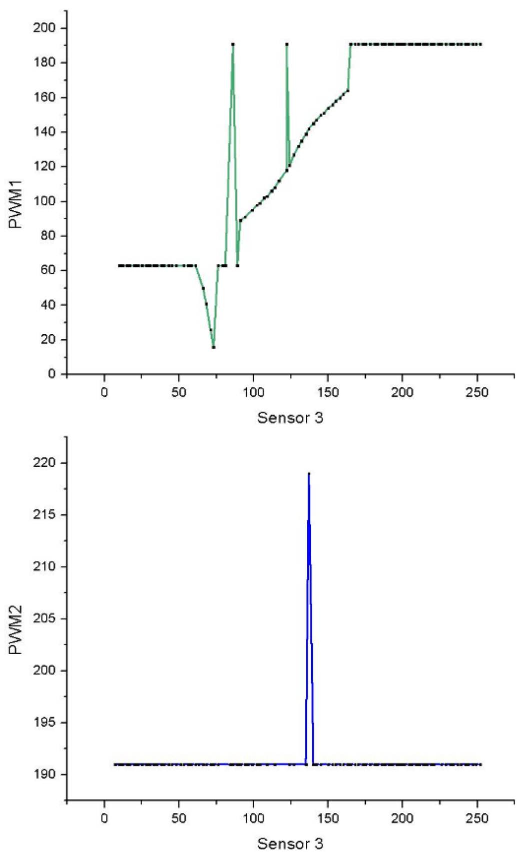

Figure 7: Sensor 3 input (PWM1) and output (PWM2) values.

The output of PWM1 and PWM2 are obtained through the Fuzzification process, inference based on Rules and Defuzzification. In this test, the PWM outputs of the controller for each sensor were analyzed individually, considering that the sensors not used in the test had a non-tangible margin of inference to the process, so that there was no interference of unused sensors in the results obtained.

The respective values were obtained due to the pertinence of each sensor used in the movement of the AGV. The linearity found in Sensor 2 (Figure 6) occurred because of its greater sensitivity, during the change of trajectory, and the tendency of curve. To validate the software it is necessary to compare the results of the sensors with the MatLab simulation.

The first tests were performed on the MatLab controller simulator to evaluate the basic operation of the parameters defined in the software, according to the rules base developed, considering the three data inputs that represented the sensors of the robot and its outputs, so much the input values as output values were defined for a set universe with a range from 0 to 255. Taking into account the curve time of the robot and the range of action of the ultrasonic sensors used in the study, the rules were formulated so that the curves could occur with the greatest difference in the speed of each engine and its actions with a longer distance from the present obstacle.

Analyzing the graphs, the developed in C language for the robot were satisfactory. Other methods would require more computational resources, whose application is seen as lacking in resources. As a consequence of this ness, an attempt was made to find an alternative for the development of the controller, since the simplicity of the system would imply directly in the controller response. The programming language should be low-level, requiring less resources of the physical controller, making the use of Language C the most possible programming mode for the system, compared to other commonly known codes.

In the initial tests with the software were obtained the results of the defuzzified values presented in Table 1, the input values were chosen according to the probability of reading of the three sensors with three functions of each pertinence.

Table 1: MatLab Simulator Results

RULES	S1	S2	S3	LEFT WHEEL	RIGHT WHEEL
1	51	51	51	48,6	206
2	51	51	127	206	48,6
3	51	51	200	206	48,6
4	51	127	51	48,6	206
5	51	127	127	206	48,6
6	51	127	200	206	48,6
7	51	200	51	206	206
8	51	200	127	206	48,6
9	51	200	200	206	48,6
10	127	51	51	48,6	206
11	127	51	127	48,6	206
12	127	51	200	206	48,6
13	127	127	51	48,6	206
14	127	127	127	48,6	206
15	127	127	200	206	127
16	127	200	51	48,6	206
17	127	200	127	206	206
18	127	200	200	206	127
19	200	51	51	48,6	206
20	200	51	127	48,6	206
21	200	51	200	48,6	206
22	200	127	51	48,6	206
23	200	127	127	48,6	206
24	200	127	200	127	206
25	200	200	51	48,6	206
26	200	200	127	127	206
27	200	200	200	206	206

The output values presented in the simulator correctly followed the expected behavior in each controller rule.

After the initial tests, the answers were analyzed with the final algorithm developed, already implemented on the Arduino board with the three ultrasonic sensors connected to provide the input values of the controller (0 to 255). The output values responsible for the movement of the motors are were obtained through the PWM pins of the board which have also been configured to operate in the range of 0 to 255.

The test preparation methodology aimed to obtain the output values in the PWM for each rule produced in the Fuzzy controller. For this evaluation to be carried out, the board with, the algorithm was connected with serial communication to a computer and analyzed through the serial monitor in the software of the Arduino platform, configured through the program created to present in real time the reading value of the sensors and the values present on the PWM pins of the board.

The sensors were placed at a 90º angle between them, so that obstacles could be positioned in each sensor at the desired distance without interfering with the other sensors. Objects were allocated at distances that presented the values of reading of the sensors according to the linguistic variables of the controller, thus, all rules could be tested by varying the distances of the objects in relation to the sensors with the necessary combinations.

Table 2 presents the PWM readings of the plate according to the input values, manipulated through the distance of the objects where: input values 51 belong to the linguistic value MP; 127 to the linguistic value DB; and 200 to the linguistic value ML.

Table 2: Robot Results

RULES	S1	S2	S3	PWM1	PWM2
1	51	51	51	63	191
2	51	51	127	191	63
3	51	51	200	191	63
4	51	127	51	63	191
5	51	127	127	191	63
6	51	127	200	191	63
7	51	200	51	191	191
8	51	200	127	191	63
9	51	200	200	191	63
10	127	51	51	63	191
11	127	51	127	63	191
12	127	51	200	191	63
13	127	127	51	63	191
14	127	127	127	63	191
15	127	127	200	191	127
16	127	200	51	63	191
17	127	200	127	191	191
18	127	200	200	191	127
19	200	51	51	63	191
20	200	51	127	63	191
21	200	51	200	63	191
22	200	127	51	63	191
23	200	127	127	63	191
24	200	127	200	127	191
25	200	200	51	63	191
26	200	200	127	127	191
27	200	200	200	191	191

The results of the robot obtained in bench were also satisfactory, which led to the beginning of the tests with displacement of the robot of autonomous form, aiming to observe its displacement in real situations of application.

As a way of validating the results obtained in the algorithm implemented in the robot, comparative graphs were drawn for each controller output, which could show the behavior of the results obtained for the two wheels in MatLab and in the robot according to the same input values. The Figure 6 and Figure 7 show the comparison charts for the two wheels.

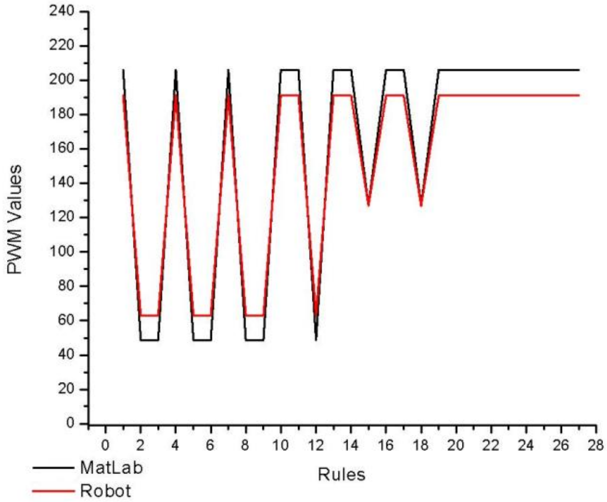

Figure 7: Comparison of the Right Wheel in MatLab and in the Robot.

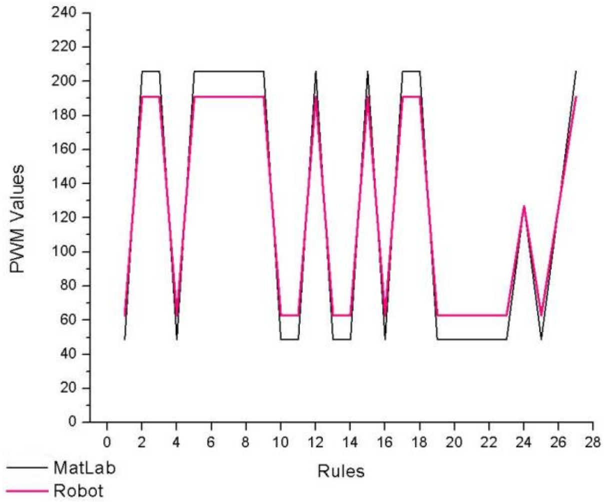

Figure 8: Comparison of the Left Wheel in MatLab and in the Robot.

The behavior of the graphs shows that the results of the algorithm developed in C language for the robot were satisfactory, following the same performance trends according to the situations to which they were submitted. However, the differences identified were the maximum and minimum PWM values. In the results obtained in tests with the robot, the output values for both motors were shown to be lower, at the maximum speed, according to the controller simulation in MatLab and, at minimum speed, presented higher output values than those obtained in simulation.

4 CONCLUSIONS

With the algorithm in operation, it was verified that the Fuzzy logic offers a smoother transition in the movements. In order to validate the efficiency of the navigation system created, simulations were performed with the robot according to the rules inserted in the Fuzzy controller, where the input values of the sensors and the output values in the PWM of the board were analyzed. The results obtained were consistent with the responses given by the simulation in MatLab, following the same trend of behavior. In comparison to the proposed objectives and the desired behavior obtained in virtual simulation, the Fuzzy controller used in the study, in an intelligent navigation system, is feasible for such an application, for presenting coherent answers in the tests made, being able to deviate from the present obstacles.

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