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ORIENTATION (YAW) FUZZY CONTROLLER APPLIED TO A DIFFERENTIAL DRIVE MOBILE ROBOT PROTOTYPE FOR INDOOR AND OUTDOOR APPLICATIONS

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Abstract: *This paper describes the development and implementation of an embedded Fuzzy Controller for a differential drive mobile robot prototype which is able to keep a desired orientation angle along the robot forward displacement. This prototype was designed for indoor and outdoor applications. In our approach we used a high and a low level of control. The high level corresponds to a closed loop control system that receives information about the desired orientation and the current measured orientation such that the fuzzy controller calculates and generates the required control action. On the other hand, the low level controller is responsible for receiving the required control action from the high level controller in order to compute that information and suitably route the PWM (Pulse Width Modulation) signals to the two DC motors which carry on the mobility of the protytype. Current vehicle orientation is measured with an IMU (Inertial Measurement Unit). Additionally, an App-Inventor application was developed in order to remotely update the mobile robot desired orientation and also start or stop the protoype movement.*

Keywords: *Differential drive mobile robot prototype, Fuzzy logic controller, Orientation control, Android, App Inventor 2, Inertial measurement unit, Bluetooth.*

1. INTRODUCTION

A considerable set of experiments with mobile robotics can be tackled by using low-budget prototypes. This approach allows assuming topics that require improvement before its implementation in real platforms like vehicles and trucks. Moreover, those simple platforms have the advantage of being easily available in terms such as smaller experimental sites, less burocracy and less power consumption. Thus, the conduction of experiments is facilitated.

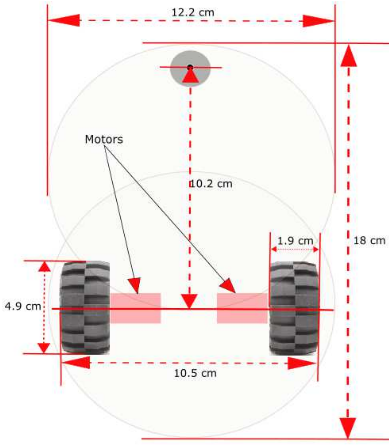
This paper exposes the results from experiments realized on a differential drive mobile robot prototype (Siegwart and Nourbaksh, 2004). A set of electronic devices was installed over the prototype to allow the driving of two DC motors and its communication with remote devices. An Arduino Mega board (Galadima, 2014) has been installed on the mobile robot structure and on that board a fuzzy logic controller which is exposed with details in (Velasquez et al., 2014) was embedded. This board receives the vehicle orientation measured by an Inertial Measurement Unit (IMU) and it is also responsible to provide the control signals to the locomotion system.

The input of the desired orientation and of the command to start or stop the prototype movement is remotely made by using a mobile application developed with App-Inventor 2 (Turbak et al., 2014) to be embedded on a mobile phone whose operational system is Android (Pereira and da Silva, 2009). Communication between the mobile phone and the mobile robot was realized using a Bluetooth device (Filipeflop, 2015). Mobile robot also has an Xbee transceiver (Faludi, 2011) which is used when it is desired to read the current information of robot performance using a remote computer.

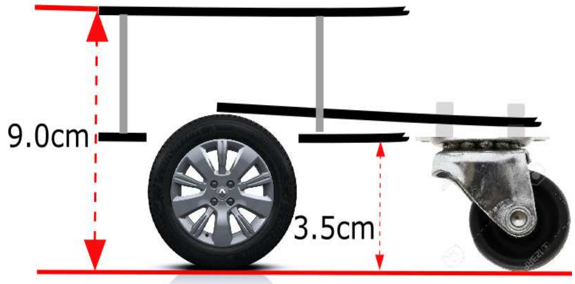
Section 2 provides a general description about the mobile robot prototype and its components. Section 3 exposes concepts regarding fuzzy logic control and its usage to realize experiments. Also the developed application with *MIT App Inventor* is exposed. Section 4 exposes the reached results. Finally, conclusions, agreements and references are presented.

2. GENERAL DESCRIPTION OF THE PROTOTYPE

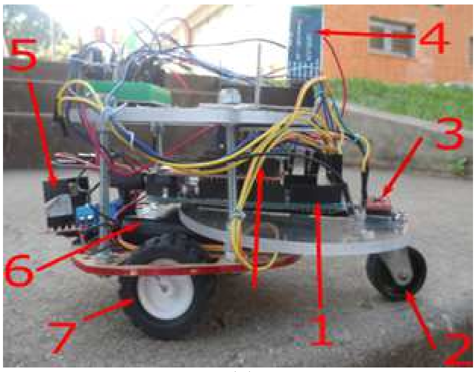
Employed mobile robot corresponds to a differential drive wheeled prototype. According to Fig. 1, the mobile robot has three circular platforms with diameter of 0.122 m. Like shown in Fig. 1(a), a caster wheel (Siegwart and Nourbaksh, 2004) supports the front platform and its center is separated 0.102 m to the rear wheels axis of the prototype. Each one of the wheels are assembled to a DC motor (Pololu, 2015). The wheels are 0.049 m in diameter and 0.019 m wide. Figure 1(b) depicts that the platform attached to the wheels is located 0.035 m high from the ground. The highest platform is located 0.09 m high from the ground.



(a)



(b)



(c)

Figure 1. Differential drive mobile robot prototype. (a) Representation of some dimensions. (b) Representation for lateral view. (c) Prototype picture depicting its components and devices

Diverse devices were installed over the platform structure. Fig. 1(c) is a picture of the build prototype and exposes the devices mounted on it: (1) Arduino board model Mega 2560 (Galadima A.A 2014); (2) the caster wheel (Siegwart and Nourbaksh, 2004); (3) an Inertial Measurement Unit (IMU) model with 9- Degrees of freedom (Sparkfun, 2015). (4) a Bluetooth module RS232 HC-05 for Arduino (Filipeflop, 2015); (5) a driver for two DC motors; (6) a 4.7Vdc and 1500 mA battery; and (7) the wheels.

2.1. Fuzzy Logic

The Fuzzy Logic tool was introduced in 1965 by Zadeh and it is a mathematical tool for dealing with uncertainty. The fuzzy theory provides a mechanism for representing linguistic constructs such as many, low, medium, often and few. In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. Real world situations are too complex, and this complexity involves the degree of uncertainty – as uncertainty increases, so does the problem complexity. Traditional system modeling and analysis techniques are too precise for such problems (systems), and in order to make complexity less daunting are introduced appropriate simplifications, assumptions, etc.

(i.e., degree of uncertainty or Fuzziness) to achieve a satisfactory compromise between the information we have and the amount of uncertainty we are willing to accept. In this aspect, fuzzy systems theory is similar to other engineering theories, because almost all of them characterize the real world in an approximate manner. For more details about the concepts related to fuzzy logic and its applications, the reader should follow the references (Velasquez et al., 2014, Sivanandam et al., 2007; Hakima and Ameli., 2010).

3. EXPERIMENTAL DETAILS

Initial results related to the working of the mobile robot exposed in this paper correspond to the executed experiments inspired on the methodology and results presented in (Velasquez et al., 2014). Basically, the experimental goal consisted in maintaining the mobile robot with a desired orientation during its forward movement.

3.1. Fuzzy Controller

Vehicle orientation control was deployed using a fuzzy closed loop control system which is represented by Fig. 3. It is worth mentioning that besides the robot structure exposed in (Velasquez et al., 2014), the entire fuzzy controller was embedded into the Arduino board.

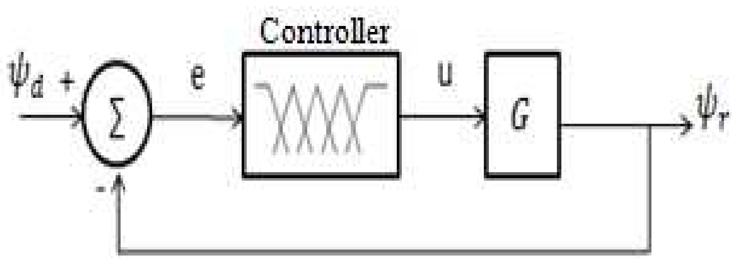


Figure 2. Block Diagram of Control System

The input (ψ_d) corresponds to the desired orientation (Yaw angle). ψ_r is a signal related to the current orientation measured by the *IMU*. The ψ_d and ψ_r are compared in order to determine an error (e) signal like shown in Eq. (1). The error signal is the input of the fuzzy controller block which calculates an appropriate control action (u) signal which will be applied on the actuators of the mobile robot represented by the (G) block.

$$e = \psi_d - \psi_r \tag{1}$$

The projected control system incorporates a fuzzy controller of one input and one output (Sivanandam et al., 2007; Hakima and Ameli, 2010). As it has been mentioned, the controller input is the error signal (e) and the controller output is the control signal (u) which is transferred to the robot actuators in order to induce a vehicle steering. The development of the fuzzy controller requires the definition of the fuzzy input and output sets, as well as the rules to relate these sets. Triangular set definitions was adopted in a similar way like was explained in (Yu and Zhang, 2008). Input Fuzzy Sets *vN (very negative), N (negative), Z (zero), P (positive) and vP (very positive)* are represented in Fig. 3 (a). The output fuzzy sets: *R (right), C (Center) and L (left)* are represented in Fig 3 (b).

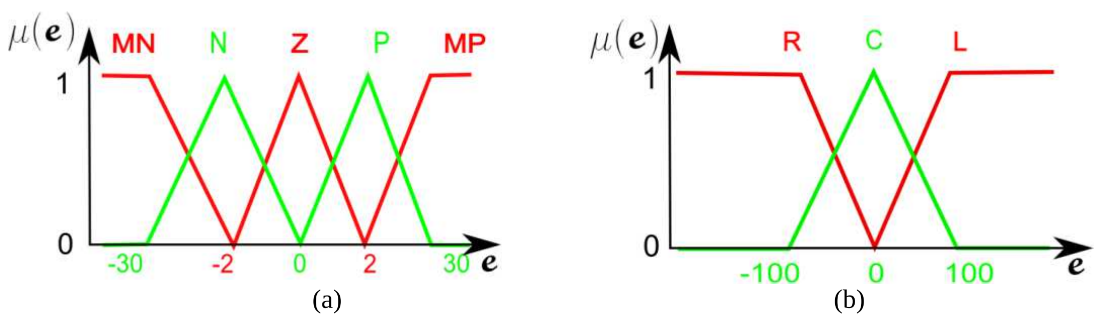


Figure 3. Input Fuzzy Logic sets

According to the fuzzy logic controller theory, it is necessary to relate the input fuzzy sets with the output fuzzy sets by rules. They were defined with respect to Eq. (1). Corresponding relation implies the development of a suitable proceeding which is explained in detail in (Velasquez et al., 2014). The referenced proceeding also was used to determine a defuzzified output.

$$\begin{aligned} &if\ e = vN, \quad then\ y = R \\ &if\ e = N, \quad then\ y = R \\ &if\ e = z, \quad then\ y = C \\ &if\ e = P, \quad then\ y = L \\ &if\ e = vP, \quad then\ y = L \end{aligned} \tag{1}$$

The defuzzified output (Z^*) is employed to decide the necessary commands to be applied. Equation (2) shows how the mobile robot steering commands are defined according to the Z^* value. Steering commands shown in Eq. (2) are sent to the Arduino board which translates them to a differential drive acting over the servo-motors

$$\begin{aligned} &if\ Z^* \le -2,\ then \quad u = Turn\,left; \\ &if\ \ -2 < Z^* < 2,\ then \quad u = go\,ahead; \\ &if\ \ Z^* \ge 2,\ then \quad u = Turn\,right; \end{aligned} \tag{2}$$

3.2. MIT App Inventor 2 App

MIT App Inventor is a blocks-based environment for creating Android mobile apps. An App Inventor project consists of a set of components and a program specifying their behavior. Components include visible user interface items (e.g., buttons, images, and text boxes) and non-visible items used in the app (e.g. camera, speech recognizer, GPS sensor). The App Inventor program is written in a blocks language. In App Inventor 1, released in 2009, the blocks editor runs as a Java Web Start application. In App Inventor 2, released in Dec., 2013, the blocks editor runs in a web browser as a JavaScript program based on the Blockly blocks framework (Turbak et al., 2014).

3.1. Software Application

An Android Application was developed in MIT App Inventor 2 in order to create a user interface to communicate the mobile robot with a mobile phone which uses the Android operational system. This application allows sending the desired orientation and turning on the fuzzy controller from the mobile phone. Moreover it shows the current orientation of the robotic platform.

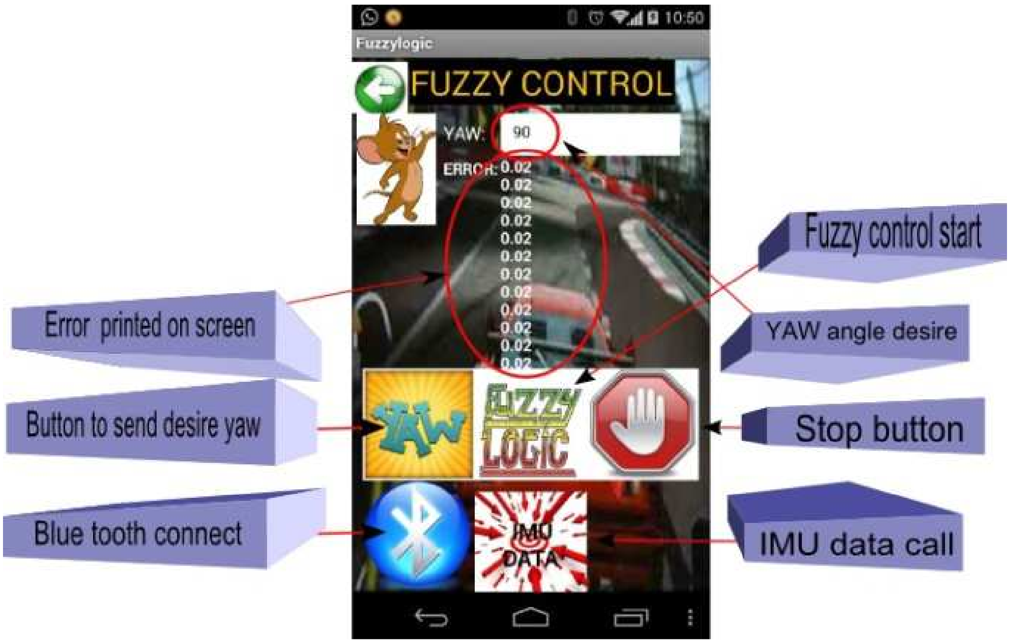


Figure 4. Visual Android Interface

Figure 4 shows the user interface which is easy to handle by anyone unfamiliar with robotics systems or fuzzy controller. This application has five buttons. The button to connect the “Bluetooth” communication is used to enable the communication between the mobile phone and the robot. The second button “*Fuzzy control start*” is used to run the fuzzy controller. The third button is “*Desired Yaw Orientation*”, which is used to inform the desired orientation to the robotic platform. The fourth button “*IMU data call*” is used to show the current orientation error on the screen of the mobile phone. Finally, the “*Stop*” bottom stops all activate processes in the robot as well as its movement.

Figure 5 shows block program used in the application which was developed with App Inventor 2. The blocks corresponding to “*Bluetooth*” depict the required processes to enable the Bluetooth communication between the android device and the robot. The blocks corresponding to “*Back*” allows returning to the main menu of the application.

When the button to send the desired *yaw* orientation in Fig.5 is touched, the block called “*Desire_Yaw*” is enabled. In this block, the application sends two values to the Arduino board; the first value is the number “*8*” which indicates that the second value is the desired orientation which has to be used by the fuzzy control system depicted in Fig. 2. When the “*Fuzzy_logic*” button is enabled, the application sends the number “9” to the Arduino board, and this number enables the fuzzy logic controller. Finally, when the button called “Stop” is enabled, the application send the number “6” to Arduino in order to stop the robot movement. When the “IMU_data call” button activate the block “IMU_data”, it first check if there are any bytes available to avoid noise data to be send to the cellular and if the Arduino is sending data, the data is plotted on the screen. The last block is “back” that send the program to a previous menu with others controllers systems to be added in future works.

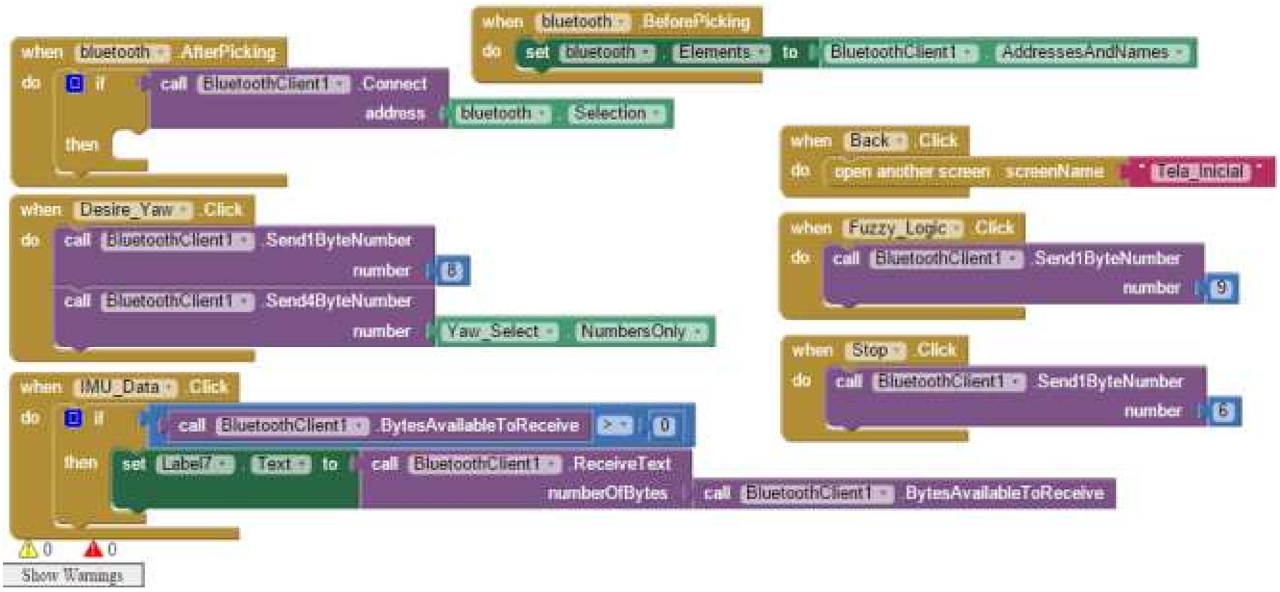


Figure 5. Routine made in app inventor 2

4. Experiments and results

The developed fuzzy controller was evaluated throughout the execution of experiments in which the prototype had to keep a desired orientation all along its forward movement. Figure 6 show reached results of the execution of four tests in which the prototype was induced to move forward over an unpaved road whereas Fig. 7 depict reached results of four similar realized tests on a paved road. According to depicted the orientation error was minimized such that the vehicle was able to keep a desired orientation even although the terrain irregularities and also a disturbance which was introduced at approximately in 10 seconds. The value of the Yaw angle was read every 100 milliseconds.

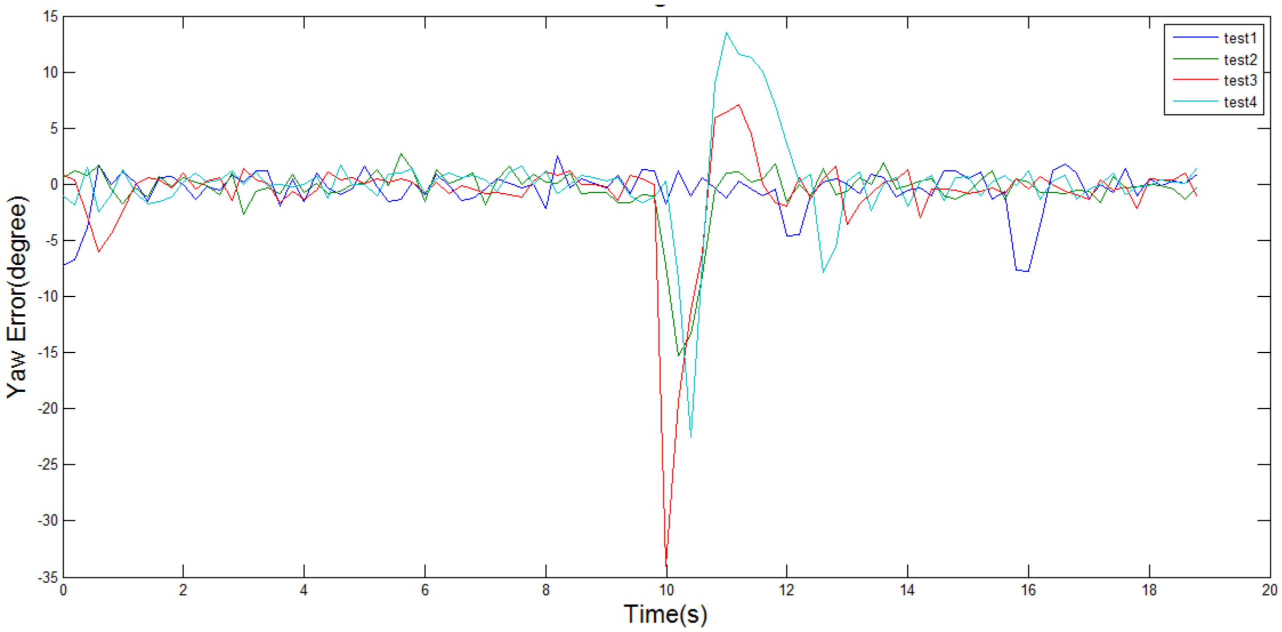


Figure 6. Results of the 4 tests made on unpaved path

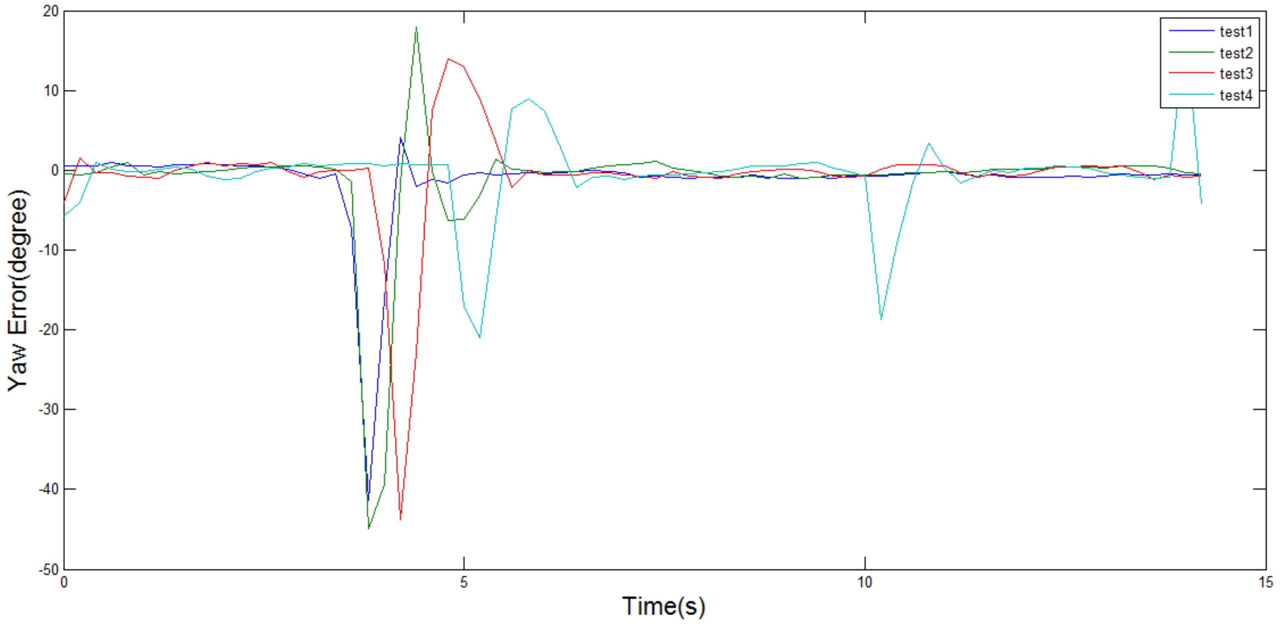


Figure 7. Results of the tests made on cement terrain

5. CONCLUSIONS

Our aim was to validate and evaluate several sensors, their respective errors and possible corrections at a low cost platform, which will be further used for coaching new students. The same knowledge obtained on controllers and tools will be applied to heavy machinery, principally in outdoor environments.

According to reached results. The assembled prototype has mechanical and electronic features that allow affirming that it constitutes itself in a suitable platform which permits the tackling of future works related to the control of differential drive mobile robots for indoor and outdoor environments.

Based on the experiments and reached results, it is possible to conclude that the fuzzy orientation controller was able to maintain the vehicle orientation during it forward locomotion even although the presence of disturbances within an acceptable performance according to the research goals.

MIT *app inventor* allows the intuitive development of apps using tactile devices like tablets and cell phones in order to deploy graphical user interfaces to control remotely diverse gadgets like the mobile robot which was exposed in this paper.

6. ACKNOWLEDGEMENTS

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