LIDAR readings based mobile robot wall-following task using a reactive fuzzy control system - A low-cost experimental approach

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Abstract - **This paper has been written to show a successful experimental approach that was undertaken to complete a review of a fuzzy control system and perception strategies based on a LIDAR (Light Detection and Ranging)and IMU (Inertial measurement unit) sensors all to undertake the wall following task for a mobile robot. For this purpose, a low-cost differential drive prototype was configured and on it, using a LIDAR and IMU sensors, a perception system was realized, aiming a study about its performance from realized experiments that will be described. Regarding the navigation task, fundamentally a reactive autonomous wall following mission was projected such that, a Mandamy Type-I closed-loop fuzzy control system was configured. The required programming part of our project was embedded on a Raspberry Pi 3B+ computer board, which supported on the Raspbian operational system based on Linux. All programmed required codes were developed using the Python programming language. Developed work was undertaken keeping in mind the consequently extensions that reported references are demonstrating as a real possibility since it is considered that wall following is the beginning stage in the area of mobile robotics navigation, which has to be dominated to take on improvements, which in the particular interest of authors consists on the reactive autonomous navigation of mobile robots among crops.**

Keywords— Computer vision, Fuzzy control system, LIDAR, Mobile robotics, wall follower.

I. INTRODUCCIÓN

According to [1], [2], mobile reactive navigation suggests making all control decisions through some light processing of the current/recent sensor data. It is suggested that the reactive approach implies less computational cost, even more, when for this paradigm the mobile robot advocates for a direct connection between sensing and action, mediated neither by heavy reasoning nor by knowledge representation (sense-act paradigm) [1]. In accordance, results interesting to undertake fuzzy logic as a control strategy. The fuzzy logic theory has been successfully adopted in control systems, since its interesting capabilities to deal with uncertainties, even in the case on nonlinear situations [3], [4], generally provides a mechanism to represent complex variables as linguistic constructs, which can be operated under math fuzzy considerations or inferencing [3], [4].

This paper has been undertaken an experimental approach in which a mobile robot prototype has been configured, incorporating a perception system based on the usage of a LIDAR as well as IMU sensors, considering that control systems, perception, and mobile robotics navigation generate an interesting mixed topic to research. The fuzzy control system with aiming at the wall following task has been developed, configuring then a reactive navigation methodology.

Section I, like read was destined for the introduction. In section II we expose detailed considerations for perception and control de mobile robots. We use section III to expose our conclusions to finally show our acknowledges and consecutively the relevant references.

II. MATHERIALS AND METHODS

In Fig 1 we show the mobile robot prototype depicting its main components. Regarding its dimensions, it is suitable to inform that the prototype is 25cm long, 20cm width, 27cm height, and its weight is 1100g. The prototype has a Raspberry PI 3B board, which had a Linux Raspbian operational system, highlighting that this device was treated as a traditional computer for which was perfectly possible to undertake all the computational aspects from traditional computer programming approaching. Additionally, Raspberry PI 3B accounts on GPIO ports which were used receive lecturers from IMU sensor and also to control de DC motors; regarding the sensors, it has been used a low-cost LIDAR well known as RPLIDAR A1, which performs an omnidirectional laser scan in a range of up to 6 meters from the environment in which it is located [6]. This sensor can be connected to the raspberry PI board via USB port connection; Also, an IMU sensor BNO055 which has 9 degrees of freedom and offers the possibility of measures tridimensional orientation. It is the connection to the Raspberry PI board is realized using I2C ports; Two 6Vd.c motors suitable coupled to reduction mechanisms are assembles to the chassis in pored to provide the maneuverability prototype characteristics; a set of suitable batteries set and an H-bridge power stage to drive the 2 motors had also been installed appropriately installed [7].

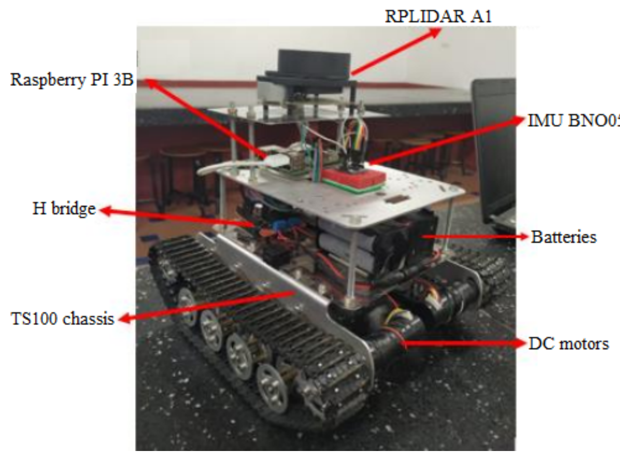

Figure 1. Mobile robot prototype

For adopted wall perception methodology, IMU sensor played a fundamental role. Since this sensor is shown acceptable performance. It delivers three-dimensional orientation measures of which only the Yaw angle is used to determine an orientation error. In accordance, the first step during experiments consisted of positioning the prototype with parallel orientation at the side of the wall to be followed. A Yaw angle is reported from IMU and stored by Raspberry PI computer as a derided orientation variable (ψ_d), such that once the vehicle moves forward, updated y measure allows a comparison to compute an orientation error ($e_\psi = \psi_d - \psi$). Orientation error is a fundamental variable used for the mode in which RPLIDAR A1 is used to determine the wall distance [7].

Wall distance determination using RPLIDAR A1 depends on the orientation error. Consequently, at first, it will be described considering $e_\psi = 0$, ergo the robot is moving forward on a parallel way to the wall. Fig. 2 shows a general representation to support the described situation. Since RPLIDAR A1 report distances to present obstacles from 0° to 360°, all reports are not necessary and, LIDAR measures are delivered to the Raspberry PI, just a limited range is considered to be used by the fuzzy controller. In this way, the project developer can define the angle value for the low threshold and the high threshold. It is suitable to keep in mind that RPLIDAR has been built such that the depicted x-axis in Fig. 2 corresponds to 0° and the rest of the positions are configured clockwise [6]. In our approach when $e_\psi = 0$ we configured our python codes such that the low threshold was 25° whereas the high threshold was 335°.

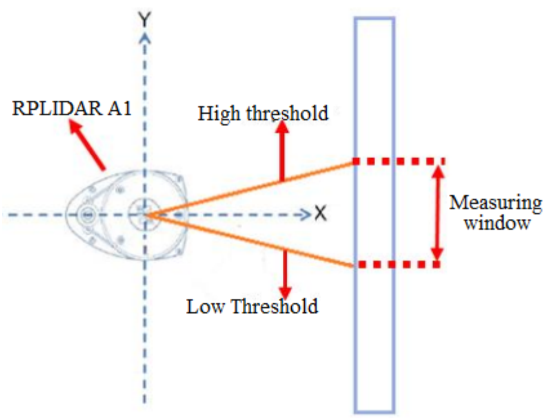

Figure 2. Window measuring $e_\psi = 0$

High and low thresholds determine the LIDAR reading to be considered. It is because between that thresholds several readings are reported. Once measures to be considered are got, the determination of wall distance is computed doing usage of trigonometrical concepts. Remembering that since $e_\psi = 0$, then abscissa projection is enough and, the average from all got projections shown acceptable results to find the wall distance when there not exist orientation error. Equation 1 indicates the mathematical determination for each one projection in which, *Dx* is each one abscissa projection, d_n is each one distance measure and α is the LIDAR angle for each d_n measurement. Equation 2 shows the average used concept, in which D is the computed wall distance, *Dx* corresponds to each one abscissa projection, *last* is a representation for the last got measurement (i.e if the last measurement was the 24th the last value will be 24) [7].

$$Dx = d_n cos(\alpha) \quad (1)$$

$$D = \frac{\sum_1^{last} D_x}{last} \quad (2)$$

Wall perception methodology also can be affected when $e_\psi \neq 0$. Figure 3 depicts a situation in which an e_ψ is happening such that the robot moves away from the wall showing $e_\psi = \beta$. Also has been depicted the solidary or own system reference to the LIDAR sensor using dashed lines for its axes and, a new reference system for which abscissa and ordinate have been indicated as X1 and Y1. In accordance, high and low thresholds must be redefined dislocating the measurement window to be considered, such that suitable calculations were computed to define an offset value regarding the orientation error. This is in particular highly helpful when the robot is at the correct distance from the wall, but it is unoriented. The determination of the distance from the wall is computed using the same previously shown trigonometrical considerations.

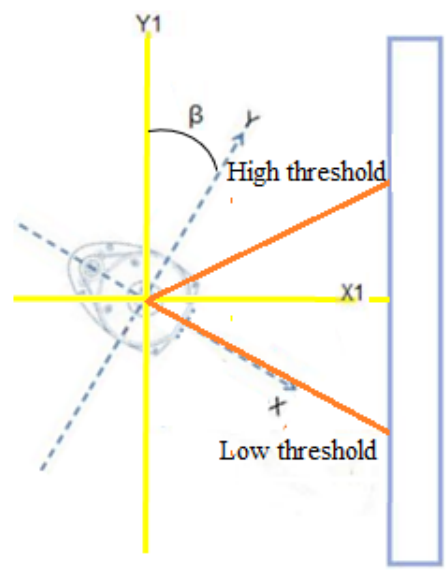

Figure 3. Window measuring $e_\psi \neq 0$

Another situation must be considered when e_ψ is such that the robot moves toward the wall. When it happens, high and low thresholds also must be redefined dislocating the measurements window, such that suitable calculations where computed to define an offset value regarding the orientation error.

A closed loop fuzzy control system was developed and incorporated to realize the wall following task. Since all computer routines were developed using python programming language, then, an input parameter is the desired distance to keep ($\boldsymbol{D_d}$) which is entered as a constant value to the computer code, whereas the measured distances ($\boldsymbol{D}$) is compared in order to get the distance error ($\boldsymbol{D_{error}}$) which an input for the fuzzy controller, as well as the orientation error ($e_\psi = 0$). Observe that desired e_ψ must be 0. Consequently, our control system considers two inputs.

The fuzzy control system demands the definition of input sets. In this way, Fig. 4 represents the fuzzy sets regarding the $\boldsymbol{D_{error}}$. The positive error means the robot is close, the negative error means the robot is far, whereas 0 error means the robot is over the desired distance. $\boldsymbol{D_{error}}$ is considered in millimeters. Figure 5 represents fuzzy sets for $\boldsymbol{e_\psi}$ which is considered in grades.

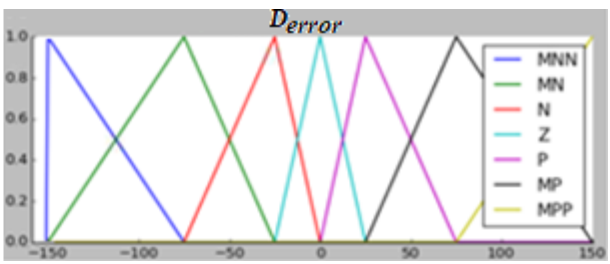

Figure 4. Fuzzy input $\boldsymbol{D_{error}}$ sets

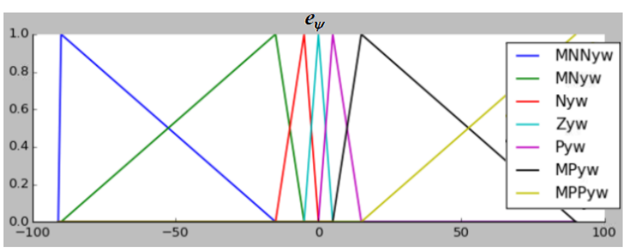

Figure 5. Fuzzy input $\boldsymbol{e_\psi}$ sets

Table 1 has been included to inform about the implemented rules, like shown we considered both inputs, $\boldsymbol{D_{error}}$ and $\boldsymbol{e_\psi}$ are included in the table as IMU and LIDAR respectively. Sets names are referenced using the nest basis: *Z* is used to indicate zero error. A *yw* suffix is concatenated when we are referring to the orientation error; *N* is for negative error, *MN* for very negative error; *MNN* for a too high error; *P* is used for positive errors; MP for very positive error; and MPP for very high positive errors in the distance. When we are referring to orientation errors, just a "*yw*" was concatenated in file heads in Table 1.

IMU/ LIDAR	MNNyw	MNyw	Nyw	Zyw	Pyw	MPyw	MPPyw
MNN	TRRR	TRR	TR	TR	DT	DT	DT
MN	TRRR	TRR	TR	TR	DT	DT	DT
N	TRRR	TRR	TR	TR	DT	DT	DT
Z	TRRR	TRR	TR	DT	TL	TLL	TLLL
P	DT	DT	DT	TL	TL	TLL	TLLL
MP	DT	DT	DT	TL	TL	TLL	TLLL
MPP	DT	DT	DT	TL	TL	TLL	TLLL

Table 1. Fuzzy control systems rules

Authors recognize that rules where perfections experimentally until all performance demonstrated an acceptable general behavior. Accordingly, it is suitable to share a video about the successful approach in [8]. From Table 1, when certain input conditions are happening, rules definite the control action to apply to the robot. For instance, when $\boldsymbol{D_{error}}$ is *Z* and $\boldsymbol{e_\psi}$ is *Zyw,* then the control action is DT (do not turn), however, when $\boldsymbol{D_{error}}$ is *MP* and $\boldsymbol{e_\psi}$ is *Zyw,* then the control action is TL (turn left). Control actions are TL (Turn left), TR (turn right), TLL and TLLL were developed to apply strong and more strong turn left actions respectively; TRR and TRRR were developed to apply strong and more strong turn right actions respectively. The developed project was realized such that the control actions must generate a differential driving of DC motors, such that TR corresponds to a soft action whereas progressively TRRR is a very strong action. A similar way was realized for actions to turn left. Since Input sets, rules, and defuzzification method was assumed using a python library known as skfuzzy [5], the defuzzification process was configured using the centroid method [3], [4], [5].

Regarding the results invite to watch the video about an experimental demonstration in [8]. Accordingly, Fig. 6 depicts reached results when an experiment to keep the robot 50 cm from the wall. According to the show, for 5 tests always distance error was close to zero.

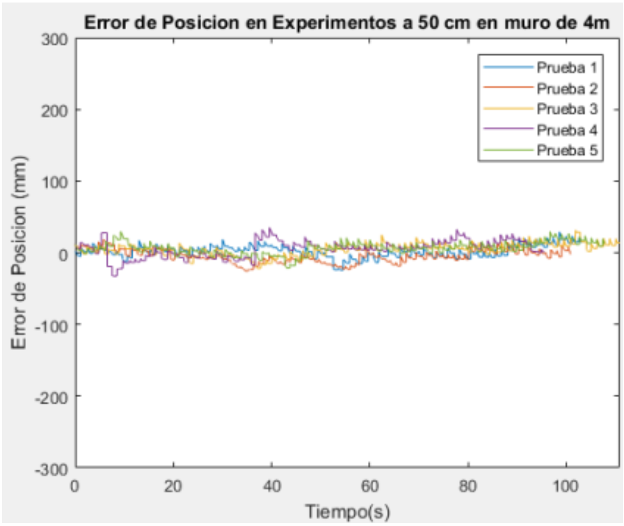

Figure 6. D_{error} during 5 tests

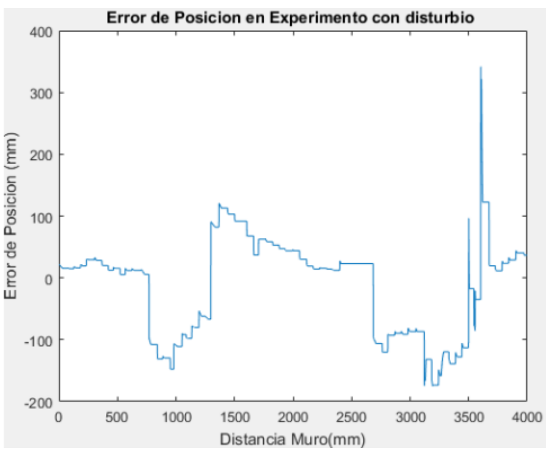

Figure 7. D_{error} response to disturbances

Figure 7 has been included to show a suitable reaction from the control system. It is shown that because of disturbances happening reported D_{error} is certainly far to the desired cero value, however, the control system reacts such that despite the prototype continuously moving forward, it can auto compensate and returns to the right position always trying a $D_{error} = 0$. It is suitable mentioning that in Fig 7 abscissa axis is used to show that this experiment was realized along 4 meters. The ordinate axis is used to show D_{error}. To highlight the reactions in front of disturbances we invite again to watch the experimental test in a video in [8].

III. CONCLUSIONS AND FUTURE WORKS

Authors have shown an experimental approach on mobile robotics reactive navigation paradigm on a low cost prototype for which was possible to develop an acceptable perception system using a LIDAR and an IMU, showing promising results to take the advantage from the configured platform to undertake in deep control systems projects from usage of this robot. Consequently, as a future work, authors propose the identification of a robot mathematical model allowing the projection of a control system using formal strategies.

Previous works demonstrated that wall following task was a first step to reach a crop following task. In this case continuous wall following has been the base for crop following. [9], [10], [11]. For the exposed work in this paper, authors also are researching to reach crop following using low cost components.

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