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# Control of non holonomic mobile robot in the presence of external disturbance

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*Abstract*— **Mobile robot is a complex system with a high non-linearity. Autonomous mobile robot must be capable to navigate in an unknown environment with high precision to ensure the safety of the user. In this paper, a kinematic model of wheeled mobile robot is introduced. Then, a fuzzy logic controller based on the least number of membership functions is implemented to insure the path following task by a non-holonomic mobile robot. Also, the behaviour of the intelligent control is investigated when the external disturbances (white noise) are introduced in the system inputs. Simulations are presented to show the performance of the controller.**

***Keywords*— tricycle mobile robot; fuzzy logic controller; goal seeking; external disturbance**

## I. INTRODUCTION

The problem of navigation for a mobile robot in which the data and the constraints are too complex, or ill-defined to establish a precise mathematical model have to be treated by approximate solutions or artificial methods such as fuzzy logic.

Current researches in this domain focus essentially on the improvement of desired skills specially the navigation task and the autonomy which means that a mobile has interaction rationally with its environment without need for a human intervention. Thus, path following is one of the basic missions of a mobile robot navigation [3]

An essential problem in autonomous navigation is the need to deal with the external disturbances and incertitude with the fact that the environment contains elements of dynamics. The techniques ability of fuzzy logic to represent linguistic terms and reliable decision making in spite of uncertainty and imprecise information makes it a very interesting solution in control mobile robot [1]-[8].

In the practical applications, mobile robot subjected to an external disturbance and noise. So, the proposed controller should be designed to be robust to cope with approximation error and external disturbances [9], [10].

The principal objective of this paper is to insure the autonomous navigation of a tricycle mobile robot in the presence of bounded unknown disturbances using fuzzy logic control. So, the proposed controller has allowed the displacement of a robot of an initial position towards any desired destination while respecting its kinematic constraints and eliminating the external perturbation. Today, the mobile robots are based on the differential drive model, in which two wheels are responsible to both drive the robot and change its direction. A controller based on fuzzy logic sends the orders of the right and left angular velocity of each wheel to the mobile robot to ensure its convergence towards the target. A Mamdani type fuzzy logic controller based on the least number of memberships has been designed on Matlab Simulink environment and Fuzzy Toolbox.

The present paper is organized as follows. In section 2, we give a brief description of the mobile robot chosen type, its characteristics and its kinematic model. Then, the fuzzy logical control is presented in section 3. The simulations and conclusions are given in section 4.

## II. KINEMATIC OF NONHOLONOMIC MOBILE ROBOT

In the interest of design controllers, a differential drive model is considered to calculate the kinematic equations of mobile robot [6], [11]. The kinematic model of a non-holonomic constraint of pure rolling and without slipping based on the configuration shown schematically in Figure 1.

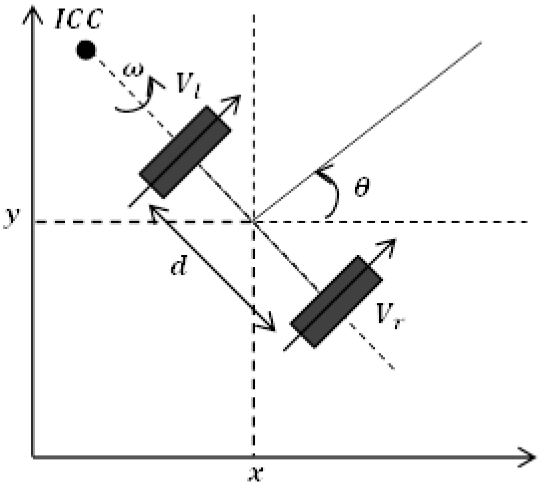

Fig. 1 Mobile Robot parameter

Where $V_r$ means the linear velocity of right wheel, $V_l$ means linear velocity of left wheel, $d$ means the distance

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between the two wheels and *ICC* means the Instantaneous Center of Curvature.

Additionally, a robot is located by its position along the X and Y the two Cartesian coordinates and its angular orientation $\theta$ taken counter clockwise from the X-axis, which constitute the posture P [12], showed by the vector (1). The angle θ is restricted within the $[-\pi, \pi]$ range.

$$P = \begin{pmatrix} X \\ Y \\ \theta \end{pmatrix} \quad (1)$$

The robot used has two drive wheels at a distance d. the linear velocities of the robot are given as [6], [13] :

$$V_r = r \times \omega_r \quad (2)$$

$$V_l = r \times \omega_l \quad (3)$$

Where r is the radius of a wheel, $\omega_r$ is the right wheel angular velocity and $\omega_l$ is the left wheel angular velocity. Or, the rear wheels move in the clockwise and anticlockwise directions.( Fig.2)

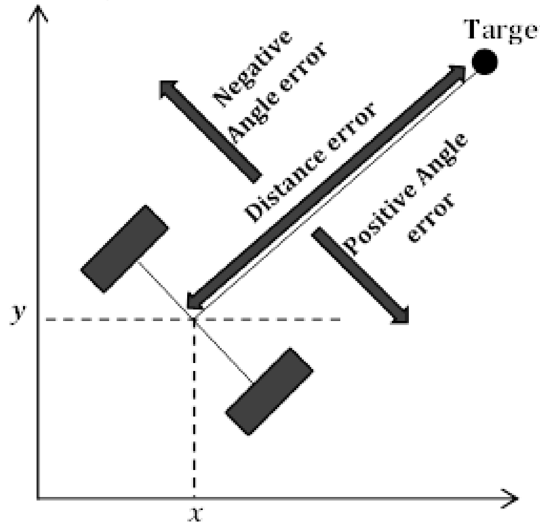

Fig. 2 Mobile Robot in Cartesian Space

The preceding equations (2) and (3) will be as follows:

$$V_r = V + \frac{d}{2} \times \omega \quad (4)$$

$$V_l = V - \frac{d}{2} \times \omega \quad (5)$$

Where V and ω present respectively the instantaneous linear and angular velocity of the robot about a point midway between the wheels respectively.

Adding Eq (4) and Eq (5), we find:

$$V = \frac{V_r + V_l}{2} \quad (6)$$

Subtracting Eq (4) from Eq (5), we get:

$$\omega = \frac{V_r - V_l}{d}$$

(7)

We developed the kinematic model [11] obtained by a simple derivation of the posture P as shown by the system of equation (8). This model is represented in the global reference system and described the velocities of the mobile robot but not the forces or torques that cause the velocity.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ \omega \end{bmatrix}$$

The vector $U = \begin{pmatrix} V \\ \omega \end{pmatrix}$ constitutes the kinematic control vector. In order to carry out path tracking control, it becomes necessary to act on the wheels of the mobile robot.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{r}{2}\cos\theta & \frac{r}{2}\cos\theta \\ \frac{r}{2}\sin\theta & \frac{r}{2}\sin\theta \\ \frac{r}{d} & -\frac{r}{d} \end{bmatrix} \begin{bmatrix} \omega_r \\ \omega_l \end{bmatrix} \quad (8)$$

These equations were used to simulate the robot in MATLAB Simulink.

The step response for each three parameters of the posture ( x, y, θ) based on state space model is shown in Fig. 3.

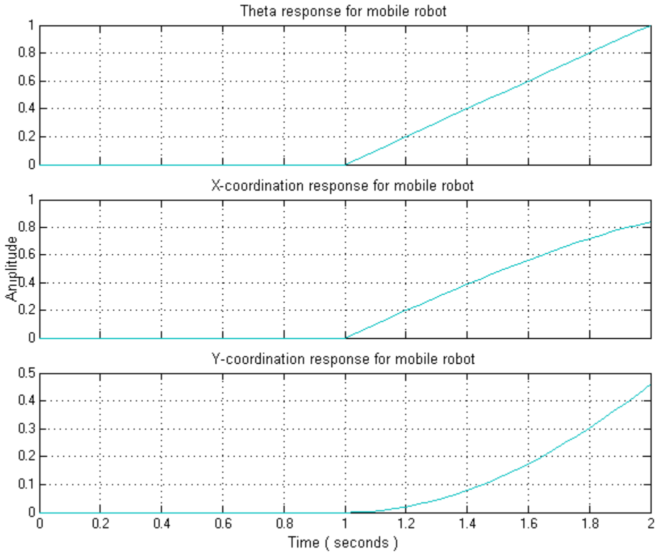

Fig. 3 The mobile robot response of the posture

## III. FUZZY LOGICAL CONTROLLER

Fuzzy Logic controller (FLC) is applied to build the control system of autonomous intelligent mobile robots. The FLC used has two inputs: error in the position and error in the angle of the robot [14].

Thus, the FLC has two outputs: right angular velocity and left angular velocity of the robot as shown in Fig. 4.

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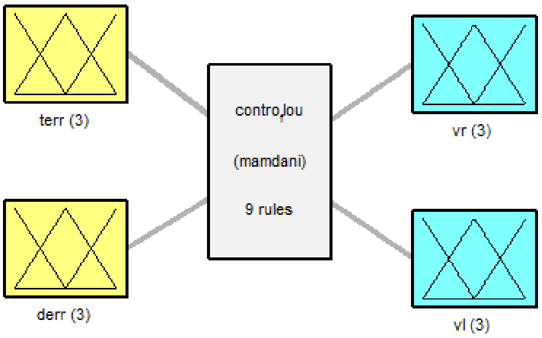

Fig. 4 Fuzzy logical control

Each control variable is normalized into three linguistic levels as presented by Table 1.

TABLE I
LINGUISTIC LEVELS FOR THE FUZZY LOGIC INPUT

| **Angle error** | **Distance error** |
|---|---|
| N: Negative | Z: Zero |
| Z: Zero | M: Middle |
| P: Positive | F : Far |

The fuzzy set value is set overlapping values represented by triangular shape that is called the fuzzy membership function. The triangular membership functions are used for their simplicity.

The output notation for making fuzzy rules is: Fast (F), Medium (M) and Slow (S).

The fuzzy memberships of the fuzzy variables are shown in Fig. 5 to Fig. 8.

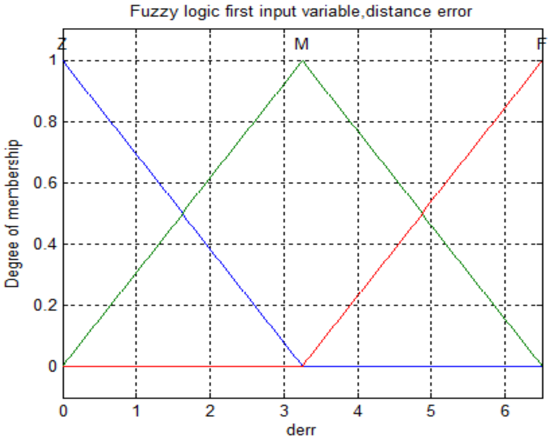

Fig. 5 Fuzzy membership functions for distance error

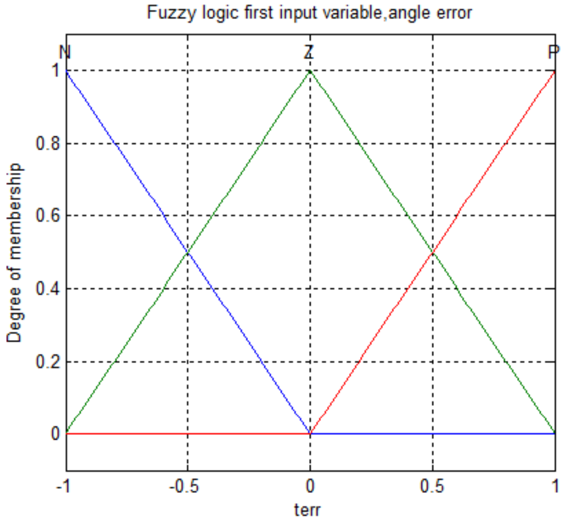

Fig. 6 Fuzzy membership functions for angle error

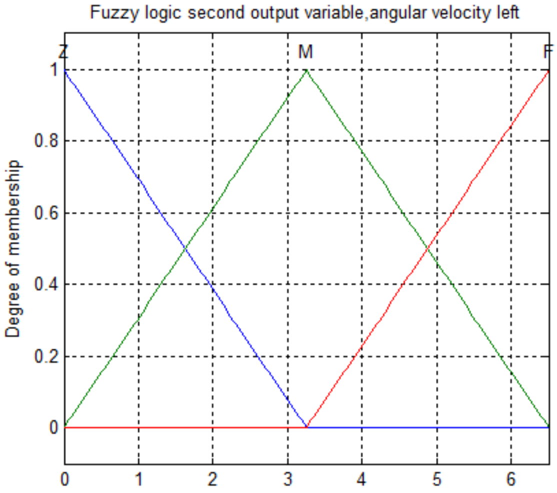

Fig. 7 Fuzzy membership function for angular velocity right

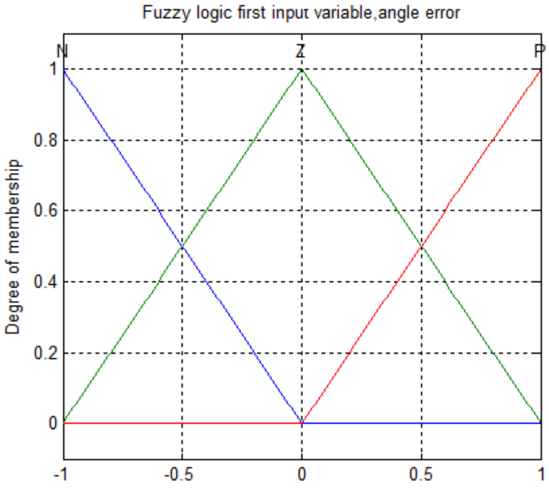

Fig. 8 Fuzzy membership function for angular velocity left

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Fuzzy logic rules for both the right and the left motor of the mobile robot are shown in TABLE II and III. Thus, there are 9 total rules for the two wheels.

TABLE II
FUZZY RULES FOR VELOCITY OF THE RIGHT MOTOR

| **Δθ/ΔD** | **F** | **M** | **Z** |
|---|---|---|---|
| **N** | M | M | S |
| **Z** | F | M | S |
| **P** | F | F | F |

TABLE IIII
FUZZY RULES FOR VELOCITY OF THE LEFT MOTOR

| **Δθ/ΔD** | **F** | **M** | **Z** |
|---|---|---|---|
| **N** | F | F | M |
| **Z** | F | M | S |
| **P** | M | M | S |

The surface of the output variable as a function of the inputs is depicted in Fig. 9 that shows the regularity of the change in the control signal [16].

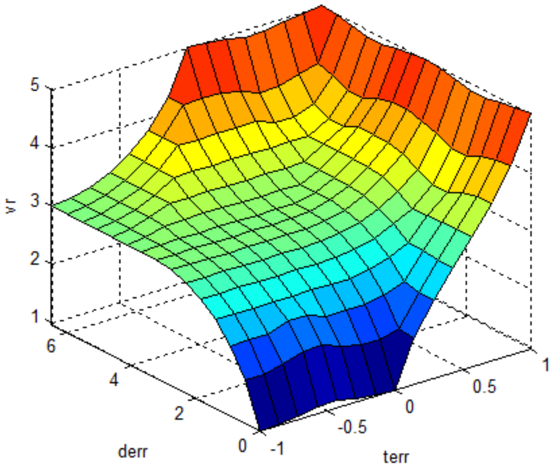

Fig. 9 Control based on angle error and distance error

The block diagram of mobile robot is shown in Figure 10

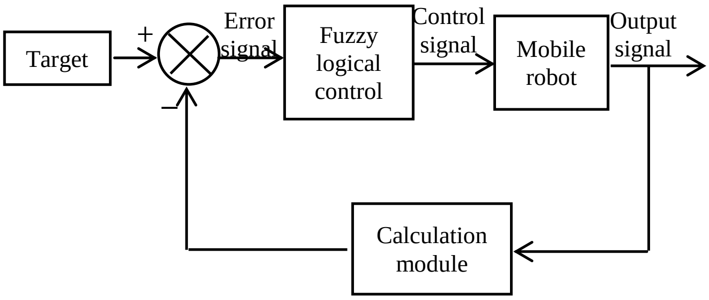

Fig. 10 Block diagram of Non-holonomic mobile robot

In our case, we have chosen Mamdani Fuzzy Inference Systems with two inputs and two outputs.

The calculation module compares the actual robot coordinates with the coordinates of the target and computes the desired orientation $\theta_T$ and the angle error $\theta_{TR}$ between the actual current orientation $\theta$ and the desired orientation $\theta_T$, are given by equations (3) (4), respectively

$$\theta_T = \tan^{-1}\left(\frac{Y_T - Y}{X_T - X}\right) \qquad (3)$$

$$\theta_{TR} = \theta_T - \theta \qquad (4)$$

The distance of robot to the desired position or the target is expressed as:

$$D = \sqrt{(X_T - X)^2 + (Y_T - Y)^2}$$

Where the vector $\begin{pmatrix} X \\ Y \\ \theta \end{pmatrix}$ represents the current position and orientation of the robot.

The vector $\begin{pmatrix} X_T \\ Y_T \\ \theta_T \end{pmatrix}$ represent the desired position and orientation of the robot.

## IV. SIMULATION AND RESULTS

The key of this application is the implementation of a controller based on fuzzy logic. The Fig. 7 shows the simulink model of the mobile robot.

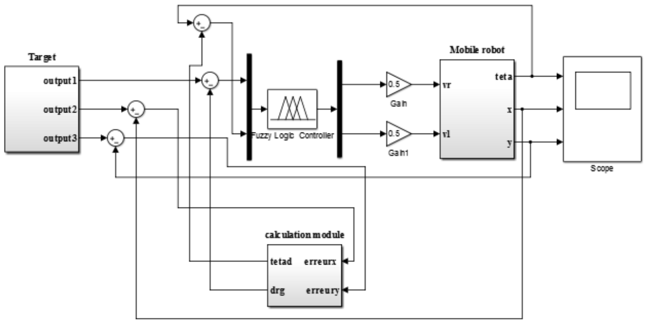

Fig. 11 Simulink model of the mobile robot

Recent research proved that Fuzzy logic controller with input membership of three has the best performance [16].

In order to verify the robustness of the proposed controller based on the least number of membership functions, different situations are chosen such as free space without and with disturbances. In the different cases, the robot task is to move from a given current position $(X = 0\,m, Y = 0\,m)$ to a desired goal position $(X = 20\,m, Y = 14\,m)$ in a free environment.

### A. *First case: Continuous case and without perturbation*

Fig. 12 shows that in simulation the robot moves from its initial position toward its final destination $(X_T = 20m, \quad Y_T = 14m)$. The desired goal is achieved correctly. The results verify the effectiveness of the proposed controller.

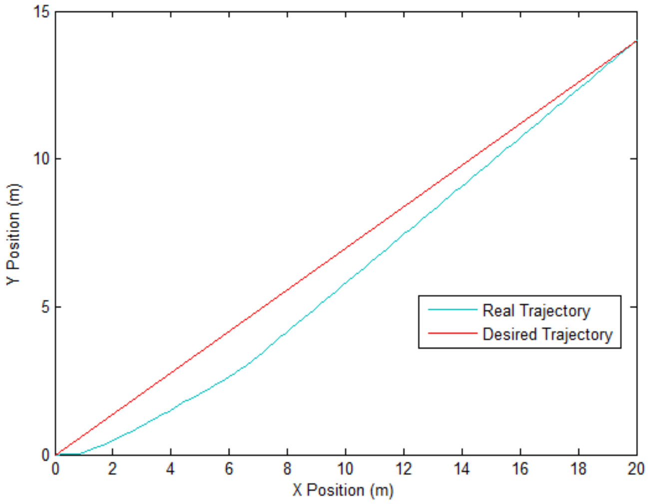

Fig. 12 Navigation of mobile robot without obstacles and disturbances

Fig. 13 shows the evaluation and the limitation of the three coordinates which describe the mobile robot.

As depicted, the control variables are bounded so the proposed controller ensures system stability.

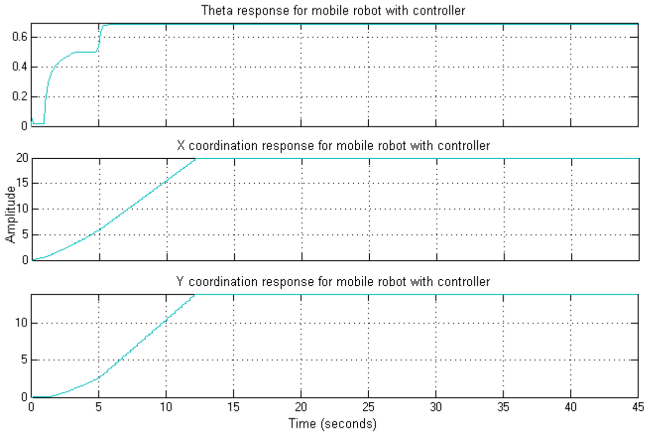

Fig. 13 The evaluation of three parameters without disturbances

The control variables (speed of left and right wheels) are progressed to reach the saturation then declined to zero.

Fig. 14 shows the control values as a function of time.

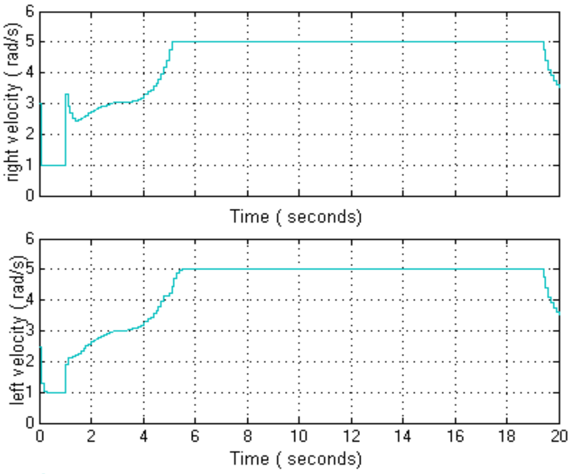

Fig. 14 The evaluation of control variables

Fig. 15 shows the errors as a function of time.

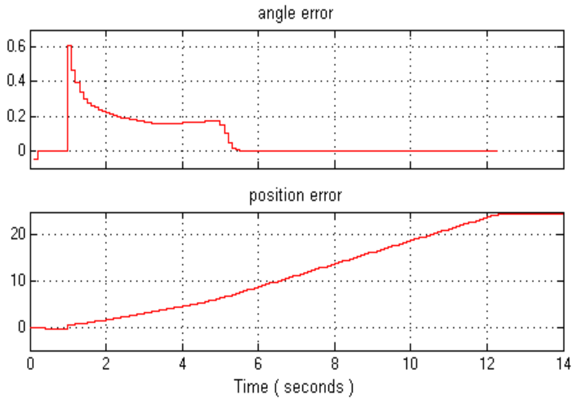

Fig. 15 Plots of error signals

### B. *Second case: continuous case with presence of disturbance*

To confirm the relevance of the proposed control, it is proposed to simulate a mobile robot navigation to reach a target in presence of disturbance. The process and measurement noise are used the Simulink block diagram as white noise. The Simulink model with external disturbance is shown in Fig 16.

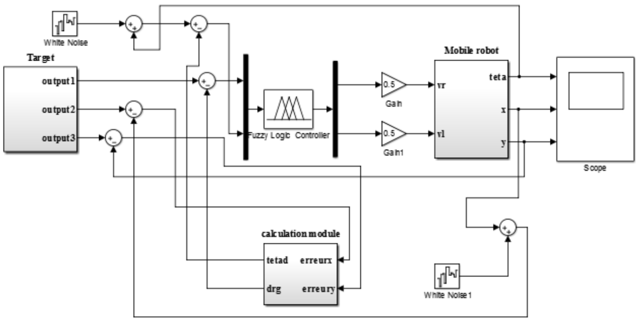

Fig 16 Simulink model of the robot with presence of disturbance

The simulation results in the presence of disturbances are given from Fig.17 to 20.

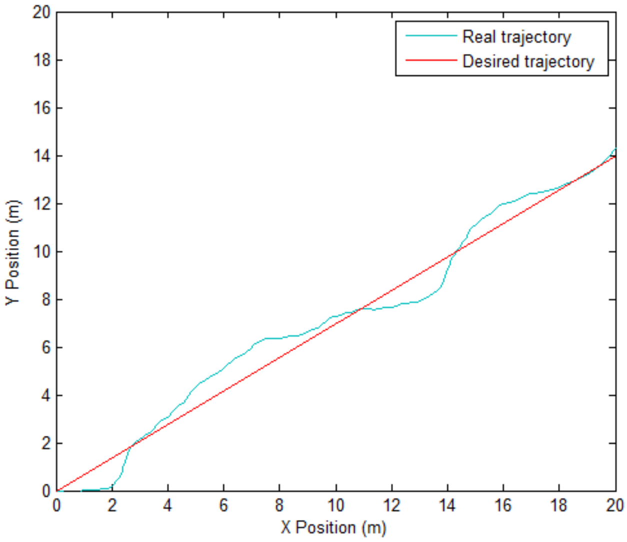

Fig. 17 Navigation of mobile robot in the presence of disturbances

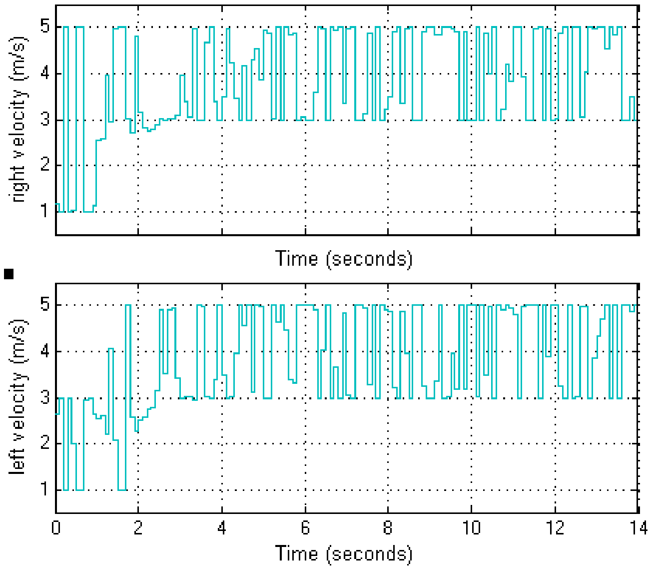

Fig. 18 The evaluation of control variables in the presence of disturbances

The plot in Fig. 18 shows the velocities as a function of time.

As depicted, the robot is capable of reaching correctly its final destination.

Simulations show the effectiveness of the proposed controller for rejection of disturbances.

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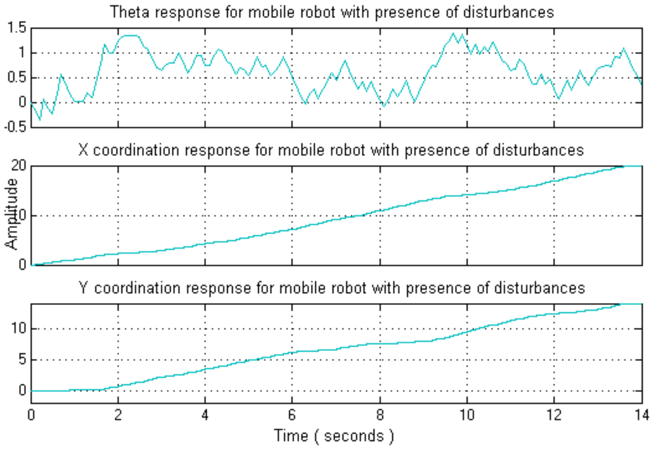

Fig. 19 The evaluation of three parameters in the presence of disturbances

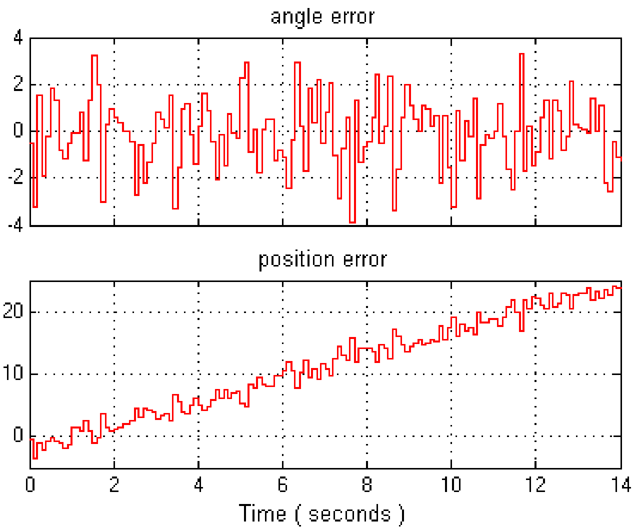

Fig. 20 Plots of error signals in the presence of disturbances

## V. CONCLUSIONS

In this paper, a fuzzy controller based on the least number of membership functions to solve the mobile robot navigation has been presented. The fuzzy logic rules were optimized for the best results. In this work, we have shown the proposed controller can be used in a successful and simple way of the autonomous navigation to deal with external disturbances. The simulation result has been shown that the designed controller can eliminate effect of white noise. In all cases, the robot is able to move from its initial position to the goal. It has also been shown that the convergence and the boundedness of all signals in the system. In future, the membership functions could be changed to have a more smooth control response.

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