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IMPLEMENTATION OF A FUZZY CONTROLLER FOR THE NAVIGATION OF A MOBILE ROBOT IN DIFFERENT ENVIRONEMENTS

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Abstract: *This article discusses the navigation of a mobile robot in different environments. The aim is to develop a comprehensive method for controlling a robot to reach a target while avoiding unexpected obstacles using the least possible means in terms of sensors and computing power. The approach developed is based on the fuzzy logic method that calculates the required parameters automatically. In our case, we choose to work on universes of discourse normalized, partitioned into five classes (in fuzzy sets) for inputs and outputs. The location and the displacement of the robot from an initial position to any desired destination, while respecting its kinematic constraints, are implemented in real time by using the data of the incremental sensors. A controller based on the fuzzy logic, sends speed commands and steering to the robot to ensure its convergence to the target while avoiding obstacles in its path.*

Key words: *Mobile robot, navigation, obstacles avoidance, fuzzy logic.*

1. INTRODUCTION

During its mission, a mobile robot develops laws controls and makes decisions based on the knowledge of environment. Data from various sensors onboard the mobile robot is sometimes imprecise, unreliable and sometimes missing which affects the goal he must reach [1 and 2].

To be useful in the real world, robots need to move safely in unstructured environments and achieve their given goals despite unexpected changes in their surroundings. The environments of real robots are rarely predictable or perfectly known so it does not make sense to make precise plans before moving. The robot navigation problem can be decomposed into the following two problems (Ratering (1995).

- *Getting to the goal*: This is a global problem because short paths to the goal generally cannot be found using only local information. The topology of the space is important in finding good routes to the goal.
- *Avoiding obstacles*. This can often be solved using only local information, but for an unpredictable environment it cannot be solved in advance because the robot needs to sense the obstacles before it can be expected to avoid them. In previous research, robot collision avoidance has been a component of high level controls in hierarchical robot systems.

To ensure the safety of the robot, it is necessary that it navigates without collision with obstacles in its environment. This navigation requires intelligent control strategies able to overcome the uncertainties presented by the real world [3 and 4].

Control of mobile robots is classified in the category of problems which are too complex [5]. Typically these systems use ultrasonic sensors; the sensors do not have a capability of accurate detection.

Techniques of artificial intelligence based on fuzzy logic are considered as very interesting solution for nonlinear systems where it is difficult to establish a mathematical model [6].

Fuzzy logic provides a better way to automate the human expertise [7], thus saving time and memory space. Experiments have shown that a fuzzy controller provides superior results than conventional controllers, and sometimes even better than the human operator.

Fuzzy logic has proved its effectiveness in the management of uncertainty and / or incompleteness of data, making it a simple and robust tool suitable to treat these problems [8].

In this paper, our goal is to demonstrate the feasibility of this approach for obstacle avoidance of a mobile robot using a minimum of equipment.

2. ROBOT BEHAVIOR

The fundamental principle of the reactive navigation of an autonomous robot is the collision avoidance with fixed obstacles (first performance) and moving toward the target (second behavior). The fuzzy controller is applied to achieve the reactive behaviors.

The simulated mobile robot is a circular platform with three infrared telemetry sensors. The distances to obstacles (*dG*, *dF* and *dD*) are provided by sensors (left side, front and right side) respectively, as shown in Fig. 1, where:

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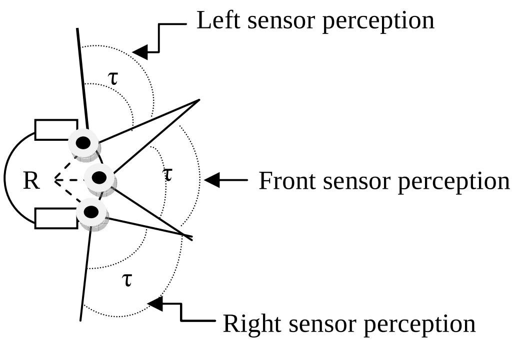

Fig. 1. Representation of the simulated robot.

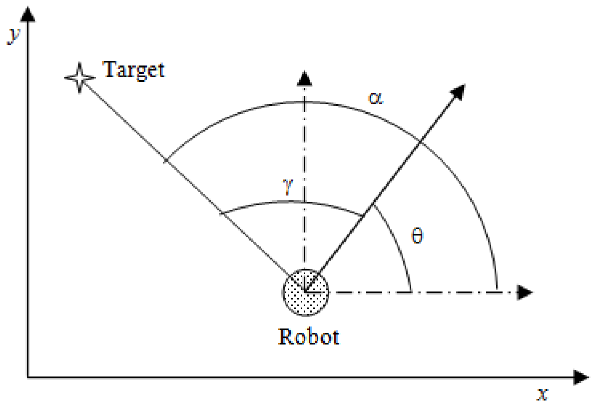

Fig. 2. Robot and target representation.

τ is the opening angle of the infrared sensor;

R – is the robot platform.

The position of the robot at a given time is given by the following kinematic equations:

$$\begin{cases} X(t) = X(t-1) + V(t)\cdot\cos(\theta(t)) \\ Y(t) = Y(t-1) + V(t)\cdot\sin(\theta(t)) \end{cases}, \quad (1)$$

with

$$\begin{cases} \theta(t) = \theta(t-1) + \Delta\theta \\ V(t) = V(t-1) + \Delta V \end{cases}, \quad (2)$$

θ – the orientation angle of the robot;

V – robot speed.

The relative position between the robot and the target is denoted γ (Fig. 2).

$$\gamma = \alpha - \theta\,. \quad (3)$$

3. CONTROL SYSTEM ARCHITECTURE

The navigation system comprises a location system of the environment (sensors) and a reactive fuzzy controller which has as input the distances to the obstacles *dG*, *dD* and *dF* (left, front and right distances) respectively, the relative position of the robot to the target *d* and γ the angle between the direction of the target and the orientation of the robot. Figure 3 shows the basic structure of the navigation system which consists of an orientation and a speed fuzzy controller [9].

From the input data and the fuzzy inference mechanism based on rules extracted from the human experience, the controller must deduce the orientation of the robot and its speed.

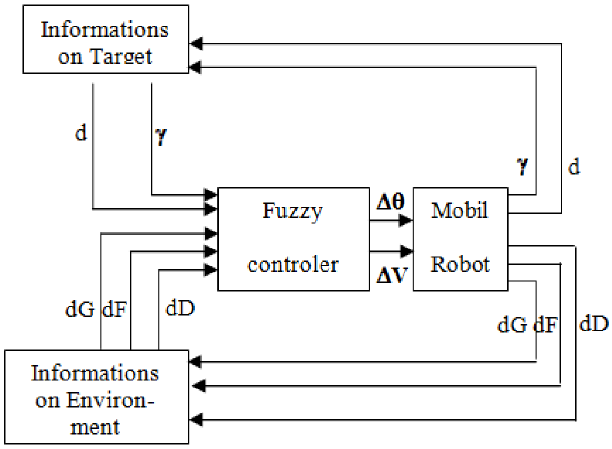

Fig. 3. Reactive fuzzy controller structure.

The outputs of the controller are:

a) The variation of the orientation angle of the robot Δθ.

b) The speed variation of the robot Δ*V*

4. FUZZY CONTROLLER DESCRIPTION (FUZZYFICATION)

4.1. Orientation fuzzy controller

Fuzzy controllers guidance receive as inputs the distances measured by the left, front and right sensors

The distances *dG*, *dF* and *dD* are evaluated against to the two fuzzy intervals characterized by linguistic variables (fuzzy) *P* and *L* respectively near and far as shown in Fig. 4.

The angle of orientation of the target relative to the robot γ is represented by five fuzzy intervals: *gg* (great left), *gp* (left small), *Z* (zero), *dp* (right small) and *dg* (wide right) covering the half front space of the robot as shown in Fig. 5.

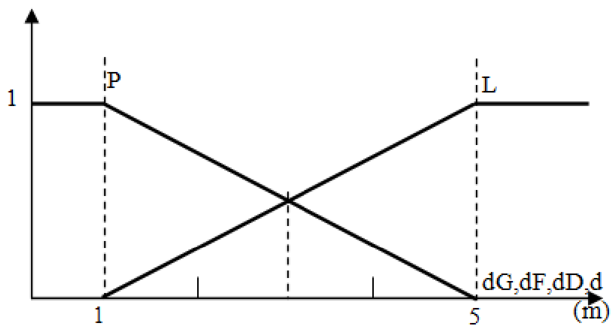

Fig. 4. Membership function of the sensor inputs.

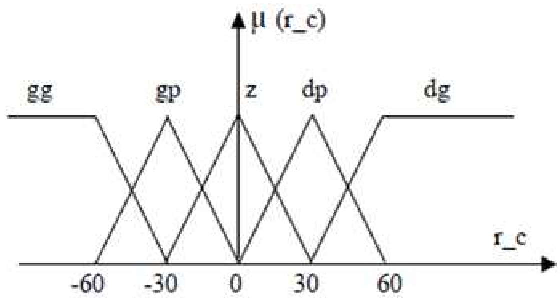

Fig. 5. Membership function of the orientation.

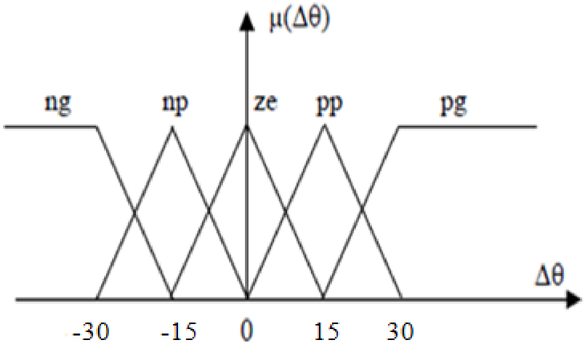

Fig. 6. Membership function of the output.

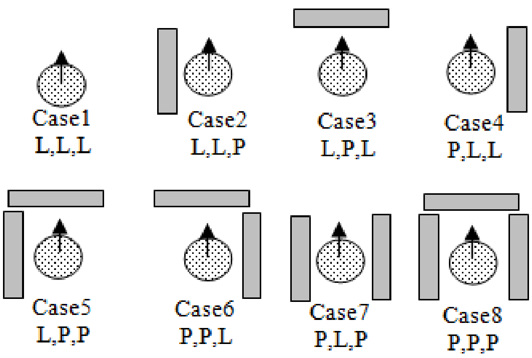

Fig. 7. The eight basic situations.

The output variable Δθ (orientation angle of the robot) is represented by five fuzzy sets: *ng*, *np*, *z*, *pp* and *pg*, with a maximum angle variation of 30° (Fig. 6).

Where *ng*, *np*, *z*, *pp*, *pg* represent negative big, negative small, zero, positive small and large positive for the values of the orientation angle variation, respectively.

The information provided by the sensors, allows the robot to recognize eight situations (Fig. 7).

4.2. Speed fuzzy controller

The speed variation is described by five fuzzy sets in: *a_ng*, *a_np*, *a_ze*, *a_pp* and *a_pg*, indicating a large and a small decrement, no change, and a small and a large increment of the robot speed (Fig. 8).

The robot moves towards the target according to a strategy defined by the first situation where the robot is away from obstacles. When the robot approaches the fixed obstacles the control of the robot uses the strategy of obstacles avoidance, defined by the last seven basic situations as shown in Fig. 7 (at least one distance is small P).

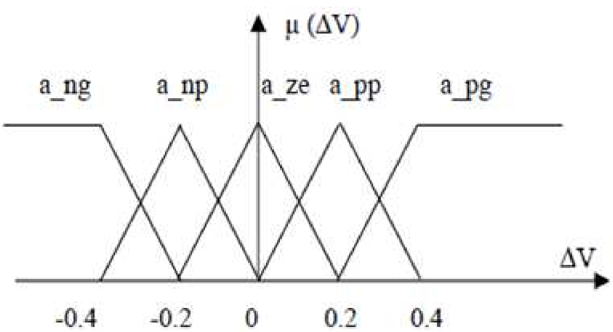

Fig. 8. Membership function of the speed variation ΔV.

The fuzzy inference mechanism evaluates the premise of each rule activated by the minimum membership degrees of the inputs rules. If several rules give the same output we choose the minimum of each one and then we take the maximum of all minimums.

5. DEFUZZYFICATION

After having established the membership functions and established the inference rules defining the behavior of the controller, we go to the defuzzification step. This allows transforming the values of the fuzzy control domain to the real domain (physical variables). We opted for the defuzzification method called *method of weighted average*, this choice is usually conditioned by a compromise between the ease of implementation and computational performance [10].

Each output of the controller is obtained by the defuzzyfication method called "weighted average".

$$\begin{cases} \Delta\theta = \sum_{i=1}^{n}(\alpha_i \cdot D_i) ... \sum_{i=1}^{n}\alpha_i \\ \Delta V = \sum_{i=1}^{n}(\alpha_i \cdot C_i) ... \sum_{i=1}^{n}\alpha_i \end{cases}, \quad (4)$$

where:

$$\alpha_i = \begin{Bmatrix} \text{Min } (\mu(dG), \mu(dF), \mu(dD), \mu(d), \mu(\gamma)) \\ \text{Max } (\text{Min } (rules\ L)) \quad L = 1, ..., m \end{Bmatrix}, \quad (5)$$

with

D_i – physical parameter of the robot orientation Δθ for $\alpha_i(\mu^{-1}(\Delta\theta))$;

C_i – physical parameter of the robot speed ΔV for $\alpha_i(\mu^{-1}(\Delta V))$.

$\mu(dG)$, $\mu(dF)$, $\mu(dD)$, $\mu(d)$, $\mu(\gamma)$ are the membership functions of the distances, left, front, right, to the target and the orientation angle, respectively;

μ^{-1} – reverse function of μ.

6. IMPLEMENTATION OF THE PROPOSED SYSTEM

We opted for a circular platform of the robot, allowing it to turn on itself without hitting the obstacles. The robot has a displacement device consisting of two driving wheels independent and a free wheel for balancing. Three infrared sensors with a minimum sensing distance of one centimeter are mounted above. One of them is frontal and the two others are lateral to ensure the system a perception covering the front half plane (Fig. 9).

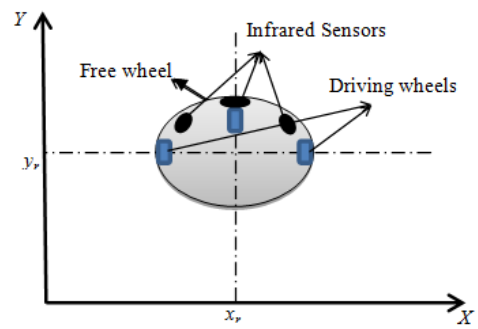

Fig. 9. The mobile robot description.

If the robot does not receive any information from sensors during its movement, it considers that the path is clear and that there are no obstacles, in this case the robot moves to the target until that an obstacle is detected by one of the sensors. At this point, the trajectory is modified by the fuzzy controller of obstacle avoidance.

The robot must respond in "real time" by running a reflex action to stop and go around the obstacle so as to reach the target.

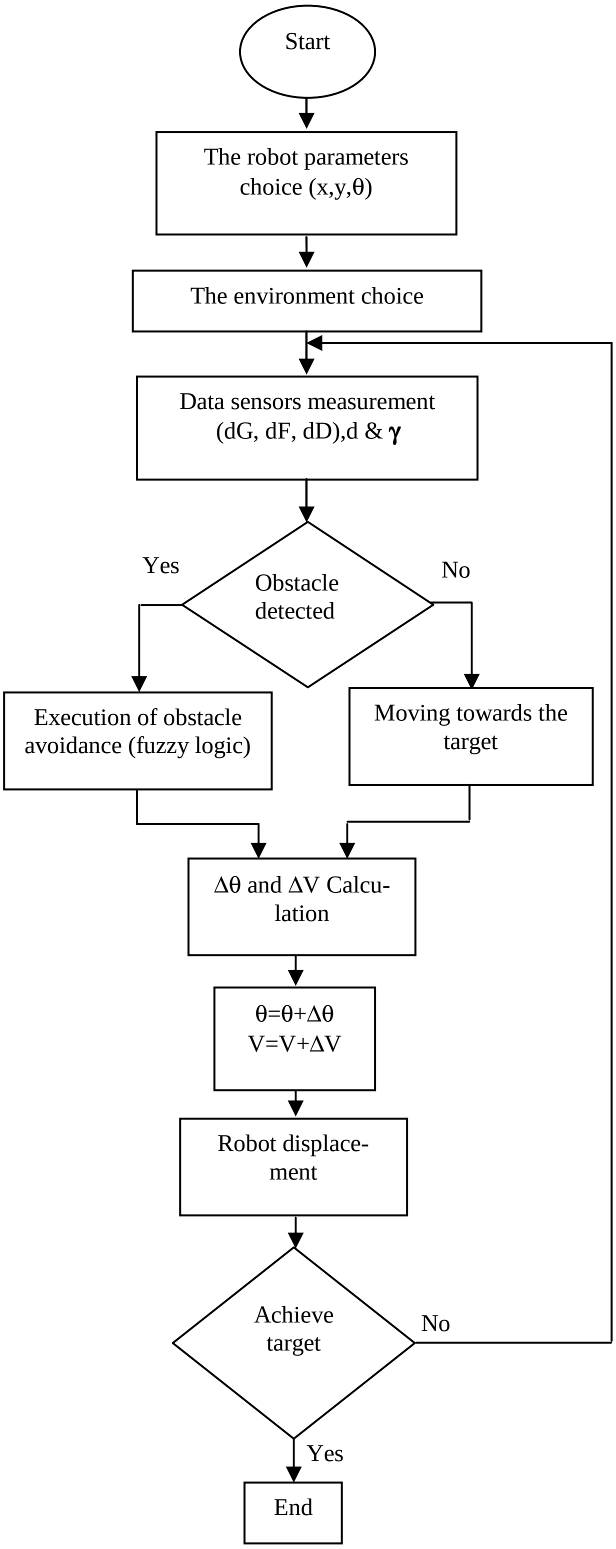

Fig. 10. Algorithm Implementation of the proposed system.

The Fig.10 represents the algorithm which we established for our simulations. It consists on, at first to upload an environment among those already developed, to positioning the mobile robot and give it an initial random orientation θ and an initial velocity. Once the mobile robot is placed we put the target somewhere in this environment.

When moving, the right, front and left sensors transmit information's on the presence or absence of obstacles. In case of free field the robot continues its course until it reaches the target. Otherwise it should have to avoid the obstacle by getting around it in changing its orientation with Δθ and its speed with Δ V so as not to collide with the obstacle and this is where the role of fuzzy controller with these steps of fuzzyfication and defuzzyfication.

7. SIMULATION RESULTS

The simulation results of mobile robot navigation materialized by a point are shown in Figs. 11–14. We used different environments in order to see the reactivity of the robot to obstacles with different shapes and to verify the robustness of the method used.

In Fig.11 the robot moves in an environment with obstacles and during its movement the action of the sensors are shown as, the left in red, the green for the front and the right sensor in blue .

It is clear that the left sensor has detected an obstacle and this is where the concept of Near (P) and far (L) comes in and the fuzzy controller acts to avoid the obstacle which is on the left of the mobile robot.

In Fig. 12 we chose an environment with obstacles regularly shaped (rectangular and square).

Let us note that the mobile robot has avoided the obstacles on his path without colliding with them with some safety margin, to finally reach the target.

It should be noted that the positions of the robot and the target are not always taken in the same places but we change them at each simulation so as to avoid that the fuzzy logic will not be confused with a learning algorithm.

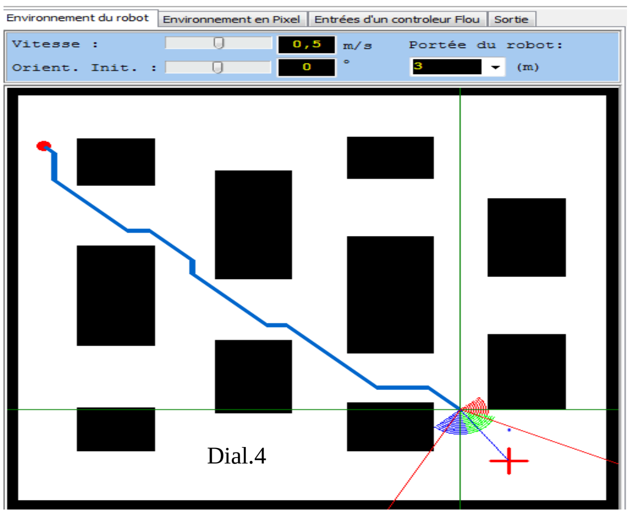

Fig. 11. Representation of the mobile robot navigation.

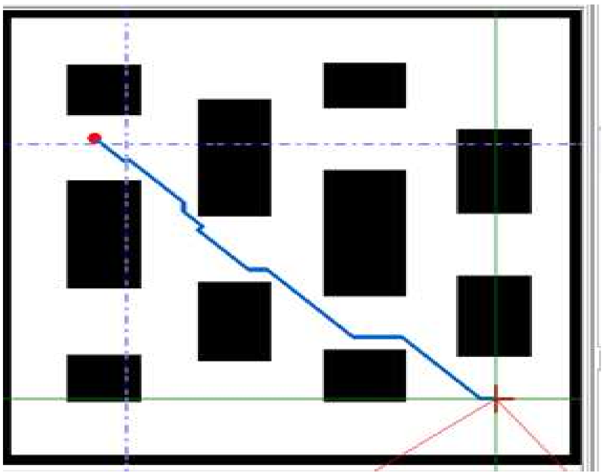

Fig. 12. Simulation of navigation in an environment with obstacles regularly shaped.

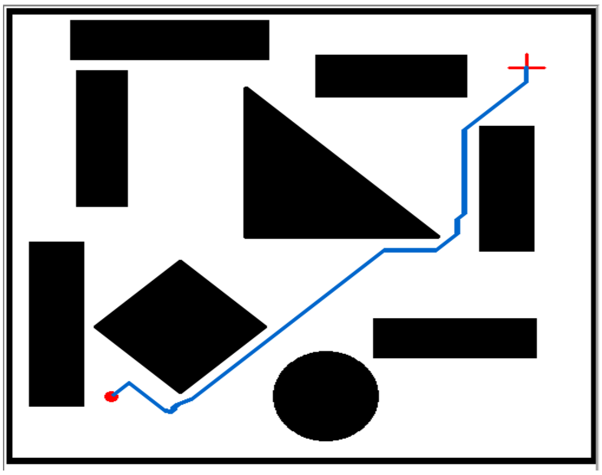

Fig. 13. Obstacles with different shapes.

In Fig. 13 we varied their forms (rectangular, square, triangular and circular), even for to show the reaction of the robot with these obstacles and to show the advantage of using fuzzy logic method.

In Fig. 14, we chose to test the simulation with an environment consisting of a labyrinth.. This case is more complicated because the obstacles can be in wedge (see 5.6 and 8 cases in Fig. 7), the decision-making is difficult and there is a risk that the mobile robot stops.

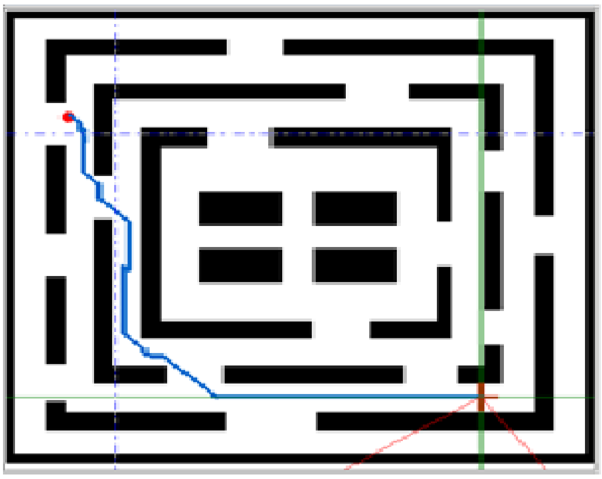

Fig. 14. Robot navigation in a labyrinth.

Using the C ++ builder, we performed a graphical interface that allows us to view our various parameters during the simulation and to see them in different quadrant (see Fig. 15).

Figure16 represents the Dial.1 with its different push buttons to visualize the different parameters during the simulations.

So if you press the push bottun.1 it will appear on, the instantaneous coordinates of the mobile robot as well as those of the target. We can also follow the instantaneous speed, the angle α between the target and robot and the value of the variation of the orientation angle Δθ (see Fig. 17).

The push buttons 2, 3 and 4 make it possible to see the graphs plots of the distance sensors, the change in the orientation angle and the speed variation during simulation (Fig. 18).

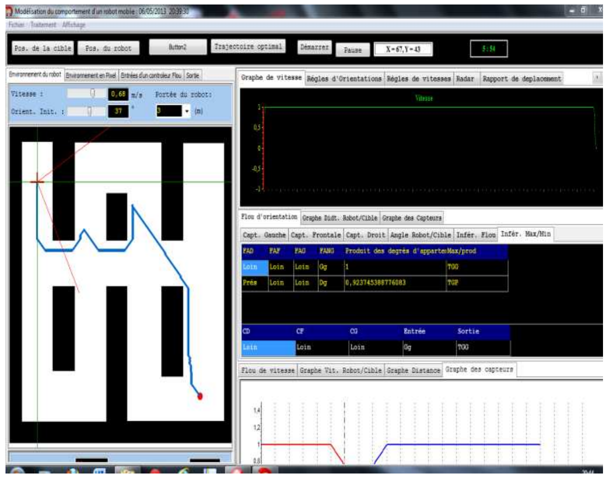

Fig.15. Graphical interface of the simulation.

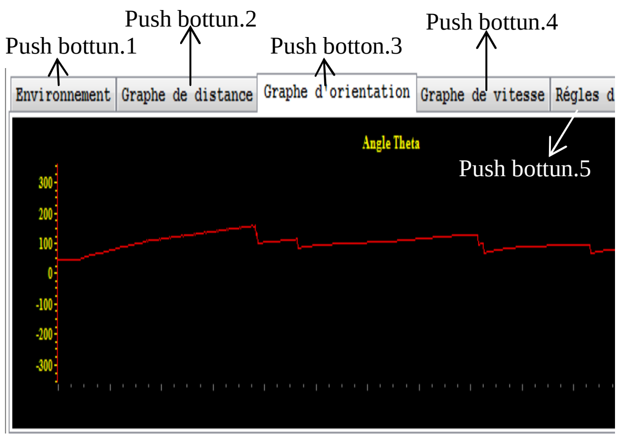

Fig. 16. Representation of the dial 1 with its various functionalities.

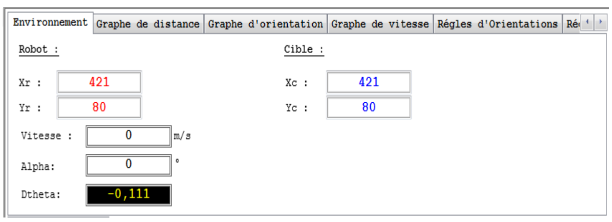

Fig. 17. Representation of the environment.

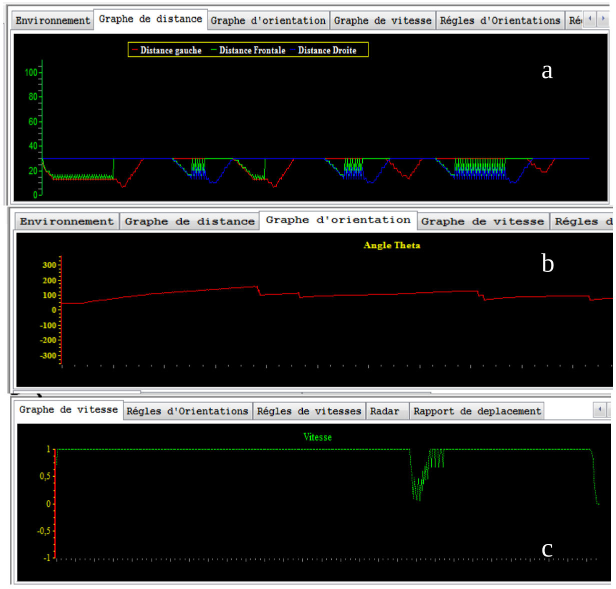

Fig. 18. Graphs of distance sensors, orientation and speed.

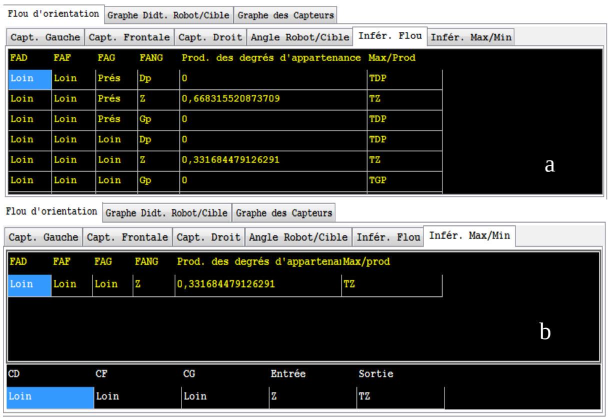

Fig. 19. The Dial.2 representation.

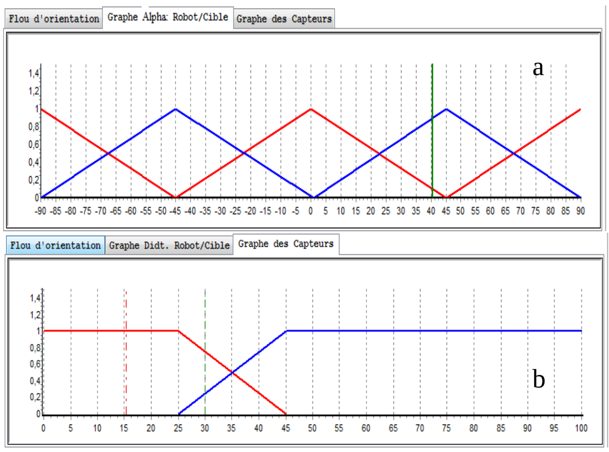

Fig. 20. Member ship function of alpha and the distance sensors.

The Dial 2 shows the various fuzzy inference rules during simulation (Fig.19,*a*.), calculates the product of membership degrees and displays the output ($\Delta\theta$). In Fig. 19,*b* the minimum of the maximum degrees membership is displayed in accordance with the selected method of the weighted average.

The Dial.3 represents the membership functions of the rules alpha and theta (see Fig. 20).

8. CONCLUSIONS

In this article we presented the path planning and navigation simulation of mobile robot using fuzzy logic controller. We have developed a fuzzy controller with five inputs representing the target location and the obstacles relatively to the robot and two outputs representing the variations of speed and orientation of the robot to reach the target. Its inference mechanism contains eighty rules involving all possible situations in which the robot can be.

The simulation results as shown in Fig.12, 13, 14 and 15 of the robot command by the fuzzy controller are very satisfying. The robot can reach the target in any environment while avoiding fixed obstacles with different shapes.

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