PATH FOLLOWING BEHAVIOR FOR AN AUTONOMOUS MOBILE ROBOT USING FUZZY LOGIC AND NEURAL NETWORKS

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ABSTRACT

In order to achieve tasks by the mobile robots, these robotic systems must have been intelligent and should decide their own action. To guarantee the autonomy and the intelligence for the path following behavior, it is necessary to use the techniques of artificial intelligence like the neural networks and the fuzzy logic. This paper presents an approach for the path following task by an autonomous mobile robot using neural networks and fuzzy logic controllers. The first controller is a Takagi-Sugeno fuzzy model and the second is a multi-layer neural network. The proposed controllers are used for pursing a moving target. The results are compared and discussed.

KEYWORDS: mobile robot, path following, neural network, fuzzy controller, moving target pursing

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1 INTRODUCTION

A mobile robot is an intelligent mobile machine capable of autonomous operations in its environment. It must be able to sensing (perceiving its environment), thinking (planning and reasoning), and acting (moving and manipulating) [1].

The navigation task is a vital issue for the movement of autonomous mobile robot. It may be considered as the process of defining a trajectory (path) for a collision-free movement, starting from an initial position and ending to a goal position in a space, by respecting the constraints kinematics of the robot and without human intervention [1][2].

Path following is one of the basic missions of a mobile robot navigation. It is a significant task that must have all the robots, because it permits the robot to execute its action with a minimum error [2]. It consists to direct the robot to follow a trajectory at the best possible precision. It must not be necessary that the robot passes exactly through the points on the trajectory, but at least passes in their proximity and arrives to a final destination. Generally, the mobile robot executes its movement with a constant velocity and estimates the trajectory position with its own odometric sensors [3].

In order to achieve a correct behavior, the control system of this autonomous mobile robot must perform many complex information processing tasks in real time. The robots operate in environment where boundary conditions are changing very rapidly [2][4]. Fuzzy logic controller is well suited for controlling a robot because it is capable of making inference even under uncertainty [5][6]. Ever since the fuzzy systems were applied in industrial applications, developers know that the construction of a well performing fuzzy system is not always easy. The problem of finding appropriate membership functions and fuzzy rules is often a tiring process of trial and error.

Techniques based on the use of Artificial Neural Networks (ANN) have a great interest in control and robotic domains [3]. The fastness of treatment and their capacity of approximating complex nonlinear functions motivate their use for mobile robot control [7][8]. The learning parameters of neural networks made them a prime target for a given task. Learning allows autonomous robots to acquire knowledge by interacting with the environment. This kind of behavior learning methods can be used to solve control problems that robots encounter in real world environment [3].

The objective of this work is to use fuzzy logic and neural network controllers for the path following task. These controllers generate the actions that will drive the robot straight on the path to reach the final destination.

The present paper is organized as follows: Section 2 gives an introduction of fuzzy logic and neural networks. In section 3, we will describe the task studied (path following behavior). The proposed controllers are introduced and explained in section 4. Section 5 shows simulation results for examples of path following. In section 6, we present a moving target pursing by a mobile robot. Section 7 concludes this paper.

2 FUZZY LOGIC AND ARTIFICIAL NEURAL NETWORKS

Fuzzy logic is a mathematical tool that can manipulate human reasoning, concepts and linguistic terms. It suits to define systems that handle imprecise information about the system model [5].

A fuzzy controller system is commonly defined as a system that emulates a human expert. The knowledge of the human operator would be presenting in the form of a set of fuzzy linguistic rules. These rules produce an approximate decision in the same manner as an expert would do [6][9][10].

On the other hand, one of the most popular artificial intelligence methods is artificial neural networks (ANN). They are considered to be simplified mathematical models of brain-like systems. Neural networks are generally trained by means of "training data", and due to their property of generalization, they can learn new associations, new functional dependencies and new patterns. Due to these properties, they have been widely used for modeling and control. The ''multi-layer perceptron'' has been applied in a large domain and especially at control [11].

3 PATH FOLLOWING BEHAVIOR

3.1 Mobile robot kinematics

The robot under consideration is a tricycle mobile robot with non-holonomic property that restricts its mobility in the sideways direction and with limitation of angle. The kinematic model of the mobile robot has two rear driving wheels and a passive front wheel. The inputs of this system are the steering angle α and the velocity v_r. The outputs are: (x_r, y_r, θ_r). In perfect adhesion conditions (movement without sliding), this kinematic model can be described by the following equations [1]:

$$\begin{aligned} \dot{x}_r &= v_r \cos(\theta_r) \\ \dot{y}_r &= v_r \sin(\theta_r) \\ \dot{\theta}_r &= \frac{v_r}{L} tg(\alpha) \end{aligned} \qquad (1)$$

Where: (x_r, y_r) are the position coordinates and θ_r is the orientation of the robot. L is the robot long.

3.2 THE PATH FOLLOWING STRATEGY

Generally, the trajectory to follow is stored in the memory in the form of a three elements vector (x_p, y_p, θ_p) [3]. In the present work, we will only consider a vector with two elements (x_p, y_p), the third parameter will be calculated by the robot during displacement. In its actual position, the robot (Fig. 1) calculates the orientation φ which allows it to go ahead to the desired point of path.

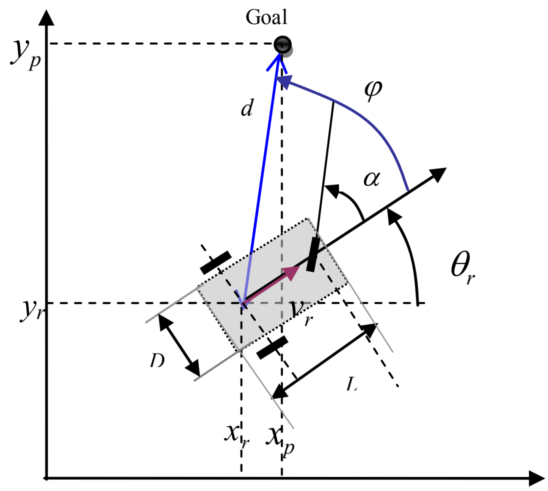


Figure 1: Mobile robot Parameters

4 PROPOSED CONTROLLERS

4.1 Fuzzy logic controller

The bloc diagram of the robot controller is shown in Fig. 2. The calculation module compares the actual robot coordinates with the coordinates of the path and computes the angle noted φ. This value is compared with the orientation of the robot delivered by the odometry module in order to compute the error *e*. The fuzzy controller uses this angle and the error variation noted *de* in order to generate the appropriate action α.

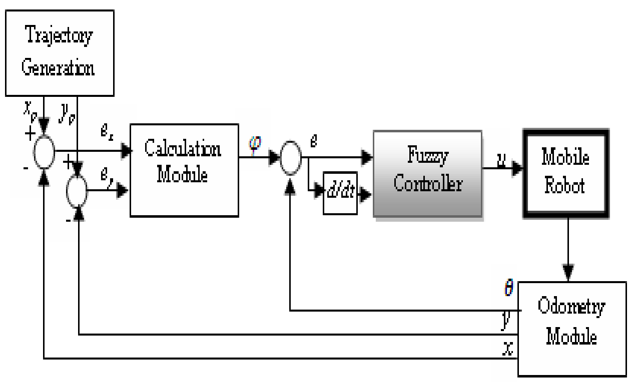


Figure 2: Fuzzy controller

The membership functions used for input-outputs variables are:

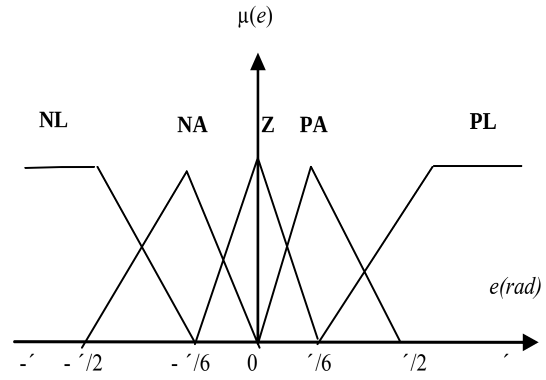


Figure 3: The membership functions of e.

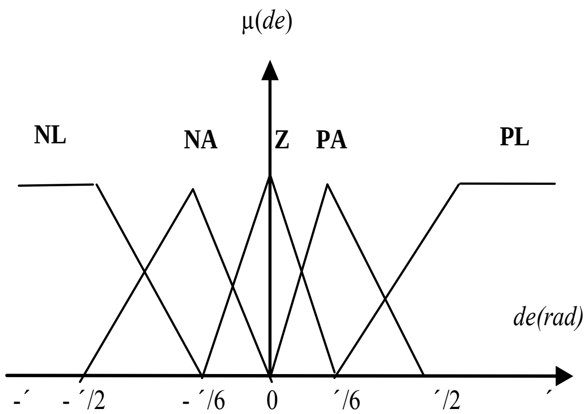


Figure 4: The membership functions of de

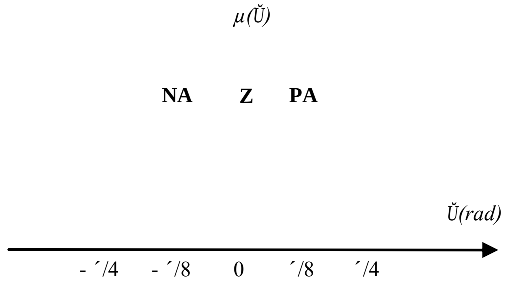


Figure 5: The membership functions of the output control.

With the following linguistic variables:

Z: Zero, **PA:** Positive Average**, PL:** Positive Large, NL**:** Negative Large, **NA:** Negative Average

The proposed strategy control is expressed symbolically by the fuzzy rules presented at table 1.

TABLE I: Rule base for the Path-following task

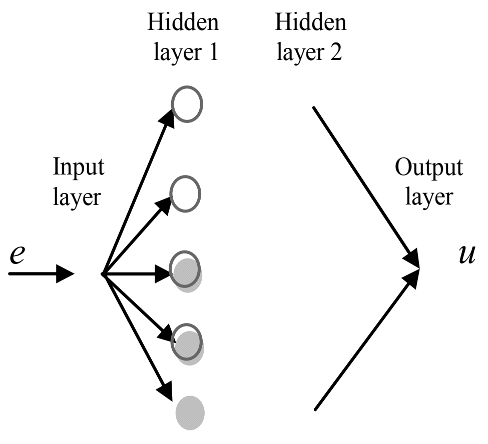
de	**e**				
	NL	**NA**	**Z**	**PA**	**PL**
NL	NL	NL	NL	NA	Z
NA	NL	NL	NP	Z	PA
Z	NL	NA	Z	PA	PL
PA	NA	Z	PA	PL	PL
PL	Z	PA	PL	PL	PL

While the principle input for the path following task is the angle error. In the next section, in order to simplify the studied strategy, we use only this value as an input for the neural network controller. With an assumption With an assumption of that, the robot firstly is located on the path.

4.2 Neural network controller

The robot control realized in this work use the inverse neural model (INM) to generate at every step Δt, the control α corresponding to the realized movement (angle variation *e* representing the difference between previous θ_r and actual orientation).

For the design of the robot inverse neural model, a multi-layer perceptron with two hidden layers composed of sigmodal hidden neurons and a linear output neuron is elaborated. The figure 6 presents the proposed network and the training structure is presented in figure 7.



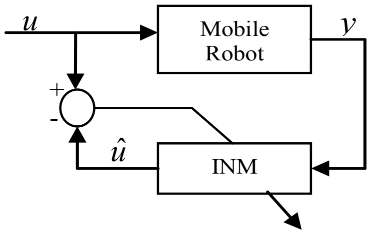


Figure 7: Inverse neural model training structure.

The back-propagation training algorithm is used to minimizing the criterion J:

$$J = \frac{1}{2}\sum_{i=1}^{N}(u_i - \hat{u}_i)^2 \quad (2)$$

With:

u : Robot input.

$\hat{u}$: INM output.

To guide the studied robot to follow the path, the produced INM is used as shown in figure 8. At each sample, the movement represented by the angle error e is given to the controller to let the robot to reach the next reference. This controller should generate the appropriate command α allowing executing the right movement.

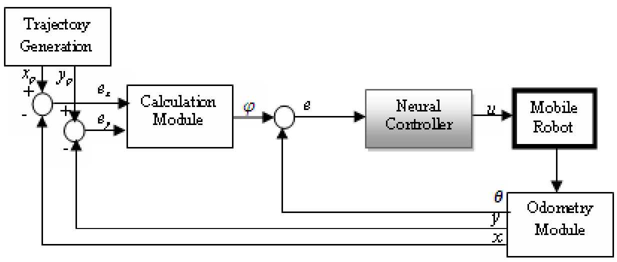


Figure 8: Neural cotroller

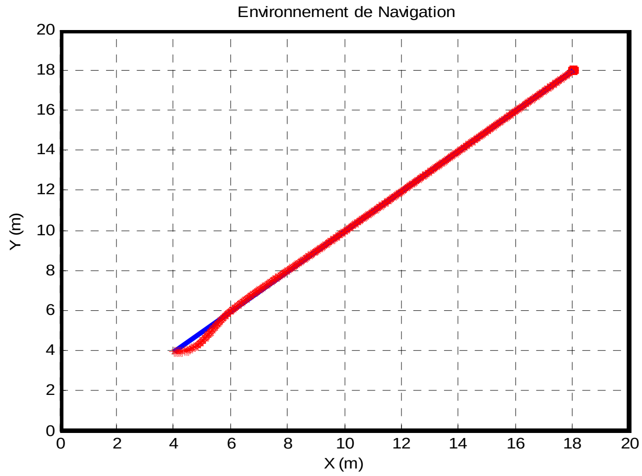
5 SIMULATION RESULTS

In order to test the designed controllers, different reference paths are chosen to provide several direction changes and types of curves. The paths are composed of several segments (discontinuous curve which does not respect the kinematic constraints of the robot). These paths lead the robot to the final destination.

The simulation results for a path with one segment are given in Fig.9 and Fig.10 for the fuzzy controller and neural controller respectively. The path following is good and the robot can follow the path with a minimum error.

For different straight paths with different slopes following using the two controllers, the results are shown in Fig.11 and 12. In this case, the robot is initially at (10, 10) point with a null orientation. As depicted, the proposed controllers can behave correctly in all cases and this behavior is realized correctly. The robot tend to overlapping the trajectory by few errors at the first turning.

(a)



(b)

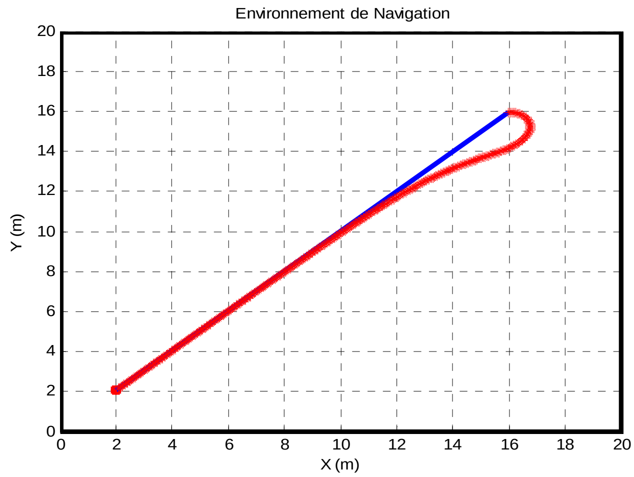
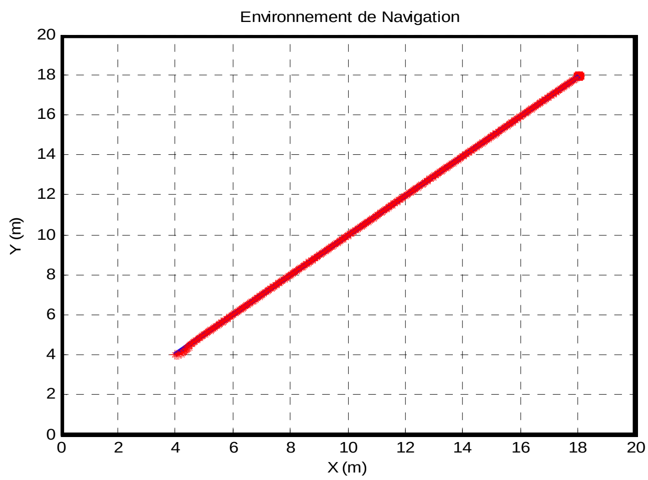


Figure 9: Line following using fuzzy controller

(a)



(b)

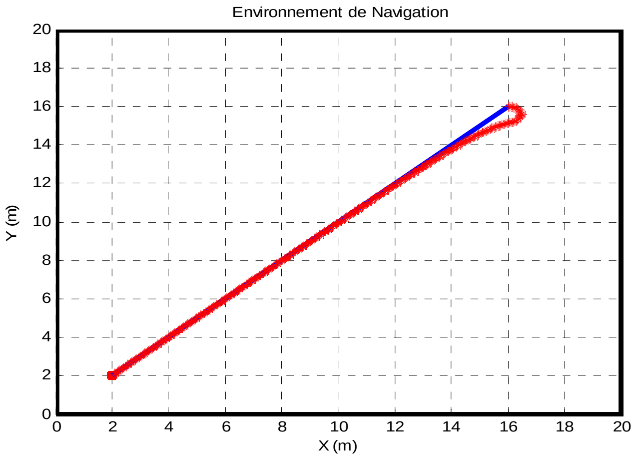


Figure 10: Line following using neural controller

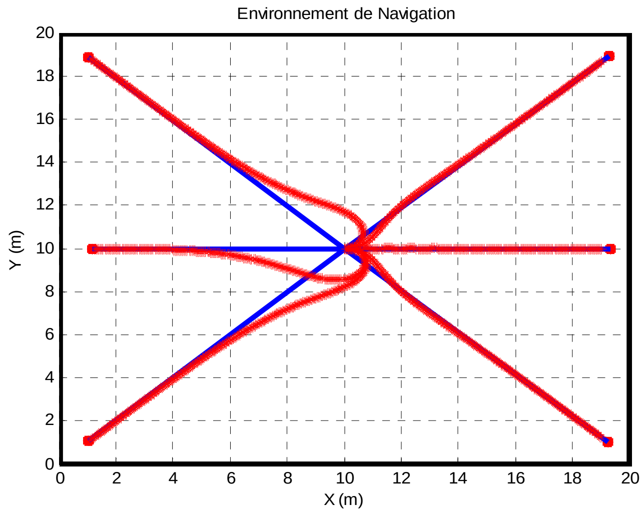


Figure 11: Straight paths following using fuzzy controller

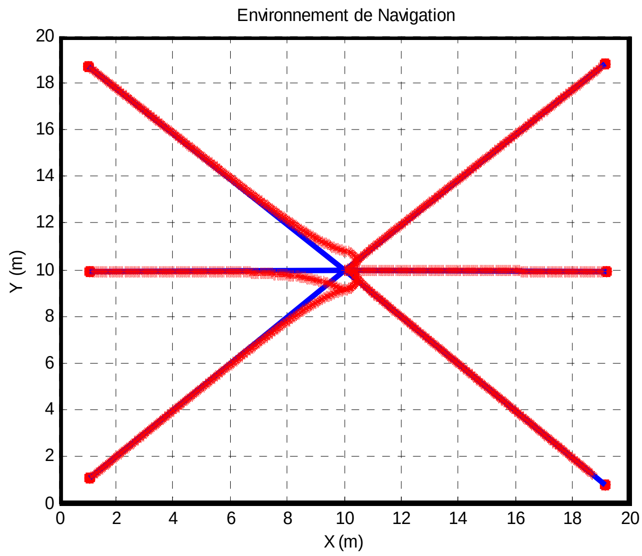


Figure 12: Straight paths following using neural controller

The application of these controllers for a trapezoidal path composed of several segments leads to the robot trajectory depicted in figure 13. The path following is good with a minimum error. This is due to the curvature discontinuity which leads to abrupt change of α at segments end. This error is smaller when using the neural controller due to the data base used in training task

(a)

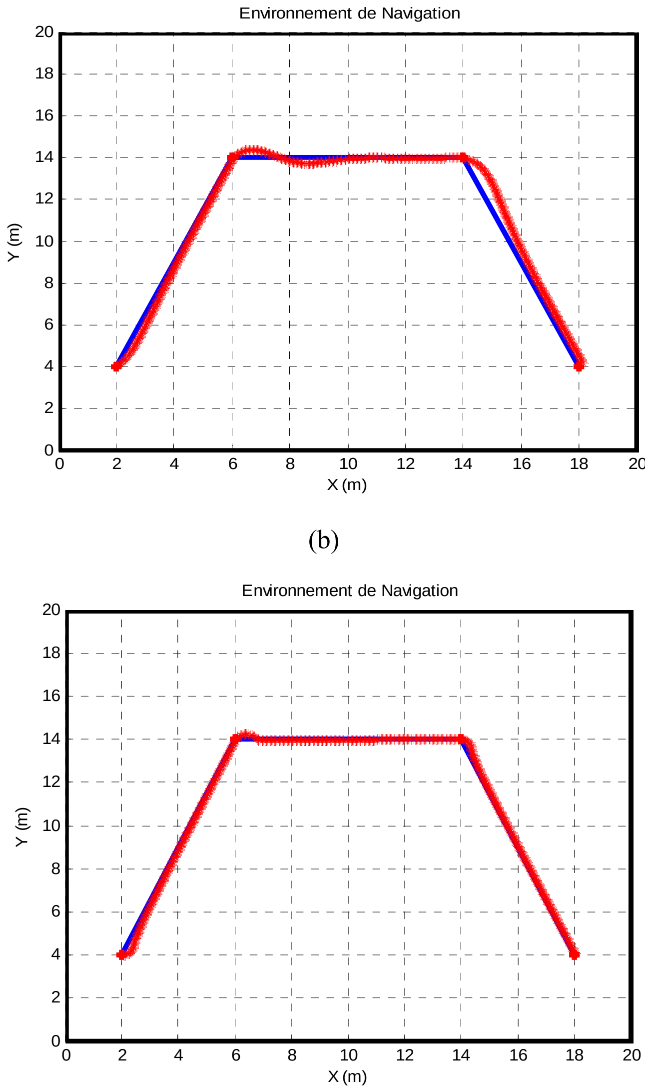
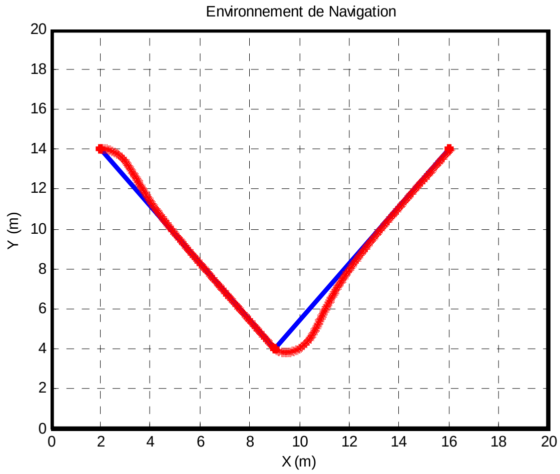


Figure 13: Robot trajectory for trapezoidal reference path using fuzzy controller (a) and neural controller (b).

For a V and N shaped references trajectories composed of segments and presenting attenuated angles (not respecting the kinematic constraints of the robot and steering limitation). The results are presented in Fig.14 and Fig.15. The behavior in this case is satisfactory; the tracking error exists at changed points of the trajectory. This is due to the sudden direction change and especially to the limitation of the steering angle (control value).

(a)



(b)

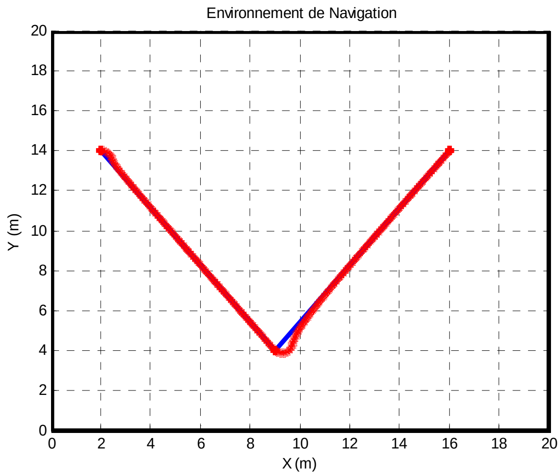
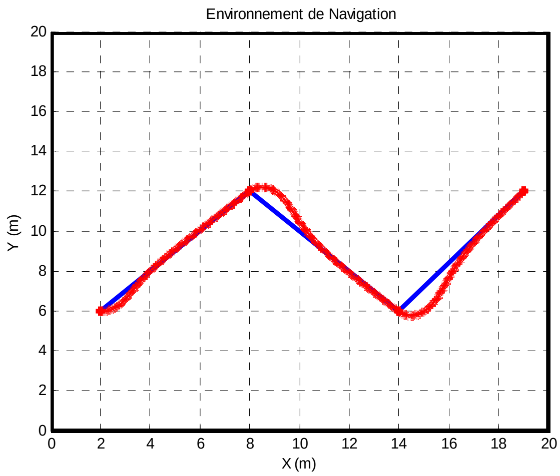


Figure 14: Robot trajectory for V shaped reference trajectory using fuzzy controller (a) and neural controller (b).

(a)



(b)

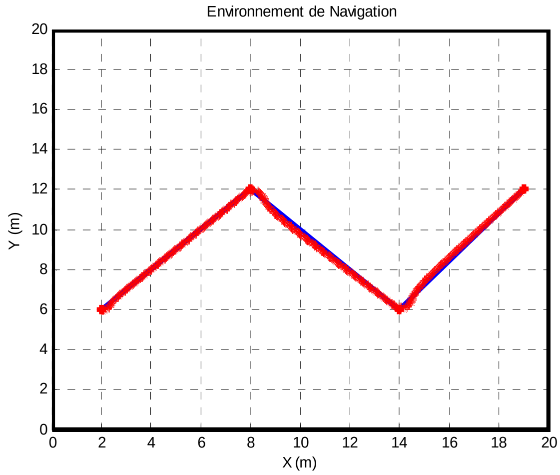


Figure 15: Robot trajectory for N shaped reference trajectory using fuzzy controller (a) and neural controller (b).

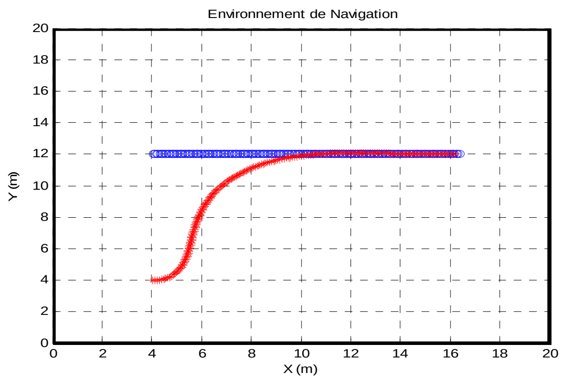
6 MOVING TARGET PURSING

We consider now a moving target. The task of the robot is to purse this target; while there coordinates are known at any time. The mobile robot purses the target by the calculation of the steering angle that conducts the robot ahead to the target.

In the first example, the mobile robot is initially located at point (4,4) with a null orientation. The target is located at (4,12) and will start moving along a straight line parallel to the abscissa axis with a linear velocity. Until the target starts moving the mobile robot begins pursing it. The pursing will be halted when the robot catches the target. The results are shown in figures 16, which illustrate the efficiency of the robot control. It is also shown that the proposed controllers can guide the robot toward the target.

In figures 17, 18 and 19, examples of a moving target pursing will presented. In each example, the target has a different path (curve, sinusoidal and a circle). The results illustrate the efficiency of the proposed controllers. The robot can purse the target effectively. But as mentioned previously, we observe that the neural control is quite than the second one due to the control values generated, as depicted on robot trajectories.

(a)



(b)

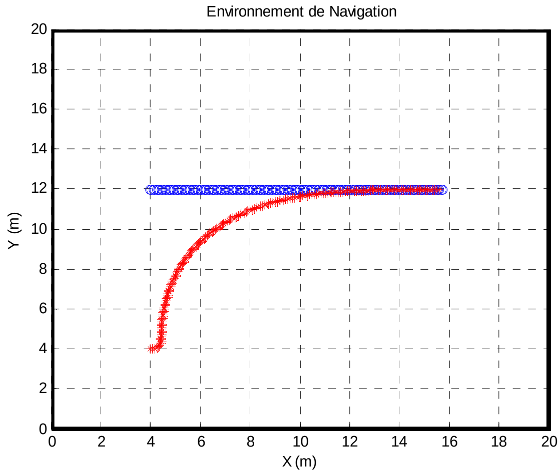
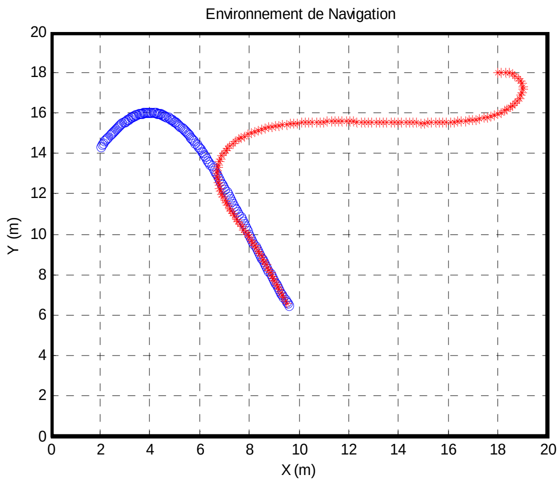


Figure 16: Moving target pursing using fuzzy controller (a) and neural controller (b).

(a)



(b)

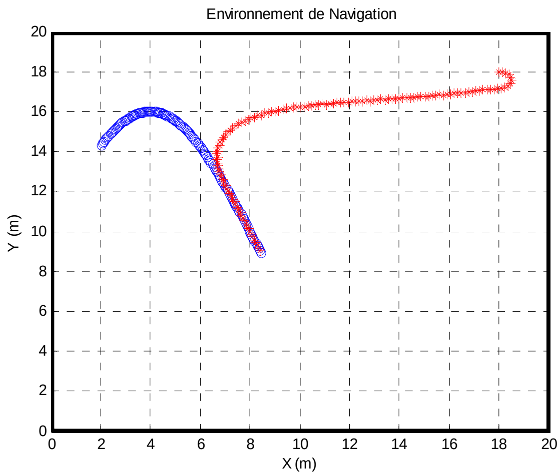
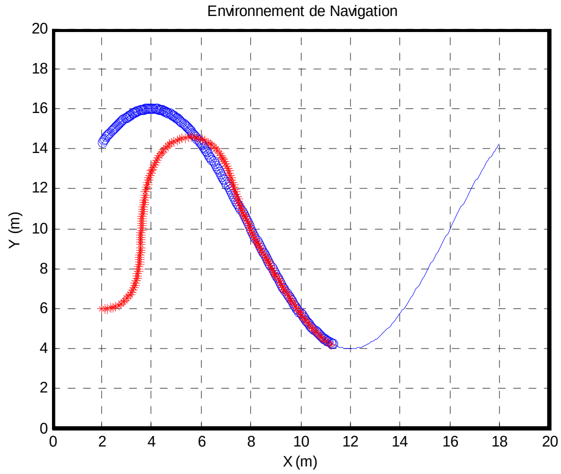


Figure 17: Pursing a target with a curve path using fuzzy controller (a) and neural controller (b).

(a)



(b

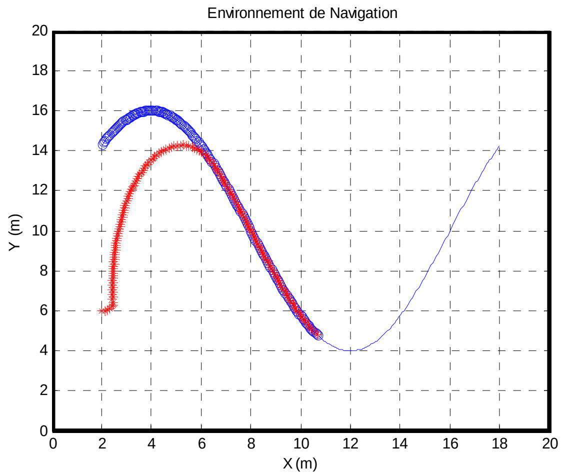
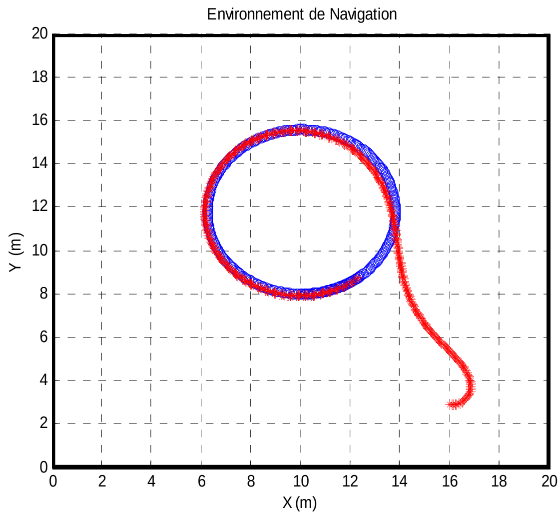


Figure 18: Pursing a target with a sinusoidal path using fuzzy controller (a) and neural controller (b).

(a)



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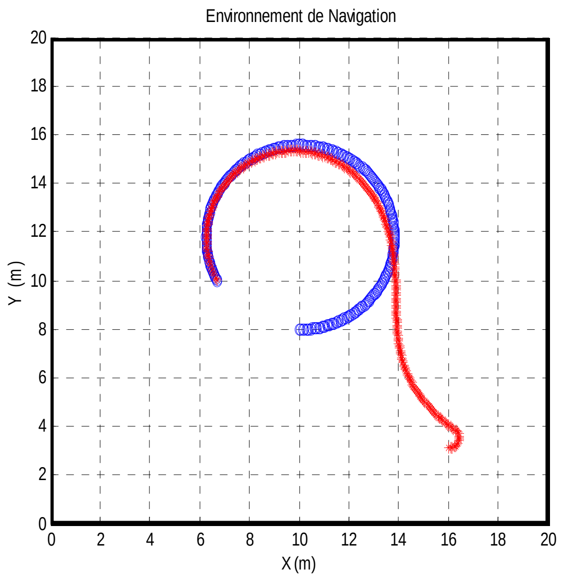

Figure 19: Pursing a target with a circle path using fuzzy controller (a) and neural controller (b).

7 CONCLUSION

In this paper, we presented control systems based on intelligent techniques for the mobile robot navigation. The first technique is based on the fuzzy logic control, and the second is a neural network controller. These controllers are used in order to realize the path following behavior and for a target pursing. Different reference trajectories with different curves are simulated. The simulation results show the efficiency of the two proposed controllers for the robot control and permitting to equip the mobile robot with a certain degree of intelligence. The results show a big similarity between the two approaches. The advantage of the proposed controllers is the simplicity and the efficiency for the robot control.

As prospects, it is interesting to improve the robot behaviors and apply this strategy on real mobile robot. In designing fuzzy controllers for mobile robots, an approach can be realized for the automatic design of fuzzy inference systems through the use of the neuro-fuzzy architecture, where the learning process is used to adapt the fuzzy inference parameters using a data base.

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