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Type-2 fuzzy logic controller optimized by wavelet networks for mobile robot navigation

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ABSTRACT

In this work, we will use a new control strategy based on the integration of a type-2 fuzzy reasoning optimized by wavelet networks as part of a navigation system of a mobile robot. The proposed approach is able to facilitate the navigation task in an autonomous manner, in order to determine which commands must be sent at each moment to the mobile robot. This operation must take into account convergence towards a goal with the shortest possible path in the minimum delay between the starting position and the target position. Once the goal is reached, the robot stops.

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1. INTRODUCTION

The theory of fuzzy logic has been established by L.zadeh [1]. This logic allows the representation and processing of inaccurate or approximate knowledge. It is expressed by a set of linguistic rules called fuzzy rules, which are used to control complex systems or scarcely modeled [2-4]. The number of applications based on fuzzy logic theory in the field of mobile robotics has increased significantly in recent years [5-12].

Since fuzzy systems are built from the knowledge provided by the human expert, they are tainted with uncertainties. These uncertainties are injected into the membership functions of the fuzzy antecedent and consequent sets that will be uncertain. These fuzzy systems, called fuzzy type-1 systems, are incapable of modeling these uncertainties because they use specific membership functions, which have a two-dimensional representation. Therefore, fuzzy type-2 systems, whose membership functions themselves are unclear, are the extension of type-1 fuzzy systems. In recent years, several works have been developed based on type-2 fuzzy systems. They are used inimage processing [13-15], the control of electrical machines [16-19], and the control of mobile robots [20-23]. But the disadvantage of fuzzy logic is the empirical choice of parameters, which can make the control of the system long and delicate in certain situations.

This problem prompted researchers to propose methods for the automatic optimization of certain parameters of the fuzzy controller, we can quote the work of [24] who designed an evolutionary algorithm to optimize the type 2 fuzzy controller and used it for tracking control of autonomous mobile robots trajectory, there is also the work of [25] who proposed a new method namely the uncontrolled genetic sorting algorithm for optimizing a proportional-integral-derivative type-2fuzzy logic controller for the follow-up control of trajectory of a Delta parallel robot. In the work [26], the authors controlled the cooperation of the robots and the tasks of reaching the target when navigating for several mobile robots using a type-2 fuzzy logic controller optimized by the PSO method. Our goal is to optimize type-2 fuzzy logic controller formobile robot navigation. To perfect our goal we have opted for the use of wavelet networks that combine the capacity of neural networks in learning and those of wavelets in the decomposition of signals.

Our work is broken into two parts the first is to use two type-2 fuzzy systems, one to generate the control in angular velocity and the other for the linear speed of the robot to achieve the convergence of the mobile robot towards a goal. The second part concerns the optimization of controllers applied using wavelet networks.

2. RESEARCH METHOD

2.1. Proposed Navigation Strategy

The strategy adopted here for the navigation of the robot determines a movement order allowing the robot to move so that it can achieve its goal, from the current position of the robot and the definition of the position of the target point. This action is performed in an environment where no obstacle hinders the progress of the robot. Fuzzy logic reasoning of type-2 is used. Parameters of the robot and its environment shown in Figure 1.

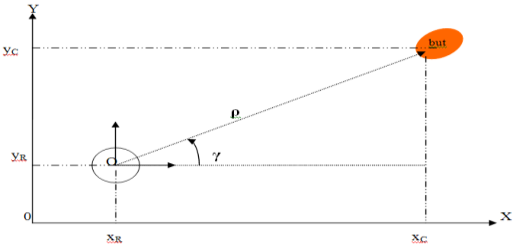

Figure 1. Parameters of the robot and its environment

2.2. Synthesis of the first Type-2 Fuzzy Logic Controller T2FLC1

This controller receives as input the orientation of the target (**γ**) and its variation (**Δγ**), and returns the output command Δθ, which corresponds to the change in the orientation of the robot.

2.2.1 Membership Functions

The speech universes of the two inputs are decomposed respectively into fivetype-2 fuzzy subsets for γ, andthree for Δγ which are represented by: LB (Left Big), LS (Left Small), Z (Zero), RS (Right Small), RS (Right Big),N (Negative), Z (Zero), and P (Positive) as shown in Figure 2 and 3.

The labels used for the fifteen fuzzy subsets relating to the change of orientation are:

NVB (Négative Very Big), NB (Négative Big), NM (Négative Medium), NMS (Négative Medium Small), NS (Négative Small), NVS (Négative Very Small), NVVS (Négative Very Very Small), ZE (Zéro), PVVS (Positive VeryVerySmall), PVS(PositiveVerySmall), PS(Positive Small), PMS (Positive Medium Small), PM (Positive Medium), PB (Positive Big), and PVB (Positive Very Big).

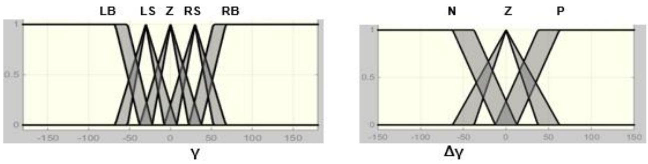

Figure 2. Membership functions of input variables

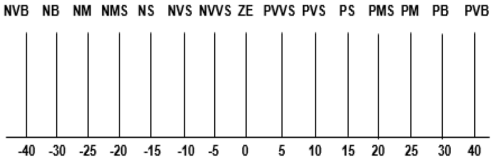

Figure 3. Membership functions of the output variable Δθ

2.2.2 Fuzzy Rules Base

The following base of the rules summarizes, in Table 1 is the variation of the orientation as a function of the angle as well as its variation. It symbolizes the following relationship: the variation of direction that the robot must adopt is all the greater as the point of arrival is located largely on the sides of the robot:

Table 1. Fuzzy Rules Base

	LB	LS	Z	RS	RB
N	PVB	PMS	PVVS	NVS	NM
Z	PB	PS	ZE	NS	NB
P	PM	PVS	NVVS	NMS	NVB

2.3. Synthesis of the Second Type-2 Fuzzy Logic Controller T2FLC2

This controller receives two inputs, the first ρ represents the distance between the robot and the target, and the second input represents the linear speed of the instantaneous robot v. The output returned by this controller represents the speed variation Δv.

2.3.1 Membership Functions

The speech universes of the inputs are decomposed into two, and five type-2 fuzzy subsets of, which can be respectively represented by: N (Near), F (Far) for ρ and VS(Very Small), S (Smal), M (Medium), B (Big), and VB (Very Big) for v as shown in Figure 4 and 5.

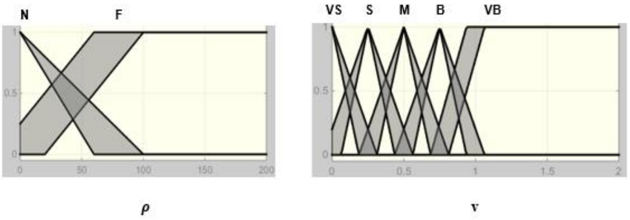

Figure 4. Membership functions of input variables

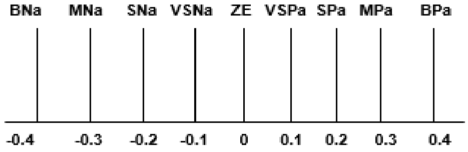

Figure 5. Membership functions of the output variable Δv

The labels used for the nine (9) relating to the subsets of the output Δv are: BNa (Big Negative acceleration), MNa (Medium Negative acceleration), SNa (Small Negative acceleration) , VSNa (Very Small Negative acceleration), ZE (Zero), VSPa (Very Small Positive acceleration), SPa (Small Positive acceleration) , MPa(Medium Positive acceleration), and BPa (Big Positive acceleration).

2.3.2 Fuzzy Rules Base

The following rule base summarizes the variation of the speed (acceleration) as in Table 2 is a function of the current speed v and the distance ρ. It symbolizes the following relationship: the robot's acceleration is all the greater as the distance between the robot and the target is high and the robot's current speed is average.

Table 2. Fuzzy Rules Base

	VS	S	M	B	VB
N	ZE	VSN_a	SN_a	MN_a	BN_a
F	BP_a	BP_a	MP_a	SP_a	VSP_a

2.4. Optimization of Synthesized Type-2 Fuzzy Logic Controllers

In our work, we use the wavelet network which presents interesting performances in identification and predictive control [27], and we show how it can be used to optimize the parameters of a type-2 fuzzy logic controller at the premise part and the consequent part by adjusting the parameters of a wavelet function.

2.4.1 Principle of the Method

This method presents a complete structural analogy with a fuzzy inference system of the SUGENO type(SIF). The latter (SIF) can be schematized in the form of a multilayer network whose connections are weighted at its output, and the square nodes are adaptive. The membership functions used are of triangular shape, which leads to the development of an algorithm that is suitable for this type of function. The wavelet network architecture used is shown in Figure 6.

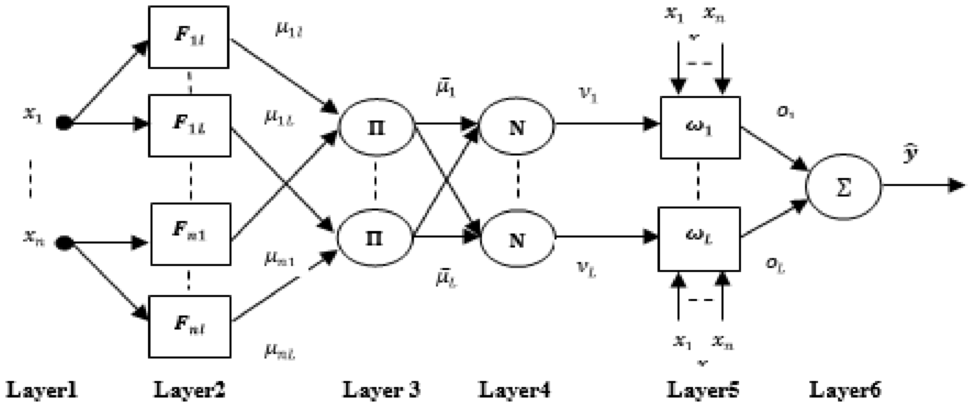

Figure 6. Wavelet network architecture used [5]

This network therefore comprises six layers:
Layer 1: Receiving the inputs and transmitting to the next layer.
Layer 2: a proper triangular membership function for each node $F_{i\ell}$

$$\mu_{i\ell} = 1 - \frac{2.|x_\ell - a_{i\ell}|}{b_{i\ell}} \tag{1}$$

Where$a_{i\ell}$and$b_{i\ell}$are the centers and basic widths of the triangular function ofthel^{th}term ofthei^{th} ith input variable respectively.
Layer 3:Multiplication of all input signals:

$$\overline{\mu_\ell} = \prod_{i=1}^{n} \mu_{i\ell} \tag{2}$$

Layer 4: several fixed nodes labeled by N, whose the ith node calculates this ratio:

$$v_\ell = \frac{\overline{\mu_\ell}}{\sum_{\ell=1}^{L} \overline{\mu_\ell}} \tag{3}$$

Layer 5: these nodes are of adaptive type and they calculate the function $\boldsymbol{\omega_\ell}$expressed by:

$$\omega_\ell = \left(\sum_{i=1}^{n} \emptyset_{i\ell}\right) w_\ell = \left(\sum_{i=1}^{n} -\vartheta_{i\ell} exp\left(\frac{-(\vartheta_{i\ell})^2}{2}\right)\right) w_\ell \tag{4}$$

where $\emptyset_{il}$ is the mother wavelet function (first derivative of the Gaussian function)

$$\vartheta_{i\ell} = \frac{x_i - m_{i\ell}}{d_{i\ell}},$$

with $m_{i\ell}$ and $d_{i\ell}$ are the translation and expansion coefficients of this wavelet and w_ℓ is the weighting parameter of this node. The output of the layer is expressed by the relation

$$o_\ell = \omega_\ell v_\ell \tag{5}$$

Layer 6: contains a single neuron that calculates the sum of all the signals coming from the fifth layer according to the following formula:

$$\hat{y} = \sum_{\ell=1}^{L} o_\ell = \sum_{\ell=1}^{L} \omega_\ell v_\ell \tag{6}$$

2.4.2 Optimization Algorithm

The gradient descent method is used to adjust the parameters$a_{i\ell}$, $b_{i\ell}$, $m_{i\ell}$, $d_{i\ell} and w_\ell$whose parameter adaptation equations are obtained by:

$$a_{i\ell}(k+1) = a_{i\ell}(k) + \eta(y(k) - \hat{y}(k)) \frac{\partial \hat{y}(k)}{\partial a_{i\ell}(k)} \tag{7}$$

$$b_{i\ell}(k+1) = b_{i\ell}(k) + \eta(y(k) - \hat{y}(k))\frac{\partial \hat{y}(k)}{\partial b_{i\ell}(k)} \tag{8}$$

$$m_{i\ell}(k+1) = m_{i\ell}(k) + \eta(y(k) - \hat{y}(k))\frac{\partial \hat{y}(k)}{\partial m_{i\ell}} \tag{9}$$

$$d_{i\ell}(k+1) = d_{i\ell}(k) + \eta(y(k) - \hat{y}(k))\frac{\partial \hat{y}(k)}{\partial d_{i\ell}(k)} \tag{10}$$

$$w_{\ell}(k+1) = w_{\ell}(k) + \eta(y(k) - \hat{y}(k))\frac{\partial \hat{y}(k)}{\partial w_{\ell}(k)} \tag{11}$$

where

$$\frac{\partial \hat{y}(k)}{\partial a_{i\ell}} = \frac{\partial \hat{y}(k)}{\partial \nu_{\ell}}\frac{\partial \nu_{\ell}}{\partial \mu_{i\ell}}\frac{\partial \mu_{i\ell}}{\partial a_{i\ell}} = \left(O_{\ell}(k) - \hat{y}(k)\nu_{\ell} signe(x_i - a_{i\ell}\right).\frac{2}{b_{i\ell}\mu_{i\ell}} \tag{12}$$

$$\frac{\partial \hat{y}(k)}{\partial b_{i\ell}} = \frac{\partial \hat{y}(k)}{\partial \nu_{\ell}}\frac{\partial \nu_{\ell}}{\partial \mu_{i\ell}}\frac{\partial \mu_{i\ell}}{\partial b_{i\ell}} = \left(O_{\ell}(k) - \hat{y}(k)\right)\nu_{\ell}\frac{1-\mu_{i\ell}}{b_{i\ell}\mu_{i\ell}} \tag{13}$$

$$\frac{\partial \hat{y}(k)}{\partial m_{i\ell}} = \frac{\partial \hat{y}(k)}{\partial \omega_{\ell}}\frac{\partial \omega_{\ell}}{\partial \phi_{i\ell}}\frac{\partial \phi_{i\ell}}{\partial \upsilon_{i\ell}}\frac{\partial \upsilon_{i\ell}}{\partial m_{i\ell}} = \nu_{\ell} w_{\ell}\phi_{i\ell}\frac{(\vartheta_{i\ell}^2-1)}{\vartheta_{i\ell}d_{i\ell}} \tag{14}$$

$$\frac{\partial \hat{y}(k)}{\partial d_{i\ell}} = \frac{\partial \hat{y}(k)}{\partial \omega_{\ell}}\frac{\partial \omega_{\ell}}{\partial \phi_{i\ell}}\frac{\partial \phi_{i\ell}}{\partial \vartheta_{i\ell}}\frac{\partial \vartheta_{i\ell}}{\partial d_{i\ell}} = \nu_{\ell} w_{\ell}\phi_{i\ell}\frac{(\vartheta_{i\ell}^2-1)}{d_{i\ell}} \tag{15}$$

$$\frac{\partial \hat{y}(k)}{\partial w_{\ell}} = \frac{\partial \hat{y}(k)}{\partial \omega_{\iota}}\frac{\partial \omega_{\iota}}{\partial w_{l}} = \nu_{\ell}\left(\sum_{i=1}^{n} - \vartheta_{i\ell}\exp\left(\frac{-(\vartheta_{i\ell})^2}{2}\right)\right) \tag{16}$$

3. RESULTS AND ANALYSIS

Figure 7 is presented simulating the evolution of the robot in the environment so that it can reach the target by controlling the change of its orientation and the variation of its speed taking into account several different situations for the robot and the target using the two type-2 fuzzy logic controllers.

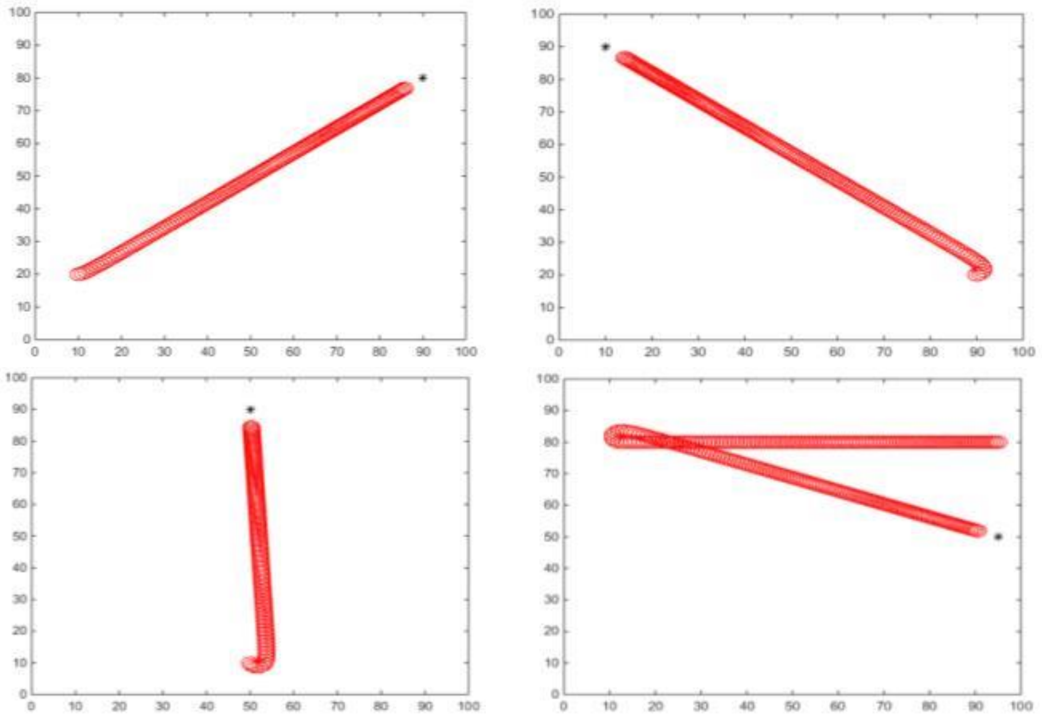

Figure 7. Simulation examples

Consider now the optimization of type-2 fuzzy logic controllers applied to generate the control of the change of orientation Δθ and of the speed variation Δv, gives the following Table 3.

Table 3. Tables Obtained

a) T2FLC1

	LB	LS	Z	RS	RB
N	49.55	3.41	8.41	-6.5	- 28 6
Z	33.26	18.5	3.5	-11.48	-26.54
P	21.73	13.5	-1.49	-16.48	-32.17

b) T2FLC2

	VS	S	M	B	VB
N	-0.08	-0.13	-0.28	-0.39	-0.33
F	0.46	0.29	0.19	0.09	-0.14

We can now give a linguistic interpretation to this table. For that , we assign the concept PVB (PositiveVery Big) to numerical values greater than 40, the concept PB (Positive Big) with numerical values between 27 and 37, the PM (PositiveMedium) concept with numerical values between 22 and 27, the concept PMS (Positive MediumSmall) with numerical values between 17 and 22, the concept PS (Positive Small) with numerical values between 12 and 17, the concept PVS (Positive Very Small) with numerical values between 7 and 12, the concept PVVS (Positive Very VerySmall) with numerical values between 3 and 7, and the concept ZE (Zero) with values close to 0, and likewise in the negative sense for the first controller.

And with regard to the second controller, we assign the conceptBPa (Big Positive acceleration)to numerical values greater than 0.38, the concept MPa(Medium Positive acceleration)with numerical values between 0.25 and 0.35, the concept of SPa (Small Positive acceleration) with numerical values between 0.15 and 0.25, the concept hasVSPa (Very Small Positive acceleration)with numeric values between 0.07 and 0.15, and the conceptZE (Zero)with values close to 0, and likewise in the negative sense. We obtain the following tables:

Table 4. Linguistic Interpretation of the Tables Obtained

a) T2FLC1

	LB	LS	Z	RS	RB
N	PVB	PM	PVS	NVVS	N
Z	PB	PMS	PVVS	NVS	NM
P	PMS	PS	ZE	NS	NB

b) T2FLC2

	VS	S	M	B	VB
N	ZE	VSNa	MNa	BNa	MNa
F	BPa	MPa	SPa	ZE	VSNa

The tables obtained are different from those proposed by the human expert, which modifies the behavior of the rules. If we compare them to tables provided by the expertise, we see that they are not homogeneous. The behavior of the rules is not close to that of fuzzy controllers proposed for the same task by a human expert. The shaded boxes in Table 4 are the difference between the two tables (For example NB replaces NM in the first table and ZE replaces SPa in the second table). We note that these tables are not close to those given in Tables 1 and 2, which means that the strategy extracted by the fuzzy logic controllers optimized is removed from that proposed by the human expert. The optimized membership functions of the input variables for both type-2 fuzzy controllers are shown in Figure 8 and 9.

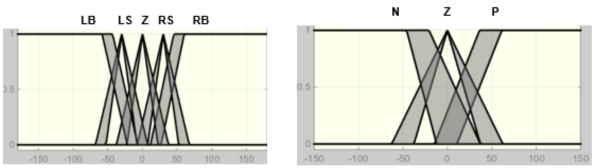

Figure 8. The optimized membership functions of the T2FLC1

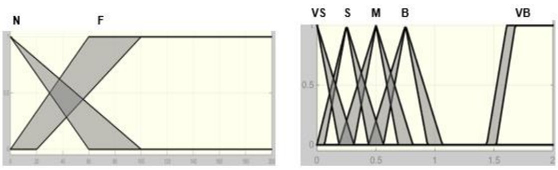

Figure 9. The optimized membership functions of the T2FLC2

To illustrate the performance of these controllers optimized by wavelet networks, we performed the same simulation tests made with the type-2 fuzzy controllers previously synthesized. These results confirm those obtained previously and show that the optimization method followed makes it possible to obtain readable rules tables that are easy to interpret. To illustrate the performance of these optimized controllers, the same examples are used.

From the results of the simulation conducted, it can be seen that the results obtained with the type-2 fuzzy controllers optimized by the wavelet networks are better compared to those obtained with the non-optimized controllers in the direction of the change of orientation of the mobile robot which is done in a manner faster. In addition, the wavelet network method has the advantage of optimizing the membership functions and the fuzzy rules simultaneously. Results of the simulation conducted as shown in Figure 10.

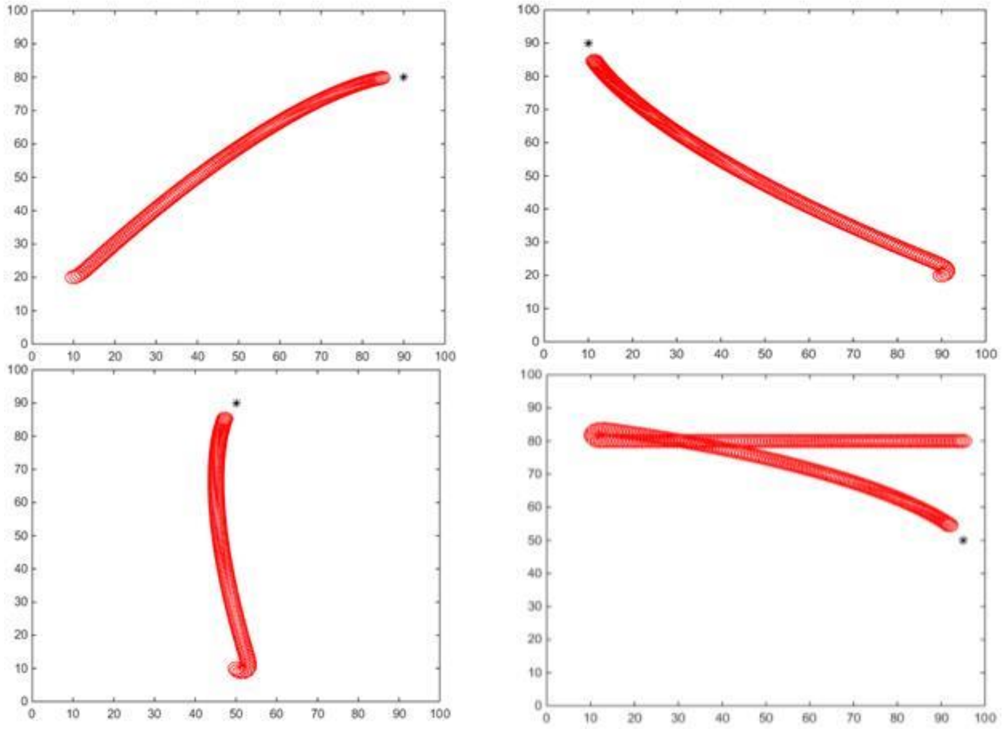

Figure 10. Results of the simulation conducted

4. CONCLUSION

In this paper, we presented a new optimization technique based on the integration of a type-2 fuzzy controller with wavelet networks for mobile robot navigation. This approach has the advantage of optimizing membership functions and fuzzy rules simultaneously.

We navigated a mobile robot using two optimized type-2 fuzzy logic controllers, one for generating the change of orientation command and the other for the speed variation. These controllers must take into account convergence towards a goal with the shortest possible path in the minimum delay between the starting position and the target position. We gave a linguistic interpretation to thesetables.

From the results obtained with type-2fuzzy logic controllers optimized by wavelet networks, we can say that these results are better compared to those obtained with the expertise. We also noticed that this new optimization technique has resulted in readable, easy-to-interpret rule tables.

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