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# Type-2 fuzzy logic control for a mobile robot tracking a moving target

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**ABSTRACT**

This paper presents a type-2 fuzzy logic control (FLC) approach for mobile robot tracking a dynamic target in cluttered environments. Robot control actions are generated by different behaviors : attraction to a dynamic target, obstacle avoidance and fusion block. The proposed controller calculates both the mobile robot linear and angular velocities from the distance and angle that separate it to the moving target/obstacle. The controller was designed using fuzzy logics theory and then, type-2 fuzzy logic was applied to better accuracy and smoothness of the robot trajectory. Simulation results illustrate that the proposed controller leads to good performances in terms of computational time and tracking errors convergence.



## 1. Introduction

An autonomous mobile robot is a programmable and multi tasks mechanical device, capable to navigate freely or execute different functions such as obstacles avoidance, target tracking ...etc. The last few decades have witnessed ambitious research efforts in the areas of mobile robotics, due to their wide range of use in different fields like military and industrial applications. These research works aim to improve their operational capabilities of navigation and interaction with its surrounding work environments through the different kinds of sensors.

Target tracking is one of the basic and an interesting function for a mobile robot, and researchers have worked to propose different control approaches to improve target tracking performances. Several control approaches like PID controllers [1], non linear controllers based Lyapunov stability analysis [2] and sliding mode control [3] have been developed to make the mobile robot track easily a moving target.

However, these approaches have showed some problems, due to the complexity of the mobile robot surrounding environment to be modeled or to the simplification assumptions

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taken for the elaboration of the mathematical model of the robot and control law.

To overcome these drawbacks and the need to exhibit robust performances while operating in highly uncertain and dynamic environments, artificial intelligence approaches have been attracting considerable research interest in recent years. Different techniques such as reinforcement learning [4], neural networks [5], fuzzy logics [6,7] and genetic algorithms [8] have been applied to synthesize control laws enabling the mobile robot to follow a moving target freely. Artificial potential field approaches [9,10] have been also developed to solve the problem of mobile robots target tracking.

The intelligent control does not require knowing exactly the mathematical model of the mobile robot or its surrounding work space, since it uses human reasoning and decision making in spite of uncertainty and imprecise information provided by the different perception sensors such as cameras, ultrasonic and infrared sensors.

Fuzzy logic is an adequate methodology for designing robust controllers that are able to deliver satisfactory performance in the presence of disturbances and uncertainties. The general framework of fuzzy reasoning allows handling much of the uncertainty, using fuzzy sets characterized by type-1 membership functions. However, in many situations, the designer has no information about the adequate membership function shapes. Thus, the use of type-2 fuzzy sets becomes natural [11,12]. Type-2 fuzzy logic is a more general formulation using fuzzy membership functions with additional dimension [13,14]. This provides additional degree of freedom to handle uncertainties and the lack of information. In this work, type-1 fuzzy logic is used to design the controllers for the basic tasks (behaviors) for robot navigation : attraction to a dynamic target and obstacles avoidance. However, the coordination and the fusion of the elementary behaviors are more difficult, since, we have no valuable online information to safely avoid obstacles and to guarantee the optimal convergence to the target. Hence, type-2 fuzzy logic is used to design the fusion controller, to compensate our lack of information. This is the core stone of our design.

In this paper, a control approach for target tracking by a mobile robot is presented, based on fuzzy logics. The remainder of the paper is organized as follows. In the next section (II), the proposed control approach and problem formulation are given. Section III details the design of the different control parts (attraction to a dynamic target, obstacle avoidance and fusion controller). Section IV discusses simulations results. Finally, section V concludes this paper.

## 2. Model system and problem formulation

Models of mobile robot systems cannot describe exactly its performance due to system uncertainties and shortage in parameter identification, so we proposed an intelligent controller to compensate for these shortages without the need for extra validation of the proposed dynamic model. The robot has the kinematics of a unicycle. It is described by the following equations :

$$\begin{cases} \dot{x} = v.\cos(\theta) \\ \dot{y} = v.\sin(\theta) \\ \dot{\theta} = \omega \end{cases} \tag{1}$$

Where $\theta$, $v$ and $\omega$ are respectively the robot orientation, linear and angular velocities.

From Figure 1. a, we define the position errors as

$$\begin{cases} e_x = (x_T - x) = D_{RT}\cos(\theta_{RT}) \\ e_y = (y_T - y) = D_{RT}\sin(\theta_{RT}) \end{cases} \tag{2}$$

Where $D_{RT}$ corresponds to the current distance between the robot and the dynamic target $T$, which is expressed by

$$D_{RT} = \sqrt{e_x^2 + e_y^2} \tag{3}$$

Similarly, the current angle of the robot according to the target, noted $\theta_{RT}$, is computed as

$$\theta_{RT} = a\tan 2\,(e_y, e_x) \tag{4}$$

The angle error is given by

$$\theta_e = (\theta_{RT} - \theta) \tag{5}$$

The control objective is to design a fuzzy logic controller to drive the robot to the desired configuration (i.e., $D_{RT}(t) = 0$, $\theta_e(t) = 0$).

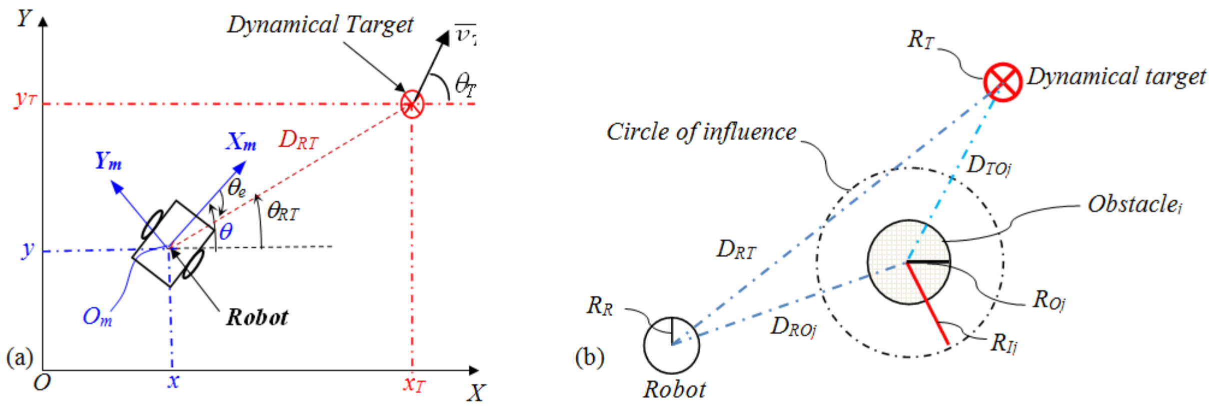


**Fig. 1**. (a) Attraction to a dynamic target and (b) The used perceptions for mobile robot.

## 3. Fuzzy control design

### 3.1. Attraction to a dynamic target controller

Basically the attraction to a dynamic target FLC has :

- Two input variables : the distance and the angle errors, between the robot and the target $T$, given by (3) and (5),
- Two output variables : linear and angular velocities denoted by va and $\omega_a$ , respectively.

Triangular and trapezoidal membership functions (MFs) are used for both input and output variables. Their shapes are given in Figure 2. The values of the input, , and the output, va , are indicated by the linguistic symbols $Z$, $M$, and $G$ which correspond respectively to the linguistic values : Zero, Middle, and Great. The values of the second input, $\theta e$, and the output, wa, are indicated by the symbols ($NB$, $N$, $Z$, $P$, $PB$) which correspond respectively to : Negative Big, Negative, Zero, Positive, Positive Big.

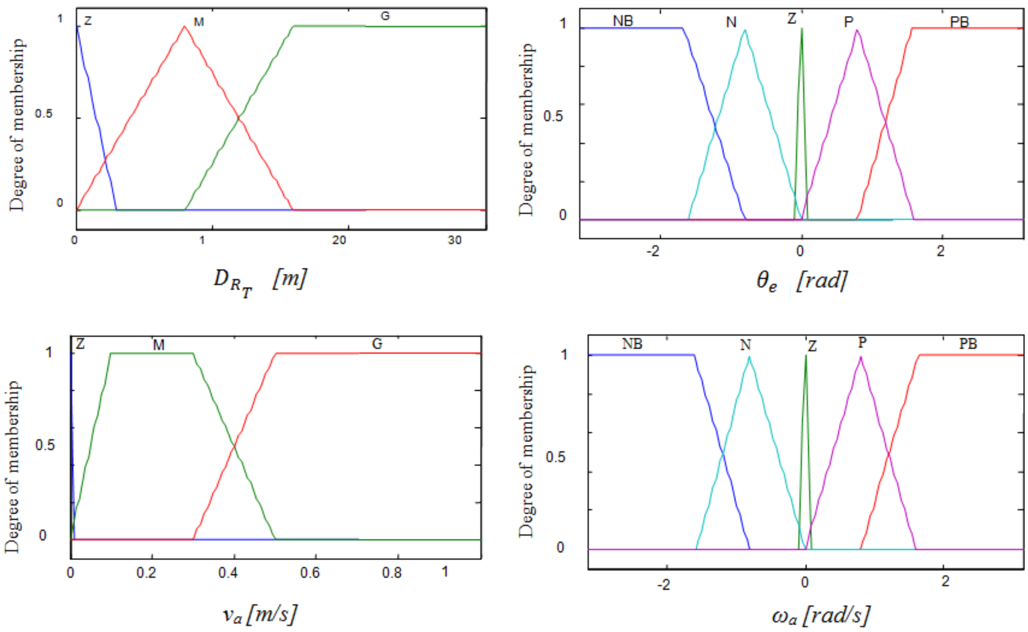


**Fig. 2**. Membership function shapes of the FLC input/output variables.

Table 1 illustrates the decision table of the FLC. The rules are of the form :

Ruler : IF is $G1$ and is $G2$ THEN $\nu_a$ is $G3$ and $\omega_a$ is $G4$

Where ($r = 1, .., 15$), and ($G1$, $G2$) are the antecedents, and ($G3$, $G4$) are the consequences. The center of gravity defuzzification method is used.

**Table 1**. Fuzzy rule sets of the attraction to the dynamic target FLC.

| $D_{RT}$ | $NB$ | $N$ | $Z$ | $P$ | $PB$ |
|---|---|---|---|---|---|
| $Z$ | $Z/PB$ | $Z/P$ | $Z/Z$ | $Z/N$ | $Z/NB$ |
| $M$ | $Z/PB$ | $M/PB$ | $G/Z$ | $M/NB$ | $Z/NB$ |
| $G$ | $Z/PB$ | $M/PB$ | $G/Z$ | $M/NG$ | $M/NG$ |

### 3.2. Obstacle avoidance controller

The obstacle avoidance controller has 2 input variables corresponding to the distance and the angle between the robot and the obstaclej (denoted by $D_{RO_j}$ and $\theta_{RO_j}$ respectively), and 2 outputs variables : linear and angular velocities (denoted by $\nu_0$ and $\omega_0$ respectively). The decision table is given in Table 2. The membership function shapes are given in Figure 3.

**Table 2**. Fuzzy rule set of the obstacle avoidance FLC.

| $D_{RO_j}$ | $N$ | $Z$ | $P$ |
|---|---|---|---|
| $Z$ | $Z/P$ | $Z/N$ | $Z/N$ |
| $G$ | $G/Z$ | $G/Z$ | $G/Z$ |

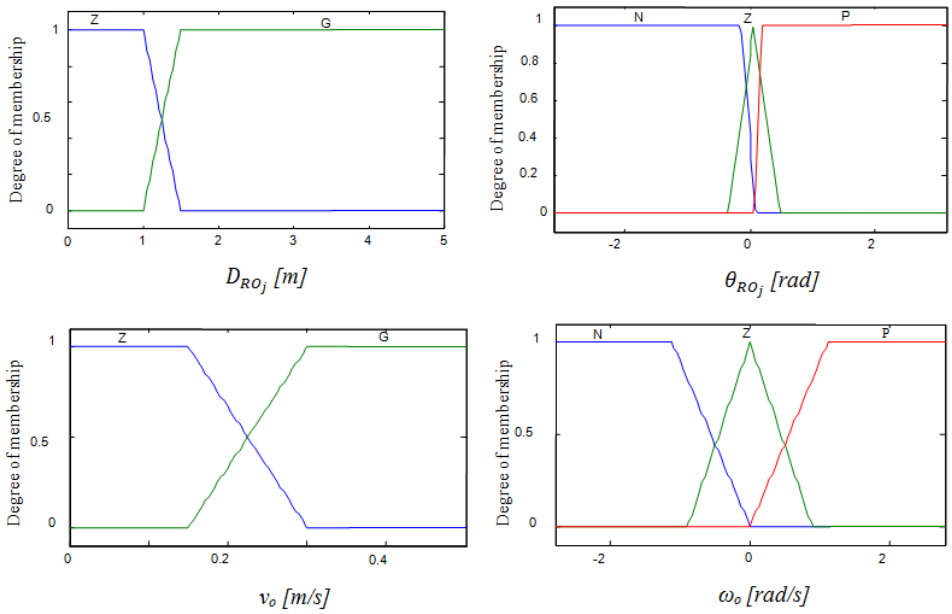


**Fig. 3**. Membership function shapes of the FLC input/output variables.

### 3.3. Fusion controller

We introduce type-2 FLC which can handle rule and numerical uncertainties [11,15]. Its implementation involves the operations of fuzzification, inference and output processing. Output processing is performed in two stages : type reduction and defuzzification.

Type-reduction schemes correspond to extended versions of type-1 defuzzifucation methods. Type reduction captures more information about rule uncertainties than does the defuzzified value (a crisp number), but it is computationally intensive [15,16]. A type-2 FLC is again characterized by IF-THEN rules, but its antecedents or consequents are now type-2 fuzzy sets. The uncertainty effect that comes from the instrumentation elements (amplifier, sensors perception, digital to analog and analog to digital converters, etc.) is simulated by adding noise to the measured FLC input vector.The control signals of the robots ($\nu_r$, $\omega_r$) are obtained by linearly combining (fusion) the outputs of the obstacle avoidance controller and that of attraction to dynamic target controller

$$\begin{cases} v_r = v_o \,.\, g + v_a \,.\, (1-g) \\ \omega_r = \omega_o \,.\, g + \omega_a \,.\, (1-g) \end{cases}$$

Where $g$ corresponds to an adaptive weighting $gain \in [01]$ generated by the fusion controller. The rules set used for type-1 and type-2 fusion FLCs are given in Table 3. Like the obstacle avoidance controller, fusion FLCs have 2 input variables corresponding to the distance and the angle between the robot and the obstaclej (denoted by $D_{RO_j}$ and $\theta_{RO_j}$ respectively) and one output variable (the gain, $g$).

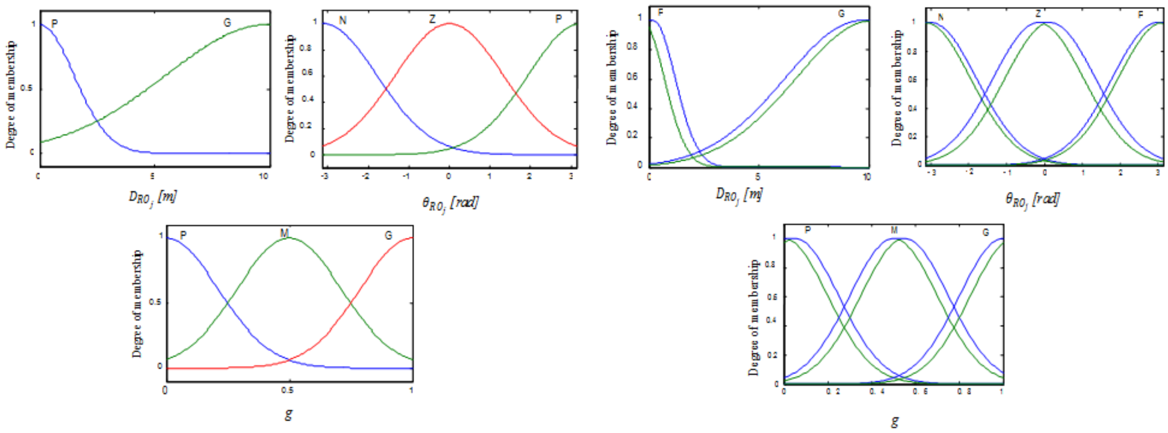

**Fig. 4**. Membership function shapes of the behavior fusion type-1 and type-2 FLC.

**Table 3**. Fuzzy rule sets of the type-1 andtype-2 fusion block.

| $D_{RO_j}$ | $N$ | $Z$ | $P$ |
|---|---|---|---|
| $Z$ | $M$ | $G$ | $M$ |
| $G$ | $P$ | $P$ | $P$ |

## 4. Simulation results

### 4.1. Joining a dynamic target after avoiding obstacle

To perceive the effectiveness of the control scheme proposed in this paper (cf. figure. 5), we have simulated it using Matlab 9.0. This robot should reach a dynamic target, moving straight (cf. Figure 6) or with sinusoidal movement (cf. Figure 7).

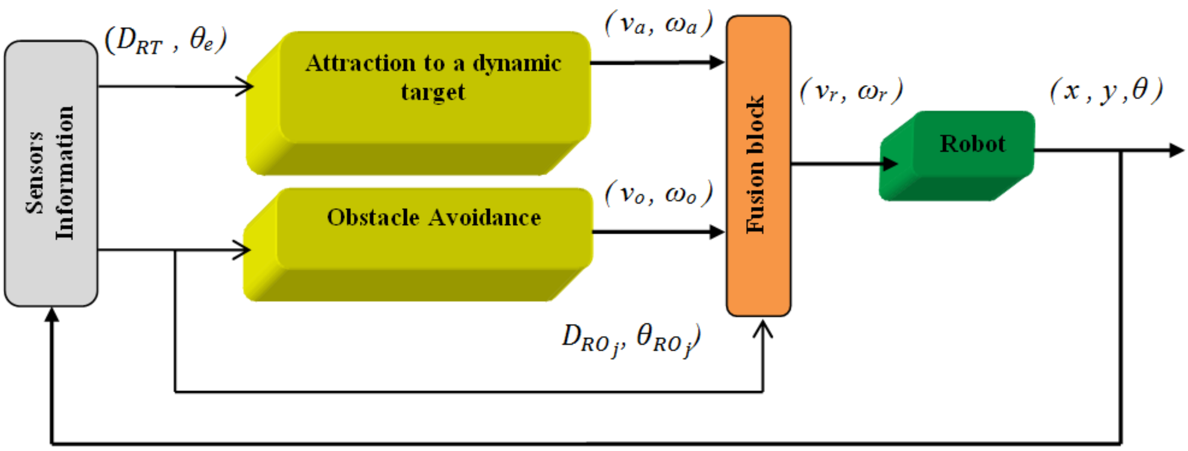


**Fig. 5**. The proposed control scheme.

The simulation results are depicted in Fig. 6 to Fig. 8. The trajectories of the target and the robot applying the two designed control laws are plotted in Figs. 6,7. Fig. 8 (a) and (b), show the variation of the tracking distance and angle errors during the motion of the target and the robot. It is clearly observed in these two simulations that the robot succeeded to converge and follow accurately the dynamic target while avoiding efficiently the cumbersome obstacles.

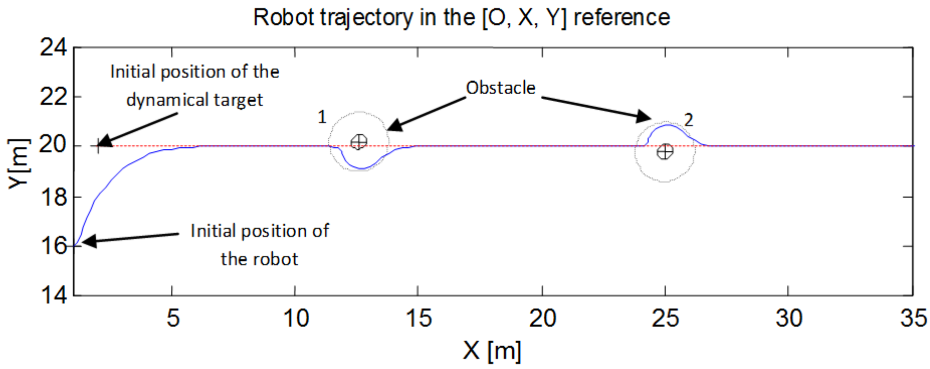


**Fig. 6**. Robot trajectory reaching a dynamic target (moving straight) while avoiding obstacles.

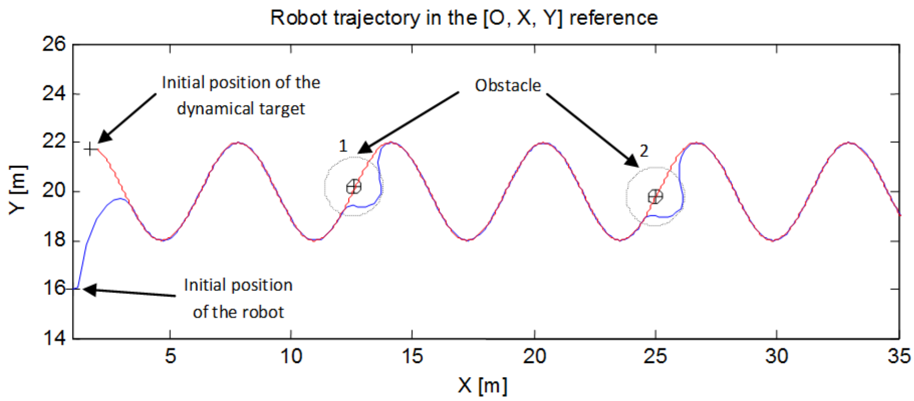


**Fig. 7**. Robot trajectory reaching a dynamic target (moving sinusoidally) while avoiding obstacles.

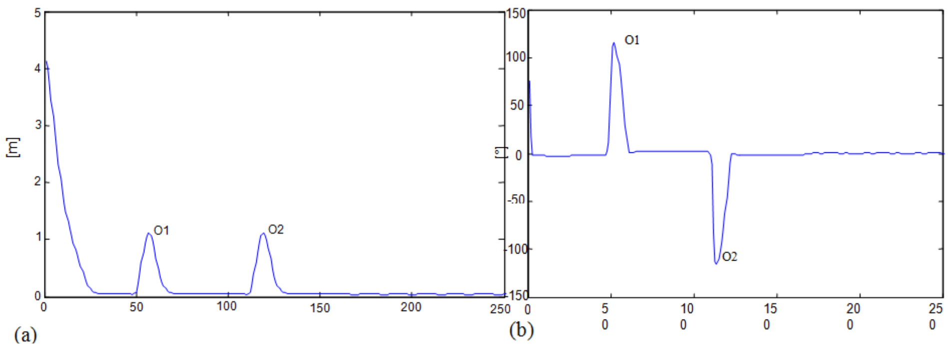


**Fig. 8**. Evolution of the distance (a) and the angle (b) errors between the robot and the dynamic target.

### 4.2. Performance test using collision time

For evaluating the performance of the type-2 and type-1 FLCs, we define the objective function

$$fitness = min(CT) \tag{6}$$

Where the CT denotes the Collision Time which can be defined as the dwell time outside of the configuration space (i.e., in the influence region of the obstacles), due to the presence of different uncertainties. Mathematically, CT is a variable which is incremented, each sampling time, when at least one robot is in the undesired region, i.e., $D_{RO} < R_{Ij}$ (cf. Figure 1. b). In this test, we ran simulations for different values of the standard deviation (std) of the noise ranging from $std = 0$ to $std = 0.5$.

For each std value, the simulation is done using Gaussian and Triangular/Trapezoidal MFs. The evolution of the collision time (CT) of the robots is given in Figure 9. It can be seen that better collision time are obtained using type-2 FLC.

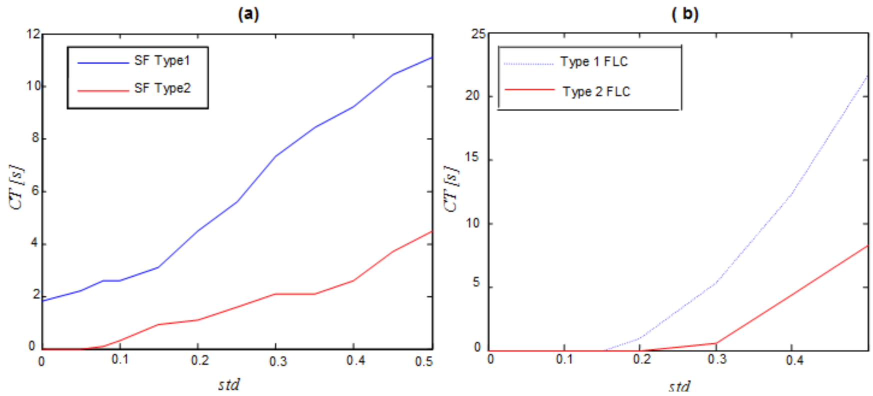


**Fig. 9**. Evolution of the Collision Time of the type-1 and type-2 FLC, (a) : gaussian MFs, (b) : triangular and trapezoidal MFs.

## 5. Conclusion

This paper addresses the problem of the tracking of moving target by a mobile robot. The proposed approach aims to design an intelligent controller based on fuzzy logic techniques. The principal role of artificial intelligence techniques is their ability to design robust controllers with good performances in spite of the lack of information about the mobile robot or its surrounding environment models. Two type-1 fuzzy logic controllers : attraction to a dynamic target and obstacle avoidance based on Mamdani model and have been adopted to determine the mobile robot's velocities to fulfill the control objectives. A type-2 fuzzy logic controller has been also implemented for better efficiency and effectiveness.

The provided simulation results show that the proposed approach acts successfully and enable the robot to track the moving target easily with good performances in term of convergence time and accuracy. The use of a type-2 FLC makes the robot's trajectory and the controllers' outputs much smoother and reduces considerably the collision time and the tracking errors.

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