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Navigation control of a mobile robot under time constraint using the fuzzy logic

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Abstract—**in this paper we will propose a fuzzy controller for a two-wheeled mobile robot moves following a Genetic Algorithms-based plan in its configuration space. In dead the fuzzy controller controls the acceleration. It aims to give the efficient acceleration so that the controlled robot can move from one position to another one in a delimited time window. First, a motion fuzzy control structure with two 2-input-and-1-output fuzzy systems is proposed. Then a Genetic Algorithms-based plan is examined where a path solution obtained with the combination between Genetic Algorithms and Constraint Satisfaction Problem techniques. The different beacons that structure this path will be the data source to the fuzzy controller. In each position of these beacons, the current velocity of the controlled robot is an input for the fuzzy controller. The second input is the time delay between the current position and the next sub goal to reach. Our work is centered on combining the paradigms of the genetic algorithms to develop a minimized path tracking and the fuzzy logic to realize a fuzzy controller that converge the time delay between positions in the path tracking closely to a time window.**

***Keywords*—Path tracking; Mobile robot; Temporal constraint; Genetic algorithms; Fuzzy logic.**

I. INTRODUCTION

The navigation under constraints sometimes engenders ambiguous solutions. This urges us to think of a strong strategy and intelligent as the fuzzy logic. This approach of artificial intelligence was used for the command of a small robot, to insure the follow-up of a complex and pre-calculated trajectory. It was also the basic of the strategy developed for the positioning directed by a vehicle of outside [1].

In this work, a controller based on the fuzzy logic is adopted on the model of the two-wheeled mobile robot described in [2]. The objective of this work is to respect as close as possible the time window solved in the previous work [3]. In dead, the problem of time window was solved using the techniques of the Constraint Satisfaction Problem. The solver realized was based on the genetic algorithms, so that it yields a minimized path length. Furthermore, the definition of the time constraint was integrated and resolved in the crossover operator of the generated algorithm as mentioned in [3]. In this solver we have calculated the velocity that corresponds to a time delay between two successive positions. This time mustn't be over a time window fixed according to navigation of the mobile robot. Then, we notice that we can improve the result by making the time delay closer to the value of the time window. Our idea was how we can change the parameters that impacted the navigation of the mobile robot. To answer this, we have centered on the acceleration. Besides, we have enhanced our solution by the paradigm of the fuzzy logic to make the results more natural and efficient.

This paper will be organized as following. Firstly, we describe the problem statement in section 2. Secondly, we define in section 3, the new way to use fuzzy logic approach with Constraint Satisfying Problem. Thirdly, the section 4 deals with the fuzzy controller. Then, the section 5 exposes the new GA-plan. We end this work by the section 6 that gives an example of the executed plan.

II. PROBLEM STATEMENT

The problem to be solved is the navigation with time window for a mobile robot using a fuzzy controller. The time window was solved using Constraint Satisfaction Problem and it's considered as a temporal constraint [3]. The result was a path tracking of a mobile robot that respects a time window and has the minimum distance. The optimization was studied in [4] using the genetic algorithms. The objective of the present work is to change the velocity of the mobile robot so that the time between two positions in the path will be as closer as possible to the time window. For that reason we would like realizing a fuzzy controller to fulfill this goal. The inputs are the time delay between the current position and the following one as well as the velocity of the mobile robot. The output will be the necessary acceleration to correct the time delay to pass from a position to the following one on the path tracking.

In a previous work, we have resolved the problem of the time window using the combination between genetic algorithms and Constraint Satisfaction Problem techniques.

The linear velocity is defined by the equation (1):

$$v_{k+1} = v_k + a\,dt \quad (1)$$

Where:

v_k : Linear velocity in the position k;

v_{k+1} : Linear velocity in the position k+1;

a : Acceleration needed so that dt will be closer to the value of the time window;

dt : Time delay between two positions of the mobile robot (k+1 and k);

And the temporal constraint is defined as following:

$$t_{k+1} - t_k \leq T \quad (2)$$

k =1,………., n.

Where:

t_k : Time in the position k;

t_{k+1} : Time in the position k+1;

T : The value of time window.

The solution presented by the solver of the previous work [3] based on the method of neighborhood, allows having the closest following position respecting the constraint of the equation 2. In the present solution we shall be anxious to fit the time delay (dt) to the value of T by acting on the velocity of the mobile robot by the acceleration a. Our work shall answer to the cases of the kind:

- If dt close to T then the robot has to keep the same speed;
- If dt far from T then the robot has to accelerate;
- If dt very close to T then the robot has to slow down;
- If dt very far from T then the robot has to accelerate;

The best way to answer these choices it is the use of fuzzy logic.

III. Proposed Fuzzy Logic Approach Control

The studies on fuzzy logic theory have increased tremendously since its development by Zadeh [5]. The application of fuzzy logic theory to a control system by Mamdani and his colleges [6] has given a push to the Fuzzy Logic real world applications. The implementation of a fuzzy controller requires the affectation of the values of the function of membership for the variables of the inputs and outputs since these later are linguistic variables having no quantitative value. For the variables of inputs their values of membership function are often measured and are affected before being used by the interference engine. This section is called the fuzzification. The inference engine is based on a set of rules: If-Then describing linguistic variables. It's the data of the second section called the inference. As result of the interference engine, the inputs variables will have numerical values gathered in a fuzzy set. Later the defuzzification, this third section affects a single value to the output of the fuzzy controller.

We won't give the theory of fuzzy sets and fuzzy logic is not going to be repeated here. However, the design procedure of the proposed fuzzy logic controller is given in detail in the next section. Classical Constraint Satisfaction Problem has been extended to incorporate different types intelligent techniques frequently found in real problems. One successful example is fuzzy logic. The present application of this paradigm is a new way to the use of fuzzy logic in the resolved constrained problem. Because in our work, we use the fuzzification to give results according to the range of values that satisfy the temporal constraint defined by equation 2.

IV. FUZZY CONTROLLER MODEL

As shown in Fig. 1, the fuzzy system to be developing is a two-input-and-one-output fuzzy system. There are two inputs to the fuzzy inference system. One is the velocity of the mobile robot in the position of the current beacon, which refers a surveyed site, the other one is the time needed to reach the next goal. These two inputs are firstly fuzzified and converted to fuzzy membership values. The output corresponds to the acceleration so that the mobile robot reaches the next surveyed site in a time close to the time window.

The fuzzy rule base, which may also be called as the fuzzy decision table, is the unit mapping two crisp inputs, velocity and time to the fuzzy output space defined on the acceleration.

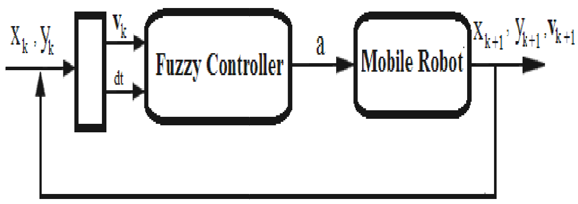

Fig. 1 Diagram block of the fuzzy controller system for a two-wheeled mobile robot

The fuzzy rules represent the knowledge and abilities of a human operator who makes necessary adjustments to operate the system with needed velocity and to respect the time window. The output from the fuzzy logic controller, which is the acceleration, models the actions that a human operator would decide: whether the velocity of the mobile robot is to be increased or decreased according to the time remained to reach the next beacon.

A. *Fuzzification*

Observing our fuzzy controller, we can describe the velocity, time and acceleration as following: the Big Negative (BN), the Medium Negative (MN), the Small Negative (SN), the Zero (Z), Small Positive (SP), Medium Positive (PM), Big Positive (BP)), the Big (B), the Very Big (VG), the Small (S), the very Small (VS), the Very Low (TF), the Low (F). These linguistic terms, are represented by fuzzy sets partitioned into crisp universes.

The figure 2 indicates the functions member of triangular membership used to describe fuzzy sets variables of inputs and output, respectively.

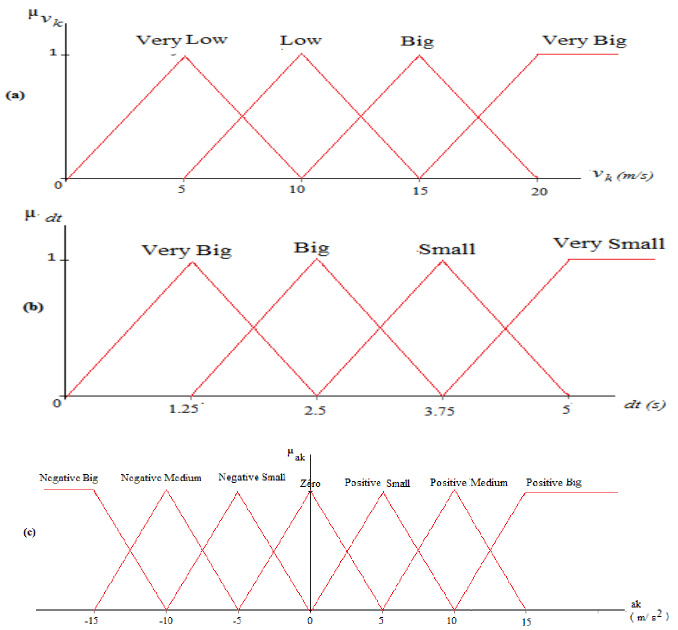

Fig. 2 (a) fuzzy subsets of the velocity v, (b) fuzzy subsets of the dt, and (c) the fuzzy subsets of the acceleration a.

Triangular type membership functions are used for partitioning the crisp universes into fuzzy subsets. Different membership functions such as Gaussian, trapezoidal, and bell could have also been used. Each one of these membership functions has its own effects on the fuzzy logic controller output [7]. However, triangular membership functions are more convenient for expressing the concept because it is easier to intercept membership degrees from a triangle. Therefore the following function is used to represent the fuzzy triangular membership functions.

$$\mu(x) = \max\left[\min\left(\frac{x - x_1}{x_2 - x_1}, \frac{x_3 - x}{x_3 - x_2}\right), 0\right] \quad (3)$$

Where, x is the crisp values from one of the three universes v, dt, and a. x1 is the left end point on the corresponding crisp universe as the x2 and x3 are the crisp points corresponding peak and right end points, respectively.

B. *Inference*

A rule decision table can be formed as shown in Table 1. This table is built manually.

TABLE I

FUZZY BASE RULE OF THE FUZZY CONTROLLER SYSTEM FOR THE MOBILE ROBOT

a		v_k			
		VL	***L***	***B***	***VB***
dt	***VB***	PB	PB	PM	PS
	B	PB	PM	PS	Z
	S	PM	PS	NS	NM
	VS	PS	Z	NB	NB

The mode of use of this table is illustrated by the fuzzy rules proposed by the system described as follows:

- R1: if (((dt is VB) and ((v_k is VL) or (v_k is L)) or ((dt is B) and (v_k is VL)) Then (a is Positive Big);
- R2: if (((dt is VB) and (v_k is L)) or ((dt is VB) and (v_k is B))) Then (a is Positive Medium);
- R3: if (((dt is B)) and (v_k is B)) or ((dt is VB)) and (v_k is VB)) or ((dt is S) and (v_k is L)) or ((dt is very S) and (v_k is VL))) Then (a is Positive Small);
- R4: if (((dt is B)) and (v_k is VB))) or ((dt is VS) and (v_k is L))) Then (a is Zero);
- R5: if ((dt is S) and ((v_k is B)) Then (a has is Negative Small) ;
- R6: if ((dt is S) and ((v_k is VB)) Then (a is Negative Medium));
- R7: if ((dt is very S) and ((v_k is VB) or (v_k is B)) Then (a is Negative Big);

These seven rules will form the base rule of the studied fuzzy controller. We notice that in these rules we use of logical operators "AND" and "OR". The realization of these logical operations connected to the method of used inference. In our case we shall use the method Max-Min as it's mentioned in the section *A*.

This method of inference realizes the conditions connected by OR using the maximum whereas the conditions connected by AND using the minimum.

C. *Défuzzification*

The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled.

After establishing the base of rules and specifying the membership functions of variables, we go to the defuzzification. This stage allows converting the linguistic variables of the fuzzy controller into the physical variables. Based on the weighted average method, the final outputs of the controller fuzzy system can be described by:

$$a = \frac{\sum_{i=1}^{7} \mu_{a(\alpha_i)} {}^{*}\alpha_i}{\sum_{i=1}^{7} \mu_a(\alpha_i)} \quad (4)$$

V. New Genetic Algorithm

Genetic programming [8] has in recent times been verified to be a practical approach for mobile robot control and navigation [9]. In this, we address the design of fuzzy logic controllers handling temporal constraint in a Genetic Algorithms-based plan.

The new algorithm is a combination between the genetic algorithms, the approach of Constraint Satisfaction Problem and the approach of the fuzzy logic. The execution of this new algorithm generates the value of the necessary acceleration in every position of the optimized path. This later yield from the hybridization of the genetic algorithms and Constraint Satisfaction Problem techniques conducted on in [3]. In fact, the evolutionary approach gives the shortest path to go and the Constraint Satisfaction Problem techniques bound the passageway between two successive beacons by a time window. By using the fuzzy logic, we correct the time delayed between every two consecutive beacons in the path tracking. Consequently, the result is a minimal path tracking for a mobile robot respecting as much as possible a time window which is described by the following figure 3.

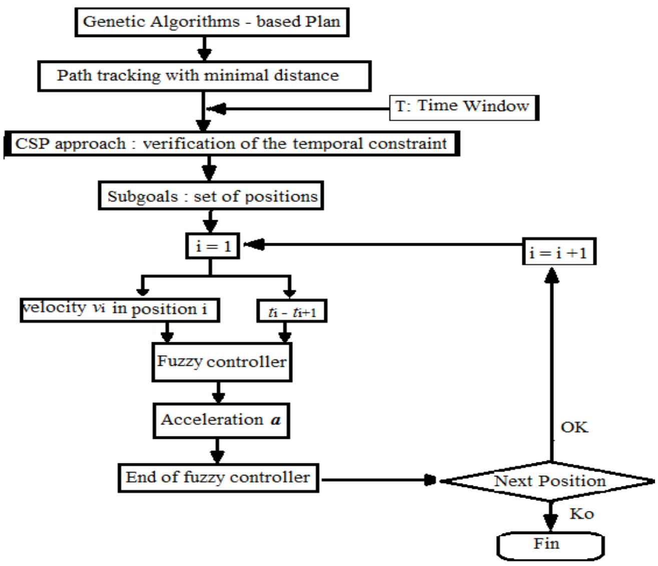

Fig. 3 Organigram : combination between the genetic algorithms, Constraint Satisfaction Problem approach and fuzzy logic

VI. Results

The simulation of the fuzzy controller of the acceleration is realized by using the programming language C ++ under the development environment of the Microsoft Visual Studio 2010.

We assume that the mobile robot is a one particle in its configuration space. It's a horizontal plan equipped by a number of artificial beacons (n = 5). Each one represents an objective to reach. The time window has for value T=5mn and the number of neighborhood is fixed to 3.The positions of the artificial beacons are represented in the table 2.

TABLE III

Coordinates of Artificial Beacons' Positions

artificial beacon Code	0	1	2	3	4
Axe X	7.0	9.0	5.0	3.0	5.0
Axe Y	8.0	1.0	2.0	4.0	6.0

The figure 4 represents the path tracking solution of the generated algorithm which is encoded by the integer sequence: 04321. The different positions of this path (0, 4, 3, 2) will be used for the studied fuzzy controller.

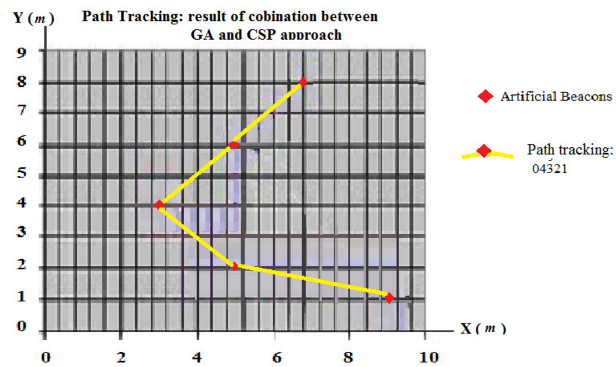

Fig. 4 Path tracking: result of the hybrid algorithm combining genetic algorithms and Constraint Satisfaction Problem techniques

The definition of the linguistic variables inputs and output: dt, v_k and a, are defined in a class called: RM_En_Flou. In this class we define the various membership functions of the linguistic variables as member functions of this class. The inference is concretized by a class that we have conscript RB_Moteur_Inference. In this class we have defines an array corresponding to the inference table (Table 1). Among the member functions in the class of inference, we have program the function of inference Max-Min (equation 3) and the function used for the defuzzification which bases on the equation 4.

The values of the acceleration calculated by the fuzzy controller for the deferent points of the trajectory are recapitulated in the following Table 3. The trajectory is yielded by the new algorithm that combines the approach of the genetic algorithms and the techniques of the Constraint Satisfaction Problem.

TABLE IIIII

THE WHOLE DECISION USING FUZZY LOGIC

Code position	0	4	3	2
v_k (m/s)	2	20	13.4 4	67
$\boldsymbol{dt}$ (mn)	3	2.7	2	4.3
$\boldsymbol{a}$ (m/s^2)	6	-1.14	6.9	9.7

Points studied in the trajectory are 0, 4, 3, and 2; we notice the absence of the point 1 of this trajectory because this point marks the end and as a consequence it hasn't successor. The next figure 5 represents respectively the variation of the velocity and the acceleration along the resultant path tracking (04321).

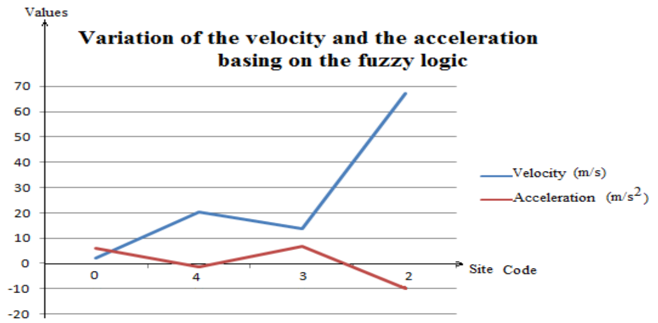

Fig. 5 Variation of the speed and the acceleration of the Mobile Robot by basing itself on the vague logic along the trajectory crossing sites to be watched and respecting a temporal window.

VII. CONCLUSION

A mobile robot is a complex system. In fact, it has to satisfy several requirements during its navigation. This requires a reliable and very precise decision-making. A typical example is to execute an optimal plan which respects temporal constraints. In order to reach the various purposes described along this plan, we aim at specifying as much as possible the parameters of the movement of the mobile robot: the acceleration and the velocity. These arbitrations were insured by some control approach such as the genetic algorithms, the techniques of Constraint Satisfaction Problem and the fuzzy logic. This hybridization shows a new way to treat a constraint defined on a system with fuzzy logic. Actually, this new method approve that the solver can be guided by human preferences.

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