

# OPTIMIZATION OF MEMBERSHIP FUNCTION PARAMETERS FOR FUZZY CONTROLLERS OF AN AUTONOMOUS MOBILE ROBOT USING THE FLOWER POLLINATION ALGORITHM

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Oscar R. Carvajal, Oscar Castillo, José Soria

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## Abstract:

In this work we describe the optimization of a Fuzzy Logic Controller (FLC) for an autonomous mobile robot that needs to follow a desired path. The FLC is for the simulation of its trajectory, the parameters of the membership functions of the FLC had not been previously optimized. We consider in this work with the flower pollination algorithm (FPA) as a method for optimizing the FLC. For this reason, we use the FPA to find the best parameters with the objective of minimizing the error between the trajectory of the robot and the reference. A comparative study of results with different metaheuristics is also presented in this work.

**Keywords:** Flower Pollination Algorithm, membership functions, optimization problems, fuzzy system

## 1. Introduction

The use of fuzzy logic as a control technique has been gaining popularity in control systems [1], [2], [3], [4], classic control is less intuitive so in many applications due to the complexity of implementation we would rather use fuzzy systems than classic control systems, nowadays there are a lot of applications that are working with fuzzy logic and they have been growing rapidly [5], [6].

The FPA was introduced by Xin-She Yang in 2012 [7], it has been used in application areas such as classification, pattern recognition and in this case for optimization. The FPA is based on the inspiration of the flower pollination process when the pollen is moved by pollinators such as insects or animals like honeybees, kind of birds, butterfly, etc.

The rest of the paper is structured in the following way. In Section 2 we describe the FPA algorithm, its performance and characteristics, the equations that represent the functionality of the global and the local search and some of the applications of this algorithm. In Section 3 we show the design of the Fuzzy Logic Controller, then in Section 4 we define the parameters that we have to optimize, in Section 5 we describe the results and simulation of the robot. Finally, in Section 6 there is a conclusion of this work.

## 2. Flower Pollination Algorithm

The Flower Pollination Algorithm is a meta-heuristic introduced in 2012 by Xin-She Yang, some of the applications of this algorithm are mainly to solve problems with single objective or multi-objective problems. The FPA has been inspired in a natural process called pollination of flowers, there are thousands of species of plants in this natural process, it is the transfer of pollen from a flower to another flower either from the same plant or a different plant. The pollination process needs two parts, the first one, is the pollinator and the second is the plant with at least a flower, there are two types of pollinators, they are abiotic and biotic, abiotic like the air, and water, and biotic can be animals and insects, like butterflies, bees, and some species of animals, for example some kinds of bats. A study shows us that the 90 percent of the pollination is performed in the biotic way, so the 10 percent is carried out in the abiotic way. The biotic way can be view as the global search of the algorithm, and the abiotic way can be as the local search of the FPA. Sometimes the biotic way is called cross pollination and the abiotic way self-pollination.

There are four characteristics in this method, they are the following [7]:

1. Biotic and cross-pollination can be considered processes of global pollination, and pollen-carrying pollinators move in a way that obeys Levy flights (Rule 1).
2. For local pollination, abiotic pollination and self-pollination are used (Rule 2).
3. Pollinators such as insects can develop flower constancy, which is equivalent to a reproduction probability that is proportional to the similarity of two flowers involved (Rule 3).
4. The interaction or switching of local pollination and global pollination can be controlled by a switch probability  $p \in [0, 1]$ , slightly biased toward local pollination (Rule 4).

The four characteristics of the FPA have been converted in equations that describe the features of this algorithm. In the global pollination the pollen is carried out by animals and insects that can travel to longer distances and a wider range. Equation 1 is for the global pollination [7].

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(g_* - x_i^t) \quad (1)$$

Where is the pollen  $i$  at the iteration and is the best solution in the current iteration.

The in Equation 2 is the parameter that represents the strength of pollination and it is based on the Levy Flights [7].

$$L \sim \frac{\lambda \Gamma(\lambda) \sin(\pi\lambda/2)}{\pi} \frac{1}{s^{1+\lambda}}, s \gg s_0 > s \quad (2)$$

Here is the standard gamma function and it is valid for larger steps greater than zero.

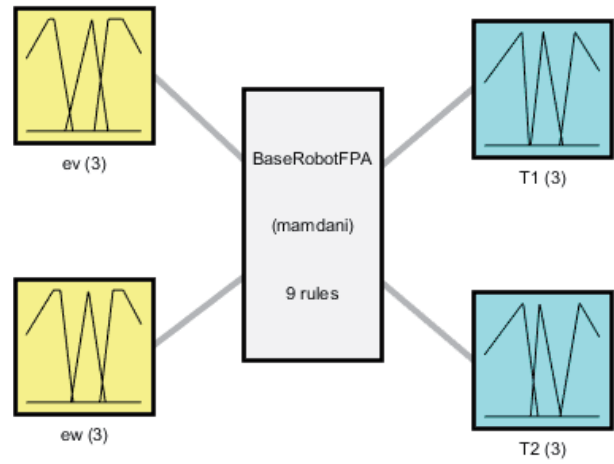
Global Pollination can be represented in equation 3 [7]:

$$x_i^{t+1} = x_i^t + \epsilon (x_j^t - x_k^t) \quad (3)$$

Where and are pollen of different plants of the same species. The parameter is for a random search for a uniform distribution in [0, 1].

### 3. Fuzzy Controller

The FLC is of Mamdani type, as the Figure 1 shows us it has two inputs and two outputs. Where the inputs are the error in angular velocity (ew) and the error in linear velocity (ev). The outputs are torque one (T1) and torque two (T2) that need to have each wheel of the robot in this case the robot has two wheels with servomotors [8], [9], [10], [11].



System BaseRobotFPA: 2 inputs, 2 outputs, 9 rules

Fig. 1. Fuzzy Controller Structure

The inputs and outputs membership function's linguistic values are N, Z, and P, they stand for Negative, Zero, and Positive respectively, and they are in the range [-1,1]. The outputs of the FLC are triangle membership functions, and the input membership functions are of triangle type in the Z linguistic variable, and trapezoidal form in the N and P linguistic variables [11], [12], [13]. We have an example in Figure 2.

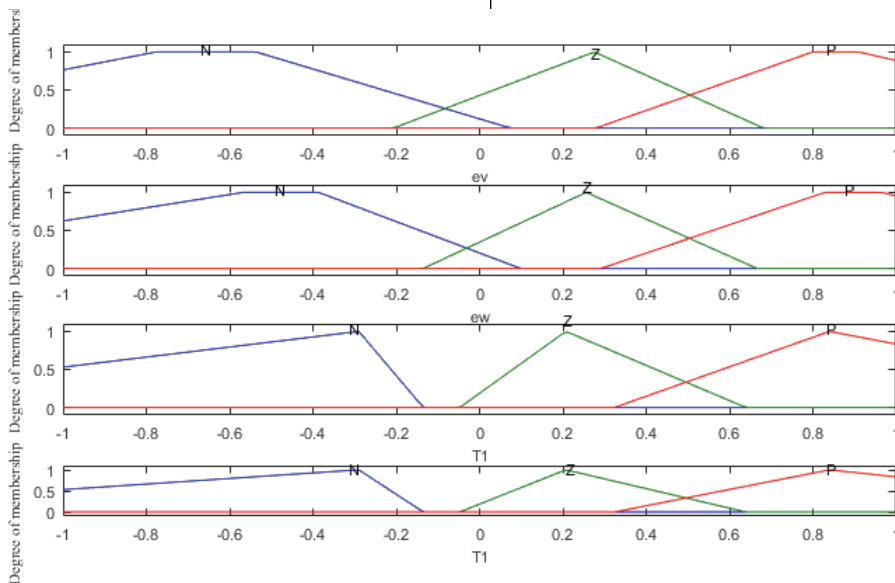


Fig. 2. Membership functions of the FLC

Fuzzy rules can be considered like the knowledge of an expert in a specific field, they are represented in the sequence IF-THEN to associate a condition through linguistic variable.

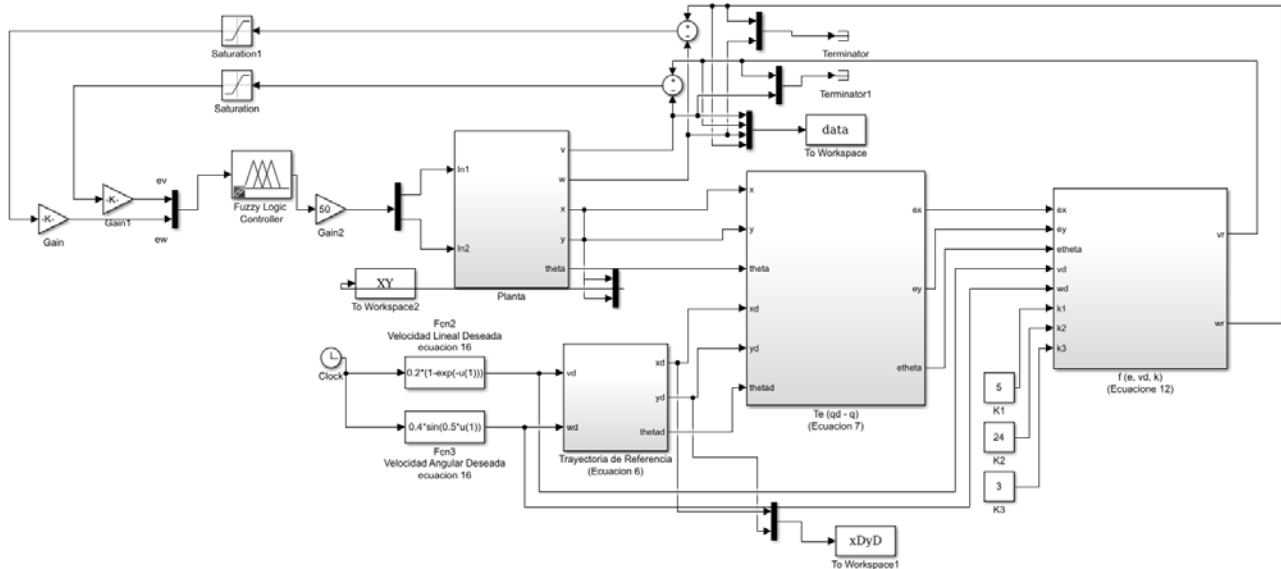
There are 9 rules for the FLC to deal with the robot, they are the following [8], [14]:

1. If (ev is N) and (ew is N) then (T1 is N) (T2 is N)
2. If (ev is N) and (ew is Z) then (T1 is N) (T2 is Z)
3. If (ev is N) and (ew is P) then (T1 is N) (T2 is P)
4. If (ev is Z) and (ew is N) then (T1 is Z) (T2 is N)
5. If (ev is Z) and (ew is Z) then (T1 is Z) (T2 is Z)

6. If (ev is Z) and (ew is P) then (T1 is Z) (T2 is P)
7. If (ev is P) and (ew is N) then (T1 is P) (T2 is N)
8. If (ev is P) and (ew is Z) then (T1 is P) (T2 is Z)
9. If (ev is P) and (ew is P) then (T1 is P) (T2 is P)

### 4. Optimization of Parameters of the Membership Functions

The parameters were optimized using the FPA, the simulation model is shown in Figure 3, it is based on the kinematics of a differential robot [15], the mod-



**Fig. 3. Simulation model of the differential robot**

el has a classic closed loop control system where the controller is the FLC. In Figure 2 we show you an example of the parameters of the membership functions that we have optimized.

The model is called by the FPA to update all the variables of the simulation every short time to determine the actual error, this error determines the stopping criteria of the algorithm, it means that when the error is acceptable, the algorithm finishes its process and show the results. In some cases, the FPA needs more iterations for convergence to the solution and in other cases it needs fewer iterations.

### 5. Simulation Results

For the simulation 30 experiments using the FPA were performed, we have obtained good results, an average of the error with the medium square error (MSE) is 0.00483803 and a standard deviation of 0.002779863. The parameters of the FPA that were moved manually are the following, the population size (n) between a recommended range of 10 to 25, iterations, and the probability value where a 0.8 value has been recommended since 2012. In Table 1 we show all the experiments that we have explained before.

**Table 1. Experiments of optimization using the flower pollination algorithm**

FPA Experiments				
Experiments	MSE Error	Population	Probability	Iterations
1	0.0046	n = 25	p = 0.9	20000
2	0.009	n = 23	p = 0.8	876
3	0.0035	n = 25	p = 0.8	2182
4	0.006	n = 10	p = 0.8	13959
5	0.0004	n = 15	p = 0.8	2414
6	5.69E-04	n = 17	p = 0.8	1211
7	0.0044	n = 18	p = 0.8	4219
8	0.0062	n = 17	p = 0.8	20000
9	0.000089862	n = 17	p = 0.2	10589
10	0.0029	n = 20	p = 0.3	4080
11	0.0064	n = 22	p = 0.4	4610
12	0.0053	n = 24	p = 0.5	12091
13	0.0039	n = 18	p = 0.6	6415
14	0.0072	n = 25	p = 0.7	9547
15	5.41E-04	n = 10	p = 0.8	6796
16	0.0073	n = 11	p = 0.8	1969
17	0.0065	n = 12	p = 0.8	2706
18	0.0065	n = 13	p = 0.8	9451
19	0.0091	n = 14	p = 0.8	20000
20	8.20E-03	n = 16	p = 0.8	9500

FPA Experiments				
Experiments	MSE Error	Population	Probability	Iterations
21	0.0085	n = 17	p = 0.8	630
22	0.0010404	n = 19	p = 0.8	15101
23	0.0066	n = 20	p = 0.8	8950
24	0.0041	n = 20	p = 0.9	10755
25	0.0085	n = 25	p = 0.85	1217
26	0.002	n = 23	p = 0.85	1200
27	0.0032	n = 23	p = 1	2037
28	0.0054	n = 22	p = 0.95	17500
29	0.0058	n = 23	p = 0.83	3405
30	0.0014	n = 23	p = 0.78	9641
Average	0.00483803	-	-	-
Standard Deviation	0.002779863	-	-	-

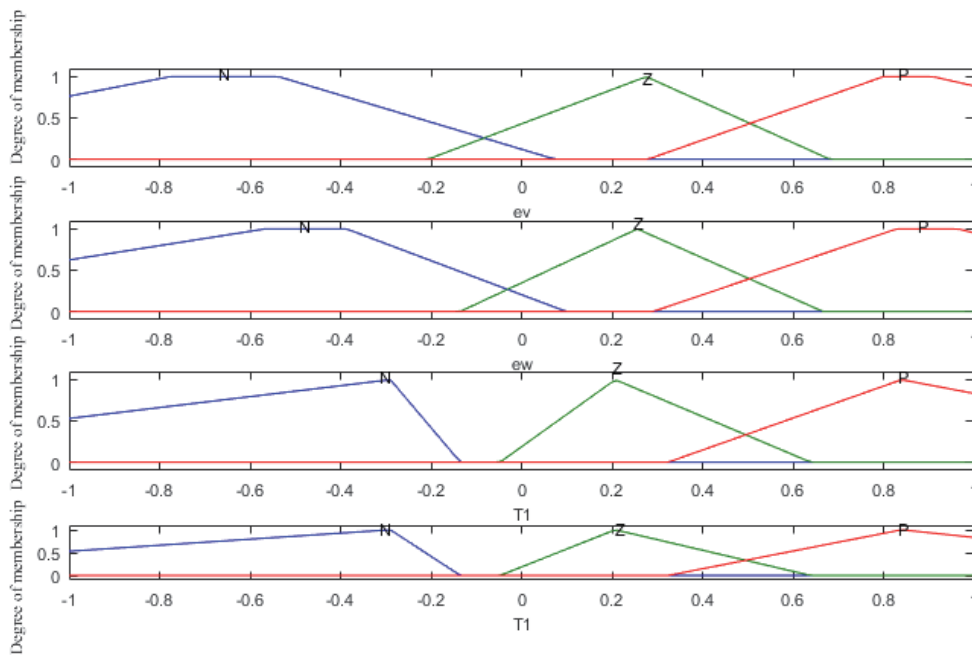


Figure 4. Membership functions and trajectory of the robot with respect a reference of experiment 6

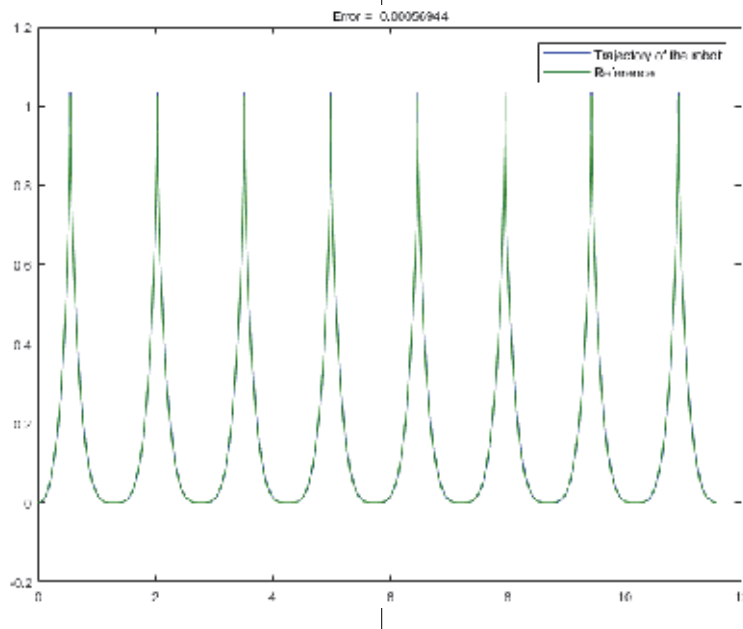


Figure 5. Experiment 6

For example, in experiment 6 we obtained an MSE of 0.000569, with a population size of 17, the probability value is 0.8, and 1211 iterations. We illustrate the result of the parameters of the membership functions, and the trajectory of the robot and we compare it with the reference, we have the result as we can see in figure 4. In Figure 5 we focus on the trajectory and the reference as we can see they are very close.

Table 2 shows the comparison of the MSE of each metaheuristic, the FPA obtains a better average in all of them. The comparison is with Genetic Algorithms with type-1 and type-2 inference system and with the Ant Colony Optimization with type-2 inference system and dynamic adaptation of parameters.

**Table 2. Comparison of the methods for the same optimization problem**

MSE	FPA	GA + T1FS [13]	GA + T2FS [13]	ACO + T2FS DINAMIC [27]
Average	0.00483803	0.438709	0.400899	0.0096
Standard Deviation	0.00277986	0.050195	0.00325	0.0148
Experiments	30	30	30	30

As we can see with the proposed method we obtained better results compared with the methods mentioned before, with the GA+T1FS and GA+T2FS the parameters of the membership functions are also moved manually, however with the ACO + T2FS the parameters were moved dynamically but we also obtained better results.

## 6. Conclusions

In this work we proposed a methodology to solve the control problem for the optimization of the trajectory of an autonomous mobile robot. We used a fuzzy system of Mamdani type to determine the trajectory and a bioinspired algorithm to optimize its parameters so we obtained the best FLC for the best trajectory for the simulation of the robot.

We performed a comparative study with respect to other metaheuristics based on the average and standard deviations, and we have obtained better results. In future work we can consider moving the parameters of the FPA dynamically and compare with other algorithms.

We have realized that the FPA is a more effective method for the optimization for the simulation of the differential autonomous mobile robot than other methods in the literature.

In the future we envision using the optimization method with type-2 fuzzy controllers for the autonomous mobile robot. Of course, it is more difficult to optimize type-2 fuzzy controllers, but these can be more effective in dynamic and uncertain environments for the robots”.

## AUTHOR

**Oscar R. Carvajal, Oscar Castillo\*, José Soria** – Tijuana Institute of Technology, Tijuana BC México.

\* Corresponding author.

E-mail: ocastillo@tectijuana.mx

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