Optimization of a Reactive Fuzzy Logic Controller for a Mobile Robot Using Evolutionary Algorithms

Abraham Meléndez, Oscar Castillo, Arnulfo Alanis

Abstract:

This paper describes an evolutionary algorithm application for the optimization of a reactive fuzzy controller applied to mobile robot navigation. The evolutionary algorithm optimizes the fuzzy inference system and the position and number of the sensors on the robot, while trying to use the less power possible.

Keywords: *fuzzy control, genetic optimization, genetic fuzzy systems, robotic systems.*

1. Introduction

Robots are being more commonly used in many areas of research and a reason for this is that they are becoming more accessible economically for researchers. In this paper we consider the optimization of a fuzzy controller; that gives the ability of reaction to the robot. This may be too general, so let's limit what in this paper will be described as ability of reaction - this is applied in the navigation concept, so what this means is that when the robot is moving, and at some point of its journey it encounters an unexpected obstacle, it will react to this stimulation avoiding and continuing on its path. The trajectory and path following are considered independent parts and are not consider on this paper [19].

There are many traditional techniques available to use in control, such as PD, PID and many more, but we took a different approach in the Control of the robot, using an area of soft computing which is fuzzy logic that was introduced by Zadeh [1]. Later this idea was applied in the area of control by Mamdami [2], where the concept of FLC (Fuzzy Logic Controller) originated. It is also important to mention that this is not the only area were the fuzzy concepts are applied but it is where the most work has been done, and were many people have contributed important ideas and methods like Takagi and Sugeno [2].

There are many recent papers on controlling mobile robots with intelligent techniques, in particular with fuzzy logic and genetic algorithms [3], [4], [5], [6], [7]. However, in this paper the proposed approach is to use an evolutionary algorithm to optimize the fuzzy logic reactive controller of a mobile robot. There are also several works on using fuzzy logic for tracking control and navigation of mobile robots [8], [9], [10], [11], [12], [13], [14], [15], [16], [19] ,[20].

This paper is organized as follows: in section 2 we describe the mobile robot used in these experiments, section 3 describes the development of the evolutionary method. Section 4 shows the simulation results. Finally, section 5 presents the Conclusions.

2. Mobile Robot

The robot is based on the description for mobile robots presented in [21] and assumes a wheeled mobile robot consisting of one or two conventional, steered, unactuated and not-sensed wheels and two conventional, actuated, and sensed wheels (conventional wheel chair model). This type of chassis provides two DOF (degrees of freedom) locomotion by two actuated conventional non-steered wheels and one or two un-actuated steered wheels. The Robot has two degrees of freedom (DOFs): y-translation and either x-translation or z-rotation [21]. Fig. 1 shows the robots configuration, it will have 2 independent motors located on each side of the robot and one castor wheel for support located at the form of the robot.

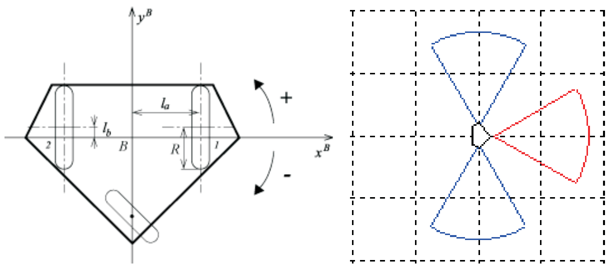

Fig. 1. Kinematic coordinate system assignments [21].

The kinematic equations of the mobile robot are as follows:

Equation 1 is the sensed forward velocity solution [21]

$$\begin{pmatrix} V_{Bx} \\ V_{By} \\ \omega_{Bz} \end{pmatrix} = \frac{R}{2l_a}\begin{pmatrix} -l_b & l_b \\ -l_a & -l_a \\ -1 & 1 \end{pmatrix}\begin{pmatrix} \omega_{W1} \\ \omega_{W2} \end{pmatrix} \quad (1)$$

Equation 2 is the Actuated Inverse Velocity Solution [21]

$$\begin{pmatrix} \omega_{W1} \\ \omega_{W2} \end{pmatrix} = \frac{R}{R(2l_b^2+1)}\begin{pmatrix} -l_a l_b & -l_b^2-1 & -l_a \\ l_a l_b & -l_b^2-1 & l_a \end{pmatrix}\begin{pmatrix} V_{Bx} \\ V_{By} \\ \omega_{Bz} \end{pmatrix} \quad (2)$$

Where under the Metric system we have the following:

V_{Bx}, V_{By} - Translational velocities [m/s],
ω_{Bz} - Robot z-rotational velocity [rad/s],
ω_{W1}, ω_{W2} - Wheel rotational velocities [rad/s],
R - Actuated wheel radius [m],
l_a, l_b - Distances of wheels from robot's axes [m].

3. Evolutionary Method Description

In this section we will describe the Genetic Algorithm applied to the problem of finding the best fuzzy logic reactive controller for a mobile robot. The genetic algorithm optimizes the structure of the fuzzy system for control, which means tuning the membership functions and optimizing the number of fuzzy rules.

The purpose of using a evolutionary method, is to obtained the best reactive control possible, for the robot, but also taking into consideration other desirable characteristics on the robot that we want to improve making this a multi objective [17] problem, for this we will take advantage of the HGA (Hierarchy Genetic Algorithm) intrinsic characteristic to solve multi objective problems, now let us state the main goal of our HGA.

The main goal is to optimize the Reactive Control taken in to consideration the following:

- Fine tune the Fuzzy Memberships
- Optimize the FIS if then fuzzy rules
- The mobile robot Power Usage

In Fig. 2, we show the global cycle process of the GA, under the Evaluation of the each individual, is where we are going, to measure the goodness of each of the FIS (Fuzzy Inference System) represent by each Individual chromosome, in our test area, that will take place in a unknown environment (Maze [18]) to the robot where the robot's objective will be find the exit, avoiding hitting the walls and any other obstacle present.

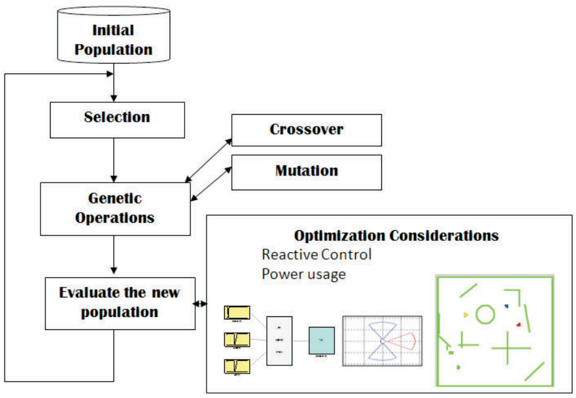

Fig. 2. Genetic Algorithm process.

Our criteria to measure the Fuzzy Inference System (FIS) global performance will take into consideration the following:

- Cover Distance,
- Time used to cover distance,
- Battery life.

All of these variables are the inputs of the Evaluation FIS that we will use to obtain the fitness value of each chromosome. In Figure 3 the structure of the fuzzy inference system is illustrated.

The FIS that we optimized is a Mamdani type fuzzy system, consisting of 3 inputs that are the distances obtain by the robots sensors describe on section 2, and 2 outputs that control de velocity of the servo motors on the robot, all this information is encoded on each chromosome.

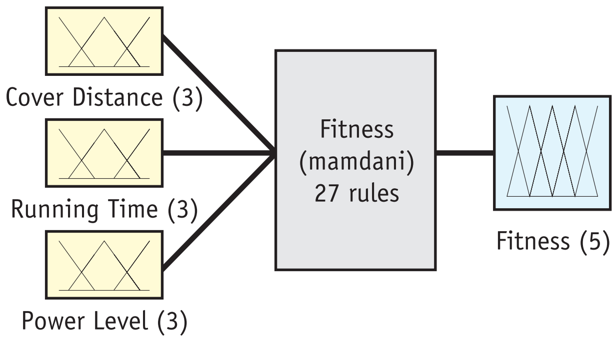

Fig. 3. Fitness FIS.

The chromosome architecture, is shown in Fig. 4, where we have encoded the membership functions type and parameters, we have set a maximum number of 5 membership functions for each of the outputs and input and output variables.

All the results obtain will get persisted on a Data Base, were we will store each step on the genetic cycle, keeping track of the genealogy of each chromosome, and with this we can examine each of the top individuals and can back track the behavior of the genetic algorithm.

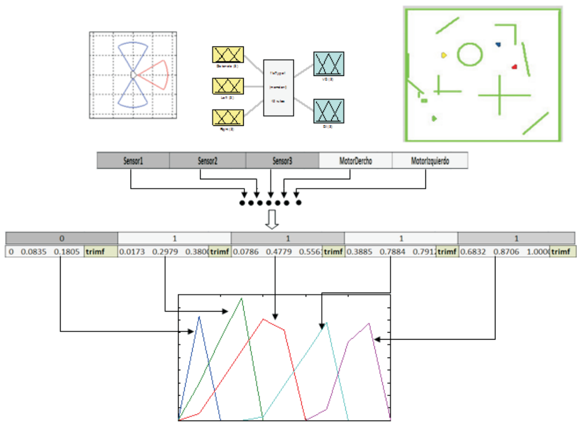

Fig. 4. Chromosome Architecture.

4. Simulation Results

We have worked on the reactive control for a mobile robot before, where we use a particular maze problem to test the effectiveness of each of the reactive controls, and we did not use any optimization strategy to fine tune the controllers as it was a manually process, and because of that experience we decided to apply GA to this problem. In Fig. 5 and Table I one can see the results we obtained in our prior experiments for fuzzy systems of 27 rules and 10 rules, respectively.

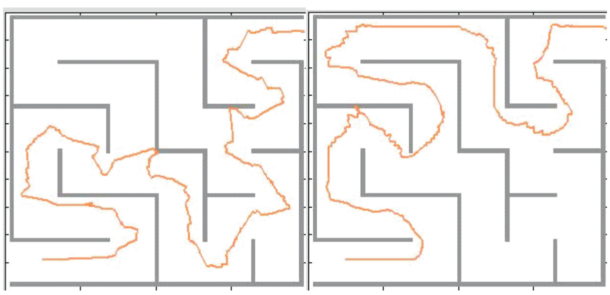

Fig. 5. Sample trajectories of the proposed approach.

Table 1. Reactive Control Non Optimized Results.

Experiment	**LAS**	**RAS**	**Time**	**LFE**
27 Rules FIS				
9	38.26	38.46	60.34	Yes
10	40.42	40.64	59.50	Yes
12	40.06	40.12	60.70	Yes
Average	*39.58*	*39.74*	*60.18*	
Standard Deviation	*1.16*	*1.14*	*0.62*	
10 Rules FIS				
1	31.51	47.43	55.75	Yes
2	35.55	54.33	51.80	Yes
3	36.66	53.68	55.40	Yes
4	36.66	53.68	54.10	Yes
5	36.91	54.18	49.95	Yes
6	35.44	52.51	46.65	Yes
7	36.14	51.66	49.85	Yes
8	33.48	49.58	51.76	Yes
9	37.61	51.51	55.15	Yes
Average	*35.55*	*52.06*	*52.27*	
Standard Deviation	*1.92*	*2.32*	*3.10*	

* LAS=Left Motor Average Speed
* RAS= Right Motor Average Speed
* FE= Found Exit

We show in Table 2 the results of two experiments with the evolutionary algorithm.

On the experiment #1 we can see that the top individual has a fitness value of 0.3568 and 40 active rules, comparing this with the experiment # 2 where the top individual that has a fitness of 0.3566 and only 12 active rules, we can conclude that the solution of 12 rules is preferred.

5. Conclusions

Preliminary results show promising data and as expect the HGA improves the overall performance of the controller for the mobile robot, and improves the results obtained previously. The best reactive controller obtained with the HGA with the same maze problem outperforms the best reactive controller obtained manually, which supports the idea that an evolutionary algorithm optimizes the structure and parameters of the fuzzy logic controller.

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AUTHORS

Abraham Meléndez, Oscar Castillo*, Arnulfo Alanis - Graduate Division, Tijuana Institute of Technology, Tijuana, BC 22379, Mexico. Email: ocastillo@hafsamx.org

* Corresponding author

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Table 2. Reactive Control Optimized Results with the Evolutionary Algorithm.

Experiment # 1

Fitness	Generation	Num_Rules
0.3568	179	40
0.3561	16	18
0.3561	22	12
0.3560	5	48
0.3560	7	27
0.3537	194	3
0.3494	67	48
0.3415	120	12
0.3415	122	12
0.3386	148	6
0.3386	1	9
0.3384	45	2
0.3384	84	2
0.3384	90	2
0.3384	94	12
0.3384	96	12
0.3384	168	12
0.3384	168	12
0.3379	6	18
0.3372	129	36

Experiment # 2

Fitness	Generation	Num_Rules
0.3566	185	12
0.3340	0	6
0.3340	6	24
0.3340	9	8
0.3340	17	18
0.3340	101	12
0.3339	191	4
0.3339	194	18
0.3339	232	16
0.3339	132	6
0.3338	1	32
0.3338	6	18
0.3327	2	2
0.3302	8	12
0.3302	14	8
0.3302	53	16
0.3302	85	8
0.3302	140	9
0.3302	129	16
0.3302	159	24

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