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A new model of fuzzy system for mobile robots in unknown environment

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Abstract: - This paper introduces a new model of control system for mobile robot navigation in unknown environments. This model follows two approach, the first one is based on fuzzy logic and the second one is based on neuro fuzzy. Both approaches are directed to generate a collision free path avoiding static obstacles. This paper presents a possible optimization skill for the fuzzy controller designed on genetic algorithm.

Key-Words: - Fuzzy, Neuro Fuzzy, Genetic Algorithm, Inference

1 Introduction

Robot navigation is based on the control of the motion from a start point to an end point in a workspace following a wanted path.
Control systems of robots in unknown environments have concentrated research over the past few years.[1,2,3]
Autonomous navigation systems are usually classified in the following categories according to the characteristics of the environment in which they have to move:

- structured or known environment;
- semi-structured or partially known environments;
- unstructured or unknown environments.

When the robot moves in a partially or completely unknown workspace, the off-line techniques cannot be applied. Thus, the sensor-based local path planning, called obstacle avoidance is required in the navigation of mobile robots. The repulsive force [4] and the virtual force filed concepts could be applied. However, these methods have shortcomings as it is difficult to find the force coefficients of effect on the velocity and direction of mobile robots in complex workspaces that can not be described as a mathematical model[5]. Another classical way is to send the robot to discover its world and define some landmarks that can used for navigation[6]. In similar conditions, the robot relies heavily on its sensors, map making and updating. However, natural workspaces present a large amount of uncertainty, and mapping techniques are time and memory consuming techniques.
So it is necessary an approach based on fuzzy logic or based on neural network with fuzzy logic (neuro fuzzy) that deal with the uncertainty and can operate with several situations with no knowledge about models or maps of the workspace.
This paper suggests an algorithm that determine a collision free path avoiding static obstacles. The robot is equipped with a vision system based on laser scan. The

algorithm subject of this paper will be implemented by an inferencial fuzzy system otherwise with neuro fuzzy networks.
In the end will be show a possible optimisation of the adopted solutions by genetic programming.

2 Problem Formulation

Both implementations of the avoid obstacle algorithm, that is fuzzy and neuro fuzzy, are based on the same work's assumptions:

a) always consider nearest obstacle: step by step robot detects an enviroment with only a obstacle;
b) before every decision, the robot will be direct with the direction of the target, that is it rotates of an angle θe.

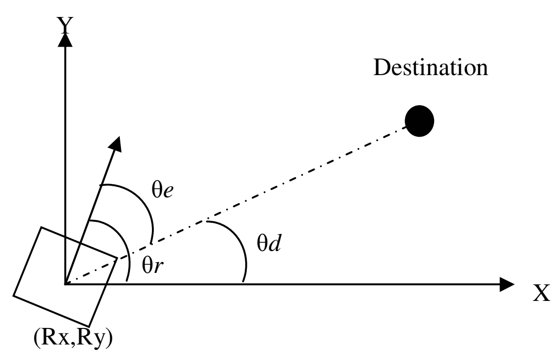


Fig. 1 Positioning of the robot toward the target

For an intelligent robot behavior to avoid obstacle be necessary consider that:

1. Bigger far is the obstacle than less will be the robot detour (little steering angle);
2. bigger is the inclusive angle between obstacle direction and target direction than less will be steering angle.

This movement is quantified on physical consideration: indicate with **θ*l*** the angle included between target direction and obstacle direction, with **RO** the distance between obstacle and robot. Hence the inputs to the inferencial engine will be **θ*l*** and **RO.** Indicate with **θ*out*** the steering angle and with ***Movement*** the movement performed by the robot; they are both outputs of the inferencial engine.

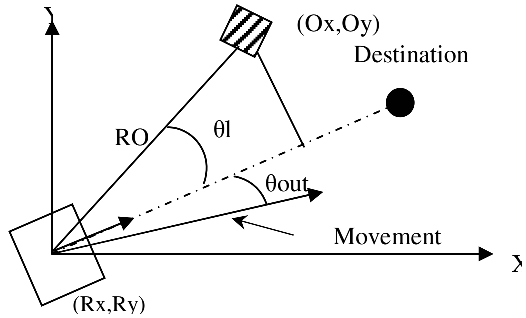


Fig. 2 Avoid obstacle behavior

In this paper it is supposed that the **θ*out*** angle in a range between -90 and 90 degree and furthermore and it is assumed the following convention:

- **θ*l*** is negative when the obstacle is on the left side of the robot (that is the robot will rotate of a positive angle **θ*out***)
- **θ*l*** is positive when the obstacle is on the right side of the robot (that is the robot will rotate of a negative angle **θ*out***)

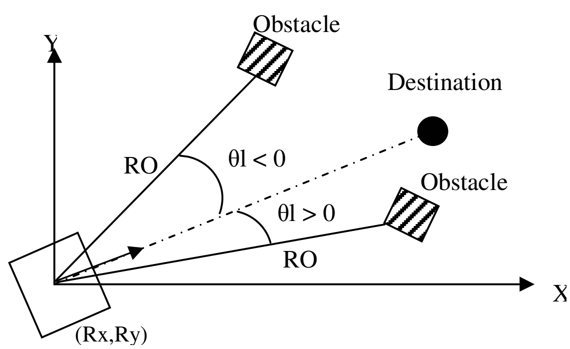
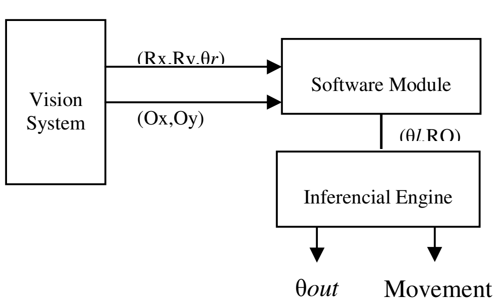


Figure 3. Convention for angle θ*l*

For example if **θ*l*** is equal to zero, the obstacle will be along the direction of the target.
Data coming from the vision system are robot position and its orientation, nearest obstacle position, target position.
Through a software module are generated the inputs for the inferencial engine:

- the inclusive angle between target direction and obstacle direction;
- the distance from the obstacle.



From the controller based on inferencial system we want to obtain:

- robot detour regard the target direction, represented by a steering angle;
- movement of the robot.

If no obstacle is detected by the vision system, that is the obstacles are too far, software module will provide, further the steering angle θ*e* of the assumption b), the movement to go toward to the target.
Basically are implemented two behaviour:

- avoid obstacle;
- move to goal.

This behaviors makes up two layer that will be activated depending on the procedure in advance:

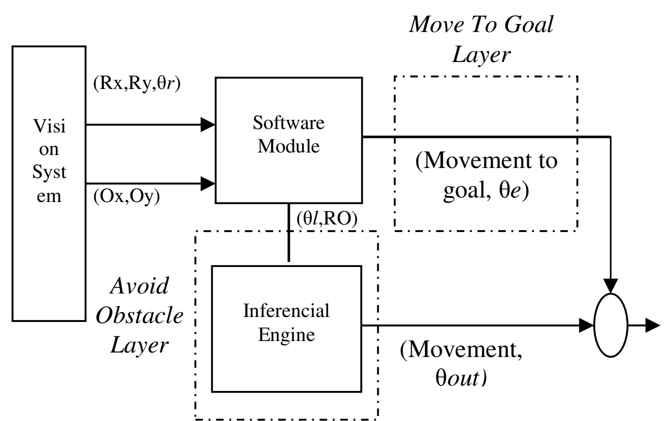


Figure 5. General blocks schema

3 Fuzzy controller

The development of techniques for autonomous navigation in real-world enviroments constitutes one of the major trends in the current research on robotics; a robot is autonomous when it is able to move purposefully with no help or intervention from a human user. One of the important aspects that is still deemed important to consider in mobile robot is collision avoidance. Prior knowledge about environment is in general incomplete because the environment changing an moreover uncertainty can occur in sensor data caused by enviromental features. In this scenario fuzzy logic play an important role. In fact it has features that make it an adequate tool to address uncertain data, processes it and obstains certain finite data.
We want to design a fuzzy logic controller that perform a steering angle ad a movement to allow the robot to avoid obstacle. Main operation that a fuzzy inference system

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have to allow are[7]:

- input fuzziication;
- fuzzy inference;
- output fuzzy composition;
- defuzzification;

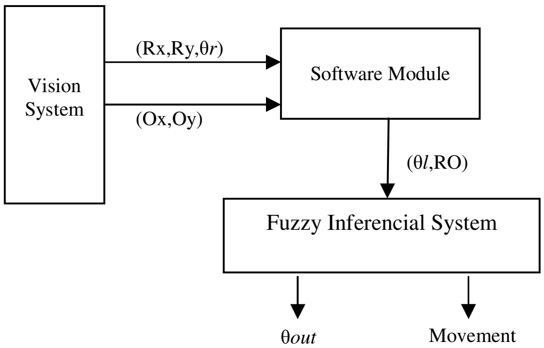

Fig. 6 Avoid obstacle with fuzzy inference system

Inputs of our system aren't fuzzy but crisp values generated by the laser scan and processed by the software module so as to have the angle **θ*l*** and the distance **RO.** So we have to fuzzifie the inputs to the inferencial engine and defuzzifie the outputs form it. We have defined this seven fuzzy set for the input **θ*l*** and for the output **θ*out***:

- *NL : Negative Large*
- *NM : Negative Medium*
- *NS : Negative Small*
- *ZE : Zero*
- *PS : Positive Small*
- *PM : Positive Medium*
- *PL : Positive Large*

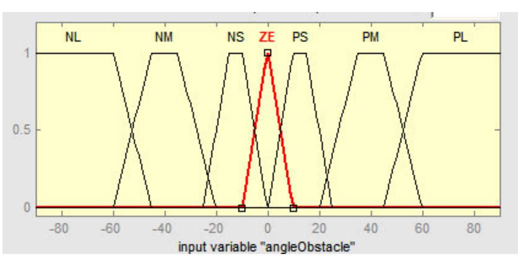

Fig. 7 Fuzzy sets for the angle

The fuzzy sets for the input **RO** and the output **Movement** are:

- *ZE : Zero*
- *VN : Very Near*
- *NE : Near*
- *FA : Far*
- *VF : Very Far*

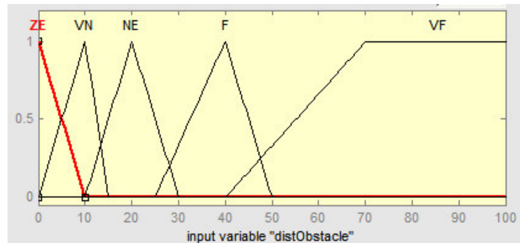

Fig. 8 Fuzzy sets for the distance

So we have seven membership function for the angle and five for the distance, selected among triangular and trapezoidal shape. Therefore we have 35 fuzzy rules of the following type:

1. If (distObstacle is ZE) and (angleObstacle is NL) then (move is VN) (1)
2. If (distObstacle is ZE) and (angleObstacle is NM) then (move is VN) (1)
3. If (distObstacle is ZE) and (angleObstacle is NS) then (move is VN) (1)
4. If (distObstacle is ZE) and (angleObstacle is ZE) then (move is VN) (1)
5. If (distObstacle is ZE) and (angleObstacle is PS) then (move is VN) (1)
6. If (distObstacle is ZE) and (angleObstacle is PM) then (move is VN) (1)
7. If (distObstacle is ZE) and (angleObstacle is PL) then (move is VN) (1)
8. If (distObstacle is VN) and (angleObstacle is NL) then (move is VN) (1)
9. If (distObstacle is VN) and (angleObstacle is NM) then (move is VN) (1)
10. If (distObstacle is VN) and (angleObstacle is NS) then (move is VN) (1)
11. If (distObstacle is VN) and (angleObstacle is ZE) then (move is VN) (1)

Fig. 8 Fuzzy rules

For the inferencial engine we have selected a Mamdani engine with COG method for the defuzzification of the outputs. To verify the validity of the results we have implemented a simulator described after in the paper.

4 Neuro fuzzy controller

Another solution we have realized is based on adaptive neuro fuzzy networks (ANFIS).

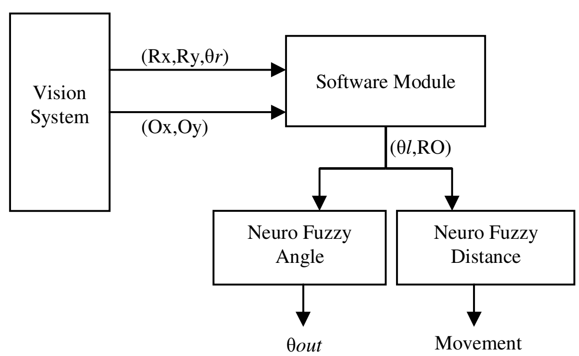

Fig. 9 Avoid obstacle with neuro fuzzy inference system

There are two neuro fuzzy networks, everyone with two inputs and one outputs. To train the networks is been made up a mathematic model based on the observation 1) and 2) of the paragraph "Problem formulation". Based on them emerge that for increasing of angle **θ*l*** and distance **RO**, the angle **θ*out*** decrease so there is an inverse proporzionality. So we have built two function called ***ρθ*** and ***ρd*** that weighs respectively the input for the angle and the input for the distance to obtain a formulation for the output **θ*out*** so to consider the proporzionality in advance:

(1) $\theta out = -sgn(\theta l) * 90 * \rho d * \rho\theta$

$0 \leq \boldsymbol{\rho d} \leq 1$ e $0 \leq \boldsymbol{\rho\theta} \leq 1$

The minus sign is due to the convention for the angle θl. The form of the function $\boldsymbol{\rho\theta}$ and $\boldsymbol{\rho d}$ is a quadratic curve,that go through typical point we have established, made up with Curve Fitting Toolbox of Matlab:

(2) $\rho_\theta = 7.778e^{-0.05} * \theta l^2 - 0.01811 * \theta l + 1$

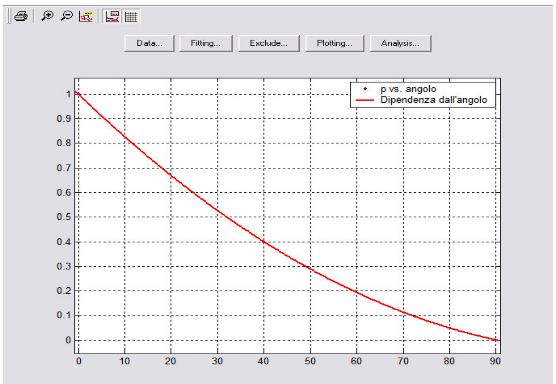

Fig.10 Function ρθ vs θl

(3) $\rho_d = 8.333e^{-0.05} * RO^2 - 0.018333 * RO + 1$

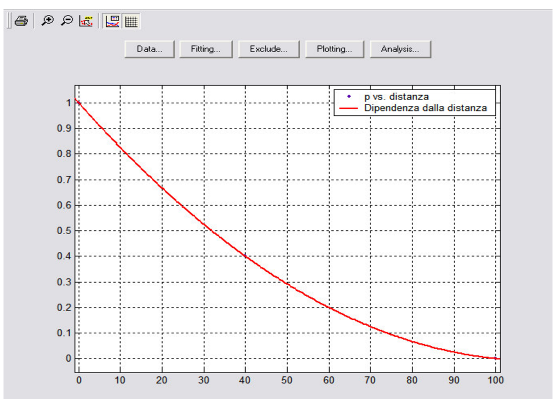

Fig.11 Function ρd vs RO

If $\boldsymbol{\theta l} = 0$ the obstacle is along the direction between the robot and the target so the robot steering angle have to be maximum (90 or -90 degree) that is the weigh to apply have to be one. In fact when $\boldsymbol{\theta l} = 0$ the function $\rho\theta$ is one. In this situation it's necessary consider the distance between the robot and the obstacle: if the obstacle is near then the weigh $\boldsymbol{\rho d}$ has to be big so $\boldsymbol{\rho d} * \boldsymbol{\rho\theta}$ will be one, instead if the obstacle is far from the robot then $\boldsymbol{\rho d}$ has to be little so $\boldsymbol{\rho d} * \boldsymbol{\rho\theta}$ will be approximately zero.
For the movement we consider that the robot detect always nearest obstacle. Hence a safe movement can be:

(4) Movement = RO * cos $\boldsymbol{\theta l}$

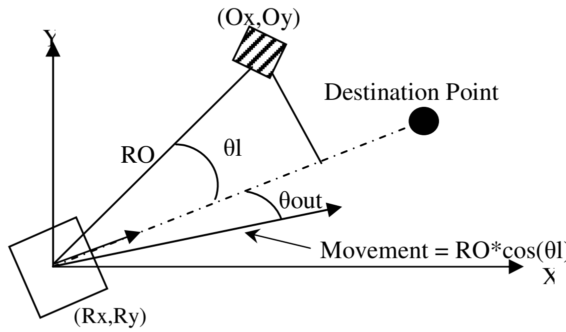

Fig. 12. Avoid obstacle behavior

4.1 Training set generation

Adaptive neuro fuzzy network required a prior knowledge (training set) for modelling the workspace. For the design of the ANFIS we have used the Anfisedit Toolbox of Matlab. A restriction of this toolbox is that through it it's possible design only one output networks. This cause our choose to create two networks.
The training set is the same for both networks and it has been generated based on mathematic model described in the previous paragraph. We have generated the values for the angle θl, included in the range -90° e +90°, and the values for the distance RO, in the range 0 ÷ 100, randomly. The outputs θout and Movement has been calculated with the mathematic model.

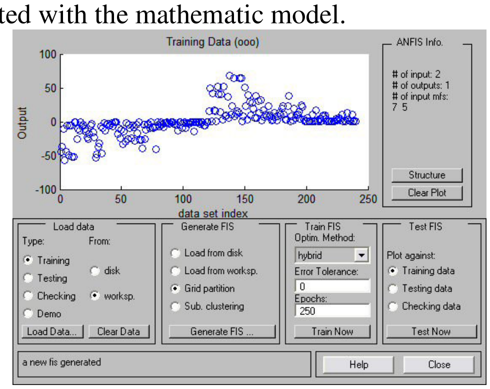

Fig. 13 Training set for ϑ_{out}

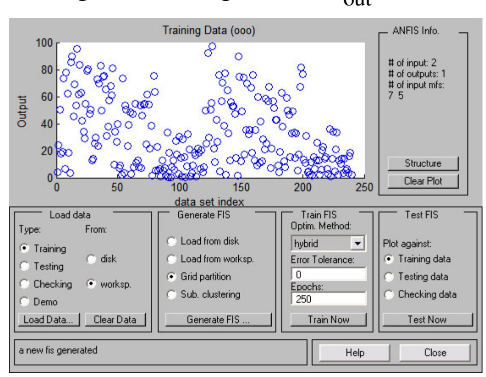

Fig. 14 Training set for Movement

With ANFIS the inferencial engine is Sugeno type. The number of training epochs has been fixed to 250 and we have obtained an error for the first network equal to 2.7451 degree and an errore for the second network equal to 0.14987

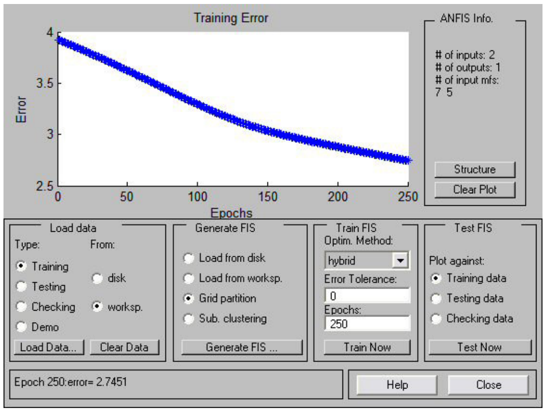

Fig. 15 Progress of the error for ϑ_{out}

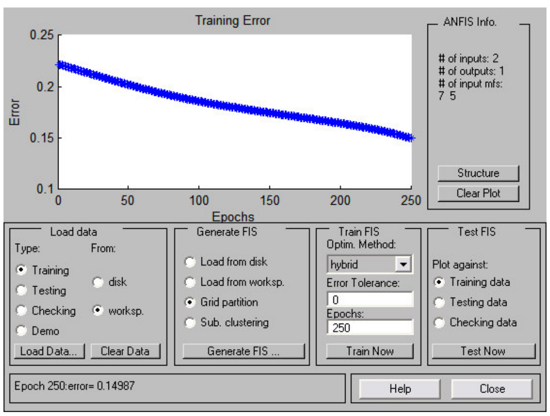

Fig. 16 Progress of the error for Movement

After several test it has been obtained a good generalization for new input – output couple unknown for the networks.

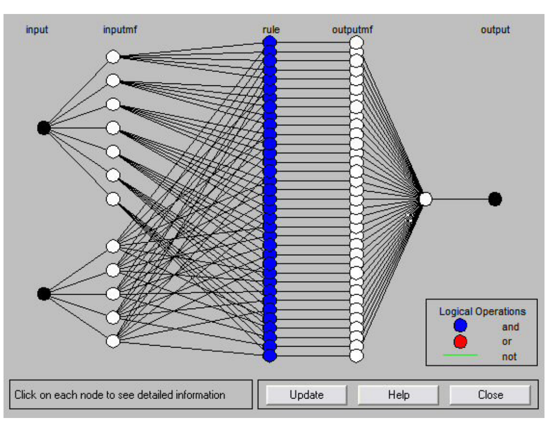

Fig. 17 The neural network create by Anfisedit

5 Optimisation of the fuzzy controller

One of the central factors in the design of efficient and robust fuzzy logic controllers is the selection of the membership rules and parameters. The existing approaches for choosing the membership functions are based on trial-and-error process, and lack learning and autonomy[8]. One method of removing the uncertainty associated with the selection of these variables is the use of genetic algorithms (GA). These have been widely used in a variety of problems especially in machine learning and function optimisation. GAs were created by John Holland[9] in the 1960's13 and proved capable of solving complex problems in large scale of applications. Genetic algorithms do not have any special requirements regarding the fitness function, thus granting maximum liberty in chosing an appropriate function[10]. All they need are a lot of genes, which represent encoded parameter sets. The totality of the genes represent the chromosome that is a potential solution of the optimisation problem; in this contest the fitness function describes the quality of the solution. In our case it's possible to consider the fitness function like the error function turn in sign based on difference between the outputs of inferencial engine and the correspondet outputs of the mathematic model used for the neuro fuzzy networks. The requirement to consider the error changed in sign is originate from the fact that usually in the genetic algorithm theory is maximized the fitness function; we want to minimize the error so we maximize the error changed in sign.

Membership function used in fuzzy system are triangular and trapezoidal. So they present three or four parameters:

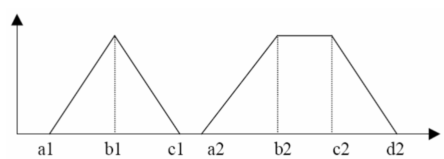

Fig. 18 Encoded parameter set

The chromosome for our problem is:

a1	b1	c1	…	…	…	a2	b2	c2	d2	…	…	…	…	….

Fig. 19 Chromosome

where a1, b1, ecc are the encoded parameters in the single gene.

The domain for the distance is $0 \div 100$; that one for the angle is $-90 \div 90$ degree.

For the genes of the distance domain, it's necessary to have enough bit to encode at least the value 100; so we can use 7 bit for every gene that encoded the parameters for the membership function in the distance domain. With 7 bit it's possible obtain up to 128 configurations of bit; so we have to discart those chromosome that presents inadmissible configurations.

At the same way, for the genes of the angle domain we can

use 8 bit to encode at least the value 180 (we shift the range -90 ÷ 90 into 0 ÷ 180).
The chromosome generation occurs by applying the evolution operation that are:

- Crossover: creates a new chromosome by combining two existing chromosomes with high fitness ratings and mutation occasionally randomly change the value of a gene in a chromosome;
- Mutation: occasionally randomly change the value of a gene in a chromosome, a 0 is changed to a 1 and vice versa; usually this operation is made up after the crossover

In our case after every evolution, the value of the genes of every chromosome have to be take back in the correspondent parameter in a MF and with the totality of the MF defined in this way it's necessary to determine the fuzzy outputs correspondent to a set of inputs (a prior fixed, like a training set) and compare them with the outputs correspondent to the same set of input obtained with mathematic model used for the neuro fuzzy networks. For every comparison we have an error so the totality of the errors constitutes an error vector, so we can consider like fitness function the medium quadratic error changed in sign that ponders all the component of the vector.
In Internet it's possible to find a large number of freeware software that allows to manipulate genetic algorithm simply and specially allows to lose one's interest of the evolution operations demands only the definition of the chromosome's structure (in term of the type of the genes, ad example Boolean, integer, ecc), the definition of the fitness function and the number of the individual that will constitute the initial population.

6 Simulation

To simulate the behavior of the robot driven by the controllers it's been built an ad-hoc simulator based on Java / C language.
The simulator has two main layers:

- Graphic interface layer, written in Java language, for the interaction with the user and to show the trajectory that the robot follows based on the behaviour implemented by the controllers;
- Wrapping layer between .fis files and graphic interface, written in C language.

Fis files are the result of the fuzzy inferencial engine and neuro fuzzy design with Matlab. Wrapping layer understands the features of the inferencial engine represented in .fis file and allow to estimate the output corresponding to the inputs just like Fuzzy Toolbox of Matlab. In this way it's possible take advantage of the flexibility that Matlab allows to design fuzzy and neuro fuzzy system and after to use the same systems like stand – alone applications.

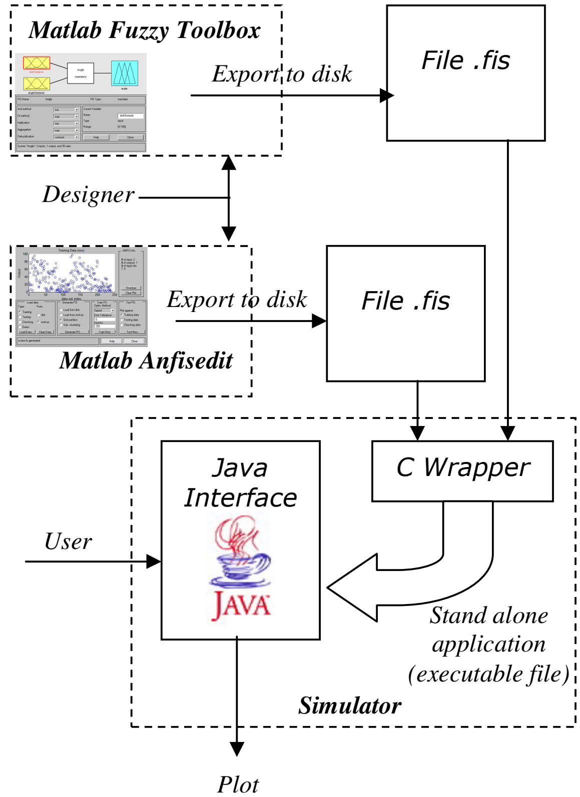

Fig. 20. Simulator blocks schema

The user have to insert data about initial position of the robot, position of the target, position of the obstacle
Now it's possible to plot the robot trajectory driven by the controllers. These will be generate step – by – step allowing user to observe the behaviour of the inferencial systems. Moreover the user will be able to make evolve the fuzzy trajectory or the neuro fuzzy trajectory. At the end it will be show a diagram with both trajectories. In the follow it has been analyzed three typical situation:

- obstacle is along the direction between robot and target;
- obstacle is on the right side of the direction between robot and target;
- obstacle is on the left side of the direction between robot and target;

7 Conclusions

In this paper the problem about navigation of mobile robot in unknown environment is solved using more popular soft computing methodology, that is fuzzy logic and neuro fuzzy, locating in the genetic algorithms a possible optimisation solution. From the results obtained it is possible to conclude that the design answer to the prefixed targets regarding the tollerances and the made work supposition.

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