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FL-GA method for optimization of 3PRR planar parallel manipulator for a prescribed workspace

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Abstract
Manipulator design can be expressed as a function of workspace requirements. This work presents a hybrid fuzzy logic - genetic algorithm (FL-GA) method for optimization and dimensional synthesis of a 3PRR (prismatic- revolute- revolute) planar parallel manipulator for a prescribed workspace. The algorithm is made of classical genetic algorithm coupled with fuzzy logic. The fuzzy logic controller monitors the variation of genetic algorithm variables during the first run of GA and modifies the initial bounding intervals to restart the next run of the algorithm. Links of robot are minimized while desired workspace is achieved.

Keywords*:* Genetic Algorithm, Fuzzy Logic, Optimization, Workspace, Parallel Robot

1.Introduction
Planar parallel manipulators have high utility in industrial automation since they can carry high payloads with high mechanical stiffness due to their closed-loop kinematic chain architecture. However the optimization of parallel robot can be challenging since it can involve many parameters, like workspace, physical size of robot, stiffness, accuracy, singularity, isotropy, forces, velocities and acceleration transmission [1,2]. The old techniques for optimization are all gradient based search methods and hence require the calculation of derivatives. This characteristic makes these techniques very demanding in computation time and in some cases they may even fail to converge. Lately, new methods based on artificial intelligence or probabilistic approach has emerged. The most famous is genetic algorithm. Genetic algorithm is a probabilistic technique that uses a population of designs rather than a single design at a time. Choosing a large bounding interval could lead to the same problem because the limited number of individuals of the population are scattered randomly over a large interval. Choosing large number of individual could cover more regions of the interval, but will slow the optimization without guaranteeing the global optimum, thus we improve the performance of GA search ability through the adaptive search range mechanism through fuzzy logic.
Our problem can be formulated as follows: given specific points inside the boundary of a desired workspace, find the minimum dimension for parallel robot where the workspace contains the desired points [3,4]. A combined fuzzy logic- genetic

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algorithm method (FL- GA) is proposed. This algorithm has the capability to adjust its starting population to avoid local minimum and to obtain accuracies that classical genetic algorithms fail to obtain. The process is started with an initial population chosen within the initial bounding intervals. The fuzzy logic controller monitors the evolution of the different variables during the optimization and adjusts the bounding intervals for each design variable. These new intervals are then used to start a second round of optimization in order to improve the final result [5].

2.Structure of 3PRR Robot

In this section, we briefly introduce 3PRR planar parallel manipulator. This planar parallel manipulator is designed for maximum workspace with minimum dimension. This manipulator has a moving platform, a base platform and three links, each of which has a prismatic joint and two consecutive revolute joints. Only the prismatic joints are actuated. Three degrees-of-freedom (DOF) of the PRR manipulator are the translations along the X, Y axis and the rotation about the Z axis. P_i is the length of ith prismatic joint and L_i's are defined in Fig.1. Workspace of 3PRR planar parallel robot is shown in Fig.2. [3].

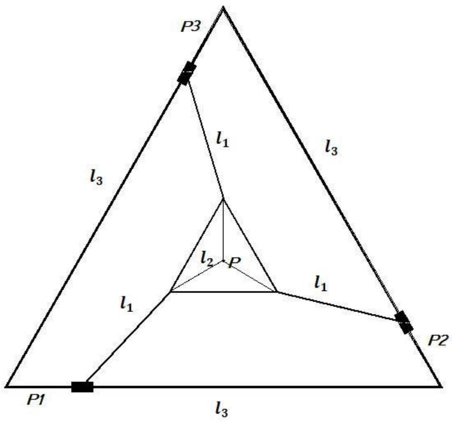

Figure 1. 3PRR Planar Parallel Manipulator

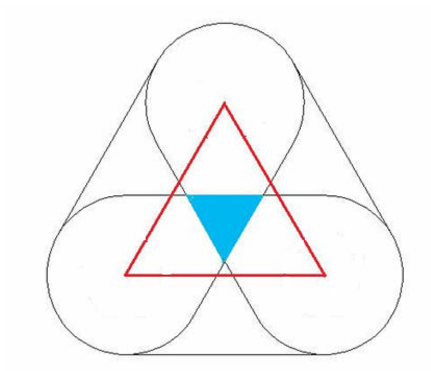

Figure 2. Workspace Of 3PRR Planar Parallel Manipulator

3.Genetic Algorithms (GA)

The GA is a well-known efficient global optimization algorithm that utilizes the concept of biological structure to natural selection and survival of the fittest. Due to the fact that the method requires no previous experience on the problem. An initial randomized population that consists of a group of chromosomes and represent the problem variables, produces new populations through successive iterations, using various genetic operators. The common operators are selection, mutation, crossover and elitism. A function called fitness function determines when a new chromosome will replace a previous one or not, according to its worth.

Table 1. Coordinates of the points of desired workspace

x(m)	0.05	0.25	0.35	0.15	0.02
y(m)	0.05	0.10	0.25	0.30	0.20

Table 2. GA parameters

The Size Of The Population	30
Maximum Number Of Generations	80
Number Of Variables	4
Number Of Bits	8
Crossover Rate	0.7
Mutation	0.02

4. Formulation of the problem

The aim of this section is to develop and to solve the optimization problem of selecting the geometric design variables for the 3PRR planar parallel manipulator having a prescribed workspace.

Given: a specified area defines by some points

Find: the parameters of the 3PRR robot having a workspace that includes the specified area.

To define the objective function, we note this theorem that the total distance of a point in the equilateral triangle from 3 lines of the equilateral triangle is equal to the height of equilateral triangle. The algorithm is as follow:

Select 2 points A(x1, y1) and B(x2, y2) and compose 2 equilateral triangles with these 2 points (Figure 3). Then we determine the distance of each point of prescribed workspace from 3 lines of 2 triangles. If the total distance in each part is equal to the height, this triangle can be the workspace of 3PRR planar parallel manipulator. We want to find the minimum area for this triangle.

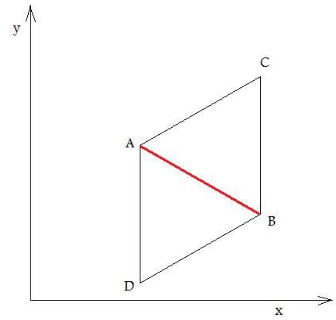

Figure 3. Objective Function definition

A penalty function method is used to handle the constraints. The objective function is accordingly constructed as:

F=F1+F2 (1)

Where:

$$F1 = \sqrt{(x1 - x2)^2 + (y1 - y2)^2} \quad (2)$$

And F2 is a penalty function defined as follows:

F2=C.V (3)

Here, C is a large positive constant and V is a number that relate to the minimum number of point of desired workspace where outside of 2 triangles.

5.Fuzzy logic controller- Genetic algorithm (FL-GA)

Fig. 4 shows the combined FL- GA algorithm. The process, which is the classical genetic algorithm optimization, is started with initial population chosen randomly within the initial bounding intervals. The FL monitors the evolution of the different variables during the optimization process and adjusts the bounding intervals of each variable for the next round of optimization process. These new intervals are then used to start a second round of the genetic algorithm.

The knowledge base is built during the first run of the genetic algorithm optimization. By analyzing the final result, a parameter Dx is determined and the bounding interval for the design parameter X is corrected using the following equation:

$$x^*_{\min} = x_{ave} - \frac{Dx}{2}(x_{\max} - x_{\min}) \qquad (4)$$

$$x^*_{\max} = x_{ave} + \frac{Dx}{2}(x_{\max} - x_{\min}) \qquad (5)$$

Where x_{ave} is the average value of the design variable x of all the individuals of the last generation and $[x_{\min}\ x_{\max}]$ initial bounding interval. The coefficient Dx (the output variable) is obtained from the knowledge of the two inputs, variables E and Kx where E is the error found after the first run of the genetic algorithm optimization and Kx is a counter of the variation of each parameter during the last 30 generations. Kx is a counter for each one of the variables and it is ranging between 0 and 30. It starts at 0 and during the last 30 generations it is incremented by 1 each time the variable changes.

$$E = \frac{x_{last} - x_{\min}}{x_{\min}} \qquad (6)$$

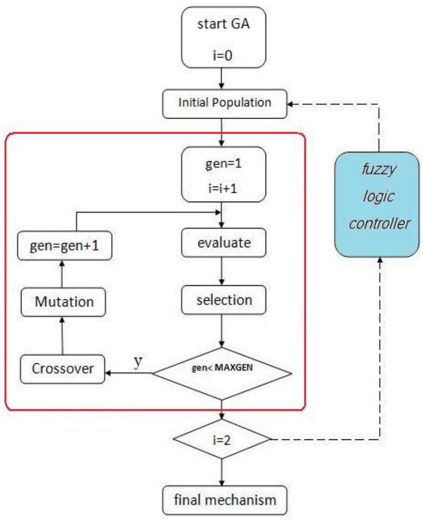

Figure 4. The modified FL- GA optimization scheme

Fuzzification of the input variables is the first step in the design of a fuzzy logic controller. Fuzzification of the input variables involves quantizing the universes into a number of fuzzy sets. The output variables also need to be quantized in a similar manner. Quantization involves breaking up a fuzzy input (and also output) variable into several fuzzy subsets. Fig. 5 shows the membership functions chosen for the 2 fuzzy input variables and the output variable and Table 3 contains the definition of the linguistic parameters.

Table 3.The linguistic parameters

VS	Very Small
S	Small
M	Medium
H	High
VH	Very High

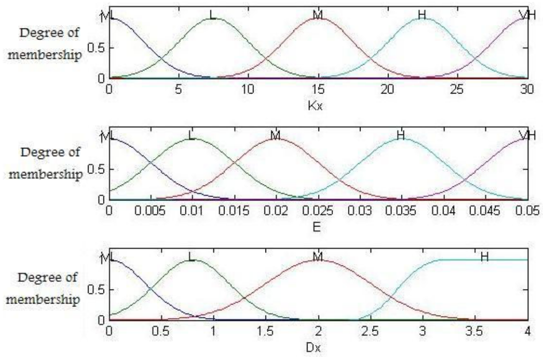

Figure 5. Membership function for the two input and the output

Table 4. Rule matrix

Dx		***Kx***				
		VS	***S***	***M***	***H***	***VH***
E	**VS**	VS	S	S	M	M
	S	VS	S	M	H	M
	M	S	S	H	M	H
	H	M	M	M	H	H
	VH	H	H	M	M	M

6.Results

Fig. 6 shows the comparison of two methods for 80 generations and table 5 shows the initial and corrected boundary for each parameter of GA. Results shows the efficiency of combination of FL with GA.

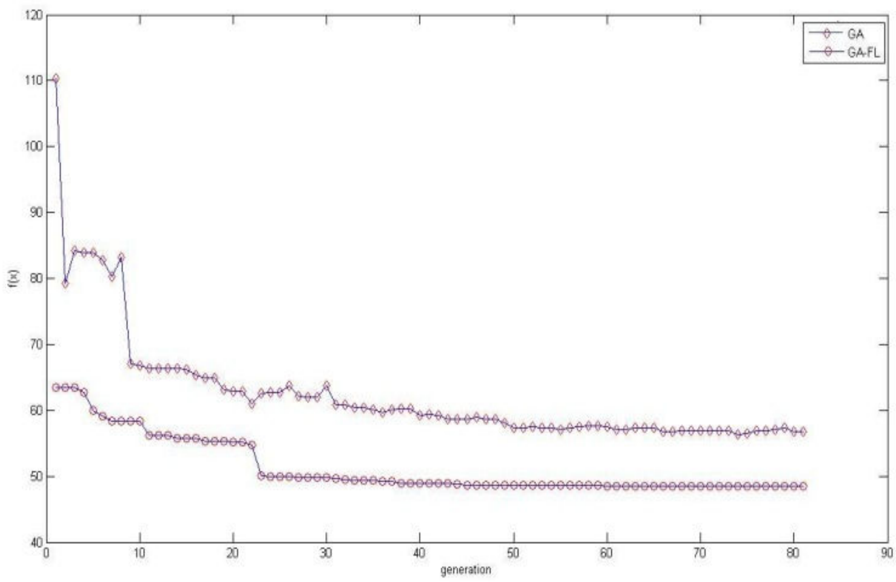

Figure 6. Comparison of GA and FL-GA

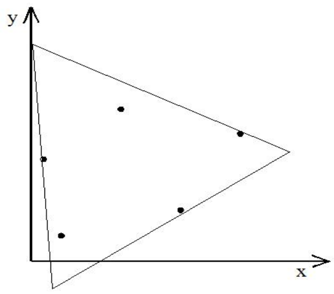

Figure 7. The optimized workspace with FL-GA

Table 5. Parameters of the FL-GA method

	X1	Y1	X2	Y2
Initial boundary	[0 80]	[0 80]	[0 80]	[0 80]
Kx	14	8	12	13
E	0.0085	0.0085	0.0085	0.0085
Dx	0.0617	0.303	0. 602	0.6135
Corrected boundary	[-10.2 36]	[44.6 65.4]	[30.6 74.4]	[1.6 23.9]
F(GA)	57.2			
F (FL-GA)	48.46			

For optimal dimension we have:

$$L1 + L2 = 41.96 \quad (7)$$

7. Conclusion

This work presented a combined fuzzy logic - genetic algorithm method for workspace optimization of a 3PRR planar parallel manipulator. The proposed method is made of a classical genetic algorithm coupled with a fuzzy logic controller. This controller monitors the variation of the variables during the first run of the genetic algorithm and modifies the initial bounding intervals to restart a second round of the genetic algorithm. The desired workspace of the robot was obtained. The links for this robot are all minimized. We showed that the obtained result is always better than the one obtained by only the genetic algorithm.

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