

OPTIMUM DESIGN OF ROBOT GRIPPERS USING GENETIC ALGORITHMS

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1. Abstract

In this paper a bicriterion optimization model of the robot gripper is built. In this model the decision variables are geometrical dimensions of the gripper, which are under side constraints and those constraints which are yielded by the assumed structure of the gripper. The objective functions are: the difference between maximum and minimum gripping forces for the assumed range of the gripper ends displacement and the force transmission ratio between the gripper actuator and the gripper ends. Both functions are computationally expensive functions. Thus a special Genetic Algorithm based method has been developed. The method uses the tournament selection mechanisms which does not require evaluation of fitness values in order to create a new population of chromosomes for the next generation. The tournament is arranged in this way that objective functions are evaluated only for feasible solutions. The presented results show the effectiveness of the proposed method.

2. Keywords

Robot Gripper, Bicriterion Optimization, Genetic Algorithm.

3. Introduction

Genetic Algorithms are widely used to solve different design optimization problems (see review paper [2]). The main advantage of the use of GAs in multicriterion optimization problems is that while running the GA program the full set of Pareto optimal solutions (nondominated solutions) can be obtained and the designer has a full picture of the possible compromise solutions. In this paper the optimization problem is formulated as follows:

Find $\mathbf{x}^* = [x_1^*, x_2^*, \dots, x_N^*]$ which will satisfy the K inequality constraints

$$g_k(\mathbf{x}) \geq 0 \quad k = 1, 2, \dots, K \quad (1)$$

and minimize two objective functions

$$\mathbf{f}(\mathbf{x}^*) = \min [f_1(\mathbf{x}), f_2(\mathbf{x})] \quad (2)$$

where: $\mathbf{x} = [x_1, x_2, \dots, x_I]$ is the vector of decision variables, the elements of which represent dimensions of the gripper elements,

$f_1(\mathbf{x})$ is the function which describes the difference between maximum and minimum gripping forces for the assumed range of the gripper ends displacement,

$f_2(\mathbf{x})$ is the function which describes the force transmission ratio between the gripper actuator and the gripper ends.

Both functions are to be minimized.

4. Problem formulation

Let us consider an example of a robot gripper the scheme of which is presented in Fig.1. For this gripper the vector of decision variables is $\mathbf{x} = [a, b, c, e, f, l, \delta]^T$, where a, b, c, e, f, l , are dimensions of the gripper and δ is the angle between b and c elements of the gripper.

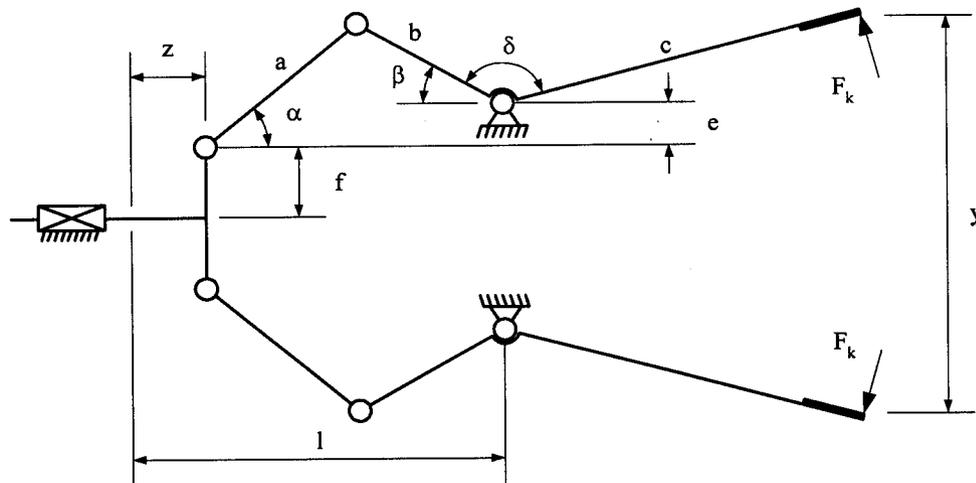


Fig.1 The scheme of robot gripper mechanism.

The geometrical dependences of the gripper mechanism are (see Fig.2):

$$g^2 = (l-z)^2 + e^2, \quad g = \sqrt{(l-z)^2 + e^2}, \quad b^2 = a^2 + g^2 - 2 \cdot a \cdot g \cdot \cos(\alpha - \phi), \quad \alpha = \arccos\left(\frac{a^2 + g^2 - b^2}{2 \cdot a \cdot g}\right) + \phi$$

$$a^2 = b^2 + g^2 - 2 \cdot b \cdot g \cdot \cos(\beta + \phi), \quad \beta = \arccos\left(\frac{b^2 + g^2 - a^2}{2 \cdot b \cdot g}\right) - \phi, \quad \phi = a \tan\left(\frac{e}{l-z}\right)$$

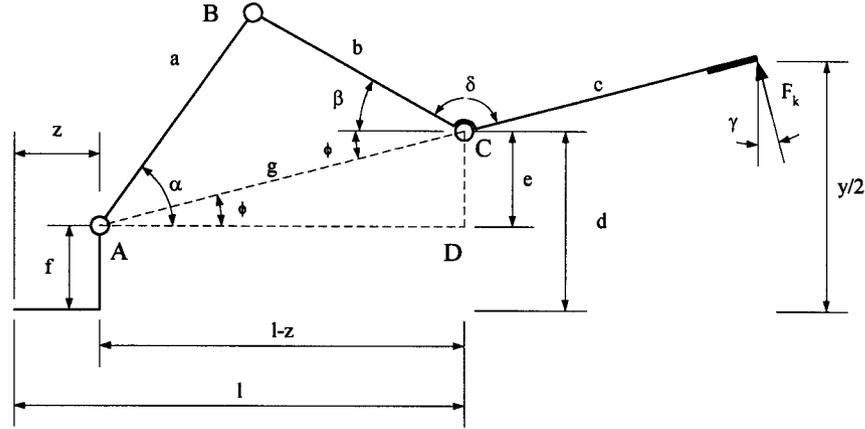


Fig.2 The geometrical dependences of the gripper mechanism.

The distribution of the forces is presented in Fig.3 and from this figure we have:

$$R \cdot \sin(\alpha + \beta) \cdot b = F_k \cdot c, \quad R = \frac{P}{2 \cdot \cos(\alpha)}, \quad F_k = \frac{P \cdot b \cdot \sin(\alpha + \beta)}{2 \cdot c \cdot \cos(\alpha)}$$

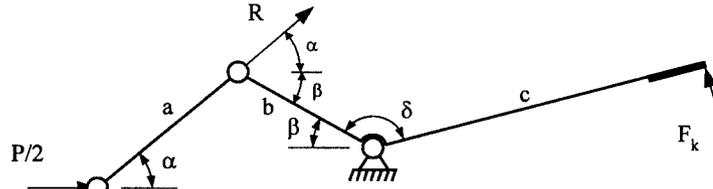


Fig.3 The distribution of the forces in the mechanism of the gripper.

Using the above formulas the objective functions can be evaluated as follows:

- The first objective function is the difference between maximum and minimum gripping forces for the assumed range of gripper ends displacement: $f_1(\mathbf{x}) = \max_z F_k(\mathbf{x}, z) - \min_z F_k(\mathbf{x}, z)$
- The second objective function is the force transmission ratio: $f_2(\mathbf{x}) = \frac{P}{\min_z F_k(\mathbf{x}, z)}$

Both objective functions depend on the vector of decision variables and displacement z.

For the given vector \mathbf{x} we have the values of $f_1(\mathbf{x})$ and $f_2(\mathbf{x})$ are evaluated using a procedure which makes these functions computationally expensive.

From the geometry of the gripper the following constraints can be derived:

- (I) $g_1(\mathbf{x}) = Y_{\min} - y(\mathbf{x}, Z_{\max}) \geq 0,$
- (II) $g_2(\mathbf{x}) = y(\mathbf{x}, Z_{\max}) \geq 0,$
- (III) $g_3(\mathbf{x}) = y(\mathbf{x}, 0) - Y_{\max} \geq 0,$
- (IV) $g_4(\mathbf{x}) = Y_G - y(\mathbf{x}, 0) \geq 0,$
- (V) $g_5(\mathbf{x}) = (a+b)^2 - l^2 - e^2 \geq 0,$
- (VI) $g_6(\mathbf{x}) = (l-Z_{\max})^2 + (a-e)^2 - b^2 \geq 0,$
- (VII) $g_7(\mathbf{x}) = l - Z_{\max} \geq 0,$

where: $y(\mathbf{x}, z) = 2 \cdot [e + f + c \cdot \sin(\beta + \delta)]$ displacement of the gripper ends,

Y_{\min} – minimal dimension of gripping object,

Y_{\max} – maximal dimension of gripping object,

Y_G – maximal range of the gripper ends displacement,

Z_{\max} – maximal displacement of the gripper actuator.

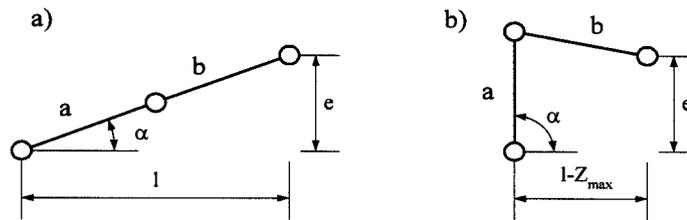


Fig.4 Constraints presentation: a) constraint V, b) constraint VI

5. Method of solution

Several Genetic Algorithm (GA) based methods for solving multicriteria optimization problems have been developed recently. The main approaches are: Vector Evaluated Genetic Algorithm [6], Niched Pareto Algorithm [3], Nondominated Sorting Genetic Algorithm [7], Distance Method [4]. Most of these methods use the fitness function to evaluate the population for the next generation. For highly constrained optimization problems the use of fitness function causes some difficulties in selecting the solutions for next generations. In this paper a new method for solving multicriteria constrained optimization problems is presented. The method uses the tournament selection mechanisms which does not require evaluation of fitness values in order to create a new population of chromosomes for the next generation.

To solve multicriteria optimization models the Pareto set distribution method [5] is applied. The general idea of this method is as follows: Within each new generation a set of Pareto optimal solutions is found on the basis of two sets: the set of Pareto solutions from a previous generation and the set of solutions created by GA operations within the considered generation. The new set of Pareto solutions thus created, is distributed randomly to the next generation for half of the population. The remaining half of the population is bred by randomly generated new strings. Note, that similarly to the tournament selection method, this method does not use the fitness function to select solutions for the next generation

The tournament selection method used together with this Pareto set distribution method can be briefly described as follows. In each generation two chromosomes are selected at random and the tournament is made using the following rules:

- if both chromosomes represent infeasible solutions the one which has better feasibility, i.e., the one for which constraints are less violated, is taken to the next generation.
- if one chromosome represents a feasible solution and another one an infeasible solution, this one which is feasible is compared with the existing set of Pareto optimal solutions. Only for the feasible solution the values of the objective functions are calculated.
- finally if both chromosomes represent feasible solutions, the objective functions are calculated for both solutions and both are compared with the existing set of Pareto optimal solutions.

The comparison of the existing set of Pareto optimal solution with the feasible solution means that the latter can fall in any of three categories:

- (i) It is a new Pareto solution which dominates some or at least one from set of Pareto solutions found so far. In this case dominated solutions are removed from the set and the new Pareto solution is added to the set.
- (ii) Although it is a new Pareto solution, it does not dominate any of the existing Pareto solutions. In this case the new solution is added to the set.
- (iii) It is not a new Pareto solution, thus there is no change in the set of Pareto solutions.

Note that using this method the objective functions are calculated only for feasible solutions. This makes the process of calculations more effective especially for problems for which the objective functions are computationally expensive functions.

The GA method described above was run using the following data:

1. The geometric constraints:

$$10 \leq a \leq 150, \quad 10 \leq b \leq 150, \quad 100 \leq c \leq 200, \quad 0 \leq e \leq 50, \quad 10 \leq f \leq 150, \quad 100 \leq l \leq 300, \quad 1.0 \leq \delta \leq 3.14$$

$$Y_{\min} = 50, \quad Y_{\max} = 100, \quad Y_G = 150, \quad Z_{\max} = 100, \quad P = 100.$$

2. The parameters for GA:

- Length of the string for every decision variable 18 bits.
- Crossover rate $R_c = 0.6$, mutation rate $R_m = 0.08$, penalty parameter $r = 10^3$.
- Population size = 400, number of generations = 400.

The results of optimization are shown in Fig. 5. Eight hundred fifty Pareto optimal solutions were generated. From this set of solutions, four are presented in Tab.1 and illustrated graphically in Fig.6 and Fig. 7 using the same scale.

Comparing with the Pareto set distribution method the proposed method gives about 50% reduction of a computing time.

Table 1. Example solutions from the set of Pareto optimal solutions.

Item	$f_1(x)$	$f_2(x)$	a	b	c	e	f	l	δ
1	5.02	1.95	150.00	131.10	196.50	12.94	133.80	175.00	2.60
2	6.22	1.50	150.00	131.30	152.60	13.02	127.40	175.00	2.77
3	7.94	1.18	150.00	131.30	119.00	13.00	112.6	175.10	2.80
4	10.38	0.97	149.90	132.40	100.00	12.50	93.56	175.10	2.70

6. Conclusions

In the paper the GA based method is used to solve a bicriterion optimization problem of robot grippers. The method provides the designer with a full set of Pareto optimal solutions, which can be used in making the right decision. Some experiments carried out on other grippers indicate that the method can be also used for selecting the best structure. This will be a subject of further investigations.

Acknowledgments

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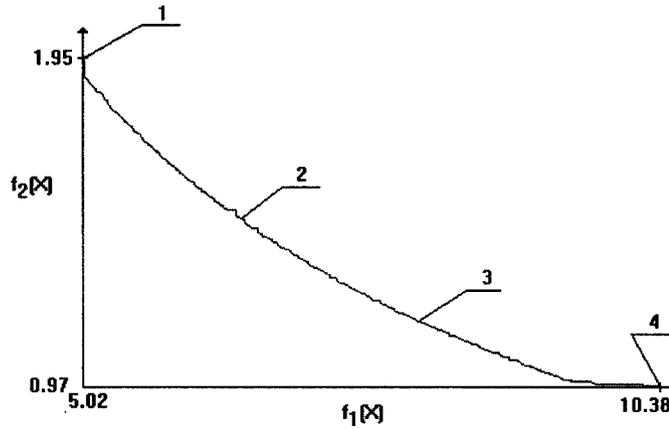


Fig.5 Obtained set of optimal solutions

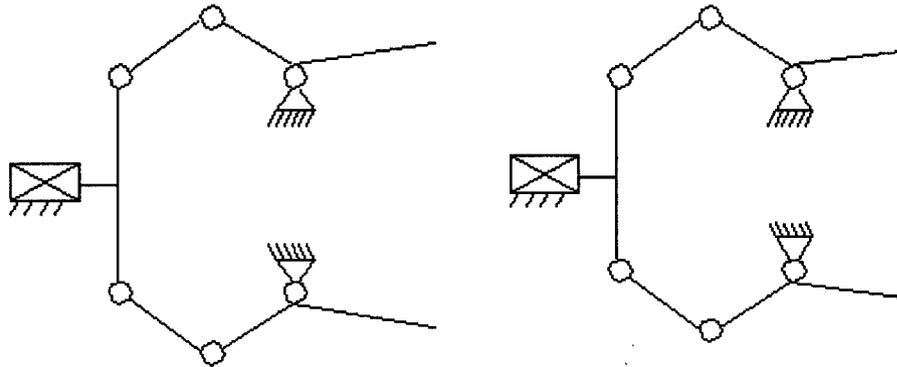


Fig.6 The schemes of mechanism for solutions 1 & 2

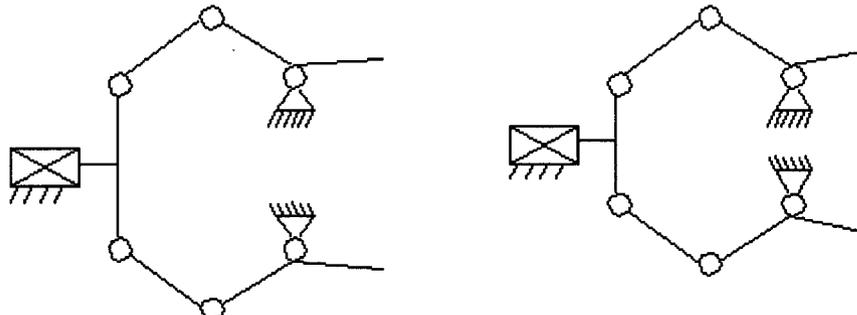


Fig.7 The schemes of mechanism for solutions 3 & 4

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