EVOLUTION OF A HYBRID METHOD FOR INDUSTRIAL MANIPULATOR DESIGN OPTIMIZATION

Article · June 2012

5 authors, including:

G. Mansour
Aristotle University of Thessaloniki

Dimitrios Sagris
Technological Educational Institute of Centr…

Christos Tsiafis
University of Kragujevac

Journal of Production Engineering
Vol.16 No.1

Original Scientific Paper

Mansour, G., Sagris, D., Tsiafis, Ch., Mitsi, S., Bouzakis, K.-D.

EVOLUTION OF A HYBRID METHOD FOR INDUSTRIAL MANIPULATOR DESIGN OPTIMIZATION

Received: 7 June 2012 / Accepted: 31 August 2012

Abstract: *In the present paper an evolution of a hybrid optimization method is described to find the geometric design parameters and the joint angles when some end-effector poses are prescribed. The problem is solved by minimizing the sum of the deviation squares between the prescribed poses and the real poses of the considered end-effector. The evolution of the proposed algorithm is developed in MatLab software. The developed method is applied in two degrees of freedom spatial serial RR manipulator, in three numerical examples, where one, two or three end-effector poses are prescribed. Furthermore, a comparison of the results between the evolution of the method on MatLab and the initial one based on Fortran demonstrates a higher efficiency of the Matlab approach, regarding the minimum value of the fitness function as well as the computational time.*
Key words: *optimization, genetic algorithm, geometric design, robot, industrial manipulator*

Evoluciona hibridna metoda pri projektovanju postupka optimizacije industrijskog manipulatora. *U ovom radu je opisana evolucija hibridne optimizacione metode za pronalaženje geometrijskih parametra i zajedničkih uglova pri propisanim pozama hvatača. Problem je rešen minimiziranjem zbira kvadrata odstupanja između propisane i stvarne poze hvatača. Evolucija predloženog algoritma razvijena je u Matlab softveru. Razvijeni metod primenjuje se u dva stepena slobode prostornog serijskog RR manipulatora, u tri numerička primera, gde se hvatač jedan, dva ili tri propisano postavljeni. Nakon toga, ređenjem rezultata između evolucione metode u Matlab-u i početne osnove u Fortran-u, pokazuje veću efikasnost primene Matlab-a, u pogledu minimalne vrednosti fitnes funkcije, kao i računskog vremena.*
Ključne reči: *optimizacija, genetski algoritmi, geometrijsko projektovanje, robot, industrijski manipulator*

1. INTRODUCTION

The performance of a robot can be considerably improved by optimal evaluation of the robot geometric design parameters, taking into account different criteria, especially in industrial applications. During the last decades several design methodologies have been developed for spatial task oriented robotic systems. These methodologies may be classified into two categories: exact synthesis and approximate synthesis. The exact synthesis methods [1] have the advantage to find all the possible solutions, but only in few spatial manipulators the geometric design problem has been solved. So, the polynomial elimination technique is used in [2, 3] to determine the dimensions of the geometric parameters of RR and 3R manipulators are prescribed. The approximate synthesis methods, involving an optimization algorithm, are used in geometric design problems, where the precision points are less or more than the exact synthesis required points. A combination of the exact synthesis techniques with optimization methods is used in [4] to design a spatial RR chain for an arbitrary end-effector trajectory. A methodology of dimensional approximate synthesis where the problem is expressed in terms of multiobjective optimization by taking account simultaneously several criteria of performance, regarding a Delta mechanism is presented in [5].

The presented evolution of the optimization methodology, is classified in the approximate synthesis methods. This optimization method is already tested in several problems, such as optimum robot base location [6, 7], as well as geometric design optimization of 3R serial robot with geometric restrictions [8], obtaining remarkable results.

2. MATHEMATICAL FORMULATION

In this paper the manipulator is considered as an open space chain with two revolute joints (Fig. 1). A reference frame Pi attached at each link i (i=0,1,2) The relative position between two successive frames is described using the 4x4 homogeneous transformation matrices and the Denavit-Hartenberg parameters [9]. Using the homogeneous transformation matrices, the pose of the end-effector P_3 with respect to the fixed frame P_S is given by:

$$A_S^3 = A_S^0 \cdot A_0^1 \cdot A_1^2 \cdot A_2^3 \qquad (1)$$

where the matrix A_{i-1}^i describes the pose of frame i with respect to frame i-1, through the corresponding D-H parameters. The elements of the matrix A_S^3 are known since they define the position and orientation of the end-effector frame 3 at each prescribed pose, with respect to fixed frame Ps. The right side of equation (1) contains all the unknown Denavit-Hartenberg parameters that are θ_i, α_i, a_i and d_i (i=0,1,2).

In order to determine these unknown parameters the objective function is developed. This function consists of the sum of the deviations squares between the prescribed values of the elements of the matrix and the real values.

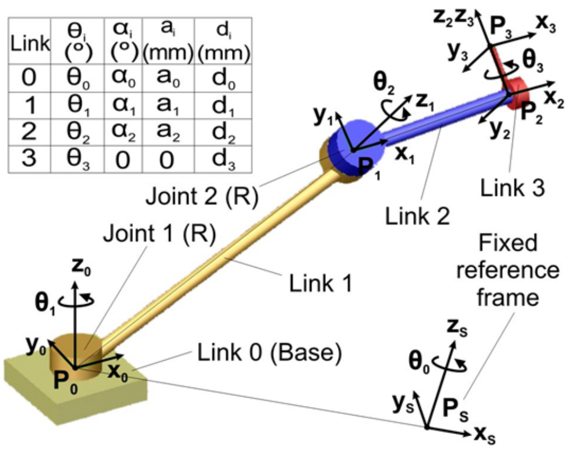

Fig. 1. 2-DOF robot and Denavit-Hartenberg params

The objective function can be described by:

$$F=\sum_{k=1}^{n}\sum_{i=1}^{3}\sum_{j=1}^{4}\left(A_{S\,r}^{3}(i,j)-A_{S\,pr}^{3}(i,j)\right)_k^2 \qquad (2)$$

where n is the number of prescribed poses, $A_{S\,r}^{3}(i,j)$ is the real value of the element (i,j) of the A_S^3 matrix and $A_{S\ pr}^{3}(i,j)$ is the prescribed value of the element (i,j). From the minimization of the objective function, the values of the unknown parameters occur. During the optimization procedure the imposed constraints regarding the unknown variables are described by:

$$x_{\ell\ \min} < x_\ell < x_{\ell\ \max} \quad \ell = 1,2,\ldots m \qquad (3)$$

where m is the number of the variables and x_{imin} and x_{imax} are the lower and upper limits of the variable i.

3. PROPOSED ALGORITHM

The described mathematical model is solved with the evolution of a hybrid method [6, 7, 8] that combines a simple genetic algorithm (GA) [10], a quasi-Newton algorithm (QNA) [11] and a constraints handling method (CHM). The basic steps of the proposed algorithm are illustrated in Fig.2.

In the first loop (L1), starting populations are randomly generated to set variables values, which are used to calculate the fitness function value. Genetic algorithm [10] considering these starting populations uses selection, crossover and mutation procedures to create new generations. The optimum variables values of first loop (L1) are inserted in the QNA [11] as an initial variables vector guess. The QNA modifies the values of this vector using a finite-difference gradient method in a way that the fitness function is minimized. Afterwards these output variables values are used in the third loop (L3) to reduce the bounds of each variable, about this optimum selected one.

The minimum calculated value of the fitness function defines the optimum obtained variables values, which represent the location of robot base, the robot links geometry, as well as the robot configurations for all the prescribed end-effector poses.

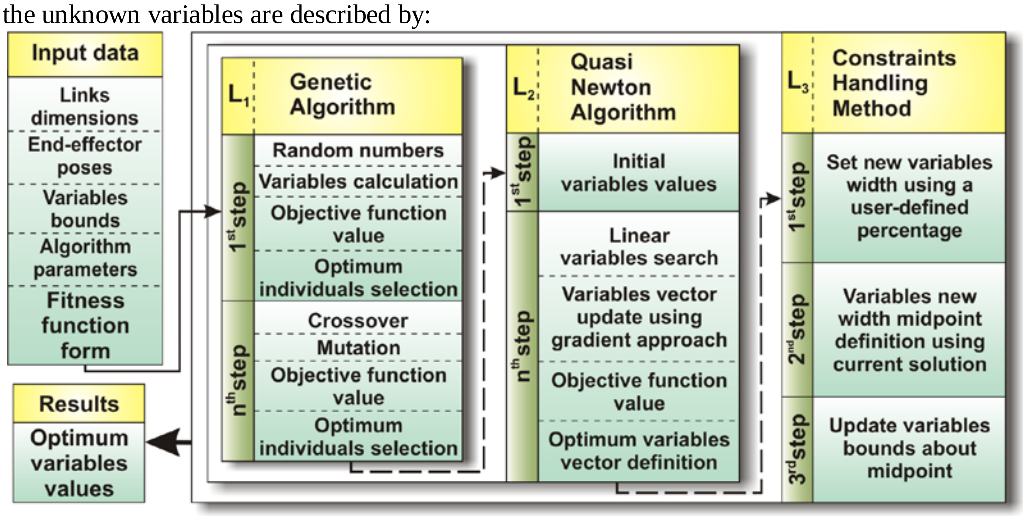

Fig. 2. Flowchart diagram of the developed algorithm.

The introduced methodology is applied in a spatial manipulator with two degrees of freedom and two revolute joints. The input data used for the algorithm are the variables bounds, the algorithm parameters and the end-effector poses. The initial applied variables limits are presented in Table.

Variables \ i	θi (o)	αi (o)	ai (mm)	di (mm)
0	0-360	0-360	0-1000	0-1000
1	0-360	0-360	0-100	0-100
2	0-360	0-360	0-100	0-100
3	0-360	-	-	0-100

Table 1. Initial variables limits.

Three numerical applications corresponding to one, two and three target points are presented. The three poses of the tool frame (T1, T2, T3) with respect to the fixed Cartesian coordinate system Ps are prescribed. Using these poses the matrices $A^3_{s\_prk}$ (k=1,2,3), of the prescribed end-effector poses are evaluated.

For each additional point, two more joints variables are used, which grow up the problem and the solution becomes slower and more difficult.

In order to make obvious the accuracy advantage of the proposed method, four different algorithms were tested in each numerical example. The first one uses only GA, the second combines the GA with the CHM, the third one uses a combination of GA with the QNA and the fourth is the proposed one. The parameters involved in all tests, mainly in GA procedure, are the same and selected as optimums through many applied tests: population of individuals=50, cross probability=70% and mutation probability=8%. All the other algorithm parameters involved in the problem are different in each case and are presented in Table 2. The loops number of GA, QNA and CHM are selected in a way that the total generations number in four tests are equal, in order to be comparable.

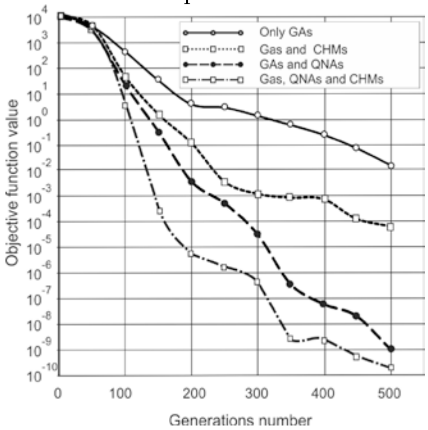

Fig.3. The evolution of the objective function value for one prescribed end-effector pose.

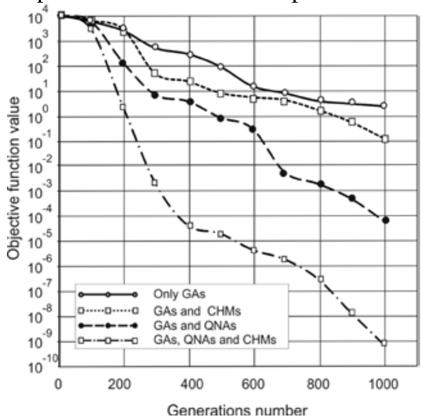

Fig.4. The evolution of the objective function value for two prescribed end-effector poses.

Fig. 3., Fig. 4. and Fig. 5. illustrate the value of the fitness function versus the generations number of the four compared methods for the first, second and third numerical example using one, two and three prescribed end-effector poses.

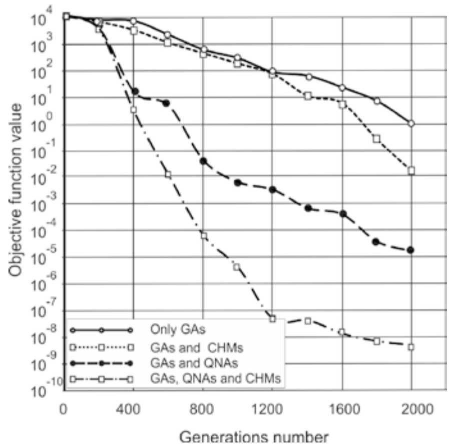

Fig. 5. The evolution of the objective function value for three prescribed end-effector poses.

As shown in these figures, the performance of the proposed algorithm is substantially better than that of the three other methods during the whole procedure both in accuracy and computational time. The obtained value of the fitness function in the three examples illustrates clearly the advantage of the proposed algorithm.

Regarding the application of the method on the Fortran environment, the comparison between the calculated elements of the matrices and the corresponding elements of the prescribed ones shows that the maximum positional deviation is lower than 0.0008 mm. The maximum deviation of orientations is lower than 0.0009 rad (0.052 degrees) in first and second example, which is insignificant value, and lower than 0.0318 rad (1.822 degrees), which is acceptable value.

On the other hand the application of the method on the Matlab environment, obtains better results than FORTRAN regarding the Fitness Function value in a lower computational time as presented in Table 2. The comparison between the calculated elements of the matrices and the corresponding elements of the prescribed ones shows that the maximum positional deviation is lower than 0.0007 mm in the three numerical examples. The maximum deviation of orientations is lower than 0.0006 rad (0.037 degrees), which is insignificant value and even lower than the Fortran approach.

Tool poses	Algorithm	Compu-tational time	Number of loops			Range redu-ction	Fitness function value
			GA	QNA	CHM		
One	GA	00:35	500	-	-	-	2.10e-02
	GA+CHM	00:32	250	-	2	55%	9.24e-05
	GA+QNA	00:18	10	50	-	-	2.08e-09
	Proposed	00:08	10	10	5	85%	3.64e-10
Two	GA	00:57	1000	-	-	-	3.84e+00
	GA+CHM	01:05	250	-	4	85%	2.24e-01
	GA+QNA	00:38	10	100	-	-	1.26e-04
	Proposed	00:25	10	50	2	35%	1.66e-09
Three	GA	01:43	2000	-	-	-	1.34e+00
	GA+CHM	01:37	500	-	4	15%	2.24e-02
	GA+QNA	01:21	40	50	-	-	2.29e-05
	Proposed	01:08	10	50	4	55%	7.03e-09

Table 2. Algorithms' parameters and obtained fitness function value

Example	Poses	Parameters				FORTRAN Results		MATLAB Results	
		Number of loops			Variables range reduction	Compu-tational time	Fitness value	Compu-tational time	Fitness value
		GA	QNA	CHM					
1st	1	100	500	4	85%	0:13:04	**1.20e-09**	0:07:05	**3.47e-10**
	1	10	10	1	85%	**0:00:03**	4.73E-06	**0:00:03**	8.65e-05
2nd	2	100	500	9	65%	0:36:13	**4.33E-06**	0:12:53	**2.54e-09**
	2	100	100	4	65%	**0:02:48**	2.66E-02	**0:01:18**	4.57e-05
3rd	3	100	500	19	30%	2:44:29	**4.22E-03**	0:53:25	**3.39e-10**
	3	100	200	9	55%	**0:22:06**	1.20E-01	**0:13:18**	7.77e-07

Table 3. Fortran and MatLab approaches comparison.

In order to have a clear comparison between the solutions on FORTRAN and MATLAB environments, using the same methodology, an additional test is applied where these two approaches are compared both in accuracy and speed. The testing examples are the same with the presented in Table 2, but two variations regarding the repetitions are applied. The first test is applied using a great amount of repetitions in order to examine the efficiency of the Fortran and Matlab approaches regarding the fitness function value, without any computational time restrictions. The second test is applied using a small amount of repetitions in order to examine the efficiency of the compared approaches regarding the computational time, without any fitness function value restrictions.

The parameters of the applied tests, as well as the obtained computational time and fitness function value, are presented in Table 3. The comparison of the proposed method applied on Fortran and MatLab environment, demonstrates an advantage of MatLab approach both on computational time and fitness function value.

5. CONCLUSIONS

In the present paper a comparison between an optimization algorithm based in Fortran and an evolution approach of the same algorithm based in MatLab, to find an optimum solution in a combined problem is presented. The problem involves simultaneously the robot geometry, the robot base position and the joint angles of a 2-DOF spatial RR manipulator. The optimization is obtained through a fitness function that consists of the sum of the deviations squares between the prescribed poses and the real poses of the end-effector, taking into account the workspace restricts and variables limits.

The compared algorithms are written in MatLab and Fortran and the solid graphics are developed in Solid Works environment. Both algorithms and graphics can be modified to agree with any manipulator or problem conditions.

6. REFERENCES

[1] Pamanes, J.A., Montes, J.P, Cuan, E., Rodriguez, F.C.: Optimal Placement and Synthesis of a 3R Manipulator, International Symposium on Robotics and Automation (ISRA 2000), Monterrey, Mexico, 2000.

[2] Mavroidis, C., Lee, E., Alam, M.: A New Polynomial Solution to the Geometric Design Problem of the Spatial R-R Robot Manipulators Using the Denavit-Hartenberg Parameters - Transactions of the ASME, Journal of Mechanical Design, Vol. 123, pp.58-67, 2001.

[3] Lee, E., Mavroidis, C., Solving the Geometric Design Problem of Spatial 3R Robot Manipulators Using Polynomial Homotopy Continuation, Trans. of the ASME, Journal of Mechanical Design, Vol. 124, pp.652-661, 2002.

[4] Perez, A., McCarthy, M. J.: Dimensional Synthesis of Spatial RR Robots, in: Advances in Robot Kinematics, Kluwer Academic Publ., Netherlands, pp.93-102, 2000.

[5] Kelaiaia, R. , Company, O., Zaatri, A., Multiobjective optimization of a linear Delta parallel robot, Mechanism and Machine Theory, Vol. 50, pp. 159-178, 2012.

[6] D. Sagris, S. Mitsi, K.-D.Bouzakis, G.Mansour, 5-DOF robot base location optimization using a hybrid algorithm, Mecatronica, Vol.1, pp.76-81, 2004.

[7] S. Mitsi, K.-D. Bouzakis, D. Sagris, G. Mansour, Determination of optimum robot base location considering discrete end-effector positions by means of hybrid genetic algorithm, Robotics and Computer-Integrated Manufacturing, Vol.24, pp.50-59, 2008.

[8] D. Sagris, S. Mitsi, K.-D. Bouzakis, G. Mansour, Spatial RRR robot manipulator optimum geometric design by means of a hybrid algorithm, The Romanian review precision mechanics, Optics & Mechatronics, No. 39, pp. 141-144, 2011.

[9] Denavit, J., Hartenberg, R.S.: Transactions of the ASME - Journal of Applied Mechanics, E22, 1955, pp.215-22.

[10] Coley, D.: An Introduction to Genetic Algorithms for Scientists and Engineers - World Scientific Press, 1999.

[11] IMSL: Fortran Subroutines for Mathematical Applications - Visual Numerics, 1997.

Authors: **Ass. Prof. MANSOUR Gabriel, Dr.ing. SAGRIS Dimitrios, TSIAFIS Christos dipl.ing., Prof. MITSI Sevasti, Prof. BOUZAKIS Konstantin,** Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department Aristoteles University of Thessaloniki, Greece.

E-mail: mansour@eng.auth.gr, dsagris@eng.auth.gr, tsiafis@gmail.com, mitsi@eng.auth.gr, bouzakis@eng.auth.gr