MULTI-OBJECTIVE DESIGN OPTIMISATION OF A PLANAR MICRO PARALLEL ROBOT USING GENETIC ALGORITHMS

Sergiu-Dan Stan*, Vistrian Mătieş, Radu Bălan**

*Technical University of Cluj-Napoca, *Department of Mechanics and Programming, **Department of Mechatronics*

Abstract: *Choosing the best dimensions of a micro parallel robot is still a chalanging task. This paper is aimed at presenting a study on the optimization of a micro parallel robot, with two-degree-of-freedom (DOF) with constant struts. The robot workspace is characterized and the inverse kinematics equation is obtained. In the paper, design optimization is implemented with Genetic Algorithms (GA) for optimization considering transmission quality index, design space and workspace. Here, intended to show the advantages of using the GA, we applied it to a multicriteria optimization problem of 2 DOF micro parallel robot. Genetic algorithms (GA) are so far generally the best and most robust kind of evolutionary algorithms. A GA has a number of advantages. It can quickly scan a vast solution set. Bad proposals do not affect the end solution negatively as they are simply discarded. The obtained results have shown that the use of GA in such kind of optimization problem enhances the quality of the optimization outcome, providing a better and more realistic support for the decision maker.*

Keywords: *optimization, GA, micro parallel robots, design, 2 DOF.*

1. INTRODUCTION

Parallel robots seem capable of answering the increase needs of industry in terms of automation. The nature of their architecture tends to reduce absolute positioning and orienting errors [1]. Their closed kinematics structure allows them obtaining high structural stiffness and performing high-speed motions. The inertia of its mobile parts is reduced, since the actuators of a parallel robot are often fixed to its base and the end-effector can perform movements with higher accelerations. One drawback with respect to open-chain manipulators, though, is a typically reduced workspace and a poor ratio of working envelope to robot size. By offering possible solutions to the above technical challenges, the present paper addresses the key questions detailed above with respect to two types of strut design.

There is a strong and complex link between the type of robot's geometrical parameters and its performance. It's very difficult to choose the geometrical parameters intuitively in such a way as to optimize the performance. Several papers have dealt with parallel robots to optimize performances [14].

However, many of these are limited to only one performance optimization. For example, various methods to determine workspace of a parallel robot have been proposed using geometric or numerical approaches. Early investigations of robot workspace were reported by Gosselin [1], Merlet [2], Kumar and Waldron [3], Tsai and Soni [4], Gupta and Roth [5], Sugimoto and Duffy [6], Gupta [7], and Davidson and Hunt [8]. The consideration of joint limits in the study of the robot workspaces was presented by Delmas and Bidard (1995). Other works that have dealt with robot workspace are reported by Agrawal [9], Gosselin and Angeles [10], Cecarelli [11]. Agrawal [12] determined the workspace of in-parallel manipulator system using a different concept namely, when a point is at its workspace boundary, it does not have a velocity component along the outward normal to the boundary. Configurations are determined in which the velocity of the end-effector satisfies this property. Pernkopf and Husty [13] presented an algorithm to compute the reachable workspace of a spatial Stewart Gough-Platform with planar base and platform (SGPP) taking into account active and passive joint limits. Stan [14] presented a genetic algorithm approach for multi-criteria optimization of PKM. Most of the numerical methods to determine workspace of parallel manipulators rest on the discretization of the pose parameters in order to determine the workspace boundary [15, 16].

In the discretization approach, the workspace is covered by a regularly arranged grid in either Cartesian or polar form of nodes. Each node is then examined to see whether it belongs to the workspace. The accuracy of the boundary depends upon the sampling step that is used to create the grid. The computation time grows exponentially with the sampling step. Hence it puts a limit on the accuracy. Moreover, problems may occur when the workspace possesses singular configurations. Other authors proposed to determine the workspace by using optimization [14]. There it was proposed an algorithm that allows for the determination of some parameters of the parallel manipulators using a genetic algorithm method in order to obtain a workspace as close as possible to a prescribed one.

Numerical methods for determining the workspace of the parallel robots have been developed in the recent years. Exact computation of the workspace and its boundary is of significant importance because of its impact on robot design, robot placement in an environment, and robot dexterity.

The objective of this paper is to propose an optimization method for a planar micro parallel robot that combines performance evaluation criteria related to the following robot characteristics: workspace, design space and transmission quality index. Furthermore, a genetic algorithm is proposed as the principle optimization tool. The success of this type of algorithm for parallel robots optimization has been demonstrated in various papers [14].

2. TWO DEGREES OF FREEDOM MICRO PARALLEL ROBOTS

2.1 Geometrical description of the parallel robots

A general planar micro parallel robot with two degrees of freedom activated by prismatic joints is shown in Fig. 1.

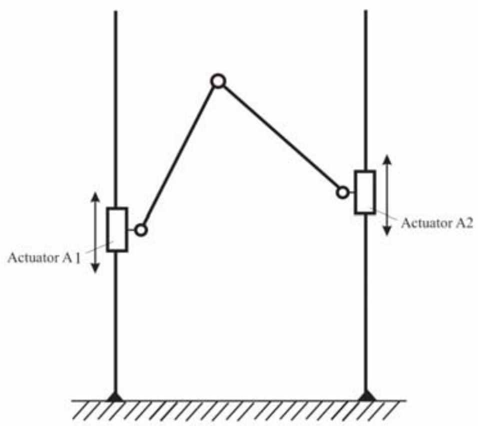

Fig. 1. Constant length struts parallel robot

2.2 Kinematic analysis

Robot kinematics deals with the study of the robot motion as constrained by the geometry of the links.

Typically, the study of the robot kinematics is divided into two parts, inverse kinematics and forward (or direct) kinematics. The inverse kinematics problem involves a known pose (position and orientation) of the output platform of the robot to a set of input joint variables that will achieve that pose.

The forward kinematics problem involves the mapping from a known set of input joint variables to a pose of the moving platform that results from those given inputs.

However, the inverse and forward kinematics problems of our parallel robot can be described in closed form so both, the direct kinematic problem (DKP) and the inverse kinematic problem (IKP) have an exact analytic solution.

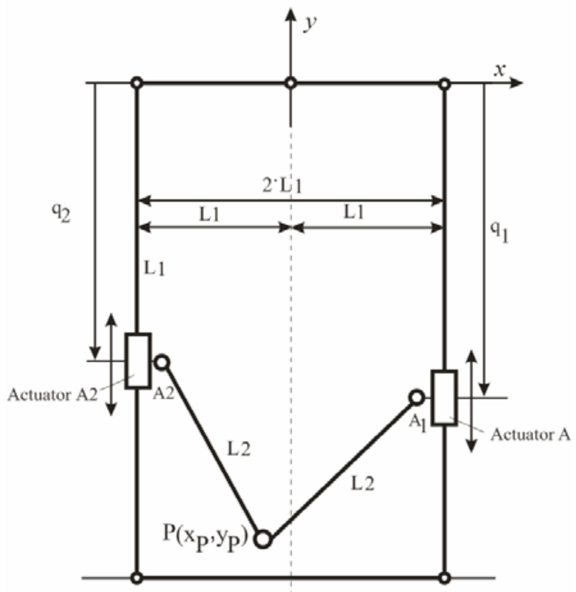

Fig. 2. The general kinematic scheme of a PRRRP micro parallel robot

This property is advantageous for the robot control as numeric iterative calculations are not necessary. Therefore the cycle times can be minimized for a better performance of the robot control.The kinematics relation between **x** and **q** of this 2 DOF micro parallel robot can be expressed solving the:

$$f(\mathbf{x}, \mathbf{q})=0 \quad (1)$$

Then the inverse kinematics problem of the parallel robot can be solved by writing the following equations:

$$q_1 = y_P \pm \sqrt{L_2^2 - (x_p - L_1)^2} \quad (2)$$

$$q_2 = y_P \pm \sqrt{L_2^2 - (x_p + L_1)^2}$$

The TCP position can be calculated by using inverted transformation, from (6). The forward and the inverse kinematics problems were solved under the MATLAB environment and it contains a user friendly graphical interface.

The user can visualize the different solutions and the different geometric parameters of the parallel robot can be modified to investigate their effect on the kinematics of the robot.

This graphical user interface can be a valuable and effective tool for the workspace analysis and the kinematics of the parallel robots.

The designer can enhance the performance of his design using the results given by the presented graphical user interface. The MATLAB-based program is written to compute the forward and inverse kinematics of the parallel robot with 2 degrees of freedom.

3. WORKSPACE DETERMINATION AND OPTIMIZATION

3.1. Workspace evaluation

The workspace is one of the most important kinematic properties of manipulators, even by practical viewpoint because of its impact on manipulator design and location in a workcell [17].

A general numerical evaluation of the workspace can be deduced by formulating a suitable binary representation of a cross-section in the taskspace.

Other authors proposed to determine the workspace by using optimization [14]. The following presents the main factors affecting workspace.

For ease of comparison a cubic working envelope with a common contour length is used together with a machine size that is calculated from the maximum required strut length.
Other design specific factors such as the end-effector size, drive volumes have been neglected for simplification.

3.2 The working envelope with variable and constant length struts

The working envelope to machine size using variable length struts is dependent on the following factors:

1. The length of the extended and retracted actuator (L*min*, L*max*);
2. Limitations due to the joint angle range.

Fig. 3 clearly illustrates the limiting effect of the joint limits.

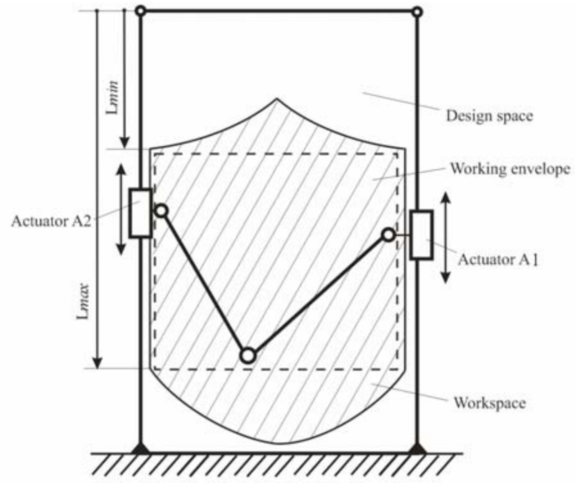

Fig. 3. Workspace of the micro parallel robot with constant length struts

In this section, the workspace of the proposed robots will be discussed systematically. A GUI for computing the shape of the workspace is presented in Fig. 5.

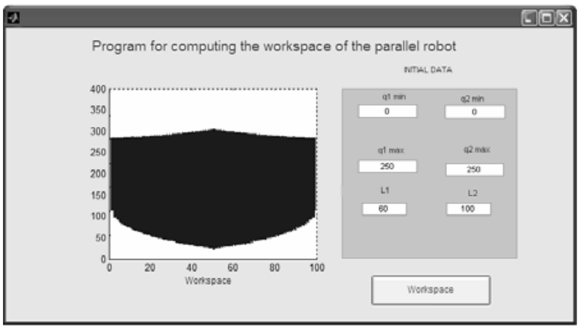

Fig. 4. The GUI for calculus of workspace for the planar 2 DOF micro parallel robot with constant length struts

Analysis, visualization of workspace is an important aspect of performance analysis, see Fig. 4 and Fig. 5. A numerical algorithm to generate reachable workspace of parallel manipulators was introduced.

It is very important to analyze the area and the shape of workspace for parameters given robot in the context of industrial application. The workspace is primarily limited by the boundary of solvability of inverse kinematics.

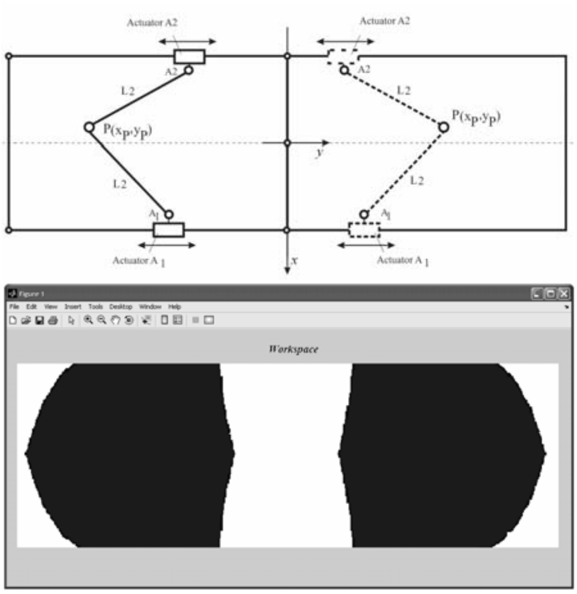

Fig. 5. Two different areas of workspace in two possible configurations

Then the workspace is limited by the reachable extent of drives and joints, occurrence of singularities and by the link and platform collisions. The mechanism PRRRP realizes a wide workspace as well as high-speed.

A fundamental characteristic that must be taken into account in the dimensional design of robot manipulators is the area of their workspace.

It's crucial to compute the workspace and its boundaries with perfect precision, because they influence the dimensional design, the manipulator's positioning in the work environment, and its dexterity to execute tasks.

3.3 Performance evaluation:

Beside workspace which is an important design criterion, transmission quality index is another important criterion.

The transmission quality index couples velocity and force transmission properties of a parallel

robot, i.e. power features [21].
Its definition runs like this:

$$T = \frac{\|E\|^2}{\|J\| \cdot \|J^{-1}\|} \qquad (3)$$

where E is the unity matrix and J is the Jacobi matrix. T is between 0<T<1; T=0 characterizes a singular pose, the optimal value is T=1 which at the same time stands for isotropy [14].

$$\|J\| = \sqrt{tr\left(J^T wJ\right)};\; w = \frac{1}{n}1 \qquad (4)$$

in which n is the dimension of the Jacobian matrix and **1** the n x n identity matrix.

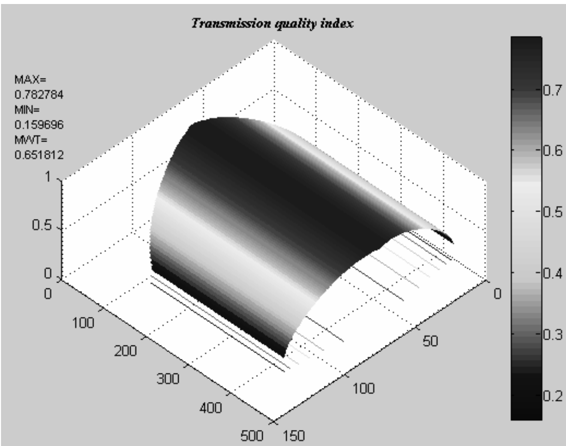

Fig. 6. Transmission quality index for PRRRP mini parallel robot

As it can be seen from the Fig. 6, the performances of the PRRRP mini parallel robot are constant along y-axis. On every y section of such workspace, the performance of the robot can be the same.

However, in practice, optimization of the robot geometrical parameters should not be performed only in terms of workspace maximization.

Some parts of the workspace are more useful considering a specific application. Indeed, the advantage of a bigger workspace can be completely lost if it leads to new collision in parts of it which are absolutely needed in the application.

However, it's not the case of the presented structure.

3.4. Optimization results for PRRRP micro parallel robot

An objective function is defined and used in optimization. Objective function contains workspace and transmission quality index.

Optimization parameter was chosen as the link length L2.

The constraints was established as 1<L2<1.2. After performing the optimization the following results were obtained:

	Method	GAOT Toolbox MATLAB
Goal functions	Z=W_1·T+W_2·W, W_1=0,7 and W_2=0,3	*L2* = 1.1
	Z=W_1·T+W_2·W, W_1=0,3 and W_2=0,7	*L2*= 1.1556
	Z= W_1·T, W_1=1 and W_2=0	*L2*=1
	Z=W_2·W, W_1=0 and W_2=1	*L2*=1.2

Table 1. Results of Optimization for Different Goal Functions

Based on the presented optimization methodology we can conclude that the optimum design and performance evaluation of the micro parallel robot is the key issue for an efficient use of micro parallel robots.

This is a very complex task and in this paper was proposed a framework for the optimum design considering basic characteristics of workspace and isotropy.

ACKNOWLEDGEMENT

Support for this work was provided through the CNCSIS under research grant TD 261.

CONCLUSION

The fundamental guidelines for genetic algorithm to optimal design of micro parallel robots have been introduced. It is concluded that with three basic generators selection, crossover and mutation genetic algorithm could search the optimum solution or near-optimal solution to a complex optimization problem of micro parallel robots. In the paper, design optimization is implemented with Genetic Algorithms (GA) for optimization considering transmission quality index, design space and workspace. The obtained results have shown that the use of GA in such kind of optimization problem enhances the quality of the optimization outcome, providing a better and more realistic support for the decision maker.

REFERENCES

[1] C. Gosselin. "Determination of the workspace of 6-d.o.f. parallel manipulators". *ASME Journal of Mechanical Design*, 112:331–336, 1990.

[2] J. P. Merlet. "Determination of the orientation workspace of parallel manipulators". *Journal of intelligent and robotic systems*, 13:143–160, 1995.

[3] A. Kumar, KJ. Waldron. "The workspace of mechanical manipulators". *ASME J. Mech. Des*. 1981; 103:665-672.

[4] YC. Tsai, AH. Soni. "Accessible region and synthesis of robot arm". *ASME J. Mech Des*. 1981, 103: 803-811.

[5] KG. Gupta, Roth B., "Design considerations for manipulator workspace". *ASME J. Mech. Des.* 1982, 104(4), 704-711.

[6] K. Sugimoto, Duffy J, Hunt KH, "Special configurations of spatial mechanisms and robot arms". *Mech Mach Theory* 1982, 117(2); 119-132.

[7] KC. Gupta. "On the nature of robot workspaces", *Int. J. Rob. Res.* 1986; 5(2): 112-121

[8] JK. Davidson, KH. Hunt, "Rigid body location and robot workspace: some alternative manipulator forms". *ASME J. Mech. Transmissions Automat Des* 1987, 109(2); 224-232.

[9] SK. Agrawal, "Workspace boundaries of in-parallel manipulator systems". *Int. J. Robotics Automat* 1990, 6(3) 281-290.

[10] C. Gosselin, Angeles J. "Singularities analysis of closed loop kinematic chains". *IEEE Trans Robotics Automat* 1990; 6(3) 281-290.

[11] M. Cecarelli, "A synthesis algorithm for three-revolute manipulators by using an algebraic formulation of workspace boundary". *ASME J. Mech. Des.* 1995; 117(2(A)): 298-302.

[12] S. K. Agrawal. "Workspace boundaries of in-parallel manipulator systems". *IEEE Transactions on Robotics and Automation*, 7(2):94–99, 1991.

[13] F. Pernkopf and M. Husty, "Reachable Workspace and Manufacturing Errors of Stewart-Gough Manipulators", *Proc. of MUSME 2005, the Int. Sym. on Multibody Systems and Mechatronics* Brazil, 2005, p. 293-304.

[14] S. Stan, Diplomarbeit, *Analyse und Optimierung der strukturellen Abmessungen von Werkzeugmaschinen mit Parallelstruktur*, IWF-TU Braunschweig, 2003, Germany.

[15] K. Cleary and T. Arai. "A prototype parallel manipulator: Kinematics, construction, software, workspace results, and singularity analysis". In *Proceedings of International Conference on Robotics and Automation*, pages 566–571, Sacramento, California, April 1991.

[16] C. Ferraresi, G. Montacchini, and M. Sorli. "Workspace and dexterity evaluation of 6 d.o.f. spatial mechanisms". In *Proceedings of the ninth World Congress on the theory of Machines and Mechanism*, pages 57–61, Milan, August 1995.

[17] M. Ceccarelli, G. Carbone, E. Ottaviano, "An Optimization Problem Approach For Designing Both Serial And Parallel Manipulators", *Proc. of MUSME 2005, the Int. Sym. on Multibody Systems and Mechatronics* Uberlandia, Brazil, 6-9 March 2005

[18] M. Ceccarelli, *Fundamentals of Mechanics of Robotic Manipulation*, Dordrecht, Kluwer/Springer, 2004.

[19] J.A. Snyman, L.J. du Plessis, and J. Duffy. "An optimization approach to the determination of the boundaries of manipulator workspaces". *Journal of Mechanical Design*, 122:447–455, 2000.

[20] L.J. Du Plessis and J.A. Snyman. "A numerical method for the determination of dextrous workspaces of Gough-Stewart platforms". *Int. Journal for Numerical Methods in Engineering*, 52:345–369, 2001.

[21] J. Schoenherr, Bemessen, „Bewerten und Optimieren von Parallelstrukturen", In: Proc. 1st Chemnitzer Parallelstruktur Seminar, Chemnitz, Germany, 85-96, 1998.