Optimization of a Parallel Robot 2RRR, Based on Metaheuristic Optimization Using Genetic Algorithms, Evaluating the Global Performance Index System for Kinematic.

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Abstract

Parallel robots have many useful characteristics, compared to linear robots like their greater structural rigidity, among others. The process of designing parallel robots take in consideration many variables such the workspace, the performance and the influence of the dimensions on these features, which make it an iterative procedure known as optimal design. This article presents the optimal design of a five-bar mechanism by the utilization of genetic algorithms. For the analysis, the robot is considered entirely asymmetrical which generalize the results to a more significant scope. Also, the objective function of the algorithm was the global performance index which considered the statistical behavior of the local indexes on the workspace.

Keywords

Parallel robots, optimal design, genetic algorithms, five bar mechanism, workspace analysis.

1. INTRODUCTION

Parallel robots (PRs), associated to serial robots, have presented some useful characteristics like greater structural rigidity (stiffness), kinematic accuracy (non-cumulative joints error), higher robot-weight-ratio, compactness, and modularity [1-3]. In the past two decades, all of these benefits have won PRs particular relevance for the industry in fields of machine tooling, quick pick and place applications, vehicle driving simulators, solar tracking mechanisms, among others. One of the main subjects of PRs is their optimal design, which is the selection of a robot dimensions to satisfy specific requirements [4].

The quantification of the behavior of the PRs is realized using performance indices. This procedure reduces the physical and mathematical description of a robot to a scalar value that describes a specific property. Various researchers have proposed performance indices to different applications, e. g.; Yang et al. proposed a stiffness evaluation index to obtain the suited spindle configuration for applications of machining [5]; Vulliez et al. used kinematic indices to design a 6 degree of freedom PR for haptic applications [6]. Nevertheless, the implementation of performance indices requires the utilization of methods to describe the complete behavior of the index within a specified workspace.

Another issue in the optimization of PRs is the procedure of optimization. From the state of the art of PRs, exist two main approaches for the optimization of PRs, which are performance atlases and numerical optimization. From the former, in the literature are reported diverse applications, e. g. ; Zhang et al. construed a performance atlas to find the most suitable dimensions for a groundhog-like mine rescue robot [7]. The main drawback of this method is that it is limited to mechanisms that are not complex or uses symmetrical configurations, as it uses a graphical representation of the performance of the robot related to its dimensions and the more parameters, the harder to implement the method. For the latter, the principal methods used for this kind of optimization is genetic algorithms. Kelaiaia et al. used a genetic algorithm to optimize a linear delta parallel robot [8]. Bataller et al. designed an exoskeleton for finger rehabilitation using a genetic algorithm [9]. The principal characteristic of this method is that it is not limited to the number of dimensions in the robot, although it may increase the computational cost. Thus, the optimization of a 5-bar mechanism is conducted by the utilization of genetic algorithms. For the analysis, the robot is considered entirely asymmetrical. This consideration is based on the work of Mohan et al. who stated that an asymmetrical robot provides larger singularity-free workspace when compared with symmetrical robots [10]. The optimization is based on the global performance index system proposed by Zhan et al. [11]. The results presented that, although the robot dimensions tend towards the symmetry, the optimum is in the asymmetrical configuration.

2. PARALLEL ROBOT 2RRR

The robot, **Figure 1**, consists of a linear base, where revolute joints ubicated on each extreme of line. In where three drive arms coupled to each joint; likewise, the drive arms attached to the forearms with revolute joints. Furthermore, the platform, L_1, L_2, uses revolute joints to connect the forearms. In the kinematical behavior, the arms L_4, L_6, and their pairs, is the same, due to the parallelity relation between them, thus, the workspace analysis only considers the arms L_4 and L_6, and the platform possesses two translational grades of freedom.

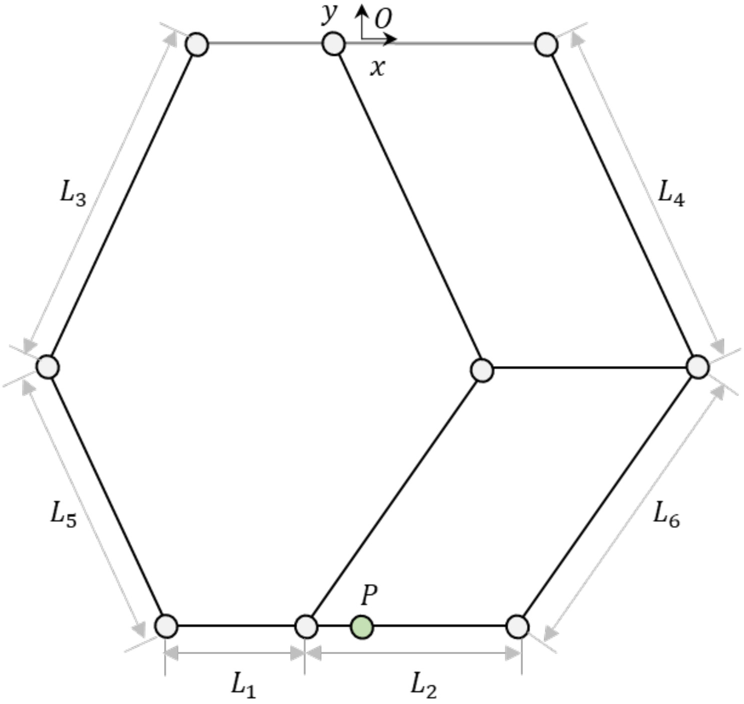

Fig. 1. Diagram Schematic of Mechanism

3. METHODOLOGY OF GENETIC ALGORITHM

The essential behavior of a genetic algorithm is showm in **Figure 2**. Each chromosome represents a possible solution and, each population is a conjunct of solutions. Furthermore, this type of algorithm works with the probability, as a method to obtain reliable results in a short time for multivariable problems. In this case, the optimization of the dimensions of the six limbs in the parallel robot 2RRR.

The chromosomes are aleatory binary numbers, which codified the arms size, and presents a series of genetic operators. The objective of these operators is generating new chromosomes from the present population, through the implementation of a crossing function and a mutation function.

Posteriorly to the application of genetic operators, the selection process is applied, which consists of two phases. The former, Selection of Elite, evaluate all solutions in the present population with the objective function and conserve the best solution. The latter, Roulette Selection, assign a probability of being preserved with the base of the performance in the objective function, apart of this, generate aleatory numbers to decide what solutions conserved. Once end the selection process, is obtained a new generation.

All process, genetic operation, and selection are repeated a determined amount of times; where the best solution of the last generation evaluate would be the closest solution to the maximum of the objective function.

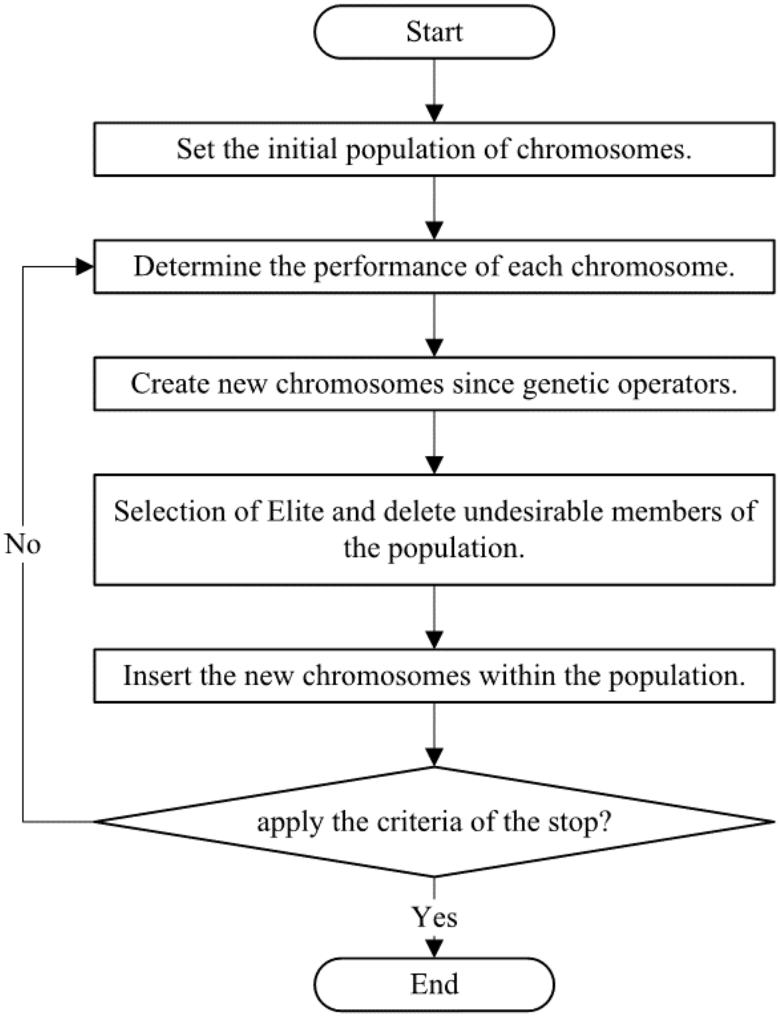

Fig. 2. Behavior of a Genetic Algorithm

4. OBJECTIVE FUNCTION: GLOBAL PERFORMANCE INDEX

The objective function is the reason for the genetic algorithms, due to obtaining the optimal value of this function is the purpose of the algorithm. Therefore, if the design of a mechanism would be optimized, one method to this is determining the optimal dimensions for a given performance Index. For this reason in this work, the Global Performance Index (GI_{kine}) [11] is selected to optimize a parallel robot 2RRR, where evaluate the Manipulability Index (M_r), Isotropy velocity index (μ_{riso}), minimum velocity index (V_{rmin}), and Kinematic Transmission Accuracy index (K_j) the definition of these index were the same as the utilized by Zhan et al in [11]. The definition of the index are expressed in equations (1-6).

$$(GI_{kine})_{integr} = \frac{\beta_1 (M_r)_{integr}}{(M_r)_{norm}} + \frac{\beta_2 (v_{rmin})_{integr}}{(v_{rmin})_{norm}} + \frac{\beta_3 (\mu_{riso})_{integr}}{(\mu_{riso})_{norm}} + \frac{\beta_4 (k_J)_{integr}}{(k_J)_{norm}} \tag{1}$$

Where:

$$\begin{aligned} \xi_{integr} &= \alpha \cdot \left|GIV_{\xi}\right| \\ &= (\alpha_1, \alpha_2, \alpha_3, \alpha_4) \cdot \left(|\xi_{avg}|, |\xi_{vol}|, |\xi_{skew}|, |\xi_{kurt}|\right)^T \\ &= \alpha_1 |\xi_{avg}| + \alpha_2 |\xi_{vol}| + \alpha_3 |\xi_{skew}| + \alpha_4 |\xi_{kurt}| \end{aligned} \tag{2}$$

α : is a vector with the appropriate values to each one of the parameters of each index.
ξ_{avg}: is the average value of the index into the workspace.
ξ_{vol} : is variance coefficient of the index into the workspace.
ξ_{skew}: is skewness coefficient of the index into the workspace.
ξ_{kurt}: is kurtosis coefficient of the index into the workspace.

4.1. Manipulability Index (M_r)

$$\begin{aligned} M_r &= \frac{\sqrt[m]{\lambda_1 \lambda_2 \dots \lambda_m}}{l^2} \\ \lambda &= eig(\boldsymbol{JJ^T}) \\ l &= \sum_{i=1}^{6} L_i \end{aligned} \tag{3}$$

4.2. Isotropy velocity index (μ_{riso})

$$\mu_{riso} = \sqrt[m]{\left(\frac{\sigma_1}{\sigma_{avg}}\right) \cdot \left(\frac{\sigma_2}{\sigma_{avg}}\right) \dots \left(\frac{\sigma_m}{\sigma_{avg}}\right)} \tag{4}$$

4.3. Minimum velocity index (V_{rmin})

$$V_{rmin} = \frac{\sqrt{\min(\lambda)}}{l} = \frac{\min(\sigma)}{l} \tag{5}$$

4.4. Kinematic Transmission Accuracy index (K_j)

$$K_j = \frac{1}{\|J\| \|J^+\|} \tag{6}$$

5. Results

Results were obtained with the genetic algorithm evaluated with the parameters presented on **Table 1**.

Table 1. Parameter's value in genetic algorithm

Parameters	Value
Population size	100
Number of generations	100
Probability of Crossing	25%
Probability of mutations	1%

The results of the lengths the robot are in **Table 2**. As seen from this results, the genetic algorithm tends to a symmetrical solution, but the optimal results remain in the asymmetry.

Table 2. final dimensions of the mechanism

Arm	Length	Arm	Length
L_1	15.00	L_4	30.00
L_2	15.00	L_5	17.00
L_3	18.80	L_6	23.00

Figure 5 shows the evolution of the results as a function of the iteration, according to these result the maximum value of the index is 1.721.

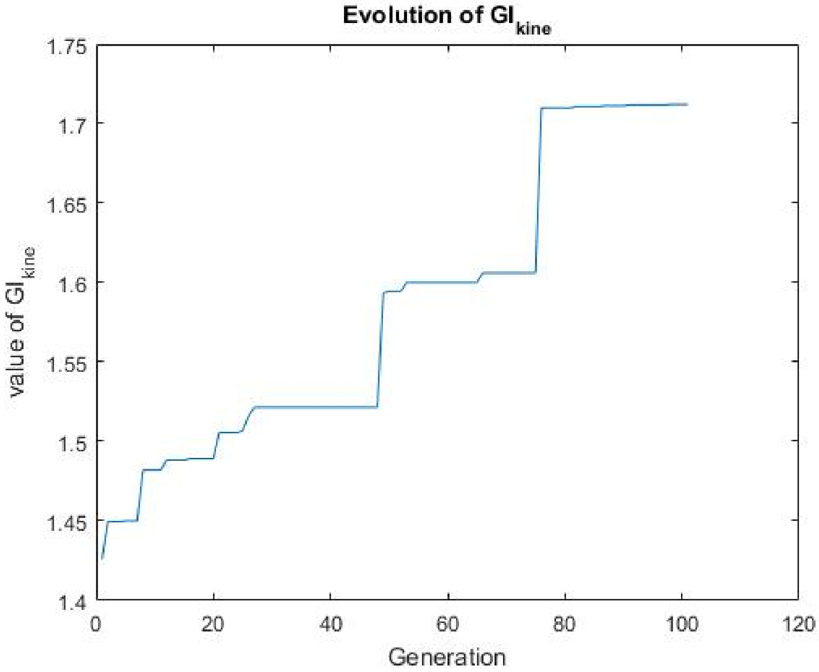

Fig. 5. Evolution of Maximum value of Global Performance Index per each population

Lastly, figure 6 presents the workspace generated by the optimum parameters. In this analysis, the workspace was selected to be a rectangle of 12x10. For the implementation of the genetic algorithm, a different workspace was calculated for each combination of dimensions maintaining the mentioned rectangle and considering the influence of singularities.

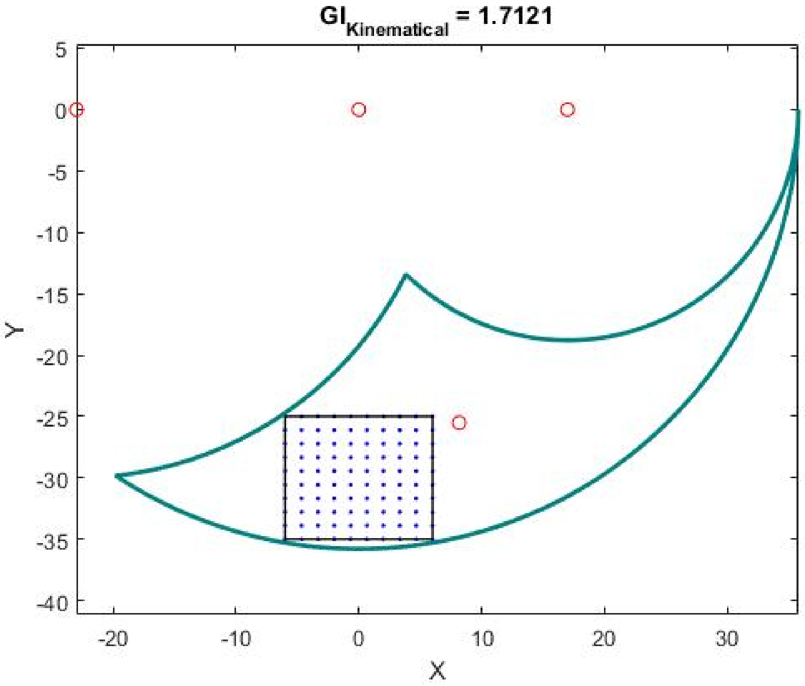

Fig. 6. Workspace generate with the optimal dimensions. External polygon: limits of the general workspace. Blue square: useful workspace.

6. CONCLUSIONS

The propitious dimensions for the best kinematic performance were obtained with the methodology presented in the article. This performance guarantees an optimized design of our mechanism, which gives us the best performance for the application in which the robot will be used. In the analysis, we considered all the possible cases of singularity for our model and, according to our state of the art, few works have this analysis due to their complexity, which adds value to the result of our research.

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8. BIOGRAPHIES

Javier Sanjuan acquired B.S and M.S. degrees in Mechanical Engineering from Universidad del Norte, Barranquilla, Colombia in 2012 and 2016, respectively. At present, he is conducting his PhD studies at University of Wisconsin Milwaukee, USA. His main research interests are the kinematical, dynamical, design, and control of parallel robots with diverse applications.

Mohammad Habib Rahman is with the Mechanical and Biomedical Engineering Department, University of Wisconsin-Milwaukee, WI, USA. As Director of the BioRobotics Lab at the University of Wisconsin-Milwaukee, he brings the resources and expertise of an interdisciplinary R&D team. For more than 15 years he has been researching bio-mechatronics/bio-robotics with emphasis on the design, development and control of wearable robots to rehabilitate and assist elderly and physically disabled individuals who have lost their upper-limb function or motion due to stroke, cardiovascular disease, trauma, sports injuries, occupational injuries, and spinal cord injuries. He received a BSc Engineering (mechanical) degree from Khulna University of Engineering & Technology, Bangladesh in 2001, a Master of Engineering (bio-robotics) degree from Saga University, Japan in 2005 and a PhD in Engineering (bio-robotics) from École de technologie supérieure (ETS), Université du Québec, Canada in 2012. He worked as a postdoctoral research fellow in the School of Physical & Occupational Therapy, McGill University (2012-2014). His research interests are in bio-robotics, exoskeleton robot, intelligent system and control, mobile robotics, nonlinear control, control using biological signal such as electromyogram signals.

Elias Muñoz is an undergraduate student in Mechanical engineering, in his last semester. he has an academic formation in design and robotics field, knowledge in thermodynamics system, and modeling of the control system. He works as a research assistant in the Design of Machine and Mechanism Lab at Universidad del Norte.

Miguel Padilla is a mechanical engineering student, in his last year. At the moment, he works in the Design of Machine and Mechanism Lab at Universidad del Norte, where he participates as a research assistant. Besides, he works on his graduation project, which is related to the design of an orthosis device for shoulder rehabilitation. he has experience programming MATLAB and SIMULINK, and CAD design software.