Optimization of a Hexapod Micro Parallel Robot
Using Genetic Algorithms

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Abstract - In this paper a mono-objective optimum design procedure for a six-degree-of-freedom parallel micro robot is outlined by using optimality criterion of workspace and numerical aspects. A mono-objective optimization problem is formulated by referring to a basic performance of parallel robots. Additional objective functions can be used to extend the proposed design procedure to more general but specific design problems. A kinematic optimization was performed to maximize the workspace of the mini parallel robot. Optimization was performed using Genetic Algorithms.

Index Terms – optimization, hexapod, 6 degree of freedom, Genetic Algorithms.

I. INTRODUCTION

The workspace of a robot is defined as the set of all end-effector configurations which can be reached by some choice of joint coordinates. As the reachable locations of an end-effector are dependent on its orientation, a complete representation of the workspace should be embedded in a 6-dimensional workspace for which there is no possible graphical illustration; only subsets of the workspace may therefore be represented.

There are different types of workspaces namely constant orientation workspace, maximal workspace or reachable workspace, inclusive orientation workspace, total orientation workspace, and dextrous workspace. The constant orientation workspace is the set of locations of the moving platform that may be reached when the orientation is fixed. The maximal workspace or reachable workspace is defined as the set of locations of the end-effector that may be reached with at least one orientation of the platform. The inclusive orientation workspace is the set of locations of nodes that may be reached with at least one orientation among a set defined by ranges on the orientation parameters. The set of locations of the end-effector that may be reached with all the orientations among a set defined by ranges on the orientations on the orientation parameters constitute the total orientation workspace. The dextrous workspace is defined as the set of locations for which all orientations are possible. The dextrous workspace is a special case of the total orientation workspace, the ranges for the rotation angles (the three angles that define the orientation of the end-effector) being $\{0,2\pi\}$.

In the literature, 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 (Parallel Kinematics Machines).

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 methods [14]. Numerical methods for determining the workspace of the parallel robots have been developed in the recent years.

In this paper, the optimization workspace index is defined as the measure to evaluate the performance of a six degree of freedom parallel micro robot.

Another contribution is the optimal dimensioning of the six degree-of-freedom parallel micro robot of type Hexapod for the largest workspace.
II. 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. A cross-section can be obtained with a suitable scan of the computed reachable positions and orientations \( p \), once the forward kinematic problem has been solved to give \( p \) as function of the kinematic input joint variables \( q \). A binary matrix \( P_{ij} \) can be defined in the cross-section plane for a cross-section of the workspace as follows: if the \( (i, j) \) grid pixel includes a reachable point, then \( P_{ij} = 1 \); otherwise \( P_{ij} = 0 \), as shown in Fig. 1. Equations (1)-(5) for determining the workspace of a robot by discretization method can be found in Ref. [18].

\[
\begin{align*}
\Delta x \times \Delta y &= \max_{i=1}^{i_{\text{max}}} \max_{j=1}^{j_{\text{max}}} (P_{ij}) \\
A &= \sum_{i=1}^{i_{\text{max}}} \sum_{j=1}^{j_{\text{max}}} (P_{ij} \Delta x \Delta y) \\
V &= \sum_{z=z_{\text{min}}}^{z_{\text{max}}} A \Delta z
\end{align*}
\]

In general, the parallel robots performances depend very much on their geometry, thus became of great interest the optimization problems of parallel robots.

A key aspect of the performances of the parallel robots is that they are very dependent on the topology and dimensioning of the robot. It became of a real interest for developing parallel robots for fulfilling the work tasks, thus introduction of the performance indices like or optimization criteria used to characterize the robot has become compulsory. In design of a robot, the workspace is of primary importance. Maximizing the workspace of the parallel robot is one of the main goals of the optimal design of parallel robots.

III. OPTIMAL DESIGN OF THE HEXAPOD

A. Six DOF micro parallel robot

The micro parallel robot is a six degrees-of-freedom parallel manipulator comprising a fixed base platform and a payload platform, linked together by six independent, identical, open kinematic chains (Fig. 2). Kinematics of this structure is presented in Refs. [14].

Fig. 1. The general scheme for binary representation and evaluation of robot workspace.

After that it is computed \( i \) and \( j \):

\[
i = \left\lfloor \frac{x + \Delta x}{\Delta x} \right\rfloor \quad j = \left\lfloor \frac{y + \Delta y}{\Delta y} \right\rfloor
\]

where \( i \) and \( j \) are computed as integer numbers. Therefore, the binary mapping for a workspace cross-section can be given as:

\[
P_{ij} = \begin{cases} 
0 & \text{if } P_{ij} \not\in W(H) \\
1 & \text{if } P_{ij} \in W(H)
\end{cases}
\]