

Singularity-free Workspace of Parallel Robots

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Parallel mechanisms are characterized by several kinematic chains connecting the base to the end-effector. Because of this characterization, parallel mechanisms have significant advantages over serial mechanisms in several aspects such as dynamic properties, load-carrying capacity, high accuracy as well as stiffness. So far, parallel mechanisms have many applications: robotic parallel manipulators, flight simulators, parallel kinematics machines, etc. However, the closed-loop nature of parallel mechanisms limits the motion of the platform and creates complex kinematic singularities inside the workspace. Therefore, how to maximize the singularity-free workspace of parallel mechanisms becomes a very important topic in the design context of parallel robots.

Many researchers conducted a lot of investigations on the workspace and singularity problems of parallel mechanisms. Qimi Jiang conducted extensive studies on the singularity-free workspace analysis of two typical parallel mechanisms. In his research work on this topic, the singularity-free workspace issue of the typical planar 3-RPR parallel mechanism was firstly addressed. Then, extensive studies of the Gough-Stewart platform were conducted. The Gough-Stewart platform is actually a typical and very popular spatial parallel mechanism. His research research work on this topic can be demonstrated by 10 journal papers [1-10].

For each of the above parallel mechanisms, a simple form of the singularity equation was derived [1,3]. The principle of the developed approach is to separate the origin O' of the mobile frame from the considered point P and make O' to coincide with a special point of the platform. Figures 1 and 2 respectively show the cases with the planar 3-RPR parallel mechanism and the Gough-Stewart platform. In this way, the singularity equation about a general point p of the platform would contain only a minimal set of geometric parameters. Besides, the centers of the workspace circles or spheres were proved to lie exactly on the singularity locus. This basic fact and the simplified singularity equation were taken as the solid basis for the singularity-free workspace analysis as well as the geometric optimization of parallel mechanisms.

For the planar 3-RPR parallel mechanism, the singularity-free workspace as well as the corresponding leg length ranges at a prescribed orientation was firstly calculated. Then, the optimal architecture that holds the maximal singularity-free workspace were studied and determined [1]. In order to guarantee a singularity-free workspace for

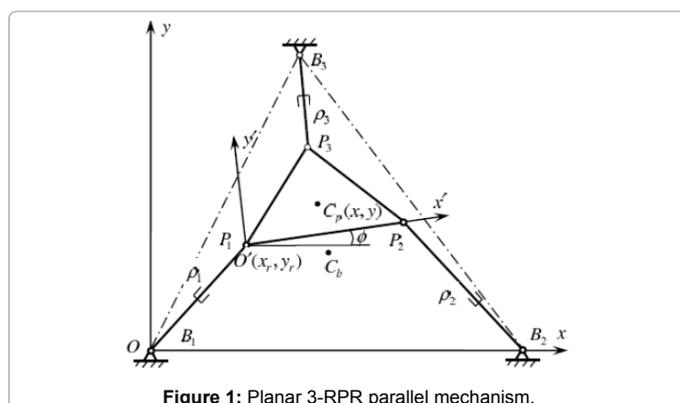


Figure 1: Planar 3-RPR parallel mechanism.

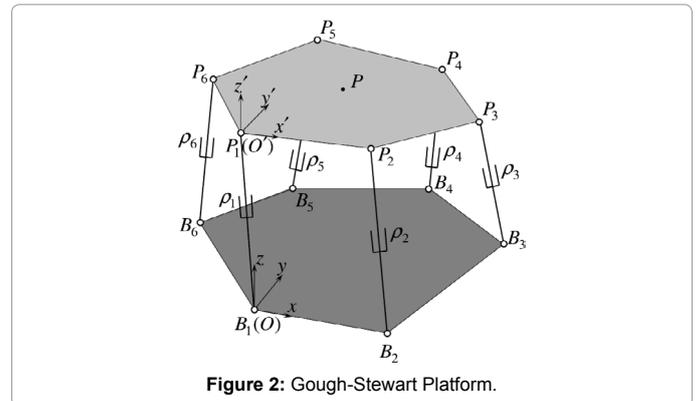


Figure 2: Gough-Stewart Platform.

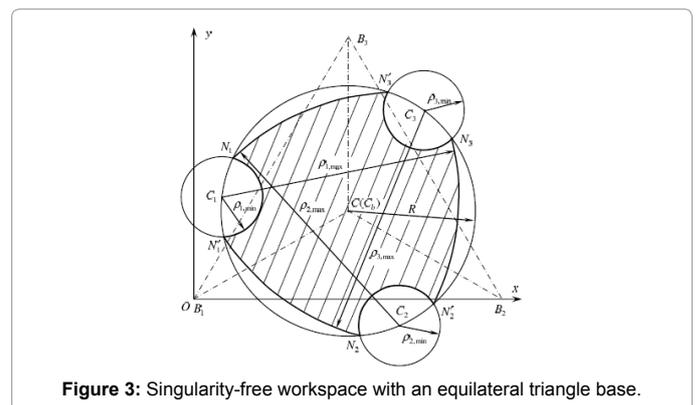


Figure 3: Singularity-free workspace with an equilateral triangle base.

a desired orientation range, the geometric synthesis was performed [2]. Using the Gauss divergence theorem, the effects of the orientation angle, the minimal leg length as well as the base shape on the singularity-free workspace were investigated. The obtained results show that for every orientation angle, an optimal minimal leg length can be determined to make the mechanism to hold the maximal singularity-free workspace. If the optimal minimal leg lengths were used for design, the equilateral triangle base would hold the maximal singularity-free workspace for any orientation angle (Figure 3). However, for a prescribed working range of the orientation angle, the optimal minimal leg length could be different from the individual optimal minimal leg lengths.

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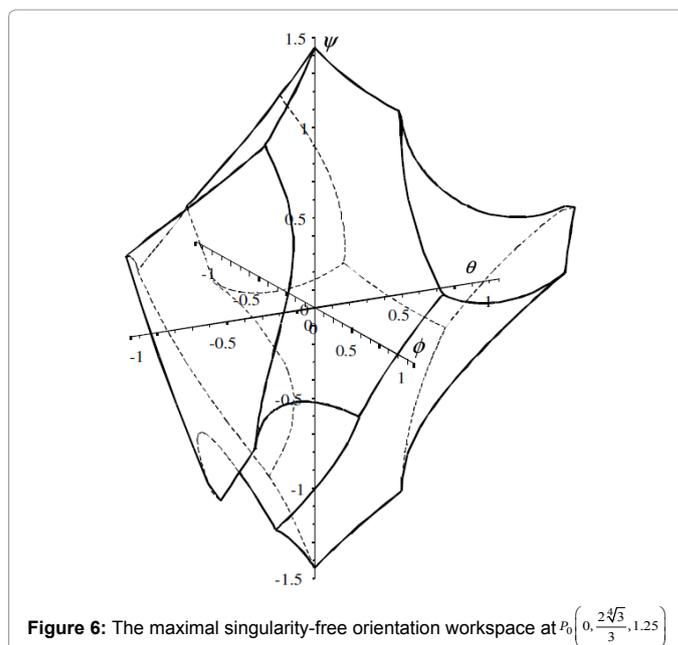
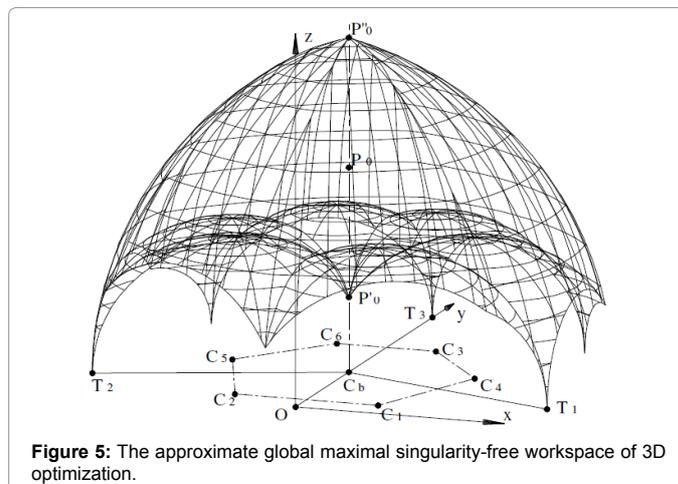
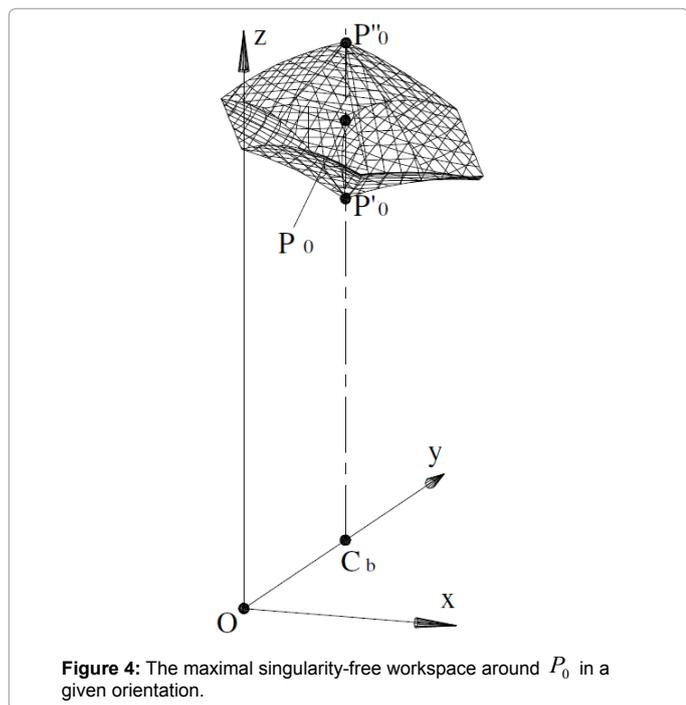
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For the Gough-Stewart platform, Qimi Jiang’s main focus is the studies of the minimal simplified symmetric manipulator (MSSM). Since the Gough-Stewart platform has 6 degrees of freedom (DOF), its workspace falls into two classes: position workspace and orientation workspace.

For the position workspace, Jiang’s research work can be exemplified by four papers [4-7]. Based on the simplified singularity equation [3], a general procedure was developed to determine the maximal singularity-free workspace around a point of interest in a given orientation as well as the corresponding leg length ranges [4]. For such a 6-DOF parallel mechanism, it is almost impossible to find an analytic approach to determine the maximal singularity-free workspace around a prescribed point in a given orientation. Hence, a numerical algorithm was developed to compute the maximal singularity-free workspace as well as the corresponding leg length ranges. The developed algorithm was based on the relationship between the maximal singularity-free workspace and the singularity surface. In order to demonstrate the developed algorithm, several case studies with different orientations were performed. As an example, Figure 4 shows the maximal

singularity-free workspace around a point of interest $P_0 \left(0, \frac{2\sqrt{3}}{3}, 1.25 \right)$ in a given orientation with $\varphi = 30^\circ, \theta = 45^\circ, \psi = 0^\circ$.

In order to maximize the orientation-based maximal singularity-free workspace, the effects of the orientation angles on the singularity-free workspace were investigated, and an algorithm was developed to optimize the three orientation angles [5]. Considering that the platform usually works in a range of orientations, two algorithms were developed to compute the maximal singularity-free total orientation workspace [6]. The maximal singularity-free total orientation workspace can be defined as the maximal singularity-free workspace, which can be reached by the end effector of the platform in any orientation within a set defined by three ranges for the orientation angles. In practice, this type of workspace is also interesting because a parallel robot often works in a given range of orientations.



Besides, an algorithm was developed to optimize the geometric parameters in order to determine the optimal architecture for the MSSM Gough-Stewart platform leading to the maximal singularity-free workspace around a point of interest in the reference orientation [7]. In order to study the effects of the geometric parameters on the singularity-free workspace, the reference orientation was used as the considered orientation as this is an impartial orientation. In this orientation, the singularity surface becomes a plane coinciding with the base plane. Accordingly, an analytic algorithm was developed to determine the singularity-free workspace. The obtained results show that: (1) for similar isosceles triangle base and platform, the optimal architecture is one for which both the base and the platform are equilateral triangles, and the size ratio between the platform and the base is 1:2; and (2) if the base and the platform are not similar triangles, the global optimal architecture is difficult to determine. Only an approximate optimal architecture could be available. Figure 5 shows such an example.

For the orientation workspace, Jiang’s research work can be exemplified by three papers [8-10]. Using the Roll-Pitch-Yaw Euler angles, the orientation workspace at a prescribed position was defined

by 12 workspace surfaces. Based on this fact, a numerical algorithm was developed to evaluate and represent the orientation workspace at a prescribed position for given leg length ranges [8]. Then, a procedure was developed to determine the maximal singularity-free orientation workspace as well as the corresponding leg length ranges [9]. Figure 6 provides an example. In order to compare the maximal singularity-free orientation workspace with the maximal singularity-free sphere, an iterative algorithm was also developed to determine the maximal singularity-free sphere. In practice, the platform could work in a position region. Hence, the effect of the working position on the maximal singularity-free orientation workspace were investigated, and two algorithms were developed to compute the maximal singularity-free orientation workspace over an interesting position region [10].

The results obtained from Jiang's research can be used for geometric design, parameter such as leg length set up, singularity-free trajectory planning, automatic control of the considered parallel robots. Besides, the developed algorithms can also be applied to other types of parallel robots.

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