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Examining the Workspace Performance of a Multi-DOF Parallel Robot Manipulatorss

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ABSTRACT

This paper proposes a parallel robot manipulator with five degrees of freedom (DOF). The 5-SPS-UPU parallel robot manipulator's kinematics, workspace, and dexterity performance were all methodically inferred. The stationary platform, five similar legs, a passive-constrained leg, the moving platform, and a few joints make up the suggested system, which has two rotations and three translations. Initially, the coordinate transformation theory and differentiation method were used to derive the inverse of kinematics and the Jacobian matrix. Second, the software uses the boundary search approach to examine the novel robot's workspace. The robot's posture and position workspace variations are analyzed numerically and reported. Third, an analysis of the suggested manipulator's dexterity performance revealed that its best kinematic dexterity is 1.1. According to the analytical findings, the robot described in this study has a large effective workspace and dexterity, making it suitable for widespread use in the industrial robots area.

Keywords: Parallel manipulator, kinematics analysis, workspace, dexterity.

INTRODUCTION

As everyone knows, the development of greater performance robotic systems is a key component of integrated production technology. High rigidity, high precision, and high loading capacities are some of the possible benefits that the parallel manipulator offers over serial robots. Nonetheless, the parallel manipulator's workspace is somewhat small. Therefore, the engineering application's workspace needs to be investigated. The fundamental parallel robot structure design, driver selection, and control mechanism are kinematic performance evaluation and optimization. General attention has been drawn to the growing usage of parallel robot manipulators in machine tools, simulators, cutting and welding equipment, and CNC machines [1], [2]. Currently, the workspace, dexterity, accuracy, stiffness, and bearing capacity are the primary focus of parallel manipulator optimization design. The dexterous workspace is the most significant kinematics performance index, which is frequently used to assess kinematics accuracy. Many researchers have recently examined five degrees of freedom parallel manipulators. For example, Wang [3] examined the kinematics of a new 4-SPS-CU parallel manipulator, Chen [4] examined the 4-UPS-UPU parallel manipulator's dexterity using mean and variance, and Zhang [5] optimized the 5-UPS-CUU parallel's global stiffness. After analyzing the kinematics performance on the 5-DOF parallel manipulators 4SPS+RPS and 5SPS-UPU, Lu proposed an isotropic mechanism [6]. After carefully examining the workspace of the new three-leg six DOF parallel manipulator (TLPM), Fu [7] drew the workspace and came to the conclusion that the robot has a sizable effective workspace with a smooth border and is suitable for a variety of industrial robot applications. These days, the majority of workspace research focuses on the robot's structural size and constraint requirements for workspace search, which are accomplished by the general inverse solution of the kinematic equation [8].

One of the most crucial functions of parallel kinematic machines is dexterity. Dimensional optimization, on the other hand, is a crucial process of parallel manipulators from their schematic diagram to the structural design, which involves two difficult problems related to the kinematic performance index and the optimal design method. Its goal is to enhance the performance of a mechanical robotic system [9]. Consequently, it is imperative to carry out the dexterity analysis and optimal design of the parallel kinematic machines within the early stages of design. Performance evaluation and optimal design of parallel manipulators have made extensive use of the Jacobian matrix's determinant and condition number [10], [11]. However, Rezania et al. [12] noted that when these indices are used with parallel manipulators that have a mixed number of degrees of freedom for translation and rotation, the unit inconsistent issue occurs. Some attempts were made to assess the motion or force transmissibility utilizing screw theory in addition to the kinematic performance index linked to the Jacobian matrix [13]. While Wu et al. [15] suggested the input or output transmission index and effectively handled kinematic evaluations of a 3-DOF parallel manipulator, Tsai [14] defined the virtual coefficient between the transmission wrench screw and the input velocity screw.

The following describes the construction of a new parallel manipulator that can produce two rotational degrees of freedom and three translational degrees of freedom. Its mathematical and kinematic models are built, and the differential method is used to derive the Jacobian matrix. Based on the inverse solution of the kinematics, the workspace—one of the most crucial indexes of the parallel manipulator—is calculated while taking the link length and angle limitations into account. Finally, using MATLAB software, a workspace with a new orientation was created. To address the issue of non-homogeneous units, we concentrate on the submatrix of the Jacobian matrix and use the dexterity performance index.

II. ANALYSIS OF KINEMATICS

A. Parallel Manipulator Structure

This work's suggested 5-DOF parallel robot manipulator, shown in Fig. 1, is made up of one constraint passive leg (UPU) that connects the base to the moving platform and five variable active legs (SPS) with the same topology [16]. The 5SPS-UPU mechanism, in which S stands for spherical joint, U for Hooke joint, and P for the independently actuated prismatic pair, connects the moving platform to the fixed base. The moving platform's mobility is limited to five degrees of freedom by the center leg.

B. Analysis and Calculation of Freedom

Fig. 1 depicts the 5SPS-UPU parallel manipulator's construction. The Chebychev-Grübler-Kutzbach criterion is used to list the possibilities.A first assessment of a kinematic chain's mobility can be obtained using the Chebychev-Grübler-Kutzbach formula [17].

C. Jacobian analysis and inverse kinematics

Figure 1 depicts the kinematic structure of the suggested 5-DOF parallel robotic manipulator. Assume that the base and platform's S joint centers are situated on circles with radiuses of a r and b r, respectively. The base center O has a fixed coordinated frame O XYZ coupled to it, while the platform has a movable coordinate frame p xyz. The x-axis points to 1 A and 1 B, respectively. The distribution of spherical joints was uniform.

III. ANALYSIS OF THE WORKSPACE

The workspace, which is a very significant metric to gauge the effectiveness of the parallel manipulator, is the collection of all sites where the moving platform's reference point can be reached in the area of the robot manipulator.
Workspace research may be divided into two categories: dexterous workspace, which was absent from the mechanism because the middle branch prevented rotation around the z axis, and position attainable workspace, which is searched with constant orientation. The constant orientation workspace is the one we use in this paper. The workspace of the parallel robot manipulator can be analyzed using a variety of techniques, including geometrical, analytical, numerical, and so forth. In this part, we investigate the 5-SPS-UPU parallel manipulator's workspace using the boundary search method, a numerical approach that simulates Monte Carlo.

It is especially crucial to note that workspace should be taken into account when designing the mechanism that establishes the dimensions of the parallel manipulator working range actuator. Additionally, it serves as the basis for the ensuing optimization. Driven chains, constraint chains, and angle constraints are the primary means of limiting the parallel manipulator's workspace.

A. Condition of Design Constraints

The size and shape of the structure are primarily influenced by two elements, according to its characteristics.
(1) The link length restriction: min i max l ≤ l ₣ l (12) is the expression for the link length constraint, which is imposed by its structure.
(2) Joint angle constraints: ball joints, which are equivalent to U joints, are typically used to attach the links to the stationary platform and to the moving platform. Although a ball joint can freely spin along all axes, the physical structure of the geometry relation actually limits the moving platform's motion.

The MATLAB software, which is comfortable and makes it easy to visualize the results of calculations, is programmed to seek out figures in various poses. As can be seen from the above picture, the constraint constraints limit the workspace's shape to a significant degree, making it ellipsoid. The mechanism's position workspace reaches its maximum when the roll angle $\psi = 0$ and pitch angle ぱ = 0.

IV. The cases and the dexterity analysis

A. Description of dexterity

The relationship between input and output is extremely nonlinear when the parallel manipulator is approaching a singular potion. The kinematic dexterity index is used to characterize the extent of movement distortion. The kinematic local dexterity of a pure translation and rotation parallel manipulator can be described by the invers of the condition number of the Jacobian matrix, and the dexterity is measured by the condition number of the Jacobian matrix, which can be written as follows [18–19]:

The parallel manipulator has the best kinematic transmission performance when the condition number is in the range of 1; when it approaches infinity, it is in the singular position. The parallel manipulator is referred to as kinematic isotropy when the condition number achieves the minimum value of 1.

B. Discussion and Analysis of the Case

Figure 7 shows the distribution of dexterity by position. The distribution of the condition number under perfect workspace is shown in Fig. 7. The contour distribution of the condition number in the reachable workspace is assessed using the computation results, taking into account the actuators' stroke limit and rotational joint angle, as shown in Fig. 7. The best kinematic dexterity is Jc=1.1, as seen in Fig. 7. However, the kinematic dexterity range is (1.1, 2.2).

One can choose the workstation as the best area for a task. The condition number progressively increased as the location increased in the dexterity range, suggesting that the parallel manipulator's dexterity was deteriorating. The parallel manipulator has no single configuration in the ideal workspace and good kinematic dexterity throughout the reachable workspace, as evidenced by the condition number range in the search space, which ranges from 1.2 to 2.2 and is far from the ill condition region.

V. FINAL RESULTS

In order to improve the mechanism's workspace and dexterity, this article creates a 5-DOF parallel manipulator design. The following is a summary of this paper's primary contributions:

(1) A new parallel robot manipulator 5-SPS-UPU that can produce two-degree rotation and three-degree translation was examined. The International Journal of Engineering and Technology, Vol.

11, No. 1, February 2019 Jacobin matrix was simultaneously inferred after the kinematic and mathematical models were also examined.
(2) Using the inverse solution, a general method called the boundary search method is created to find the position workspace of the suggested parallel manipulator.
(3) This work generated the workspace of the parallel robot manipulator 5SPS-UPU, and the best kinematic dexterity is 1.1. This provides a good foundation for the application research design and serves as a good guide for other parallel mechanisms of a similar nature. A prototype will be made for next projects, and a number of pertinent experiments will be carried out.

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