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Non-singular transitions based design methodology for parallel manipulators

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ABSTRACT

In this paper, a design methodology intended for the so-called *cuspidal parallel manipulators* is presented. The methodology is valid for three-degree-of-freedom planar or spatial parallel manipulators. The paper explains step-by-step a process to take advantage of a parallel manipulator that owns the cuspidality property, and thus, it can perform non-singular transitions. The latter ability enables the robot to move among different solutions of the direct kinematic problem, resulting in a wider workspace in comparison to a design that does not have this transitioning capacity. Therefore, it makes sense to incorporate the cuspidality property as one design criteria which is exactly the main purpose of the present research. The proposed design methodology exploits the cuspidality property to find a set of optimum designs that widen the workspace of the manipulator and, in addition to this, maintain a regular shape of the singularity locus existing in the workspace. Moreover, the design procedure includes the evaluation of the condition number of the Jacobian matrix, providing the set of designs that yield a well conditioned matrix.

1. Introduction

The designing process of parallel manipulators aims to find the optimum design parameters such that certain important requirements are fulfilled. From the kinematics point of view, dimensional optimization processes are mainly focused on: workspace (Merlet [1], Ottaviano and Ceccarelli [2], Bonev and Rhyu [3], Li and Xu [4], Jiang and Gosselin [5]), kinematic performance indices (Gosselin and Angeles [6], Rao et al. [7]), task development (Monsarrat and Gosselin [8], Riedel et al. [9]), accuracy (Hao and Merlet [10]), interference among links (Tao and An [11]), etc.

In this paper, a design methodology based on the ability of some parallel manipulators to perform non-singular transitions is presented. Different ways of creating non-singular trajectories have been presented in the literature (Macho et al. [12], Bamberger et al. [13], Hernández et al. [14], Husty [15], Urízar et al. [16], Husty et al. [17]). Our interest is focused on exploiting the cuspidality property, which allows one to widen the range of motion of cuspidal manipulators. The present paper is the final result of the research that during the last years the authors have carried out in the field of cuspidal manipulators. In particular, the concepts presented in the paper derived mainly from the research included in the Ph.D. thesis [18].

The main objective is to explain the guidelines of a new design methodology, valid for planar or spatial three-degree-of-freedom parallel manipulators, which takes advantage of the cuspidality property and incorporates this ability into the design criteria. To illustrate the procedure, we will make use of the 3-S$\underline{P}$S–S spatial orientation manipulator. Spatial orientation manipulators have a broad range of applications, such as: orienting a tool or a workpiece (Mahpeykar et al. [19]), camera devices (Gosselin and Hamel [20], Wu et al. [21]), solar panels and space antennas (Robertson [22]), haptic devices (Birglen et al. [23]), robotic wrists (Callegari et al. [24]),

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etc. A broad study of the capacity of the 3-SPS–S orientation platform to perform non-singular transitions has been recently published in Urízar et al. [25]. For the sake of completeness, important results of the aforementioned work will be summarized in this paper, providing a better understanding of some concepts of the methodology.

The paper is organized as follows. Section 2 introduces the guidelines of the design methodology and facilitates the comprehension of some concepts with the planar 3-RPR manipulator as an illustrative example. In the third section, the design process is applied to the 3-SPS–S spatial orientation manipulator. In the latter section some results derived from paper [25] are reported, and then, in Section 4, the dimensional synthesis of this manipulator is carried out. The dimensional synthesis will be approached using the *design parameter space* presented by Merlet [26], in which the set of most favorable designs according to different features is obtained. In particular, the characteristics of the workspace, such as size and shape, and the evaluation of the conditioning of the Jacobian matrix are considered as design criteria.

2. Guidelines of the design methodology

The purpose of this section is to explain the guidelines of the proposed design methodology in which the transitioning ability of parallel manipulators plays an essential role. The latter refers to the capacity of some parallel manipulators to move among different solutions of the Direct Kinematic Problem (DKP) without crossing any singularity. The present research focuses on the transitioning ability due to the existence of cusp points in singularity curves inside joint space sections.

The design methodology will incorporate the transitioning ability into the design stage, the final target being to obtain the set of designs that optimize different features. In particular, two main objectives are achieving a wide and regular workspace. Moreover, the proposed procedure includes another important design criterion in kinematics such as the conditioning of the Jacobian matrix.

The flow chart displayed in Fig. 1 highlights the main steps of the proposed design methodology. The guidelines are explained subsequently:

2.1. Kinematic problems

The first step is to solve the kinematics of the robot. This includes solving the position problem, obtaining the characteristic polynomial and assessing the number of DKP solutions. Differentiating with respect to time the constraint equations the Jacobian matrices are computed, which enables obtaining the DKP and IKP singularity loci.

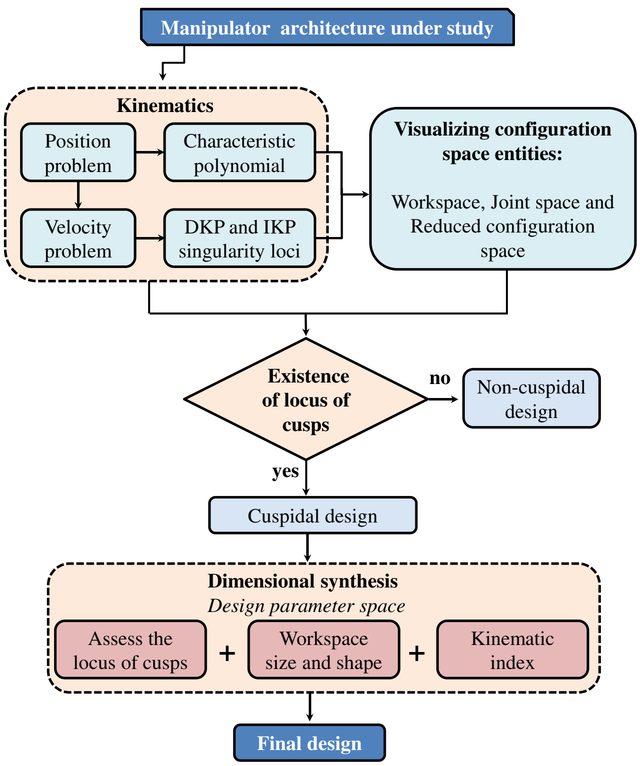

Fig. 1. Flow chart of the proposed design methodology.