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Non-singular transitions between assembly modes of 2-DOF planar parallel manipulators with a passive leg

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ABSTRACT

In the field of parallel manipulators, the possibility of changing assembly mode without passing through a singular configuration is well known. This kind of transitions was studied in detail for planar 3-DOF manipulators. This paper focuses on 2-DOF parallel manipulators actuated by two RRR legs and constrained to a 2-DOF motion by a passive leg. It first shows that when the platform movement is constrained to rotations and translations along a single direction, nonsingular assembly mode transitions are possible. The direct and inverse kinematic problems of the mechanism are solved. The singularity conditions are written in explicit form and geometrically interpreted. Numerical examples of nonsingular assembly mode transitions are then given. Subsequently, the paper proves that if the platform is instead constrained to translational motions, nonsingular assembly mode transitions become impossible. Remarks on the generalization of the results to a wider class of 2-DOF planar manipulators are finally given.

1. Introduction

In the last decades, parallel robots received growing attention. The high power and accuracy that can be achieved with this kind of structures was exploited in many contexts, ranging from their early application to flight simulators [1] and tire testing [2] to their more recent use in haptic devices [3] or palletizing [4,5].

Parallel manipulators are particularly interesting from a theoretical point of view as well [6–8]. For many aspects, parallel manipulators turn out to be dual to serial manipulators [9,10], and this can often be explained by the duality between twist and wrench [11]. One particularly interesting concept, observed both in serial and parallel robots, is the possibility of executing nonsingular transitions. It was shown that for some robots, it is possible to pass from one inverse solution to the other *without* passing through a singular configuration [12,13]. This kind of transitions is possible in the presence of a triple solution, which, when projected over the workspace, appears as a cusp point. For this reason, these robots are commonly called cuspidal [14].

A dual phenomenon can be observed for parallel robots. Transitions between different assembly modes can occur without passing through direct kinematic singularities [15,16]. Also in this case, trajectories that circle cusps in the joint space may correspond to movements that lead to nonsingular transitions between different assembly modes [17]. We note that encircling a cusp point is not the only possible way of obtaining a nonsingular transition between different assembly modes. Indeed, it was shown that it may suffice to encircle an α-curve in the joint space [18]. Nonsingular transitions have both theoretical and practical importance. On the one hand, there may be a strong desire to avoid these nonsingular transitions for being sure that given an actuator configuration the joint configuration is unique, i.e. for remaining in the same uniqueness domain [19]. On the other hand, it may be possible to exploit nonsingular assembly mode transitions to enlarge the workspace [20].

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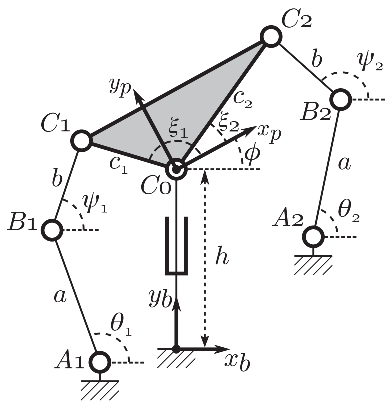

Fig. 1. The 2-$\underline{R}RR$-PR manipulator studied.

Nonsingular assembly mode transitions were often studied in the case of planar manipulators. These manipulators received particular attention [21–26] because, besides the inherent interesting potential application in planar motion systems [27], they can provide insights on the more complex case of spatial manipulators [17].

The presence of nonsingular assembly mode transitions was deeply studied for 3–$R\underline{P}R$ manipulators [17,28–31]. Special attention was given to the cases of equilateral platform [18], similar base and platform [32], and congruent base and platform [33,34]. The study of the nonsingular transitions was often conducted by keeping one of the joints fixed [29,27]. Recently, a complete characterization of the cusp points in the 3-D joint space was provided as well [35]. Another commonly studied manipulator is the 3-RRR one [36], especially the one with equilateral base and platform [37]. Also in this case, nonsingular assembly mode transitions were confirmed [38]. Further works dealt with the 3-$\underline{P}RR$ manipulator, studied in [18,39], the $R\underline{P}R$-2-PRR, examined in [40], and other configurations employing only rotational joints [41].

Much less literature can be found for 2-DOF mechanisms. Most literature focuses on the $RRRRR$ configuration [21,42–46]. Prismatic joints may be used for the joint proximal to the base or for the central joints, obtaining a $PRRRP$ manipulator [47] or a $RPRPR$ configuration [24], respectively. More recently, parallelogram based structures found application as well [48,49]. To the best of our knowledge, nonsingular assembly mode transitions were never shown for 2-DOF manipulators, excluding the case of 3-DOF manipulators with one joint fixed, for which the platform usually undergoes compound translations and rotations.

This paper investigates the possibility of executing nonsingular assembly mode transitions in simpler cases. First, it shows the possibility of executing such maneuvers for a 2-DOF manipulator whose platform is actuated by $\underline{R}RR$ legs and constrained to rotations and translations along a single direction by a passive leg. The structure is described in Section 2. The solution to the inverse and direct kinematics problems is given in Sections 3 and 4, respectively. Singularities are then analyzed in Section 5. Their geometrical interpretations are given, and the singularity loci is obtained. A nonsingular assembly mode transition, obtained by encircling one of the cusps present in the loci, is then presented in Section 6. Successively, a modified version of the manipulator, that allows only translational movements, is introduced in Section 7. The impossibility of executing nonsingular assembly mode transitions with this manipulator is proved. Section 8 then introduces a purely translational mechanism that exhibit nonsingular assembly mode transitions. Section 9 summarizes the results and discusses possible extensions of the work presented in this paper.

2. Kinematic structure

In the field of 2-DOF planar parallel manipulators, focus is usually given to manipulators in which both the degrees of freedom are purely translational. Conversely, this paper first introduces a manipulator capable of platform reorientation and displacement along a single direction. This kind of structure may be considered as the planar version of lower mobility spatial parallel manipulators that employ passive legs between the base and the platform [50,51].

The link configuration is presented in Fig. 1. The two links of length $a \gneqq 0$ are input links and the joints A_1 and A_2 are the only actuated joints. These links are connected to the platform through the links B_iC_i of length $b \gneqq 0$. Without loss of generality, the prismatic joint axis of the passive leg is taken as the vertical axis of the base reference frame. The location of the actuated joints A_1 and A_2 is denoted in this reference frame by $(o_{x,1}, o_{y,1})$ and $(o_{x,2}, o_{y,2})$, respectively. The input variables, i.e. the angles formed by the links A_iB_i with the horizontal axis, are denoted by θ_i, $i \in \{1, 2\}$. The angles[2] formed between the horizontal and the B_iC_i links are denoted by ψ_i, $i \in \{1, 2\}$.

The reference frame for the platform is an arbitrary frame with the origin located at C_0, the rotational joint that connects the passive leg to the platform. The position, in the platform reference frame, of the rotational joints C_1 and C_2 is denoted for

[2] In the following, figures included, all angles are assumed to be expressed in radians.