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New 6-screw linkage with circular translation and its variants

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ABSTRACT

The circular translation generated by a pseudo-planar parallelogram with four screw pairs having equal pitches and parallel axes is introduced and a special Delassus parallelogram producing the same motion is obtained through the addition of a second pseudo-planar parallelogram with another value of its equal pitches. A mechanical generator of spherical translation stemming from the circular translation generator is revealed. Combining a spherical translation generator and a pseudo-planar or special Delassus parallelogram leads to a new family of 6-screw (6H) paradoxical linkages with circular translation in a purely geometric way. Their architectural type belongs to the structural group with two alternate pairs of joint-axes parallel and one pair of opposite joint-axes parallel. Moreover, the one-degree-of-freedom (1-DoF) movability is conditioned by metric constraints. The already published 6R linkages having circular translation are special types of 6H with all screw-pitches zero. The parallel arrangement of three special 6R linkages produces a 3-UU parallel platform with circular translation (U denotes a universal joint with intersecting joint axes of revolute pairs). A more overconstrained *m*-UU case ($m \geq 4$) with special joint-axes arrangements is disclosed too.

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1. Introduction

Several movable 6-revolute linkages [1–10] were already proposed but the number of movable 6-screw (6H) linkages disclosed in the literature is still limited. Few combinations of the related six-bar linkages were provided in [11,12], but only the HHHH–HH and HHH–HHH combinations can be regarded as 6-screw linkages. However, the HH–*H*–HH–*H* combination having a potential finite mobility was ignored there. As for the employed notation, screw pairs having parallel axes are indicated by single underline, double underline and italic font. Although there was no new 6H paradoxical linkage found there and the geometric descriptions of chains were missing in [9], the H//H–H–H//H–H chain with two alternate pairs of joint-axes parallel among them is related to our article. Considering the helical Cardan motion, a special 6H linkage with rectilinear translation, which is a generalization of Sarrus' mechanism, was recently introduced in [13].

Up to now, finding new paradoxical 6H linkages whose mobility is conditioned by Euclidean metric constraints has still been a fascinating topic. Undoubtedly, a systematic synthesis of movable 6H linkages by geometric reasoning needs to be accomplished. Hereinafter, the pseudo-planar or special Delassus 4H parallelogram [14,15] is used to generate the 1-DoF circular translation between two opposite bars. This phenomenon is similar to the special case of planar-hinged parallelogram [16,17]. The main aim of our article is to synthesize a new category of 6H paradoxical linkages having special properties in a systematic geometric approach. In other words, the new geometric derivation through the pseudo-planar or special Delassus parallelogram method will result in a type of new 6H linkages with circular translation. This novel type can be categorized into the architectural group with two alternate pairs

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of joint-axes parallel and one pair of opposite joint axes parallel. Further, a category of the already published 6R linkages are introduced as special types of architectures originating from our proposals. Clearly, several 6R linkages can readily be retrieved from the new proposed 6H linkage by setting the pitches of all screws to be zero or by assigning proper parameters of architecture. Most of them cannot lucidly be explained only by the Lie-group algebraic properties of the displacement set. In spite of no detailed geometric information on an extended generalization of the bi-spherical 6R linkage in [8], one derived 6R of such a special type can be regarded as an R–X–X–R-chain [26]. In [10,19], three types of parallel 6R linkages are proposed by using the dual quaternion method. One is the parallel 6R linkage with translational property and the other two are the parallel 6R linkages with angle-symmetric property. However, till now, the dual quaternion method does not provide the full geometric description of all these 6R linkages. Instead, a purely geometric approach focuses on the concept of circular or spherical translation generators to establish a new derivation of special 6R linkages is described in [22], which is just a special case of our proposed 6H here. It is easy to identify that a category of the 6R linkages proposed by Gfrerrer and Li & Schicho [10,18,19] corresponds to special types of 6H linkage with zero pitches. Moreover, it is worthwhile to mention that Six and Kecskeméthy in [23] originally proposed this kind of 6R overconstrained linkage for the steering application in a combined wheeled and legged striding excavator. Later, it was also used in "Robotrac", which is the name of the vehicle studied in [24]. In a very recent paper [25], a special double-spherical 6R linkage, from which a 6R linkage for circular translation can be derived, is succinctly presented. However, the geometric conditions stated in [25] are not sufficient for obtaining a finite motion of circular translation between two bodies.

The paper is organized as follows. Section 2 presents the circular translation and its generation by pseudo-planar parallelograms and special Delassus parallelograms. Section 3 introduces a mechanical generator of spherical translation, which is derived by combining circular translation generators. In Section 4, a spherical translation generator and an articulated parallelogram are disposed in parallel to synthesize the new 6H linkage with circular translation and its variants. Our approach by pure geometry allows the verification of published cases of special 6R linkages. Section 5 presents a new parallel platform with circular translation via three special types of 6R linkages.

2. Articulated parallelograms generating circular translation

Translation is a motion type which does not change the orientation of the moving rigid body. This type of motion arises if every line segment on the moving body remains parallel to its original direction during the movement. In a 1-DoF translation, every point moves on a curve, and in a 2-DoF translation, on a surface. The 1-DoF rectilinear translation occurs when the trajectory of each point is a straight line and the rectilinear trajectories of two points are parallel. A special 1-DoF curvilinear translation is circular translation; each point of the translating body moves on a circle and all the circular trajectories are congruent. The set of all the pseudo-planar motions parallel to a given plane and having a given pitch has the algebraic properties of a 3-dimensional Lie group for the composition (or product) of rigid-body displacements. Consequently, any four-bar linkage including four helical H pairs with parallel axes and equal pitches is movable with one DoF. If opposite bars have equal lengths, then the quadrilateral of the bars can form a parallelogram. Then any one bar keeps parallel to its opposite bar and its motion with respect to its opposite bar is translational; the trajectories are congruent arcs of circles. Hence, the pseudo-planar parallelogram (*Para*) can be used to generate mechanically 1-DoF circular translation [15]. As shown in Fig. 1, a pseudo-planar parallelogram A_oABB_o has four bars jointed by four screw H pairs and the opposite bars have equal lengths, $A_oA = B_oB$ and $A_oB_o = AB$. The trajectory of point A is congruent with that of point B through the translation of vector (**AB**), which transforms point A into point B.

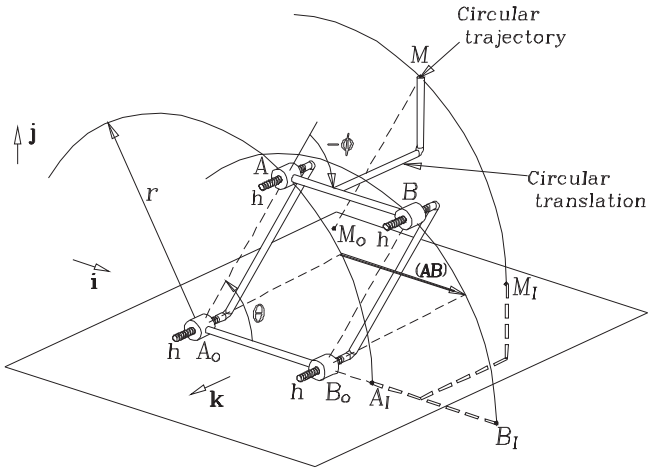

Fig. 1. Circular translation and the pseudo-planar 4H parallelogram.

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