Mechanism and Machine Theory 116 (2017) 234–247

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

Multioperation capacity of parallel manipulators basing on generic kinematic chain approach

J.I. Ibarreche [a], A. Hernández [b], V. Petuya [b], M. Urízar [b,*], E. Macho [b]

[a] Aernnova Engineering, Technological Park of Alava, 01510 Miñano (Alava), Spain
[b] Faculty of Engineering in Bilbao, Department of Mechanical Enginerring, University of the Basque Country (UPV/EHU), Bilbao, Bizkaia 48013, Spain

ARTICLE INFO

Article history:
Received 7 February 2017
Revised 10 May 2017
Accepted 30 May 2017
Available online 7 June 2017

Keywords:
Multioperation
Parallel manipulator
Generic kinematic chain
Reconfigurable

ABSTRACT

The idea of designing multioperation mechanisms capable of performing different tasks has gained prominence in the last years. These mechanisms, commonly called reconfigurable mechanisms, have the ability to change their configuration. At present, this type of mechanisms is capturing the attention of design engineers because of their great potential in many industrial applications. In this paper, the basis for the development of a methodology intended for the analysis and design of multioperational parallel manipulators is presented. First, the structural synthesis of 6 degree-of-freedom (dof) kinematic chains that can form a 6 dof manipulator is established. Next, a general purpose approach for non-redundant parallel manipulators (PM) will be presented. This procedure enables obtaining the Jacobian matrices of any 6 dof or low-mobility PM whose kinematic chains belong to the library of chains derived from the structural synthesis. To demonstrate the versatility of the procedure, it will be applied to three PM: the first one, a 6 dof PM, the second one, a reconfigurable 6 dof PM, and finally, a low-mobility PM.

1. Introduction

Traditionally, in mechanism and machine design, one of the main targets was to create a robust and reliable mechanical system intended for efficiently carrying out a certain particular task. Later on, the need of more adaptableness of the system was materialized into adjustable mechanisms, in which a greater flexibility was demanded. This requirement of higher compliance capacity was achieved by adjusting one or more dimensions using fixing or liberating elements such as screws and extensible bars. In the last 20 years, this initial idea has progressed into a new design concept based on mechanisms capable of performing different operation modes so that they can execute different tasks [1]. These mechanisms with the ability to change their configuration are typically called reconfigurable mechanisms [2–5]. Nowadays, the study of these mechanisms is becoming a relevant field of investigation in specific forums such as [6,7] because they are demonstrating their potential in a great variety of industrial applications such as packing and folding, structures and deployable antennas, biomedical applications, and so on [8].

At the present time, there exist various studies related to parallel manipulators (PMs) with six degree-of-freedom (dof) kinematic chains in which it is possible to obtain low-mobility PMs by constraining some of the inputs of the

* Corresponding author.
E-mail addresses: joseignacio.ibarreche@aernnova.com (J.I. Ibarreche), a.hernandez@ehu.eus (A. Hernández), victor.petuya@ehu.eus (V. Petuya), monica.urizar@ehu.eus (M. Urízar), erik.macho@ehu.eus (E. Macho).

http://dx.doi.org/10.1016/j.mechmachtheory.2017.05.023
0094-114X/

manipulator. Subsequently, the investigations that share a common research line with the present paper will be cited. Jin et al. [9,10] propose several 6 dof PMs with three kinematic chains in which by means of a selective actuation different motions are achieved: spherical (3R), translational (3T), mixed motions (2T1R and 1T2R) or the complete motion of 6 dof. For that, a 2 dof actuator, having one rotation and a translation in the same axis, is installed in each kinematic chain. The same authors present a methodology in [11] for the synthesis of PMs with three kinematic chains having partially decoupled 6 dof.

Fanghella et al. [12] describe a methodology to synthetize PMs by using kinematotropic chains that allow changing the number of dof, their nature or both effects at the same time. Even maintaining the motion pattern of the platform, their geometric characteristics can change. As an example, they show a PM with a Schönflies motion in the end-effector which can change the direction of the rotation axis between two established orientations. Kong et al. [13] propose an approach for the synthesis of PMs with multiple operation modes. In particular, they develop several 3 dof PMs that can perform both spherical motion and spatial translational motion.

Finistauri et al. define a procedure in [14,15] to generate reconfigurable PMs. The proposed PMs consist of two modules, each of them having three 6 dof kinematic chains, both connected to the fixed and moving platform. Whereas the first module has its three chains permanently linked to the moving platform, the kinematic chains of the second module can be disconnected from the moving platform. While some dof of the first module are being restricted (by blocking one rotation or one translation of the kinematic chains), the chains belonging to the second module are being accordingly disconnected.

Certainly, using a 6 dof manipulator it is possible, theoretically, to perform any type of spatial motion. Nevertheless, for that, the required motion has to be programmed according to the kinematic structure of the chains of the manipulator, and not all the kinematic chains adapt with the same facility to the tracing of a defined motion. For example, a simple translational motion can be easily achieved with a manipulator formed by a certain cartesian structure in its kinematic chains. In fact, a motion as simple and so typical as this one, using partially cartesian kinematic machines, very common in machine-tool applications, is achieved by blocking the unnecessary actuators. However, if we try to get this same motion with a manipulator in which its chains yield a more coupled kinematics, as for example the Gough platform, it will not be that simple. To get that purpose the controlling of all of the degrees of freedom is required, resulting in a much more complex task. As a consequence, to get a similar precision, the number of interpolation points in the trajectory has to be increased. On the other hand, some other aspects that have a greater impact in this case have to be considered, such as calibration, workspace singularities or the interferences among the legs of the manipulator. All of this results in the necessity of studying the functional operation of specific designs of the manipulator.

To do so, the concept of displacements of group structure type will be considered. The set of displacements of a solid in space can be arranged in 12 algebraic entities having group structure [16,17]. Each of these groups has a specific pure motion pattern. A manipulator in which its moving platform owns a motion pattern of group structure type, has the great advantage that this pattern remains invariable for any posture of the workspace. Under these circumstances, the approach of any type of path planning is more simple. Therefore, the hypothesis of this work is that the greater the quantity of group structure type displacements the moving platform can achieved, the higher the practical effectiveness of the corresponding PM will be. The way of obtaining the set of displacement groups of the platform consists in fixing conveniently the different actuators of the mechanism. Then, the kinematics of the resulting PM is simplified thanks to two causes: the blocking of some dof and the capability to generate permanent motion patterns along the workspace. Consequently, the control of the machine will be faster and more efficient.

To get the set of all possible 12 motion patterns a manipulator with at least 6 dof is required. Hence, in the next section the structural synthesis of 6 dof kinematic chains that can form the manipulator is established. Next, a general purpose approach for non-redundant PM will be developed, subjected to some geometric conditions that will be later on explained, but that they do not imply any limitation to the multioperation capacity (variety of motions) of the platform. This procedure enables obtaining the Jacobian matrices of any 6 dof or low-mobility PM whose kinematic chains belong to the library of chains derived from the previously cited structural synthesis.

2. Structural synthesis of 6 dof kinematic chains

Prior to initiating the structural synthesis, the characteristics of the PM will be defined. The legs of the PM will be non-redundant kinematic chains. Thus, the maximum number of first class kinematic pairs in each chain will be six, knowing that by conveniently orienting them the required 6 dof can be achieved. Similarly, the maximum number of translational joints in each chain will be three, so that positioning them along the three directions in space the 3 translational dof can be obtained.

Initially, only first class kinematic pairs will be considered: prismatic joints (P) and revolute joints (R). Any pair of higher class, such as cylindrical joint (C), universal joint (U) or spherical joint (S) can be obtained by combining P and R pairs.

Afterwards, a methodology for kinematic analysis will be developed, thus some geometrical constraints will be now established. These constraints have the only purpose of simplifying the obtained designs and also restricting the many possible cases that can arise, knowing that this does not imply a loss of generality at the time of obtaining a certain motion pattern:

1. The directions of two consecutive joints of the chain form 0° or 90°. The same occurs with the directions of the pairs that connect the chains with the moving platform.