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A new class of reconfigurable parallel kinematic machines

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ABSTRACT

The article presents a class of reconfigurable modular parallel robots stemming from the 3-CPS under-actuated topology. Proposed here is a conceptual design where the spherical joint which connects each leg to the end-effector is realized as a combination of revolute pairs; a locking system allows one to alternatively fix one of the revolute joints, giving the machine different 3-CPU kinematic configurations which correspond to different types of mobility. The first part of the paper demonstrates that the robot is able to perform different types of motion, specifically of pure translation and pure rotation; in the last part a sample design of the reconfigurable robot is proposed.

1. Introduction

The issue of re-configurability is being widely investigated by scientific community for its high potential benefits and good application perspectives. Significant scientific results have been recently attained, as the studies of Murata and Kurokawa [1] on self-reconfigurable robots capable of autonomously changing their configuration or even working together to accomplish their assigned task [2], or the researches of Fujita et al. [3] and Quaglia et al. [4] on reconfigurable robotic platforms for mobile robots. Many examples of applications of metamorphic linkages to parallel kinematics machines can be found in the recent literature [5–7] for both fields of robotics [8–11] and machine tools [12–14]: the result is typically a manipulator whose end-effector has the ability to perform different kinds of motion.

According to the interesting research developed at the King's College of London on metamorphic parallel mechanisms [15–17], a change of a machine's mobility can be obtained by means of reconfiguration of joints, as proposed in the present article. However their results turn out to be quite different from what is hereby shown due to the reconfiguration of robots with different kinematic architecture and moreover it takes place through a different modification of the universal joint which is continuous in [15] and discrete here.

It is remarked that the authors did not find any identical realisation of reconfigurability through the use of lockable joints in scientific literature: Aghili and Parsa [18] propose to lock the passive cylindrical joints of two open-loop kinematic chains, when they come to form a closed-loop chain, in order to change on-line linkage parameters and be able to control the robot; Grosch et al. [19], on the other hand, propose to actuate or release the passive revolute joints of a RRPS platform in order to approximate 6-DOF motions by using 4 or 5 DOF machine; Gu and Ceccarelli [20] simulated a system where two or more clutches are activated or de-activated according to a programmed manipulation path-planning, realizing a 1 DOF robotic arm. Industrial exploitation of research results is still being hindered by the related system's complexity and (usually) lower mechanical performance;

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nevertheless such concepts have found already application in space systems [21], where the absence of gravity allows for the use of identical modules for the whole mechanical structure of the robot.

An interesting line of research has been developed on the design of reconfigurable modular robots, where the design is explicitly driven by means of proper support tools by the task to be executed by the robot [22–25]; this kind of "specialization" of machine structure, which is selected to be compliant with the task, is similar to what is proposed in the present paper, which aims at the robustness of the system and at the possible industrial applications, such as assembly tasks.

The researchers at the Robotics Lab at the Polytechnic University of Marche, in Ancona, envisaged the architecture of a mechatronic system where two parallel robots cooperate in order to perform a complex assembly task, see Fig. 1: the kinematics of both machines is based upon the same 3-CPU topology but the joints are differently assembled so as to obtain a translating parallel machine (TPM) with one mechanism and a spherical parallel machine (SPM) with the other.

Here the idea of cooperation derives from the concept of hybrid machines, first introduced by Tsai and Joshi in [26], that proposed to decompose full-mobility operations into elemental sub-tasks, to be performed by separate minor mobility machines, as is done already in conventional machining operations.

This solution, at the cost of a more sophisticated controller, would lead to the design of simpler machines that could be used also stand-alone for 3-DOF tasks and would increase the modularity and reconfigurability of the robotized industrial process. It is remarked that this solution allows one to take advantage of the well-known benefits of parallel kinematics machines (as the lightweight construction and the high stiffness), but at the same time it overcomes many typical drawbacks, such as the limited workspace, the complex kinematics, especially for 6-DOF machines, and the presence of many singularities.

The two parallel robots have been developed till the prototypal stage: Fig. 2a shows the translating manipulator, called I.Ca.Ro. [27,28]. The kinematics of the orienting manipulator, which has been called Sphe.I.Ro. [29], is shown in Fig. 2b.

By looking at the two machines, it is seen that both are composed of three identical legs with the same joint sequence: cylindrical (C), prismatic (P) and then universal (U) pairs, usually called 3-CPU topology. In the case of I.Ca.Ro. the universal joint of each limb is arranged so that the axis of the inner revolute joint is parallel to the cylindrical joint at the robot base, thus granting a pure translation of the platform: such three directions are chosen mutually orthogonal to maximize the workspace and grant optimal manipulability. In Sphe.I.Ro., on the other hand, the axes of the cylindrical joints and those of the outer revolute pairs in the universal joints all intersect at a common point, which is the centre of the spherical motion of the mobile platform.

By taking into consideration that both machines share the same 3-CPU topology, a more recent research looked for the possibility to get at a common structure that would be able to yield both kinds of motion, of course when working in different operative conditions, i.e. [30] studied a kinematotropic 3-CPU machine which is characterized by very interesting features but is also affected by many practical problems. Nevertheless, such a robot gave the thr origin to a new reconfigurable kinematic concept, which is described in the following Section.

2. Kinematic concept

The main objective of the research was to investigate the possibility to realize a reconfigurable multi-purpose parallel manipulator starting from the 3-CPS under-actuated topology. The authors propose a conceptual design where the spherical joint which connects each leg to the end-effector is realized as a combination of three intersecting revolute pairs; a locking system

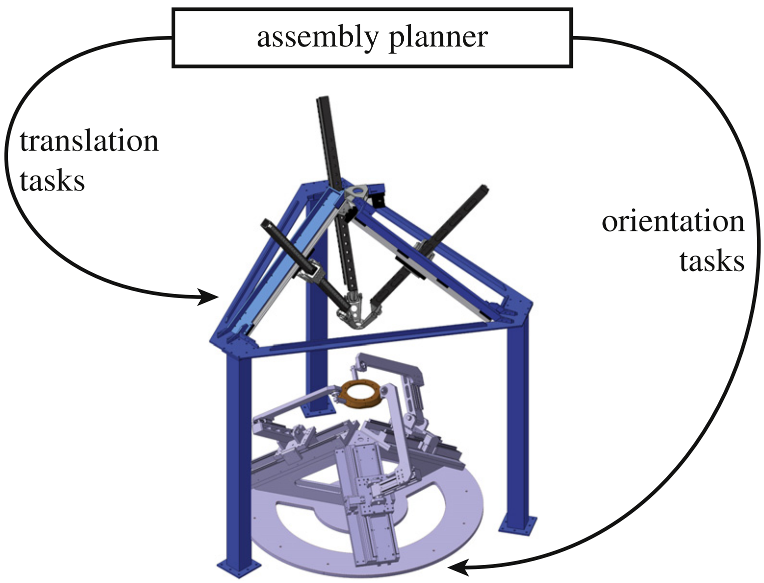

Fig. 1. System architecture of an assembly cell based on two cooperating 3-DOF parallel robots.