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# Comparative study of cable parallel manipulators with and without hybrid-driven planar five-bar mechanism

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ABSTRACT

Cable parallel manipulators (CPMs) relay on cables instead of rigid links to support and manipulate the end-effector. The CPMs are required not only for operations with lower inertia and high payload, but also for output with greater flexibility. The paper is devoted to present and analyze a cable parallel manipulator with and without hybrid-driven planar five-bar mechanism (HDPM). The cable parallel manipulator with the HDPM combines positive features of both the cable parallel manipulator and the HDPM. Comparative study of kinematics and dynamics of the CPMs with and without HDPM are studied. Drive torques and drive powers are given to compare the load carrying capacity of the two manipulators, and workspace, stiffness performance, singularity analysis are also carried out. Simulation examples are presented to demonstrate the CPMs with and without HDPM and their mechanics performance.

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## 1. Introduction

For the past several decades, parallel manipulators have been extensively studied [1,2]. Cable parallel manipulators (CPMs) are a special class of parallel manipulators in which cables replace rigid links in the manipulator structure. Research in the topic of the CPMs is highly motivated and has a very strong interest as the modern engineering demand for such manipulators is growing rapidly. The CPMs have potential advantages in terms of low inertia, high payload to weight ratio, high acceleration capability, ease of assembly/disassembly, transportability, economical structure and maintenance, full remote actuation [3,4]. Given their attractive properties, the CPMs have widely used in many engineering fields, such as large spherical radio telescopes, high speed robot, large-scale manipulation, haptic device, and material and cargo handling [5–7].

Cables can only generate unilateral pulling force, as a result, the full control of completely restrained CPMs with n Degrees of Freedom (DOF) needs at least $n + 1$ cables, but Incompletely restrained CPMs with cable numbers no more than the number of DOF, additional loads or wrenches are required to determine the pose of the end-effector together with the driving cables [8,9]. The CPMs have been receiving more and more attention from researchers over recent years. Jiang and Kumar [10] address the kinematics of cooperative transport of payloads suspended by multiple aerial robots with cables. A geometrical and systematic approach is used as a convenient tool for cable tension analysis [11]. The kinematically undetermined

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manipulator control system with three cables, described in Ref. [12]. Different aspects like analytical method, workspace [13–16], control [17], and large-scale manipulation design [18] were also studied.

Recently, because of potential engineering applications, the CPMs have attracted a lot of attention. The challenges faced in the modern engineering application area of the CPMs are similar to those encountered in Stewart parallel manipulators. Indeed, the CPMs can be required not only for operations with greater flexibility, but also for high payload [19]. Planar two degrees of freedom (DOF) five-bar mechanisms have been widely studied since it is simple and the actuators can be fixed at the base, which reduces the inertia of the mobile body [20–22]. The hybrid-driven planar 2-DOF five-bar mechanism (HDPM) is a kind of machine whose drive system consists of a constant velocity motor and a servomotor [23,24]. The HDPM can take the advantages of the complementary characteristics of both motors to generate a programmable range of highly nonlinear output motions with high power capacities at low costs [25,26]. These features combine to make the drive system a good alternative to existing manipulators, in particular in modern industrial applications in which output with greater flexibility of the end-effector are required while keeping high accuracy and high payload throughout the entire workspace.

On the basis of theories of mechanism structure synthesis, authors have performed the design of a hybrid driven cable parallel manipulator which combines four groups of HDPMs with a 4-cable parallel manipulator, and dynamic modeling is also established by using Newton Euler method [27]. Moreover, authors have also addressed singularity analysis, iterative learning tracking control, error modeling and sensitivity analysis of a hybrid-driven based three-cable parallel manipulator [28–30]. Aiming at the completely restrained 3-DOF CPM with four groups of HDPMs, the major contribution of this paper is to perform the kinematics and dynamics based on the Lagrangian formulation. It is utmost important to compare the main mechanics performance of the HDPM based CPM (HDCPM) and the CPM with conventional servomotor.

In what follows, design model and kinematics of the CPM and HDCPM are introduced in Section 2. In Section 3, dynamic modeling of the CPM and HDCPM is conducted based on Lagrange method. Workspace analysis of the CPM and HDCPM is provided in Section 4. Sections 5 and 6 are devoted to stiffness performance and singularity of the CPM and HDCPM. In Section 7, results and discussion are presented by means of a simulation. Section 8 gives the conclusions.

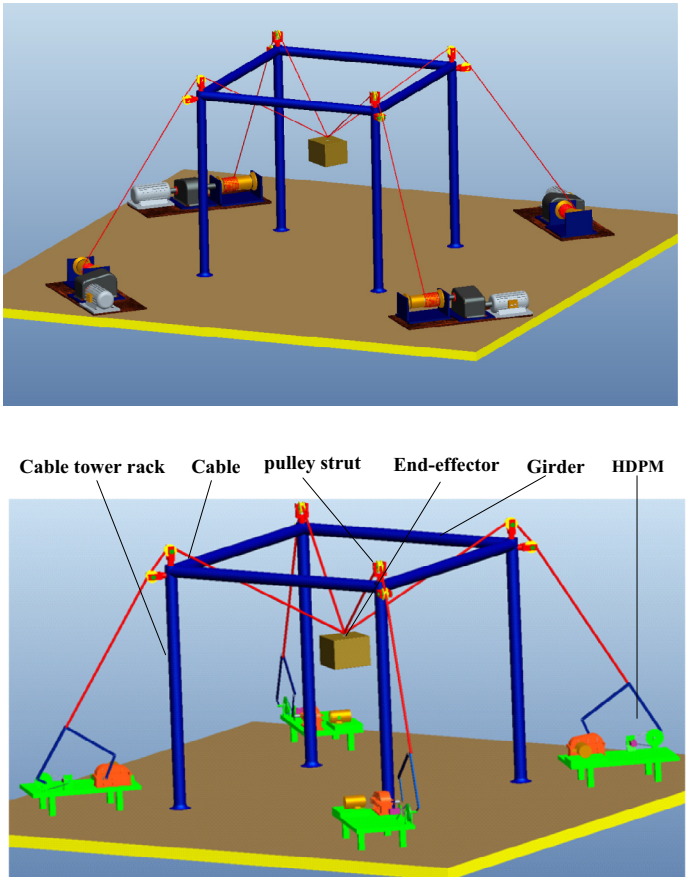


**Fig. 1.** 3D model of the CPM and HDCPM.

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