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MODERN DESIGN OF MODULAR ROBOTS

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ABSTRACT:
A modular reconfigurable robot system has the advantage to provide an optimal robot configuration for a specific task. With fewer modules and degrees of freedom (DOFs), a modular robot would have a simple configuration, high loading capacity, and low power consumption rate, so that it can perform the task effectively. A weighted sum of the number and types of modules is chosen as the objective function. Two three-legged reconfigurable parallel robot configurations are actually built according to the proposed design procedure.
KEYWORDS:
Robot, modular system, design, manipulator

1. INTRODUCTION

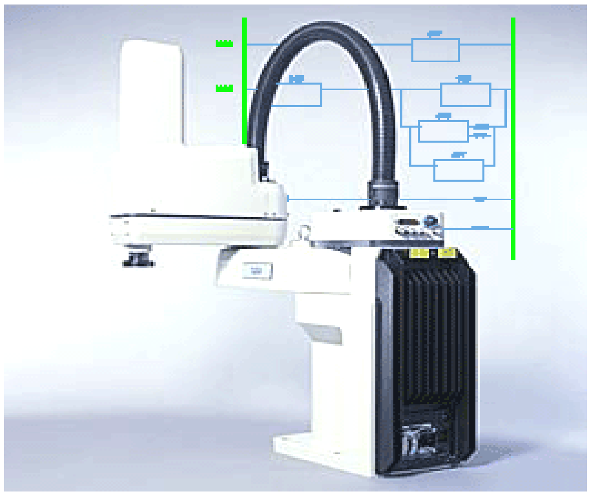
A modular reconfigurable parallel robot system consists of standardized links and joint components that can be assembled into a particular geometry for specific tasks. The focus of this work is on the configuration design, kinematics analysis, workspace visualization and kinematics calibration of the modular reconfigurable parallel robot.

The modular parallel robot can have numerous configurations. Here, we have systematically identified and analyzed a class of three-legged non-redundant parallel robots. Such robots have symmetrical geometry, simple kinematics and desirable characteristics suitable for our applications. By coupling serial manipulators together, a parallel manipulator can be formed. A parallel manipulator is a closed-loop mechanism in which the mobile platform is connected to the base by at least two serial kinematics chains (legs). The parallel-actuated manipulator features a structure where all the actuators act together to carry a common payload. Parallel manipulators with closed-loop structure present themselves as feasible alternatives to their serial counterparts in situations where the demand on high speed, precise motion, and dynamic loading outweighs those on workspace and maneuverability. Parallel manipulators whose high structural rigidity provides large strength-to-weight ratio and high positioning capability are more attractive than their serial counterparts. In recent years, much effort has been directed in the research and development of parallel manipulators for operations requiring high bandwidth and high-precision motion. Today, the use of parallel manipulators can be found in the design and implementation of numerous robotic systems, including spacecraft simulators, teleoperation hand controllers, force/torque sensors etc. In a nutshell, parallel robots are gaining importance in the automation industry today.

2. SERIAL ROBOTS

The majorities of robot manipulators in use today are serial robots employing a strictly serial arrangement of their links and associated actuators. The industry has concentrated on a monolithic design of manipulators which are suitable only for specific tasks. This class of manipulators was first explored in 1960's and has been extensively studied in terms of their design, kinematic and dynamic modeling, and control. They are now widely used in industries. Well-known serial manipulators are the Stanford arm, Angular type arm and Scara type arm (see Fig. 1).

Angular – Kuka



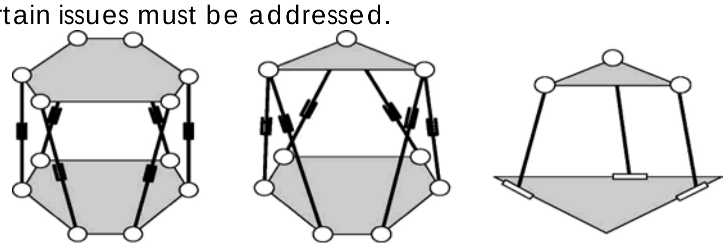
Scara - Adept

FIGURE 1. SERIAL ROBOTS

When properly designed, the serial structure has the benefit of possessing a large workspace and high maneuverability in comparison to their physical size. However, due to the serial structure of the manipulator, not all of the actuation and transmission related masses can be mounted close to the base. Hence, serial manipulators tend to have small payload capacity in comparison to the manipulator weight, poor end-effector stiffness and poor dynamic performance in terms of acceleration capabilities. In addition, the serial structure leads to additive joint errors. The additive joint errors combined with the inherent low stiffness, causes the structure to have poor accuracy at the end-effector.

3. PARALLEL ROBOTS

By coupling serial manipulators together, a parallel manipulator can be formed. A parallel manipulator is a closed-loop mechanism in which the mobile platform is connected to the base by at least two serial kinematic chains (legs). The parallel-actuated manipulator features a structure where all the actuators act together to carry a common payload. A modular reconfigurable parallel robot system consists of a collection of standardized individual actuators, passive joints, connectors, mobile platform and the end-effector components that can be assembled into particular parallel robot geometry in order to fulfill specific task requirements. A modular reconfigurable parallel robot can be rapidly constructed and its workspace can be varied by changing the leg positions, joint types, and link lengths for a variety of tasks. Modularity has many advantages. A modular parallel robot has components that are constructed with standardized units or dimensions. This allows flexibility, variety in use, rapid change-over and ease of maintenance. In order for the modular reconfigurable parallel robot system to be deployable and effective in performing its assigned tasks, certain issues must be addressed.



Stewart Platform | Triangular Symmetric Simplified Manipulator Mechanism | Equivalent Triangular Symmetric Simplified Manipulator Mechanism

FIGURE 2. GENERAL PARALLEL MANIPULATORS.

Most of the existing parallel manipulators share the simple structure of the Stewart Platform, which consists of three or six extendible legs, each with one actuating prismatic joint, connecting the upper mobile platform and the base using spherical and universal passive joints. A fully parallel manipulator is a closed-loop mechanism with an end-effector connected to the base by independent kinematic chains. Each chain has at most two links and is actuated by a prismatic or rotary actuator. However, a parallel robot, in its general form, puts no restriction on the structure, such as the number and the geometry of its legs, the number and types of active and passive joints in each leg. A very general parallel manipulator is shown in Fig. 2. Removal of such restrictions allows the design of a parallel manipulator to take advantage of both closed- and open-chain manipulators. Recently, there has been much attention to improve the Stewart Platform and design more sophisticated parallel manipulators with higher dexterity, better control and larger workspace.

4. DESIGN OF MODULAR PARALLEL ROBOT

A modular parallel manipulator can thus be rapidly configured for a diversity of tasks. The modular reconfigurable parallel robot can be rapidly constructed and its workspace can be varied by changing the leg positions, joint types, and link lengths for a variety of tasks. Moreover, its components are constructed with standardized units or dimensions thus allowing flexibility, variety in use, rapid change-over and ease of maintenance. Two types of modules, namely, actuator modules and passive joint modules are required for configuring modular parallel robots. Figure 3 shows the prismatic and revolute actuator modules used for modular reconfigurable parallel robots.

FIGURE 3. ACTUATOR MODULES

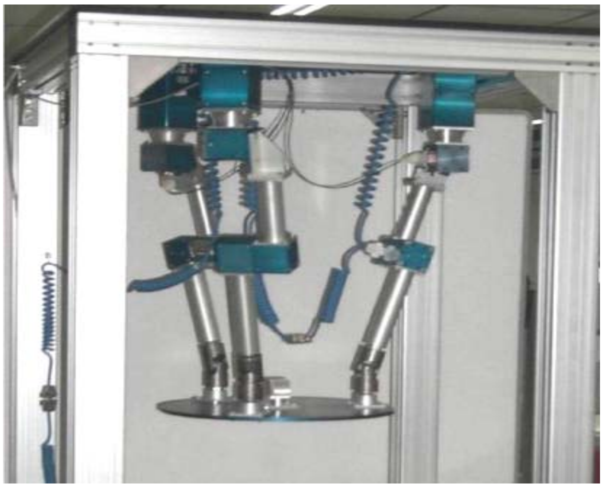


FIGURE 4. MODULAR THREE-LEGGED PARALLEL ROBOT WITH 6 DOF

Each module is a self-contained drive unit with a built-in motor, controller, amplifier, and communication interface. It has a double-cube design with multiple connecting sockets that enable two actuators to be connected in different orientations. These features make them suitable for reconfigurable modular robot design.

For the modular reconfigurable parallel robot, there is almost no limit on the number of configurations that can be constructed. For such a class of three-legged parallel robots, each leg consists of two actuated joints (prismatic and/or rotary), one passive revolute joint and one passive spherical joint. The actuator joint modules in each leg are always placed near the base because of their weight. Based on this fact, we can generate all of the possible robot configurations in this class. Through mobility analysis, the degrees-of-freedom of the manipulator designed can be verified if it has the mobility required. The degrees-of-freedom of the spatial mechanism or the manipulator can be calculated using the mobility equation for the spatial motion:

$$M = 6(n - g - 1) + \sum_{i=1}^{g} f_i$$

where

"*M*" is the mobility (number of degrees of freedom of system)

"*n*" is the number of links including the base

"*g*" is the number of joints

"f_i" is the number of degrees-of-freedom for the "i^{th}" hinge

Through proper design, hybrid parallel manipulators exploiting the advantages of both parallel and strictly serial devices can be developed for specific tasks.

5. SUMMARY/CONCLUSIONS

In this article, the actuator modules, passive joints modules, links and other components used for modular robots have been introduced. The modular reconfigurable robot system is a collection of individual standard functional units (or modules), links and joints that can be used individually or collectively when assembled into various robot configurations. A modular parallel manipulator can thus be rapidly configured for a diversity of tasks. These off-the-shelf intelligent mechatronic drives are selected as the actuator modules for rapid deployment. Each module is a self-contained drive unit with a built-in motor, controller, amplifier, and communication interface. Its double-cube design with multiple connecting sockets enable two actuators to be connected in different orientations.

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