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A spatial hybrid motion compliant mechanism: Design and optimization

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ABSTRACT

A hybrid motion system is defined as a mechanical system that combines a macro motion and a micro motion into one system to achieve a large motion and high resolution with fast response simultaneously. In this paper, a spatial hybrid motion mechanism with 3-DOFs is developed that integrates two types of motion through only one compliant mechanism: a macro motion driven by DC servomotors for large workspace and a micro motion driven by PZT actuators for high precision. A unique feature of the developed hybrid motion compliant mechanism is the elimination of coupling interaction between the macro motion and the micro motion by properly structure design. Three issues are addressed in this paper: (1) design principle and implementation of the hybrid motion mechanism; (2) kinematic analysis and dynamic analysis; and (3) optimization design of the hybrid motion mechanism. A spatial hybrid motion mechanism is developed and the optimization is conducted. The Taguchi method is used to identify significant parameters in the design optimization, and finite element analysis results verify the design principle of the parallel architecture for the hybrid motion mechanism.

1. Introduction

High precision manipulation systems with large range of motion and high positioning resolution are highly needed for industrial applications such as various machining processes, cell manipulation, and computer component assembly. A possible system that can satisfy these requirements is a macro/micro manipulator system [1–5]. In such a system, a long reach, or macro, manipulator is characterized by a large workspace with slow response due to its size. In contrast, a short reach, or micro, manipulator is characterized by a small work volume with fast and precise manipulation capability over that work volume. Such a macro/micro mechanism can be called a hybrid motion mechanism (HMM). The concept of a macro/micro manipulator was first introduced by Sharon et al. [1]. A macro/micro manipulator test-bed was developed in [2] where a 2-DOFs macro manipulator with two flexible links is attached by a 3-DOFs small robot. A macro/micro system integration using a parallel kinematic mechanism and a 2-DOFs micro manipulator for the application of deburring and finishing operations was developed in [3]. But the interaction issue between micro and macro mechanisms was not taken into consideration. An 11-axis robot to accomplish accurate positioning and velocity-controlled tasks in the presence of a flexible substructure was designed [4] through a macro/micro system combination.

As mentioned in [5], mounting a micro manipulator on a macro manipulator would produce a dynamic interaction problem that might degrade performances of the whole system. Therefore, many efforts were focused on controller design for macro/micro motion systems [6–8], rather than on the mechanism design. A hybrid position/force control of flexible manipulators by a macro/micro manipulator system was proposed in [6]. In that design, a macro manipulator was controlled to roughly realize the desired position and force by a simple PD feedback, and a micro manipulator was used to compensate the position and force errors caused by the macro part. A contact control for a flexible macro/micro manipulator was discussed in [7] where the controller combined force damping control and inertial force active damping control. Dynamic control of a flexible macro/micro manipulator system was studied in [8] where a PD feedback controller was employed incorporating a fuzzy adaptive tuner for the macro manipulator, and a control scheme was proposed for the micro manipulator.

It should be noted that all the architectures of the developed macro/micro manipulator systems are connected in series. It means that a micro manipulator is mounted on the tip of a macro manipulator. A mechanism based on such architecture can be called a serial HMM. The majority of the HMM discussed in the literature was focused on the attenuation of vibration of the macro manipulator caused by a fast action of the micro manipulator. From the above discussion, we can see that traditional macro/micro motion systems are combined simply using two separately designed motion stages. Such a design is easy to realize, but the assembly error and the backlash force will affect the accuracy of the end-effector in the combined system. Furthermore, mounting

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