A novel design of a 3-PRC translational compliant parallel micromanipulator for nanomanipulation
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SUMMARY
A novel 3-DOF prismatic-revolute-cylindrical (PRC) translational compliant parallel micromanipulator (CPM) has been designed for 3-D nanomanipulation in this paper. The system is configured by a proper selection of hardware and analyzed via the established pseudo-rigid-body (PRB) model. The CPM workspace is determined taking into account the physical constraints imposed by piezoelectric actuators and flexure hinges.

KEYWORDS: Parallel manipulators; Compliant mechanism; Nanomanipulation; Workspace.

I. INTRODUCTION
Nanomanipulation can be defined as the manipulation of nanometer size objects using an end-effector with (sub)nanometer precision.1 Several parallel manipulators employing compliant mechanisms have been designed to perform the manipulation in micro/nano meter scales with high accuracy, speed, and load capacity.2–4 However, most of the existing micromanipulators can provide only planar 3-DOF motion, or spatial 3-DOF mixed motion of translation and rotation. Since the nanometer-scale motion is usually performed via a microscope, that provides a quite limited field of vision and even a slight rotation of the end-effector will result in the manipulation easily sweeping out of the visual field, the most important motion used in such applications is translation rather than rotary motion. Consequently, a micromanipulator which can provide 3-DOF translational motion with high precision is urgently required for 3-D nano scale manipulation.

The motivation of this work is to develop a new 3-DOF spatial positioning nano-manipulator with a workspace covering the range of about $140 \times 140 \times 140 \ \mu m^3$ and the resolution of several nanometers.

II. DEVELOPMENT AND ANALYSIS OF THE CPM
As shown in Fig. 1, the designed 3-DOF CPM employing flexure hinges at all joints, consists of a mobile platform, a fixed base, and three limbs with identical PRRP kinematic structure. Since the effect of the last R and P joints is equivalent to a cylindrical (C) joint, it possesses a 3-PRC architecture indeed. With the mechanism topology identified and each flexure hinge replaced by a revolute joint and a torsional spring, the PRB model of the CPM is developed in Fig. 2.

For a 3-PRC parallel robot with conventional mechanical joints, it has been shown that such a mechanism can act as a translational parallel manipulator with some certain geometric conditions satisfied.5 Moreover, in order to generate a
regular cuboid like workspace of the manipulator, the three actuated P joints are arranged in orthogonal directions.

To achieve the goal of this work, one type of PZT (P-178.30) with the stroke of 40 µm and resolution of 0.4 nm is selected from the Polytec PI, Inc. The linear actuator of the CPM is implemented with each PZT embedded in a flexure P hinge as shown in Fig. 1. The flexure R hinge can be designed to have various profile shapes. Here we adopt the right circular one (see Fig. 3) thanks to its good accuracy. Since the ratio of yield strength ($\sigma_y$) to the Young’s Modulus ($E$) of the material heavily affects the rotary limits of flexure hinges, that partially determines the manipulator workspace, it is necessary to choose materials with higher ratio of $\sigma_y/E$ so as to obtain a larger workspace. We select a titanium alloy Ti-6Al-4V ($E = 113.8$ GPa, $\sigma_y = 880$ MPa) to build the CPM.

The desired workspace for a 3-PRC CPM is described as a maximum cuboid inscribed within the reachable workspace and defined as the usable workspace. As shown in Fig. 4, the range of $V$ denotes the workspace due to rotary limits of flexure hinges, $S$ represents the workspace range subjected to motion limits of PZT actuators, and the intersection of these two ranges forms the manipulator’s reachable workspace, i.e. the cuboid like range of $S$. Additionally, the usable workspace is denoted by $U$.

### III. CONCLUSIONS
A novel 3-PRC CPM utilizing flexure hinges for 3-D nano scale manipulation has been designed in this paper. Since the proposed CPM is composed solely of flexible elements with competent in high precision applications, it is reasonable to expect that with a suitable end-effector mounted on the mobile platform or placing the platform under a specified microscope as a precision XYZ-stage, the CPM can be employed in 3-D positioning and assembly of nano scale objects through nanomanipulation.

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### References