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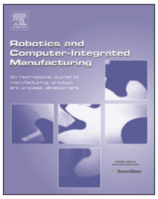

Design and analysis of a novel 3-DOF spatial parallel microgripper driven by LUMs

Ran-Ran Geng [a,*], James K. Mills [b], Zhi-Yuan Yao [a]

[a] *State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, 29 Yudao St, Nanjing 210016, China*

[b] *Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Rd, Toronto, Ontario, Canada M5S 3G8*

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ABSTRACT

A novel 3-DOF microgripper driven by Linear Ultrasonic Motors (LUMs), with nanometer positional accuracy and an operational space in the millimeter scale is proposed. A two-fingers design method based on a chopstick-like structure is presented. The operational mechanism is illustrated to demonstrate how the microgripper works. Based on the spatial parallel mechanism with joints formed by right circular multi-axis flexible hinges, the kinematic model as well as the relationship between output and input displacement are derived. The maximum displacement of the manipulation end-effector is calculated and an error analysis is conducted. A series of experimental results indicate that the reachable operational workspace of the microgripper is a 20 mm height cylinder with the major-axis of 2.3415 mm and the minor-axis of 2.1178 mm, while the displacement resolution is 100 nm. Successful experiments on gripping a single shrimp embryo demonstrate that the microgripper has good performance in gripping micro-objects.

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1. Introduction

Micromanipulators can be found in extensive applications including micromachining, scanning microscopes, optical engineering and biological cell manipulation [1–3]. To fulfill these scientific and engineering tasks, Parallel micromanipulators with high positioning accuracy and multiple degrees of freedoms have become an important area in mechanisms and robotic systems [4–7]. In the recent works published on micromanipulators, a common design attribute of micromanipulators is a two finger design, which is commonly referred to as microgrippers [8–11]. The two fingers can grasp micro objects, and adjust the position of micro-objects, since there are multiple degrees of freedom of relative motion between the two fingers. Grasping methodologies have been at the forefront by microsystem researchers since micro-scale products were introduced in the market. Therefore, the demand to accomplish fully integrated multifunctional devices has stimulated extensive research on micromanipulation methodologies.

The precision of the end-effector output trajectories is primarily determined by the internal structure of the mechanism which involves a series of motion transformations and transmission. Instead of traditional joints, a number of flexible hinge configurations are adopted in the design of micromanipulators, especially microgrippers since they possess the advantage of essentially zero friction and zero clearance [12–19]. Many researchers have conducted significant work on the design, fabrication testing and control of flexible-based parallel mechanisms. Speich and Goldfarb described a small-scale 3-DOF compliant-mechanism-based manipulator with a large range of motion, due to a unique flexure joint [20]. Bruzzone and Molfino discussed a Cartesian parallel robot with flexure joints driven by cog-free linear motors. The workspace is a cube with dimensions of 30 mm on each side, however the position accuracy achieved is 1 μm due to the non-perfect kinematic constraints [21]. Ouyang et al. proposed a parallel manipulator using a monolithic, flexure hinge mechanism actuated by piezoelectric transducers (PZT) [22]. Tanikawa et al. designed a two-fingered microhand based on the thin-plate flexure joint driven by PZT [23].

Actuator selection is one of the essential design factors to attain high accuracy as well as sufficient force and driving input to actuate the microgripper mechanism. The PZT actuator is utilized in many micromanipulators because the PZT possesses the advantages of large driving force and nano-scale resolution [24]. However, the output displacement of PZT is relatively small, and is measured in tens of microns. The LUM is a piezoelectric actuator which uses the inverse piezoelectric effect of the piezoelectric ceramics and ultrasonic vibration. It not only possesses high position accuracy, large output force, but also exhibits quick response

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* Corresponding author.
E-mail address: rrgeng@nuaa.edu.cn (R.-R. Geng).

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with a large motion stroke [25–27]. Research on LUMs has received much attention in recent years. Lee introduced a butterfly-shaped LUM which has been developed for use in electronic products such as cellular phones [28]. Zhou proposed a structure with ceramics bonded to its surface, realizing an integrated stator design [29]. Shi presented a new standing-wave-type LUM using a combination of the first longitudinal and second bending modes, a design which is readily miniaturized [30].

This paper presents a novel 3-DOF spatial parallel microgripper driven by LUMs. The structure and the mechanism design, which makes use of flexible hinges, and the operational mechanism are introduced. The kinematic model of the microgripper is established based on the use of parallel mechanism assumptions and the error analyse is explained. The workspace of the end-effector is calculated, and has been verified with experimental studies. Experimental results of gripping micro-objects are also presented to verify the performance of the proposed microgripper. This research will improve the development of LUMs, nano-scale position control and the study on microgrippers.

2. Structure design of microgripper

2.1. Structure of the microgripper

Based on the principle of the use of chopsticks, the microgripper proposed in this paper has two fingers, one of which maintains a stationary position and attitude, while the other is moveable and mounted on a spatial parallel mechanism. As is shown in Fig. 1, the microgripper adopts a spatial parallel mechanism consisting of the arm, drive components, flexible hinges, a disk, the base, one static finger and one moving finger. The arm is a cylindrical structure with diameter of 130 mm and height of 140 mm, thus the plane of the two fingers can be easily adjusted by rotating the arm. The arm is fixed on the base and is the major supporting component of the microgripper. Both the arm and the base are made of stainless steel to ensure the stability of the whole structure. To enable the drive components to be readily installed on the arm, three symmetrically located grooves of appropriate size to accommodate the drive components, were cut on the cylinder surface. The three drive components are fixed symmetrically around the central axis of the arm. Fig. 2 shows the profile schematic of the arm which illustrates the arrangement of the three drive components.

Each drive component includes one LUM, one sliding block and one linear guide rail. The guide rails are parallel to the central axis of the arm and its length is the same with the height of the arm. The distal end of each flexible hinges is fixed to the guide rail and the proximal end is fixed to the disk. The diameter of the disk is 130 mm, which is sufficiently large for the installation of the flexible hinges and accommodates the arm. The static finger is fixed on the arm and its tip is located through the center bore of the disk while the moving finger is fixed on the disk. Its distal position is symmetrical with the bottom end of one flexible hinge about the disk. The angle between the moving finger and central axis of the arm is 60°. When the microgripper is in its home configuration, the plane of the disk is perpendicular to the three guide rails and the two finger tips are positioned at the same point, as shown in Fig. 1. To prevent deformation and maintain accuracy and stability, the disk, guide rails, sliding blocks and the two fingers are all manufactured from stainless steel. The three-dimensional size of the integrated device is 130 mm × 130 mm × 250 mm.

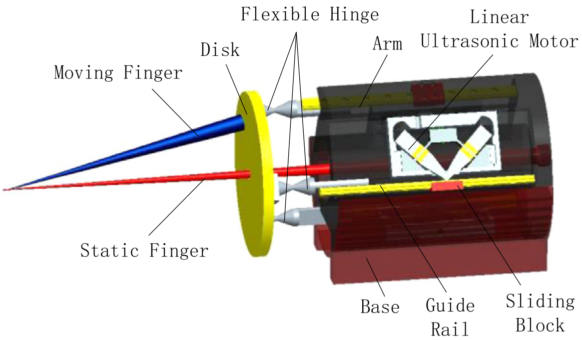

Fig. 1. Structure diagram of the microgripper.

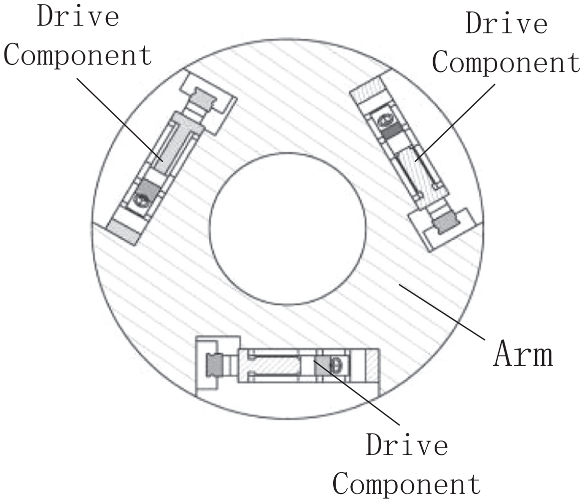

Fig. 2. Profile diagram of the arm.

As one of the crucial component of the microgripper, flexible hinges have a significant impact on the gearing performance and also provide high positioning accuracy. There are many different variations of the design of flexible hinges with different shapes and functions [31,32]. It can be seen that the flexible hinges utilized in the spatial parallel mechanism should be in three-dimensional applications. Fig. 3 shows the right circular multi-axis flexible hinge which is made of aluminum, permitting small deformation. As seen in Fig. 3, the flexible hinge is formed from a round bar, with a reduced diameter section. This part is turned on a lathe. For this configuration, which exhibits rotational symmetry, deformation is possible about any axis that is perpendicular to the axial direction [33]. Therefore, right circular multi-axis flexible hinges can translate the motion of the guide rails to the motion of the disk, hence is well suited for the parallel microgripper to be used as joints.

2.2. Operational mechanism

It is well known that the 3-PS (prismatic-spherical) parallel kinematics mechanism that connect the fixed base with the movable platform is over-constrained [34]. There is only one translational movement of the movable platform because the conventional spherical joints make the mechanism rigid. Thus, the

Fig. 3. Right circular multi-axis flexible hinge.

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