6-DOF Parallel Nano-Positioning System with flexure joints and Piezoelectric Stepping Motors

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Abstract

This paper details the development of a novel 6 degrees-of-freedom (DOF) nano-positioning system for the application of precise optic alignment. The proposed nano-positioning system is based on the tripod structure. The piezoelectric stepping motors are used to have the large motion range and the high resolution at the same time. In addition, its power-off hold is useful for the position stability after finishing the optic alignment. To achieve the nanometer resolution, all passive joints are composed of the flexural joints. All of flexural joints are designed to provide the large rotation angle. Results of this paper include that of a translation resolution of 15nm and a rotational resolution of 0.14arcsec being achieved. Meanwhile, the parallel structure provides the high dynamic bandwidth of the lowest resonant frequency of 396.1Hz. The coupled workspace of ±2mmX±2mmX±2mmX±2°X±2°X±2° is achieved and the overall size of the designed system is Φ350mmX120mm.

1 Design overview

In this paper, we present a novel nano-positioning system based on the 3-PPRRRR tripod structure which was suggested by Tahmasebi.[1] The proposed system is shown in Figure 1. In this configuration, the actuators are fixed to ground not to the limb and this structure allows the system to be compact. All joints in the limb are redesigned to achieve the nanometer resolution and accuracy. Firstly, We adopt the XY piezoelectric stepping motors due to their high resolution, high stiffness, compact size, high-force density and power-off hold characteristics.[2,3] Next, all revolute joints are replaced by the flexural joints to get rid of the friction induced imprecise motion.

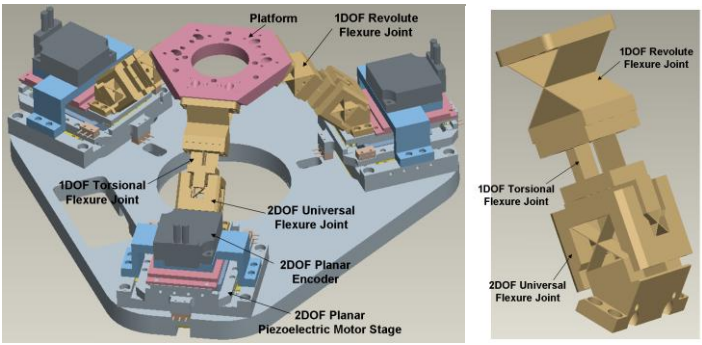

Figure 1: Embodiment of the developed novel 6-DOF nano-positioning system

1.1 Piezoelectric stepping motor

A novel XY linear piezoelectric stepping motor is proposed as shown in Figure 2. The developed motor is designed to have the nanometer resolution, high stiffness, large force and compact structure. The operation principle of the proposed piezoelectric stepping positioner is presented in Figure 3.

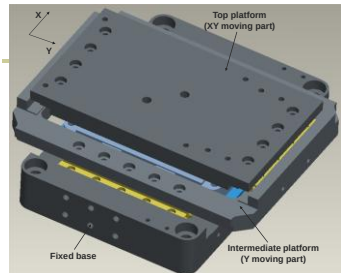

Figure 2: Novel linear XY piezoelectric stepping motor

1.2 Flexural joints

To obtain the nanometer resolution, the flexural joints are used as the revolute joints. The rotation range of flexural joints may be increased by a careful mechanism design using leaf-springs and the designed limb structure is shown in Figure 1. The uppermost 1-DOF revolute joint in the limb is the cartwheel flexure hinge and the 1-DOF torsional joint in the middle of the limb is the axial strip flexure. The bottommost 2-DOF universal joint is composed of four cartwheel flexure hinges and

it is kinematically same as the conventional universal joint. The properly designed cartwheel flexure hinge can provide the rotation range over than 10 degrees.[4]

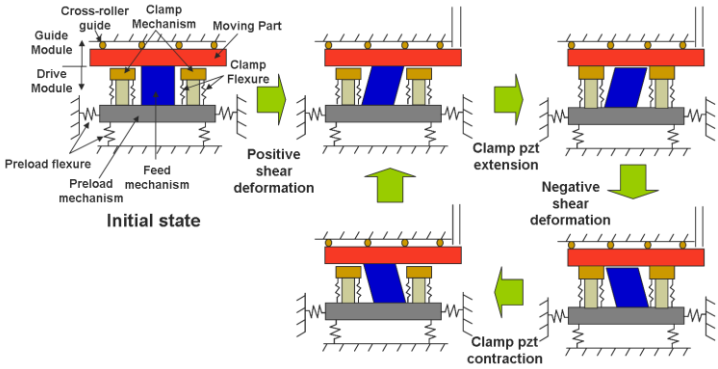

Figure 3: Operation principle of the proposed linear piezoelectric stepping positioner

2 Evaluation results

Based on the precision piezoelectric stepping motor and flexure joints, a high precision motion is obtained. As presented in Figure 4, results of this paper include that of a translation resolution of 15nm and a rotational resolution of 0.14arcsec being achieved. The simulated lowest resonant frequency of the system is 396.1Hz. A coupled workspace of 4mmx4mmx4mmx4°x4°x4° is verified. The overall size of the designed system is Φ350mmX120mm.

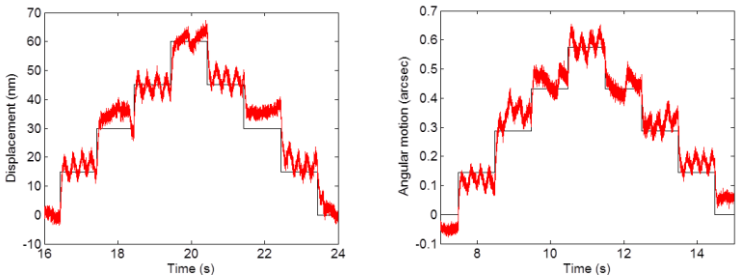

Figure 4: Translational motion resolution in x-direction and Rotational motion resolution in θ_x-direction

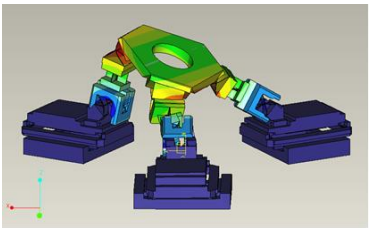

Figure 5: Lowest resonant mode shape at 396.1Hz

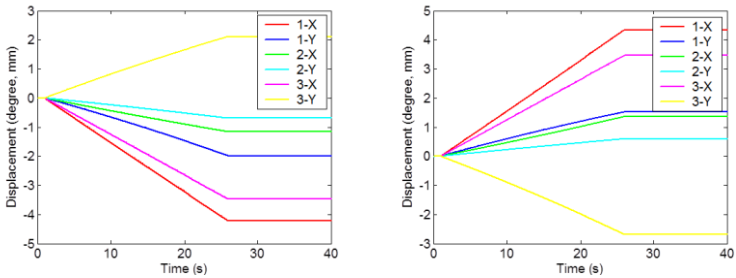

Figure 6: Coupled motion range test

References:

[1] Farhad Tahmasebi and Lung-Wen Tsai, J. Robotic Syst., **12**, 845 (1995)

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