Nanopositioning of a multi-axis microactuator using visual servoing

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Abstract—This paper reports on a visual servoing system capable of 2DOF nanopositioning using a novel multi-axis electrostatic MEMS (MicroElectroMechanical System) device. The high-aspect ratio microactuator is bulk microfabricated, producing larger electrostatic forces and requiring lower actuation voltages compared to most existing electrostatic microactuators. A real-time sub-pixel feature tracking algorithm of nanometer resolution is incorporated into the visual servoing loop. A feedforward controller is designed to increase system response. Minimal system calibration is required. The resulting system is capable of visually servoing to a positioning precision of ±16 nm in two axes using the multi-axis microactuator and standard microscope optics with a CCD camera, despite a control rate of 30 Hz which reduces disturbance rejection capability. Potential applications of the system are for nanopositioning in nanomanipulation, such as in the manipulation of subcellular structures within biological cells.

Keywords: Nanopositioning; MEMS; microactuator; visual servoing; standard microscope optics.

1. INTRODUCTION

Many microrobotic applications require multi-degree-of-freedom positioning at micro- and nano-scales. Actuation technologies, capable of providing motion at these scales, include piezoactuators [1], microstepping motors [2], highly geared electromagnetic servomotors [3] and Lorentz force-type actuators such as voice coil motors [4]. Typically, these positioning systems are expensive and require extensive calibration procedures. This paper reports on a visual servoing system capable of 2DOF nanopositioning using a novel, inexpensive multi-axis electrostatic MEMS (MicroElectroMechanical System) device, which requires minimum system calibration.

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The 3D high aspect ratio transverse comb drive microactuator, constructed by Deep Reactive Ion Etching (DRIE) on Silicon-On-Insulator (SOI) wafers, produces two orders of magnitude larger electrostatic forces than surface micromachined lateral comb drive microactuators [5–10] while the required actuation voltages are approximately 10-times smaller. By removing the substrate beneath the comb drive structure, thus resulting in a balanced electric field distribution, the microactuator does not require the use of a ground plane as is typical for other electrostatic microactuators, and the movable structure does not suffer from the levitation effect [11], i.e. an unbalanced electric field distribution, which forces the structure to move out of the actuation plane.

To increase the positioning precision of the actuation system, a sub-pixel vision tracking algorithm of nanometer resolution [12] was developed to provide feedback in the visual servo loop. The algorithm is a sub-pixel template matching approach that determines object position in two dimensions. An energy function is minimized using the Broydon–Fletcher–Goldfarb–Shanno (BFGS) first-order numerical minimization method giving the algorithm fast convergence rates. In addition, a KD-Tree is used to store edge pixels from the image in order to further increase the performance of the template matching algorithm. Further, a robust, nonlinear Cauchy error measure is used to enhance the robustness to noise within the image.

The resulting system is capable of visually servoing to a precision of ±16 nm using the novel and inexpensive bulk micromachined multi-axis electrostatic microactuator and standard microscope optics with a CCD camera. The schematic diagram in Fig. 1 shows the system setup, which requires minimal system calibration. Potential applications of the system are for nanopositioning in nanomanipulation, such as in the manipulation of subcellular structures within biological cells [13].

In Section 2, the design and fabrication of the multi-axis MEMS microactuator are described. Pull-in, hysteresis and cross-coupling are also discussed. The

Figure 1. Visually servoed nanopositioning system setup.