ELECTROTHERMAL MEMS PARALLEL PLATE ROTATION FOR REAL TIME STEREOSCOPIC ENDOSCOPIC IMAGING

Kyung-Won Jang¹, Sung-Pyo Yang¹, Seung-Hwan Bae², Min H. Kim² and Ki-Hun Jeong¹
¹Department of Bio and Brain Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, KOREA
²School of Computing, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, KOREA

ABSTRACT

This paper reports MEMS parallel plate rotation (PPR) with electrothermal actuator for real-time stereoscopic imaging. MEMS PPR allows stereoscopic imaging by generating camera shift effect with displacement in ray of the light. The device was designed opto-mechanically to operate in dynamic mode for stability, large rotation angle. The electrothermal actuation rotates over 25° in dynamic mode under low voltage, generating over 80µm baseline that indicates distance between two cameras and decides depth resolution. Finally stereoscopic images was captured by MEMS PPR and high-speed camera and reconstructed. This method can be widely used in miniaturized stereoscopic imaging system based on single camera.

INTRODUCTION

Three dimensional (3D) imaging has been rapidly utilized in many fields; from machine vision to entertainment or even medical applications. Medical endoscopes are efficient tools for in vivo optical diagnosis or clinical surgery including optical biopsy. Clinical surgeons operate on lesion with their depth perception not from visual information but from their experience, which results in inaccurate diagnosis and inefficient surgery. Depth information, therefore, is important for accurate and efficient clinical surgery and can be provided from 3D imaging technology.

Previous works have reported 3D imaging has some clinical benefits than conventional 2D imaging. S. H. Kong et al. reported 3D imaging system increased the accuracy of endoscopy performance, with improved depth perception [1]. They evaluated the effects of a 3D imaging system on laparoscopy performance compared with the conventional 2D system. In this study, 21 novices and 6 experienced surgeons performed two tasks with 2D and 3D systems in consecutive days. Performance time and error as well as subjective parameters such as depth perception and visual discomforts were assessed in this study. P. Storz et al. evaluated users’ performances in standardized surgical phantom model tasks using 3D HD visualization compared with 2D HD regarding precision and working speed. In this study, 20 medical students and 10 laparoscopy-experienced surgeons were selected in test and performed tasks. They showed that 3D HD permits superior task efficiency, even as compared with the latest 3D HD systems in Table. 1.1 [2].

These clinical benefits, many types of 3D shape imaging for endoscopy have been proposed until now. Most of all are classified into 4 groups: shape from stereo [3], time of flight (TOF) [3], shape from motion [4] and shape from shading [5] in Fig 1.2. Shape from stereo is one of the most common 3D imaging method using two cameras. This method enables high-resolution stereoscopic imaging but has limitation to downsizing of distal end. Time of flight is 3D imaging method that detects depth by using the time between incident and reflected pulse in each pixel of sensor. This method is very simple but its accuracy is low due to one optical signal used in this method and noise in signal. Shape from motion capture images at multi viewpoints and calculate depth map. This method enable downsizing with single camera but need many frames for high accuracy and the model approximation error cannot be overcome by increasing the number of frames. Shape from shading is 3D imaging method that calculate amount of defocusing for stereoscopy. This method calculate relative distance of object from two frames. It has high speed but accuracy is lower because of using just two frame for depth estimation.

The method proposed in this paper is one of the shape from stereo imaging methods for high resolution and real-time imaging in Fig 1.

![Figure 1](image-url)
OPTO-MECHANICAL DESIGN

The MEMS PPR was designed opto-mechanically for large binocular disparity from electrothermal actuation and stability. Firstly, baseline distance was set to be 100μm with minimum depth-of-field (DOF) of conventional endoscopic cameras 3mm for minimizing visual fatigue according to the 1/30 rule [6]. Based on this baseline distance, parallel plate thickness and refractive index and rotation angle was set along for the formula below:

\[
 d = t \sin \theta \left( 1 - \frac{1 - \sin^2 \theta}{n^2 - \sin^2 \phi} \right)
\]

(1)

\(d\) is the baseline distance and \(t\) the parallel plate thickness, \(\theta\) the rotation angle, \(n\) the refractive index. Large rotation angle can be obtained by using electrothermal actuation with bimorph structures of two materials with different coefficients of thermal expansion (CTE); aluminum is laid over silicon. The bimorph structures are substantially deflected during Joule heating due to stress from the length difference of two material. The maximum deflection can be decided by bimorph structure’s dimension and difference of thermal expansion coefficient and difference of temperature by governing equation [7].

In this paper, thick bimorph layer (Silicon: Aluminum = 4μm: 1μm) was used for stability and the device was designed to operate in dynamic mode for high deflection and rotation.

MICROFABRICATION

The device microfabrication was done by using a standard silicon on insulator (SOI) process at 6 inch wafer level. The cross-sectional views for the process flow are illustrated in Fig 2. 0.1μm thick silicon nitride with low pressure chemical vapor deposition (LPCVD) and 1μm thick aluminum with sputtering were subsequently deposited on a heavily boron doped SOI-wafer (Top Si: Buried SiO2: Bottom Si = 4μm; 1.5μm: 500μm in thickness). The aluminum lines were firstly dry etched and wet-etched for aluminum line width and the silicon nitride was then etched by using reactive ion etching (RIE). Top silicon was defined with the plate holder on the front side by using a deep reactive ion etching (DRIE). Next, the back side silicon was defined by using DRIE after front side passivation, where the individual chips were mechanically connected on the wafer with silicon tethers. The individual chips were separated from the silicon wafer after physically breaking the silicon tethers by applying the voltages for Joule heating [8]. Figure 2 (b), (c) clearly show the SEM and optical image of the fabricated electrothermal MEMS actuator. The plate holder has an initial deflection of 6° due to the residual stress induced by thermal mis-match between aluminum and silicon nitride.

500μm thick optical plate with anti-reflective structure was permanently mounted on the plate holder by using a UV curable adhesive and Pico pump and Device is eventually packaged on the printed circuit board (PCB) after soldering electrical wires in Fig 2.7.

DEVICE CHARACTERIZATION

The electrothermal actuation in static mode by bimorph actuator was measured by microscope. Prior to measurement, resistance was measured for checking Al line connection. Deflection was generated by applying voltage with micro-tip into Al pad. When plate holder descended by joule’s heating, displacement was measured by focusing on the end of plate holder.

Figure 3 shows rotation angle versus applied voltage. PPR MEMS device has 4.74° rotation angle in 15VDC and matched well with theoretical analysis. In theoretical analysis, resistance increase is considered due to electrothermal actuation in high temperature. Maximum voltage was set to 15V because the actuation over 15V was unstable and also aluminum is at risk for melting and has

![Figure 2: (a) Microfabrication procedure of MEMS PPR. Si$_3$N$_4$/Al were deposited by LPCVD/Evaporating and etched by RIE/Wet etching. Top/Bottom Si were etched by DRIE. After oxide removal, plate is mounted on Si. (b) The SEM image and (c) the optical image of electrothermal microactuator. The device was successfully fabricated. The physical volume of MEMS PPR was well fit within 3.4mm x 3.3mm x 1mm.](image)
Figure 3: Characterization of MEMS PPR. (a) Rotation angle from electrothermal actuation in dc voltages. (b) Two peaks in frequency response due to property of electrothermal actuation. Resonant frequency was 841Hz before parallel plate mount.

STEREOSCOPIC IMAGING WITH MEMS PPR

Stereoscopic images were captured with half-folded paper by MEMS PPR and high speed camera. In Fig 4, disparity turned up as a few pixels between left and right images. Red region in original image indicates field of view (FOV) of MEMS PPR and disparities exist in only that region. Finally disparity map was reconstructed from left and right images by using a non-local segment based stereoscopic method from a mean-shift-based segmentation method [9] and a non-local cost aggregation method [10]. In disparity map, brightness means amount of disparity: brighter region has higher disparity. The result shows that center line in half-folded paper is the brightest region in disparity map with disparity value 4, which means the line is the closest from high speed camera and disparity map has depth information.

CONCLUSION

This work presents stereoscopic imaging with MEMS PPR firstly in time division method with electrothermal actuator. The MEMS PPR is successfully fabricated and has the physical volume of 3.4mm x 3.3mm x 1mm. In static mode parallel plate is rotated by 5° in 15 dc voltages. In dynamic mode resonant frequency is 841Hz before parallel plate mount and the electrothermal actuator rotates parallel plate over 25° by actuation in dynamic motion under ac low voltages after plate mount. Finally disparity map is reconstructed successfully and is verified to have high stress. In high volt-age, rotational angle was increased more slightly, which seems that high stress and high temperature causes problems to Al, in other words, it is kind of thermal anneal to Al at high temperature. In electrothermal actuation, temperature was assessed by back calculation from rotation angle.
depth information by indicating closest line is the brightest line. This work provide new method for real-time stereoscopic endoscopic imaging with optical MEMS devices.

ACKNOWLEDGEMENT
This work was financially supported by the Ministry of Trade, Industry, and Energy (MOTIE 10041120), the Ministry of Science, ICT and Future Planning (MSIP 2013035236, 2013050154), National Research Foundation (NRF 2013M3A6A6073718) and as the Global Frontier Project (CISS-2012M3A6A6054199) of the Korea government.

REFERENCES

CONTACT
*K. H. Jeong, tel: +8242-350-4363; kjeong@kaist.ac.kr