ANALYSIS AND VALIDATIONS OF OPTICAL IMAGE STABILIZATION ACTUATOR FOR CELLPHONE CAMERA MODULES

Hsieh, Chang-Lin, and Wang, Hsiao-Yu, and Chang, Yu-Hao, and Liu, Chien-Sheng*

Department of Mechanical Engineering and Advanced Institute of Manufacturing with High-tech Innovations, National Chung Cheng University, Chiayi County 62102, Taiwan.

*Corresponding author: imecsl@ccu.edu.tw

Abstract

Along with the booming development of the mobile cellphones, the cellphones with camera modules become more and more important and popular. As a result, these days, consumers take the function of cellphone camera modules into account. With the advance of science and technology, the cellphone camera modules with only the autofocus function have been very popular and cannot satisfy consumers' requirements. Therefore, manufacturers of cellphones have started launching the optical image stabilization function as the difference between high-end cellphones. The optical image stabilization function is necessary to help users get sharper and clearer images for the cellphone camera modules with the high pixels lens. Therefore, this present study proposes a novel optical image stabilization actuator for cellphone camera modules. In this present study, we describe the structure of the proposed optical image stabilization actuator, the numerically electromagnetic simulation, and a series of experiments to evaluate its properties. The experimental results show that the proposed optical image stabilization actuator has excellent performance.

1. Introduction

Recently, the sales of smartphones grow year by year, and there are more cellphone brands attempting to share the profit. Cellphones develop rapidly due to the competitive market. For capturing consumers' attention, the manufacturers need to add the attractive functions to cellphones. The cellphone with the autofocusing (AF) camera module is basic now. Users can get clear and sharp images by camera module with AF function, but it can't satisfy users' requirement. Because of the handheld vibration, the image still may blur. Therefore, the way to solve the problem is to add the optical image stabilization (OIS) function in the cellphone camera module. It can help the user get sharper and clearer images. Recently, the OIS function can be found in the high-end cellphones because manufacturers want to attract consumers by the OIS function.

There are different kinds of literature about miniature actuators used in cellphone camera modules. These miniature actuators contain stepping motors, polymer deformable membrane [1-4], liquid lenses [5-8], ultra-sonic motors [8-10], and voice coil motors (VCMs) [11-15]. However, the VCM is the first choice for the cellphone camera modules due to its excellent performance and low cost.

The cellphone display is getting bigger and thinner for its development trend. It limits the height of the cellphone camera modules. Therefore, the limit of the size in the height is the thorniest problem for the cellphone camera modules. Hence, this present study presents a novel OIS actuator for cellphone camera modules to solve the stated problem. The height of the proposed OIS actuator was reduced with the novel chamfered magnets. Following sections include the design description and the numerical simulation of the proposed OIS actuator, and a series of experiments to evaluate its properties.

2. Novel electromagnetic structure of proposed OIS actuator

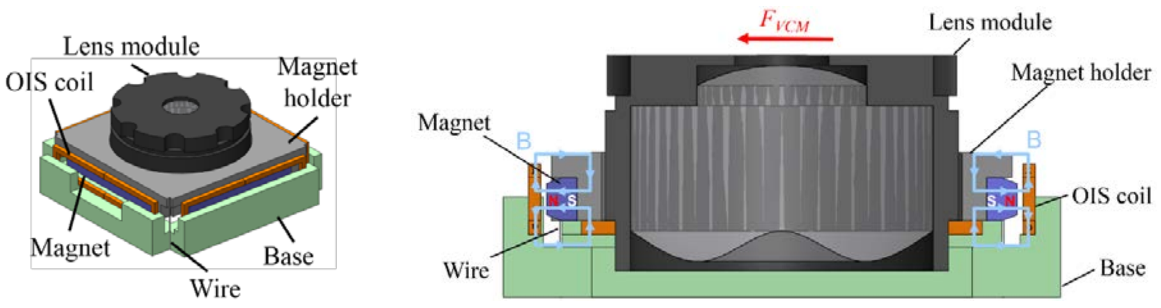
In this section, the novel electromagnetic structure of the proposed OIS actuator was introduced. Fig. 1 illustrates its electromagnetic structure and cross-section view. The proposed OIS actuator contains two parts. One is the moving part that comprises four permanent magnets, a magnet holder, and a lens module. Another is the fixed part that comprises a base, four spring wires, and four OIS coils. Through observing the structure, it’s simple to realize the characteristics of the novel electromagnetic structure and the working principle. Comparing with the commercial OIS actuator, the layout of the proposed novel design can reduce its height because the OIS coils of the proposed novel design are fixed at the lateral direction. The interaction between the OIS coils and the chamfered magnets can supply the Lorentz force F_{VCM} with a input current passed. Therefore, the moving part can be controlled by adjusting the magnitude of the input current. Fig. 2(a) and 2(b) show the distributions of magnetic flux in direction perpendicular to coil current when the displacements δ are 0.1 mm and -0.1 mm, respectively. The resultant Lorentz force F_{VCM} is given by

$$F_{VCM} = F_R + F_L, \tag{1}$$

where F_L and F_R mean the left and right Lorentz forces, respectively. When δ is 0.1 mm, the gap between the OIS coil and magnet at the right side is reduced, however, the gap between the OIS coil and magnet at the left side is increased. Hence, the OIS coil at the right side can interact with stronger magnetic flux to compensate weaker magnetic flux at the left side. In other words,

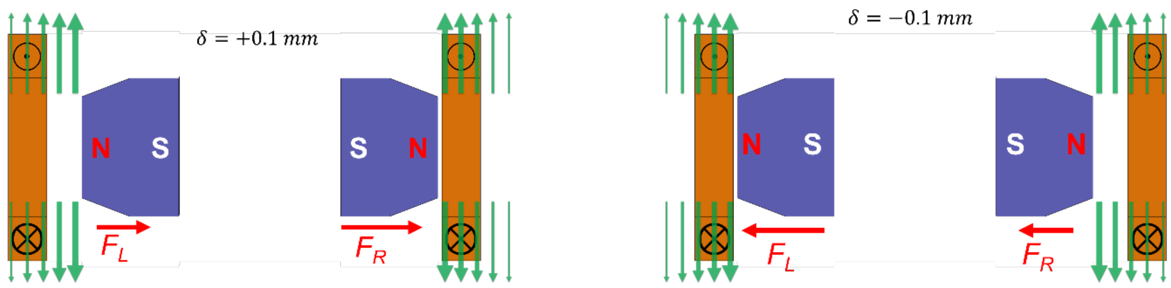
$$F_R > F_{L.} \tag{2}$$

When δ is -0.1 mm, F_L increases to compensate the reduction of F_R. Therefore, the proposed novel design can supply the stable F_{VCM}. It means the resultant Lorentz force F_{VCM} is equal to constant. Through realizing the layout and the working principle of the proposed novel electromagnetic structure, it’s obvious that the novel design can reduce the module height and supply more stable Lorentz force F_{VCM}.



(a) (b)

Figure 1: (a) Structure and (b) cross-sectional view of proposed OIS actuator.



(a) (b)

Figure 2: Magnetic flux distributions in proposed OIS actuator for various displacements δ (a) δ = 0.1 mm, and (b) δ = -0.1 mm.

3. Electromagnetic design and analysis

Numerical simulations of the proposed electromagnetic structure were performed in this section. Firstly, the properties of the commercial OIS actuator were analyzed in order to compare with the proposed novel design. Fig. 3 illustrates the cross section view of the structure for the commercial OIS actuator with the sizes of 9.5 mm × 9.5 mm × 3.11 mm [16].

With the OIS function, the Lorentz force F_{VCM} need to overcome the weight of the moving part W_{OIS} and the restoring resilience force F_W of the spring wires at different postures. As shown in Fig. 4, when the Lorentz force F_{VCM} need to actuate the moving part to the negative direction which is parallel to the direction of the gravity (see Fig. 4), its power consumption is the highest. At this most rigorous situation, the necessary Lorentz force F_{VCM} must satisfy the following equation:

$$F_{VCM} = F_W + W_{OIS}. \quad (3)$$

Therefore, this present study simulated the most rigorous situation. Fig. 5(a) and Fig. 5(b) illustrate the simulation results for the proposed OIS actuator and the commercial OIS actuator, respectively. As shown, it needs an input current of about 40 mA to actuate the moving part to the displacement of -0.1 mm for the proposed OIS actuator. However, the commercial OIS actuator needs an input current of more than 50 mA to actuate the moving part to the displacement of -0.1

mm at the most rigorous situation. The simulation results show that the proposed OIS actuator is more powerful and more efficient when comparing to the commercial OIS actuator.

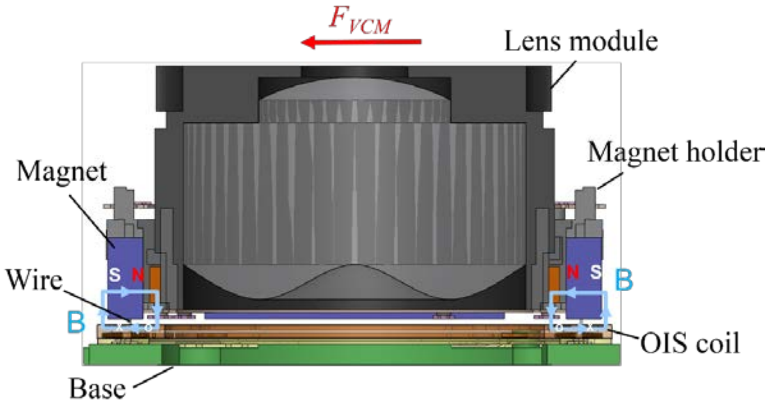


Figure 3: Cross-sectional view of structure in the commercial OIS actuator.

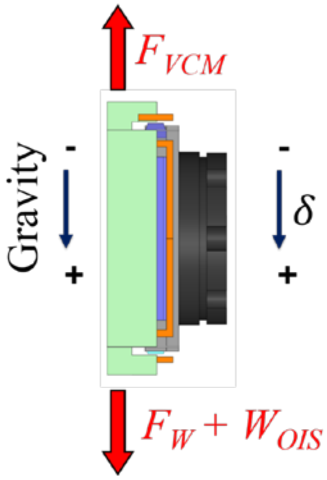
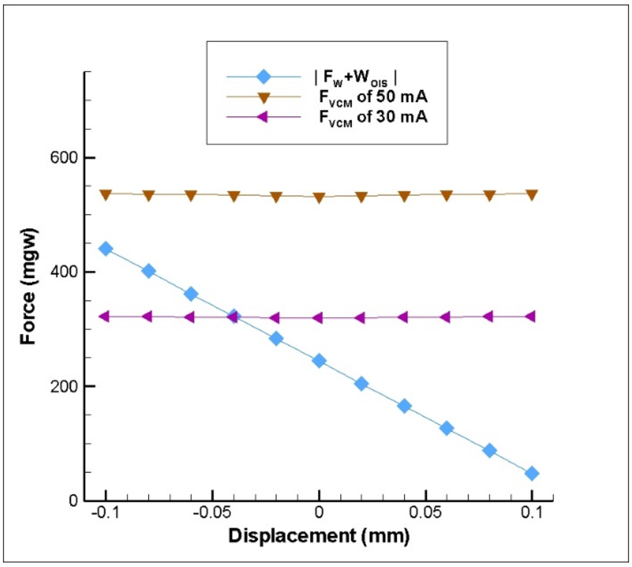
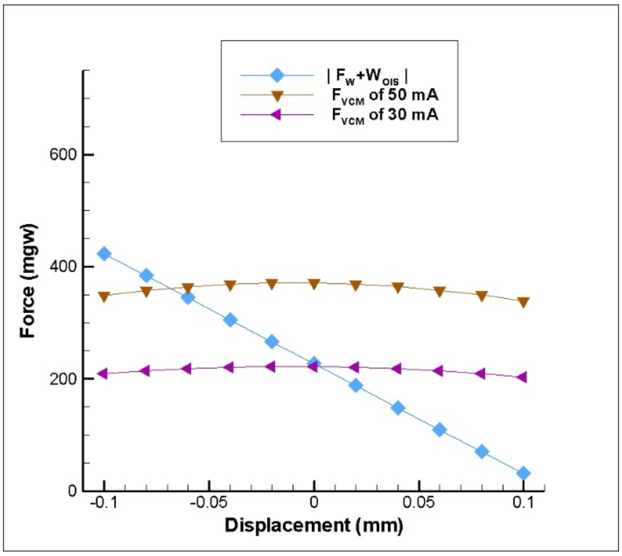


Figure 4: Free-body force diagram of proposed OIS actuator when moving part moves vertically.



(a)



(b)

Figure 5: Simulation results for variation of F_W and F_{VCM} with actuator displacement as function of input current for (a) proposed OIS actuator and (b) commercial OIS actuator.

4. Prototype fabrication and experimental evaluation

This section discusses the experimental results including the variation of the output Lorentz force with the input current, and the variation of the measured displacement with the input current. These two experiments are done using a laboratory-built prototype with the sizes of 11.4 mm $\times$ 11.4 mm $\times$ 2.26 mm (see Fig. 6).

Figs.7 and 8 show the experimental results. It can be observed that the Lorentz force F_{VCM} is stable. From Figs. 5 and 7, the maximum difference of the Lorentz force between the simulation results and the experimental results are 3.2% and 4% for the input currents of 30mA and 50 mA, respectively. From Fig. 8, the linearity of the measured displacement-input current curve is 0.998 at 0° posture. It means the curve is quite linear. There is an initial displacement of 0.029 mm at 90° posture due to gravity's effect. Therefore, the experimental results prove that the proposed OIS actuator is more efficient with a reduced module height when comparing to the commercial OIS actuator.

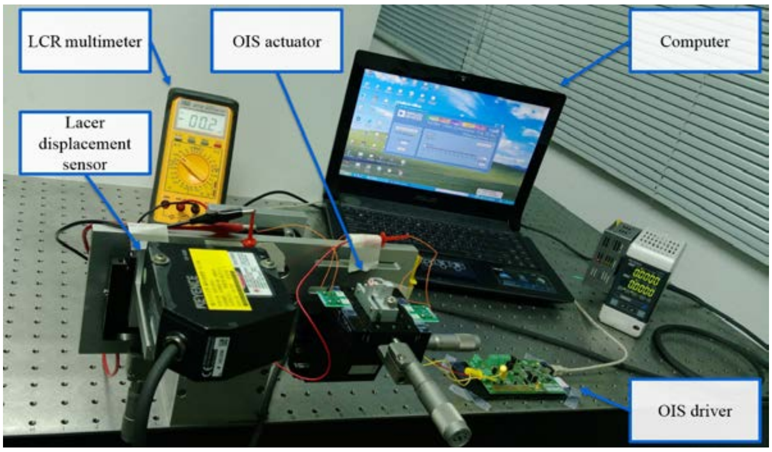


Figure 6: Photograph of experimental setup and laboratory-built prototype.

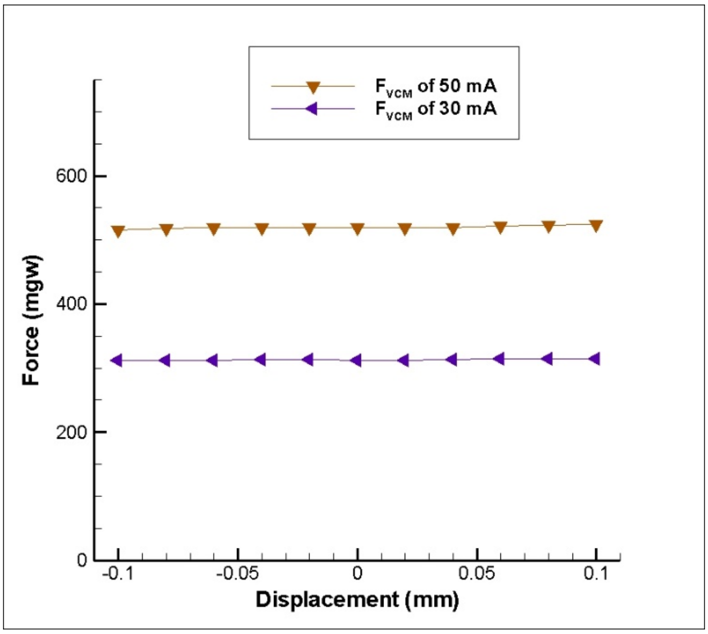


Figure 7: Experimental results for variation of F_{VCM} with current.

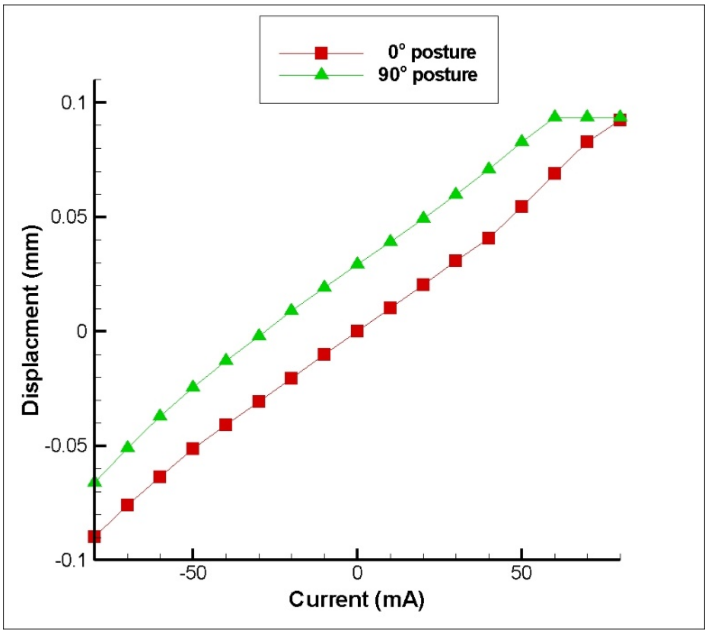


Figure 8: Experimental results for variation of displacement with input current at different postures.

5. Conclusions

This present study has presented a novel OIS actuator for cellphone camera modules. The proposed OIS actuator is analyzed through the numerical simulation and a series of experiments. The experimental results show that the performance of the proposed novel design is excellent and the proposed OIS actuator has a more stable Lorentz force, a shorter height, and a higher efficiency.

Acknowledgements

The authors gratefully acknowledge the financial support provided to this paper by the Ministry of Science and Technology of Taiwan under Grant Nos. MOST 105-2221-E-194-013-MY5, 103-2221-E-194-006-MY3, 106-2218-E-194-002, 106-2622-E-194-004-CC2, 105-2218-E-194-004, and 105-2218-E-194-003.

Reference

[1] J. L. Wang, T. Y. Chen, C. W. Liu, C. W. E. Chiu, and G. D. J. Su, "Polymer deformable mirror for optical auto focusing," ETRI J., vol. 29, pp. 817-819, 2007.

[2] J. L. Wang, T. Y. Chen, Y. H. Chien, and G. D. J. Su, "Miniature optical autofocus camera by micromachined fluoropolymer deformable mirror," Opt. Express, vol. 17, pp. 6268-6274, 2009.

[3] H. K. Lee, N. J. Choi, S. Jung, K. H. Park, H. Jung, J. K. Shim, J. W. Ryu, and J. Kim, "Electroactive polymer actuator for lens-drive unit in auto-focus compact camera module," ETRI J., vol. 31, pp. 695-702, 2009.

[4] C. Kim, S. J. Kim, H. Yang, N. C. Park, Y.P, Park,"An Auto-focus Lens Actuator Using Ionic Polymer Metal Composites: Design, Fabrication and Control," Int. J. Precis. Eng. Manuf., Vol. 13, No. 10, pp. 1883–1887, 2012

[5] H. Ren, H. Xianyu, S. Xu, and S. T. Wu, "Adaptive dielectric liquid lens," Opt. Express, vol. 19, pp. 14954-14960, 2008.

[6] F. S. Tsai, S. H. Cho, Y. H. Lo, B. Vasko, and J. Vasko, "Miniaturized universal imaging device usingfluidic lens," Opt. Lett., vol. 33, pp. 291-293, 2008.

[7] F. S. Tsai, S. H. Cho, Y. H. Lo, B. Vasko, and J. Vasko, "Miniaturized universal imaging device using fluidic lens," Opt. Lett., vol. 33, pp. 291-293, 2008

[8] H. P. Ko, S. Kim, S. N. Borodinas, P. E. Vasiljev, C. Y. Kang, and S. J. Yoon, "A novel tiny ultrasonic linear motor using the radial mode of a bimorph," Sens. Actuators A, vol. 125, pp. 477-481, 2006.

[9] H. P. Ko, H. Jeong, and B. Koc, "Piezoelectric actuator for mobile auto focus camera applications," J. Electroceram., vol. 23, pp. 530-535, 2009.

[10] T. Y. Zhou, Y. Zhang, Y. Chen, C. Y. Lu, D. Y. Fu, Y. Li, and X. P. Hu, "A nut-type ultrasonic motor and its application in the focus system," Chin. Sci. Bull., vol. 54, pp. 3778-3783, 2009.

[11] L. Ren, R. H. Lee, H. R. Park, H. Ren, C. Nah, I. S. Yoo,"A Liquid Lens Driven by Bubble Actuator," J. Microelectromech. Syst., vol. 22, NO. 5, 2013.

[12] C. S. Liu, S. S. Ko, and P. D. Lin, "Experimental characterization of high-performance miniature auto-focusing VCM actuator," IEEE Trans. Magn., vol. 47, no. 4, 2011.

[13] L. K. Lai, and T. S. Liu, "Design of compact linear electromagnetic actuator for auto-focusing in phone camera," IEEE Trans. Magn., vol. 47, no. 12, pp. 4740-4744, 2011.

[14] H. C. Yu, T. C. Chen, and C. S. Liu, "Adaptive fuzzy logic proportional-integral-derivative control for a miniature autofocus voice coil motor actuator with retaining force," IEEE Trans. Magn., vol. 50, no. 11, 2014.

[15] S. Koganezawa, H. Sano, H. Tani, and N. Tagawa, "Reduction in secondary-actuator displacement in dual-stage actuator system by imparting rotational stiffness in hard disk drives," Microsyst. Technol., vol. 21, no. 10, pp. 2187–2195, 2015.

[16] C. Y. Lu, T. S. Tseng, and W. H. Hsu, "Lens driving device," TW Patent M493077, 2015.