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## Multifunctional Liquid Lens for Variable Focus and Zoom

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### **Highlights**

- This paper presents a multifunctional liquid lens (MLL) for miniature camera modules integrated in smart devices such as smartphones and tablets.
- The MLL offers concurrent variable-focus and variable-magnification functions in a single liquid lens system.
- Imaging focus and zoom tests are carried out using a prototype MLL.
- The proposed MLL offers a simple design structure but covers a wide range of imaging focus and magnification operations used to achieve high optical performance.

This paper presents a novel multifunctional liquid lens (MLL) for miniature camera modules integrated with smart devices such as smartphones and pads. MLL firstly offers concurrent variable-focus and variable-magnification functions in a single liquid lens system using two different actuation schemes: electrowetting-on-dielectric (EWOD) actuation for controlling the curvature of liquid interface and electromagnetic actuation for controlling the height of the liquid column. Imaging focus test is carried out using the prototype of MLL. When a target electrical voltage is applied to an electrode covered by a hydrophobic dielectric layer on the inside wall of a glass cylindrical lens chamber, the curvature of liquid interface is changed according to the principle of EWOD and the focal length of the lens is changed. As a result, an initially blurred check pattern image is clearly focused. Imaging magnification test is separately conducted. When an electrical voltage is applied to an electromagnetic system located beneath the prototype of MLL, a ring-shaped magnet presses an elastic membrane down. As a consequence, liquid residing in the actuation chamber is pumped into the lens chamber through open walls of a supporting frame, and the height of the liquid column in the lens chamber rises. The height change of the liquid column as a function of the applied voltage is measured by using a CCD camera. The height of the liquid column is linearly increased from 0 mm to 1.2 mm with the rise of applied voltage from 0 V to 50 V with 5 V increment. The average height variation per volt is about 24  $\mu\text{m}$ . For the proof of concept, the sequential imaging focus and magnification test of MLL is demonstrated using simultaneous EWOD and electromagnetic actuation. Finally, the response time of MLL is measured by using a high-speed camera. The proposed MLL offers a simple design structure to be easily miniaturized but covers a wide range of imaging focus and magnification operations for high optical performance.

Keywords: Variable lens, Liquid lens, Electrowetting-on-dielectric (EWOD) actuation, Electromagnetic actuation, Miniature camera module

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