Improved stability of electroactive elastomer tunable lenses

Jonghyeon Ka[1], Imbo Gong[1] and Wooksung Kim[1, *]

wsungkim@postech.ac.kr
[1]77, Cheongam-ro, Nam-gu, Pohang-si, Gyeongsangbuk-do, Republic of Korea
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ABSTRACT

An electrically-tunable lens with dielectric elastomer actuators (DEAs) is designed to change the lens' focal-length f. The tunable lens can solve the Vergence Accommodation Conflict of the Head-Mounted Display (HMD). The tunable lens varies f by changing the radius of curvature when voltage is applied.

1 Introduction

We proposed a tunable lens composed of silicone oil, DEAs, acryl frame, and carbon grease. The lens had highly-tunable *f*, and transmittance. We also constructed the system by using LabVIEW software and a sensing circuit to estimate the DEA's capacitance and control the lens' *f*. We expect our system to be applied to a head-mounted display that has a consistently tunable *f* with high usability. Tunable lenses that can change the focal-length are essential components in optical systems and soft robotics. Heavy and bulky systems can be replaced with light and compact designs by using a tunable lens.

1.1 Vergence accommodation conflict

Existing Head Mounted Display such as VR and AR, the focal length of the lens is fixed, which causes a vergence accommodation conflict (VAC), making the user feel sickness and dizziness while wearing head-mounted display (HMD). The tunable lens can solve the VAC of the HMD by adjusting *f*.

1.2 Dielectric elastomer actuator (DEA)

Dielectric Elastomer Actuators (DEAs) have been used in the manufacture of tunable lenses. These lenses can change the focal-length *f* by applying a voltage to the DEA, changing the lens' radius of curvature. They have a fast response time, which can realize multi-focal planes, and the lens fabrication is easy because of its simple structure. However, predicting the lens' shape deformation is difficult due to DEA's viscoelastic and nonlinear characteristics. These properties of DEA degrade the system's stability and do not permit consistent change of *f*.

2 Experiment

We fabricated a lens with a *f* that can be changed using a dielectric elastomer actuator (DEA) and silicone oil. We also established a control system to prevent the continuous strain change caused by the nonlinearity of the DEA. Capacitance and resistance, which are electrical parameters of DEA, were extracted and calculated to compare with the measured *f* of the lens. In addition, by adjusting the voltage to keep the extracted capacitance constant, we confirmed experimentally whether the control system maintains a constant f.

2.1 DEA liquid lens fabrication

The lens consists of two dielectric elastomer membranes (VHB4905, 3M Co. Ltd) and silicone oil (63148-62-9, SIGMA-ALDRICH) with a refractive index of 1.4 and a viscosity of 100,000 cSt (25 °C). To increase the transmittance and lower the driving voltage, we pre-stretched two VHB films to 16 times the initial area and fixed them to an acrylic frame. To change the refractive index of the lens, we applied 10 ml of silicone oil to the fixed film and covered the other film on the oil. Finally, we applied carbon grease to all parts except where silicone oil exists to actuate the membrane.

2.2 Self-sensing algorithm experimental setup

After generating the actuation signal for extending the DEA and the sensing signal for estimating capacitance in the form of a sine wave, a high voltage amplifier boosts these signal's voltage by 1000 times. When signals enter the electronic circuit, LABVIEW software measures voltage and current. Finally, this software can estimate the DEA's capacitance by compensating for phase delay due to the impedance difference between the capacitor and the resistance.

2.3 Focal-length measurement experimental setup

We measured the lens' *f* using an optic track, halogen lamp, and collimating lens. The connected collimating lens and halogen lamp can generate parallel light rays; when they pass through the manufactured tunable lens, they converge into a point. The smallest point of the collected light was defined as the focal-length f_i under that condition i.

2.4 Experimental process

We measured the electrical parameters of the lens in its initial state with an LCR meter and the initial focal-length f_o of the lens with zero bias. After connecting the tunable lens to the measurement electronics, we increased the voltage to 4 kV in 100-V increments. The LABVIEW software measured the capacitance of the tunable lens in real-time; this capacitance changes whenever the voltage increases. Similarly, by measuring *f* which changes whenever the voltage increases, we matched the capacitance and *f*. Finally, using the measured capacitance and the initial lens radius, and assuming the lens to be spherical, we predicted the change in *f* of the lens when voltage was applied.

3 Results

We compared the measured and estimated *f* of the lens to verify the system's controllability. These experimental results verify the tunable lens's high tunability and stability by estimating the capacitance.

3.1 Experimental results

We measured the *f* and estimated it by using LabVIEW software and a sensing circuit. The comparison between measured and estimated *f* shows the accuracy of the control system. The *f* was proportional to the quadratic polynomial of the capacitance, and both *f* had similar tendencies. Both methods had the same maximum *f* of 21.1 cm, and the minimum *f* was 11.5 cm by measurement and 11.84 cm using LabVIEW software.

4 Discussion

When 4 kV was applied to the DEA, the measured *f* was 6.9 cm and the calculated *f* was 6.5 cm; i.e., the error was 6%. The *f* measurement method and lens aberration can explain the error. We assumed that the light source operates as a planewave when measuring the lens' *f*. However, the plane wave does not exist and light passing through the lens is not focused correctly, so the estimated *f* is wrong. In addition, chromatic aberration occurs when the light passes through the lens, so the accurate measurement of *f* is difficult. The *f* of the lens showed tunability by 50% compared to the initial *f*. These results verify that our lens system has high tunability and can control *f* stably. Our system can be applied to a head-mounted display and improves usability by reducing dizziness. We expect that the electrically tunable lens will enable varying focal length in optical systems without bulky and heavy optical components, leading to HMD with much smaller and compact form factors than currently available.

5 Conclusions

We designed an electrically-tunable lens composed of silicone oil, DEA, and sandwiched carbon-grease electrodes. When a voltage is applied, the lens's radius of curvature changes, so focal length is reduced. However, predicting the lens's shape deformation and maintaining a stable *f* is difficult because DEA has viscoelastic and nonlinear characteristics. Therefore, we estimated the capacitance of the DEA by using LabVIEW software and a sensing circuit, which controls the lens' shape deformation to have a stable *f*. The suggested control method showed a lower error, proving that it can control a *f* more stable. In addition, we expect that such a tunable lens will maximize its advantages when used in HMDs such as VR and MR because it is lighter and more compact than conventional lenses and solves VAC problems.

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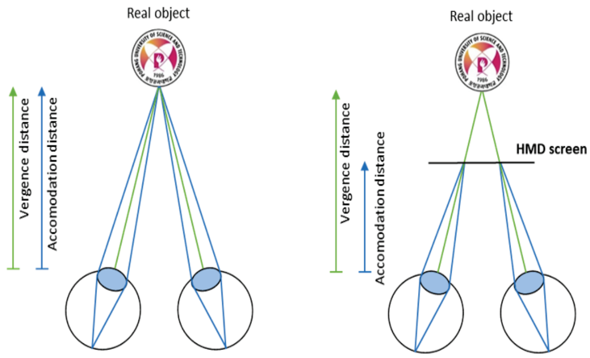

Fig. 1 Vergence accommodation conflict, natural vision (a), 3d display (b)

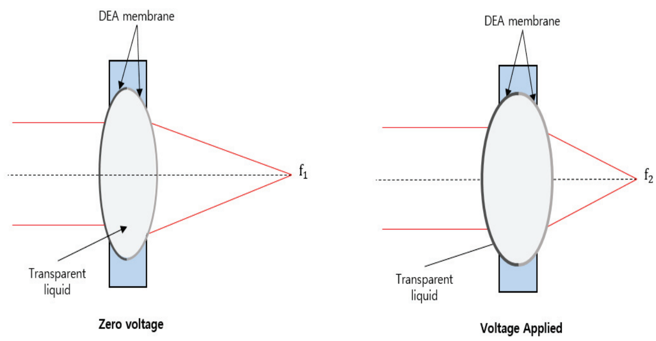

Fig. 2 Schematic design of the tunable lens, without voltage (a), voltage applied

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