Supplementary Material

Supporting material 1: Analysis of field curvature and distortion in the proposed varifocal Alvarez lenses

Field curvature leads to different sharpness levels between the center and the edges of the image, so the field curvature should be kept as small as possible. From the design results, the field curvature values at various focal lengths are minimal, with the maximum field curvature occurring at the telephoto focal length, but it is still less than 1 mm. Distortion causes image distortion but does not affect the sharpness of the image. According to the distortion results, the distortion value of this lens is minimal. The field curvature and distortion values at various focal lengths are shown in Fig. 1(a)-(c).

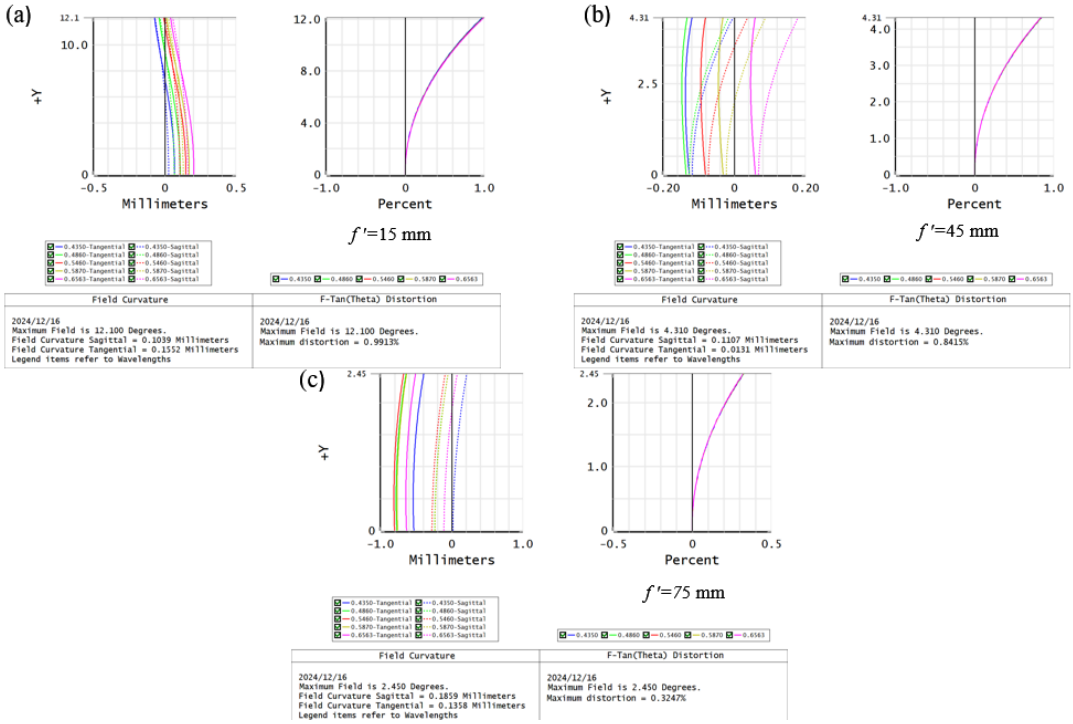

Fig. 1. (a)-(c) The field curvature and distortion diagrams at focal lengths of 15mm, 45mm, and 75mm.

Supporting material 2: Assembly of the actuator structure

The drive structure of the proposed varifocal Alvarez lenses is shown in Fig. 2. The drive structure is assembled with the overall lens structure using four screws. There are four screw holes around the frame of the drive structure, and after assembling the structure with the lens, it is fixed in place using four screws. The fixed structure is shown in Fig. 3. When assembling the drive structure with the lens, the positioning is done using the outer surface of the Alvarez lens (the relatively flat side). The central thickness of the lens is 3mm, and the thickness of the frame that holds the lens is 2.5mm. When the outer surface of the Alvarez lens protrudes 0.5mm from the lens frame, the gap between the phase plates is controlled to be 0.7mm. The driving process of the drive structure is supported by video 1.

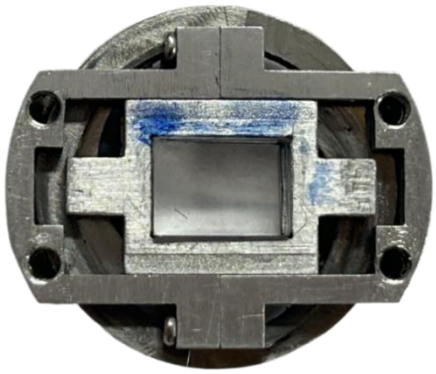

Fig. 2. The fabricated drive structure.

Fig. 3. The front schematic of the proposed varifocal Alvarez lenses, where the four screws are used for assembly with the drive structure.

Supporting material 3: Light field intensity distribution of the lens

Fig.4 shows the optical simulation results of the FFT PSF and the Huygens PSF. The results show that the varifocal lens at the long focal length has the highest energy and the most uniform spot, and it at the short focal length has poor spot quality. The intensity of the light field of the outgoing light at the three focal lengths is measured by an image quality analyzer (GCI-110102) via experiment. As can be seen in Fig. 5, the light field intensity is more uniform and higher in energy at the long focal length. The intensity of the light field at the middle and short focal lengths decreases significantly and shows an asymmetric and multi-peak structure. These experimental results are similar to the simulation results but with a slight decrease, which may be related to the alignment error during the mounting of the Alvarez lens.

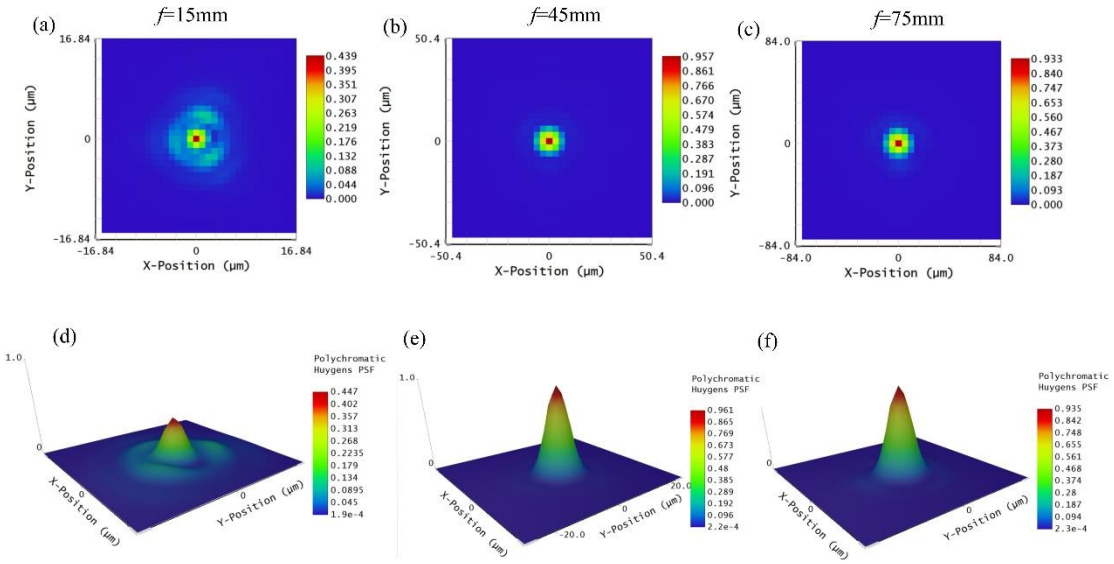

Fig. 4. Simulation diagram of light field intensity. (a)-(c)The FFT PSF of the focal length at 15mm,45mm, and 75mm. (d)-(f)The Huygens PSF of the focal length at 15mm,45mm, and 75mm.

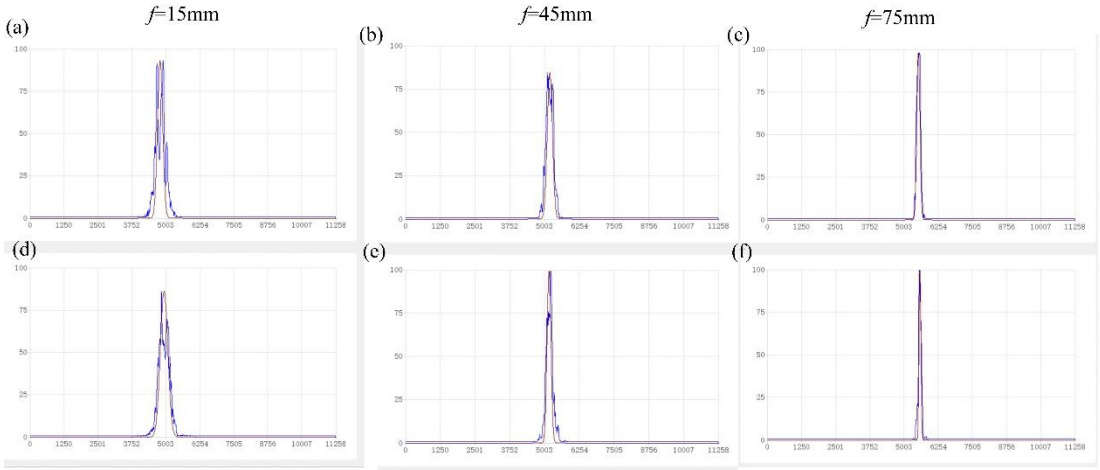

Fig. 5. Experimental analysis diagram of light field intensity. (a)-(c) Intensity distribution of the transverse light field at focal lengths of 15mm, 45mm, and 75mm. (d)-(f) Longitudinal light field intensity distribution at focal lengths of 15 mm, 45 mm, and 75 mm.

Supporting material 4: PSNR and SSIM of the lens.

We evaluated the original image for the image simulation as well as the image after being imaged by the lens, and Fig. 6 (a) shows the original image of the lens. Fig. 6 (b)-(d) are the results of image simulation when the focal lengths are 15mm, 45mm, and 75mm, respectively. They were compared with the original images, respectively, and the results are shown in Tab. 1.

Fig. 6. (a) Original image for image simulation, (b)-(d) Results of image simulation with focal lengths of 15mm,45mm, and 75mm, respectively.

Tab. 1. The PSNR and SSIM of the varifocal lens

Focal length	PSNR (dB)	SSIM
15 mm	23.27	0.87
45 mm	20.59	0.79
75 mm	20.22	0.78

Supporting material 5: Resolution version of test experiments performed on USFA1951

The sensor model OV2719 was used for the test of different resolution plates, and the resolution plate used in this experiment was USAF 1951. The resolution images captured at focal lengths of 15 mm, 45 mm, and 75 mm are shown in Fig. 7 (a)-(c).

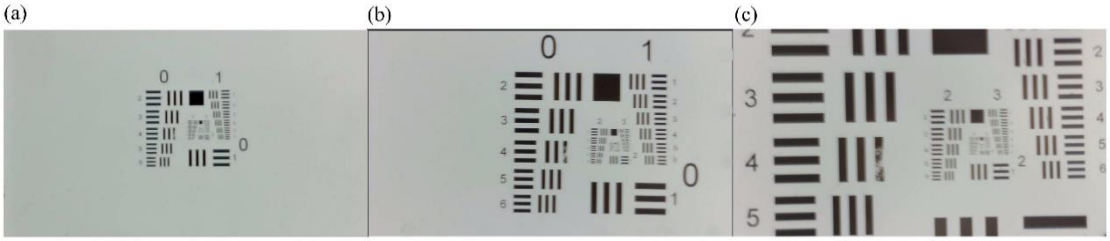

Fig.7. Imagining the USFA1951 resolution version using the model OV2719 sensor

Supporting material 6: Varifocal experiment by changing different sensors

The sensor was replaced with VEN-830-22U3C for focusing experiments on objects of different distances. The three dolls are 130mm, 217mm, and 331mm away from the lens respectively, and the zoom ring was adjusted to make the object lens focus on the objects. The imaging results are shown in

Fig. 8 (a)-(c). Through experimental analyses, neither the use of a different resolution test board nor the replacement of a different sensor affects the use of the lens.

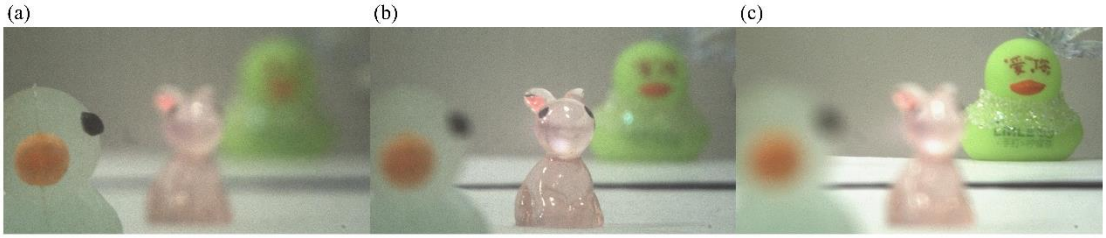

Fig. 8. Focusing experiments were conducted on different distant objects using another sensor model VEN-830-22U3C. (a) Object located 130 mm away from the lens. (b) Object located 217 mm away from the lens. (c) Object located 331 mm away from the lens.