[Invited] Pixel aperture and offset pixel aperture techniques for 3-dimensional imaging

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Abstract In this paper, the pixel aperture and offset pixel aperture techniques for 3-dimensional imaging are presented. In general, the aperture is located at the camera lens. However, in the proposed image sensor, the aperture is integrated on the CMOS image sensor chip and is formed at a metal layer of the CIS process. A pixel pattern which comprises red, blue, and white pixels with or without the pixel aperture is used for implementing the color image and extracting the depth information. In the pixel aperture technique, the focused image from the pixel aperture pixels and the defocused image from the white pixels were obtained. The depth information was obtained using two images from the pixel aperture and white pixels with different blur. In the offset pixel aperture technique, the disparity information was obtained from the left offset pixel aperture and right offset pixel aperture pixels. The CMOS image sensors with pixel aperture and offset pixel aperture techniques were fabricated using 0.11 μm CIS process and its performance was evaluated.

Keywords: CMOS image sensor, pixel aperture, offset pixel aperture, 3-dimensional imaging

1. Introduction

In a conventional CMOS image sensor (CIS), only two-dimensional (2D) images without depth information can be obtained. To obtain depth information, the techniques such as time of flight (TOF), stereo vision, and structured light have been developed [1][2].

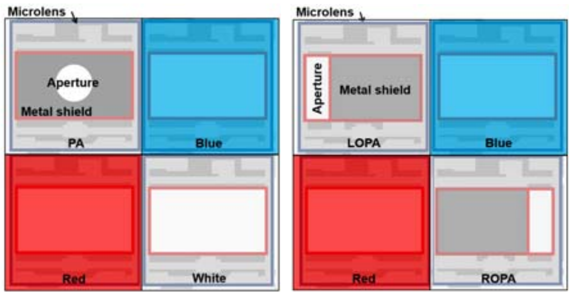
However, an external light source is required in the TOF technique. Multiple cameras are necessary for the stereo vision technique. The structured light technique suffers from high hardware cost of implementation.

In the proposed CIS, 2D images with depth information are obtained using a single camera without an external light source and the proposed image sensor is implemented using a simple system comprising of low-cost hardware. In addition, the proposed CIS using small size pixel with a four-transistor (4-Tr) active pixel sensor (APS) based on a pinned photodiode (PPD) can be easily adapted to high resolution commercial cameras such as mobile devices and digital cameras.

2. Proposed CMOS image sensor

Figs. 1(a) and 1(b) show color patterns for the pixel aperture (PA) and offset pixel aperture (OPA) techniques [3][4]. In the PA technique, the color pattern is composed of the PA, blue (B), red (R), and white (W) pixels. The PA pixel is based on the W pixel and the aperture of PA pixel was formed at the first metal layer which is located above the PPD. In the OPA technique, the color pattern is composed of the left offset pixel aperture (LOPA), B, R, and right offset pixel aperture (ROPA) pixels. The LOPA and ROPA are based on W pixel.

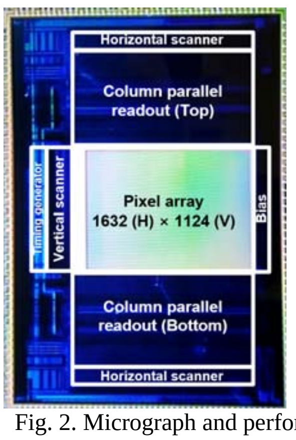
The APS is based on the 4-transistors structure with the PPD and its size is 2.8 × 2.8 μm^2. The APS was designed using 0.11 μm CIS process. The structure of an APS is composed of a microlens, a PPD, metal layers for the signal line, and other components. The microlens of the pixel is an essential element to obtain depth information and the incidence light is focused on the first metal layer by the microlens.



(a) (b)

Fig. 1. Color patterns for (a) the PA and (b) OPA techniques.

Micrograph and performances of the fabricated CIS are shown in Fig. 2. The proposed CIS with dimensions of 7 × 10 mm^2 is composed of a 1632 × 1124 pixel array, a timing generator (TG), column parallel programmable gain amplifiers (PGAs), analog to digital converters (ADCs), and scanners. The power supplies of the proposed CIS are the 3.3 V for the analog and 1.5 V for the analog and digital. The W pixel without the aperture has a sensitivity of 2.89 V/lux·s, while the sensitivity of the B and R pixels are 1.61 V/lux·s and 1.76 V/lux·s, respectively. The conversion gain of the pixel is measured to be 112 μV/e-.



Parameter	Value
Technology	0.11 μm 2P4M CIS process
Chip size	7 mm (H) × 10 mm (V)
Power supplies	1.5 V (digital / analog) 3.3 V (analog)
Number of pixels	1632 (H) × 1124 (V)
Pixel type	4-Tr pinned photodiode
Pixel size	2.8 μm × 2.8 μm
Sensitivity	B : 1.61 V/lux·s R : 1.76 V/lux·s W : 2.89 V/lux·s @ 2850 K with IR cut filter
Conversion gain	112 μV/e-
Full well capacity	7343 e-
Frame rate	15 fps
Power consumption	387 mW

Fig. 2. Micrograph and performances of the fabricated CIS.

3. Measurement results

In the PA technique, Fig. 3 shows the point spread function (PSF) images from the W and PA channels and the full width at half maximum (FWHM) of PSFs. At the top, the PSF images as functions of the distance are compared. The PSFs were obtained from 101 × 101 pixels and the camera lens was focused at a distance of 30 cm. The PSF from the PA channel is less blurred than that from the W channel, and the difference in blur size increases as the distance increases. The FWHM according to the distance is shown in Fig. 3 (bottom).

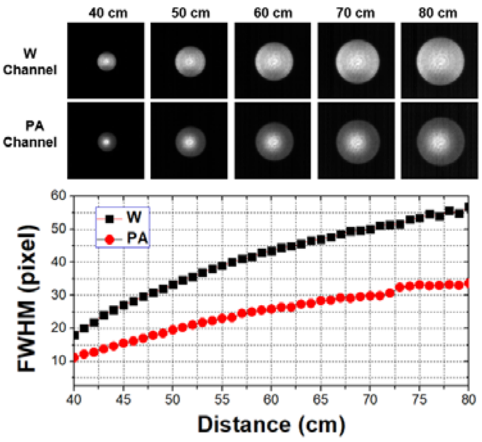


Fig. 3. PSF images captured from W and PA channels and the FWHM of the PSFs.

Fig. 4 shows the image taken by the fabricated CIS and a depth image extracted from it. The captured 2D image was obtained by the simple color interpolation using the B, R, and W channel. The depth image was obtained by the images from the W and PA channels using the depth from the defocused method.

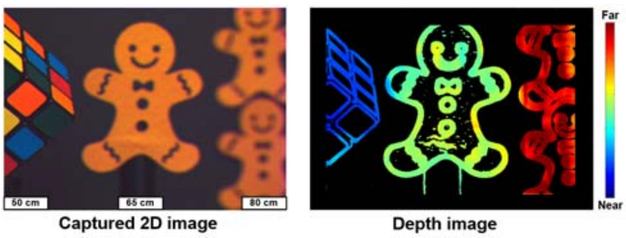


Fig. 4. Captured 2D image and the depth image.

In the OPA technique, measurement results demonstrating variations in disparity with changes in distance are shown in Fig. 5. Comparing the disparities for various distances between the camera lens and the object, the disparity when the distance between the camera lens and the object was 20 cm is larger than the disparity when the distance was 130 cm. The disparity was simply calculated by subtracting the edge of the output image from LOPA and ROPA channels. The disparity increases with the distance and the depth could be calculated based on this disparity information.

Fig. 6 shows the original image captured by the proposed CIS with OPA technique, and contains the depth information with the degree of disparity. The objects with the text were used in the distance range from 100 cm to 120 cm, and the lens was focused at the 100 cm. In addition, Fig. 6 shows the depth image obtained from the original image using the depth extraction algorithm. The depth image shows that the objects were distinguished according to the distance.

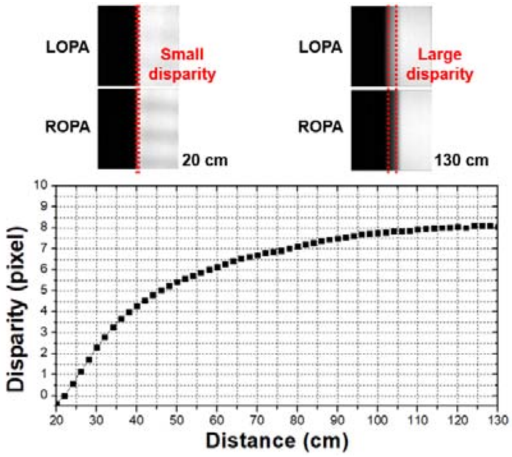


Fig. 5. Measurement results demonstrating variations in disparity with changes in distance.

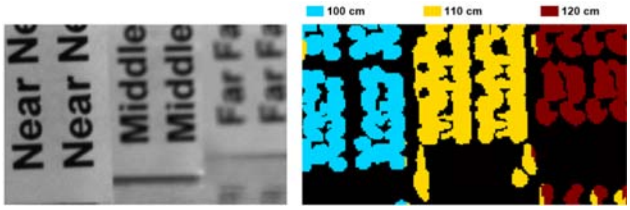


Fig. 6. Original image and depth image from the original image.

4. Conclusion

The CISs with PA and OPA technique were fabricated using the 0.11 μm CIS process and performances of the CISs were evaluated. In the measurement results, the depth information was extracted using the PA and OPA techniques and the depth image could be calculated using depth information. The proposed techniques might be useful in 3D imaging techniques using CIS and it is applicable to gesture recognition, object reconstruction, and motion detection.

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