CMOS Image Sensor with Pseudorandom Pixel Placement For Jaggy Elimination

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Abstract The pixels in the conventional image sensors are placed at lattice positions, and this causes the jaggies at the edge of the slant line we perceive, which is hard to resolve by pixel size reduction. The author has been proposing the method of reducing the jaggies effect by arranging the photo diode at pseudorandom positions, with keeping the lattice arrangement of pixel boundaries that are compatible with the conventional image sensor architecture. In this paper, the author discusses the design of CMOS image sensor with pseudorandom pixel placement, as well as the preliminary evaluation of the fabricated CMOS image sensor.

Keywords: CMOS image sensor, jaggy, displacement, Vernier accuracy

1. Introduction

The image sensors have been developed for enhancing the quality of the image representation, with the trend of pixel size reduction in conjunction with the other technologies. The pixels in the conventional image sensors are placed at lattice positions, and this causes the jaggies at the edge of the slant line[1]. The reduction of pixel size also decreases the size of jaggies, however, it is hard to completely eliminate the jaggies ``perceived'' by our eyes, since our eye system has a high sensitivity for perceiving the small steps forming jaggies, so called the Vernier accuracy[2].

The author has been proposing the method of reducing the jaggies by arranging the effective area (photo diode) at pseudorandom positions, with keeping the lattice arrangement of pixel boundaries that are compatible with the conventional image sensor architecture[1]. The author has indicated that the pseudorandom pixel placement has the effect of eliminating “perceived” jaggies compared with the conventional lattice pixel placement with the same pixel size[3]. In this paper, the author discusses the design of CMOS image sensor with pseudorandom pixel placement, as well as its preliminary evaluation.

2. Pseudorandom pixel placement

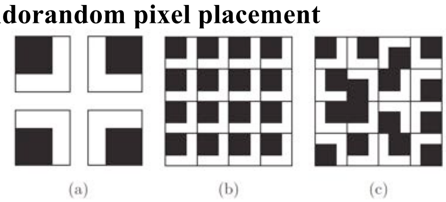


Fig.1. Pixel structure and the active area arrangement. (a)Four types of pixels, (b)Conventional lattice placement, and (c)Pseudorandom pixel placement.

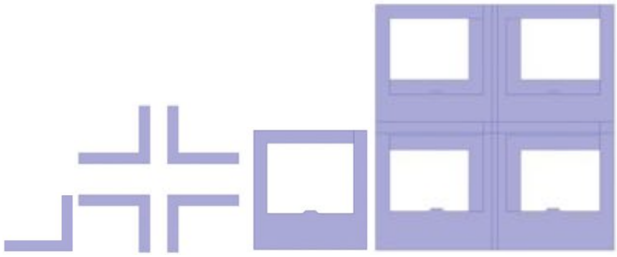
The concept and the example of pseudorandom pixel placement for jaggies reduction are shown in Fig.1. The white box and black box represent the pixel boundary and the photo diode (PD) area, respectively. Here we call the PD area as the active area, which effectively contributes to the image acquisition. Since the PD occupies a part of pixel area, we can generate several pixels with different active area positions. The four types of pixels are shown in Fig.1(a). We obtain the conventional pixel placement by placing one of these pixels at lattice positions, as shown in Fig.1(b). By placing randomly-chosen one of the four pixels at lattice position, we obtain the randomly-placed active areas, as shown in Fig.1(c), which we call pseudorandom pixel placement.

3. Design of CMOS image sensor with pseudorandom pixel placement

We designed the CMOS image sensor with pseudorandom pixel placement for evaluating the jaggy elimination effect in the captured image by the physical CMOS image sensor. It is possible to design four types of pixels with the different positions of the phot diodes, with keeping the identical physical electric terminals[1]. However, it is difficult to keep the large photo diode area under the physical design restriction to realize these pixels. For example, the pixel under this design strategy has the fill factor of 25%[1]. We started the image sensor design using the conventional CMOS image sensor. We employed a pixel with LOFIC capacitor for dynamic range enhancement[5,6,7] using CMOS 0.18um, five metal layers image sensor process. The pixel size is 7.8um x 7.8um with the photo diode of 6.26um x 5.06um, where the fill factor is 51.8%.

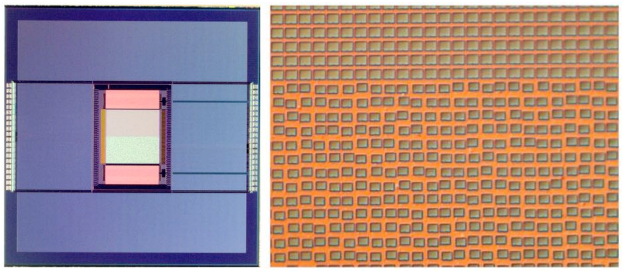
Here, we designed the photo shield as shown in Fig.2 (a) to implement the four types of pixels for the pseudorandom pixel placement. The boundary box size is equal to the size of the PD aperture of the pixel. Figure 2(b) shows the four types of the photo shield generated by rotating the photo shield. We can obtain the four types of pixels with the different “effective"” PD positions by overlappling them to the original pixel (Fig.2(c)) as shown in Fig.2(d). The fill factor is 35.7%.

Figure 3(a) shows the photograph of the fabricated CMOS image sensor. The chip size is 5mm x 5mm, and the number of pixels is 128 x 128. The upper half 128 x 64 pixels are designed without photo shields (lattice plain), while the lower half 128 x 64 pixels are designed with randomly chosen photo shield (pseudorandom plain), as shown in Fig.2. The magnified photographs of the pixel region are shown in Fig.3(b) for both the lattice and the pseudorandom plain.



(a) (b) (c) (d)

Fig.2. Partial photo shield(a), four types of photo shields(b), the top metal layout of the original pixel(c), and the four types of pixels with different photo diode positions(d).

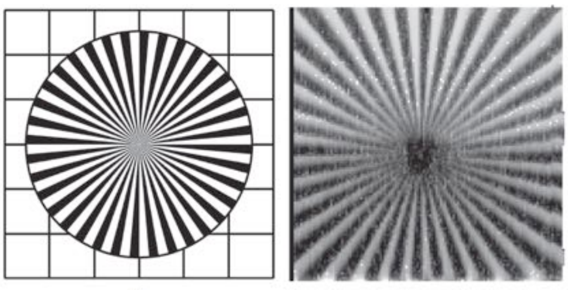


(a) (b)

Fig.3. Photograph of the fabricated CMOS image sensor(a) and magnified photographs of the pixel plains(b). (The upper area is lattice plain, and the lower area is pseudorandom plain.)

4. Evaluation of the fabricated CMOS image sensor

We carried out the evaluation of the fabricated CMOS image sensor with control signals generated by FPGA (Xilinx XC6SLX45-2FGG484C) and the signals capture by 16bit A/D converters to transf to PC. Figure 4(b) shows the the captured image for the target in Fig.4(a). Here, the pixels are represented at the lattice positions for both the lattice and the pseudorandom plain. It is confirmed that the photo sensitivity for pseudorandom plain is lower than that for the lattice plain, since their fill factors are different.



(a) (b)

Fig.4. Target object(a) and the captured image(b).

Figure 5 shows the digitized binary image generated from the captured image in Fig.4 (b). Note that the different thresholds in digitize are applied for the upper half (lattice) plain and the lower half (pseudorandom) plain, since the photo sentivities for the pixel in each area are different. The threshold is manually adjusted so as to obtain the same line width. Here, the pixels are represented based on the physical pixel parameters for both the lattice and the pseudorandom plain. One physical pixel is represented by 10$\times$10 pixels, where the pixel value is represented by the active area whose sizes are 7 x 7 and 6 x6 pixels, respectively, to reflect the physical structure of photo receptors. It is confirmed the jaggies appearance are dependent on the angle of the slant line edge in the lattice plain. For example, there are no jaggies for the vertical line edge, while a large jaggy at the slant edge with small angle, and a small jaggy at the slant edge with large angle. The jaggies appearance dependency on the line angle is one of the factors to image quality degradation[3].

We can confirm that the jaggies appearances are independent on the angle of the slant line edge in the pseudorandom plain. There are small random steps for all the line edges in pseudorandom plain, which can be easily eliminated by the pixel size reduction.

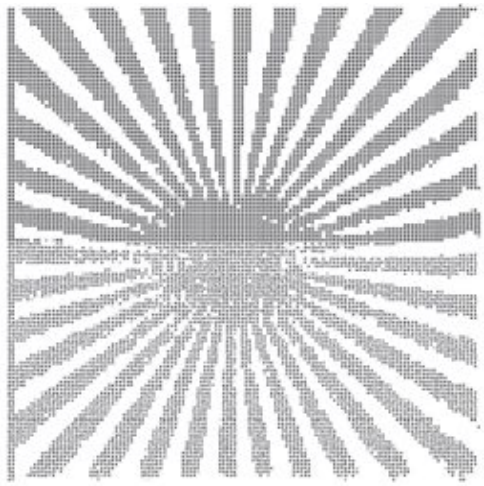


Fig.5. Digitized binary image generated from the captured image.

5. Conclusion

In this paper, we demonstrated the design and the evaluation of the CMOS image sensor with pseudorandom pixel placement. Although the pseudorandom pixel placement has the decreased fill factor and the photo sensitivity compared with the conventional ones, jaggies elimination effect has the possibility on image quality enhancement.

Acknowredgement

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