CMOS IMAGE SENSOR WITH PSEUDORANDOM PIXEL PLACEMENT FOR JAGGY REDUCTION IN LINE REPRESENTATION

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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. There exist the jaggies at the edge of the slant line as shown in Fig.1. Although the size of the jaggy can be decreased by pixel size reduction, it is hard to completely eliminate the perceived jaggies with using the conventional lattice pixel placement, since our eye system has a high perceive sensitivity for the jaggies[1, 2].

The authors have been proposing the method of reducing the jaggies effect by arranging the effective area (photo diode) at pseudorandom positions, with keeping the lattice arrangement of pixel boundaries that compatible with the conventional image sensor architecture. The authors have indicated that the pseudorandom pixel placement has the jaggy elimination effect compared to the conventional lattice pixel placement with the same pixel size[3, 4].

In this paper, we discuss the relation of the jaggies reduction effect using pseudorandom pixel placement and the pixel parameters in terms of spatial frequency of jaggies, as well as a CMOS image sensor implementation.

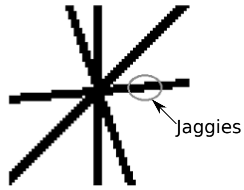


Figure 1: Example of jaggies at the edge of the slant line

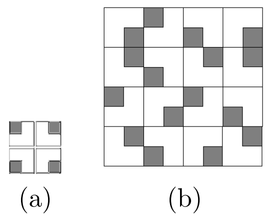


Figure 2: Four types of pixel structure(a), pseudorandom pixel placement(b).

2 EXPRESSION OF LINE WITH PSEUDORANDOM PIXEL PLACEMENT

2.1 Principle of pseudorandom pixel placement

The concept and the example of pseudorandom pixel placement for jaggies reduction are show in Fig.2, where the white box and black box represents the pixel boundary and the area and the photo diode (PD), respectively. Since the PD occupies a part of pixel, we can generate pseudorandom arrangement of the PDs by placing various types of pixels whose PD positions are different, as shown in Fig.2(a) and Fig.2(b). The spatial positions of the PDs by pseudorandom pixel placement have the small random scatter at the edge, and the jaggies steps are 'dissolved' into the pairs of the pixels.

Although we have high sensitivity on perceiving the jaggies or the isolated step[2], we have low sensitivity on perceiving the continuous random step generated by pseudorandom arrangement. Thus, the 'dissolved' jaggies are not strongly perceived. The small random scatter at the edge by pseudorandom pixel placement is not strongly perceived by human eye, as shown in Fig.4.

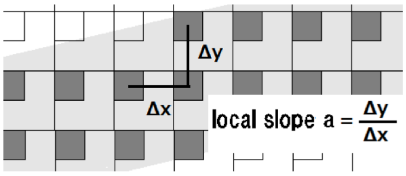
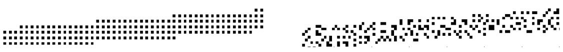


Figure 3: Definition of the local slope of a slant line.

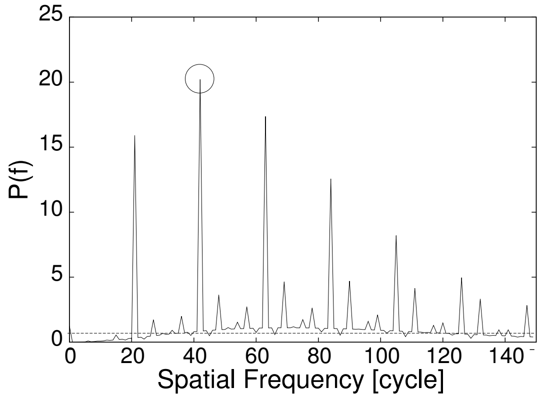


(a) (b)

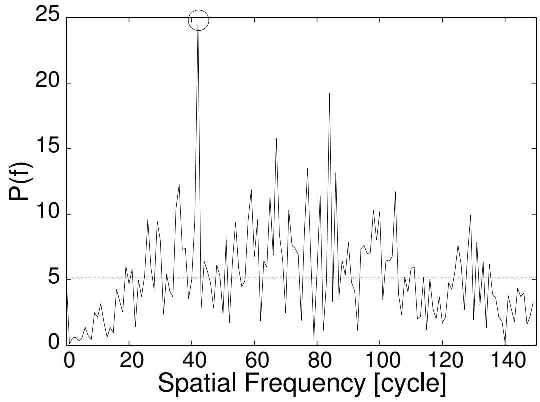
Figure 4: Examples of slant line representation with (a)conventional pixel placement and (b)pseudorandom pixel placement.

2.2 Jaggy appearance measure in a slant line representation and pixel parameters

The measure how we strongly perceive the jaggies at the edge of a slant line are relational to the cycle of jaggies, or the spatial frequency of the jaggies. Here, we assume that we watch the presented image composed of the pixels whose pitch is 0.3[mm] at the distance of 60[cm]. We define the local slope of edge of a slant line, "a" as shown in Fig.3. The value of other than 0 means the step at the edge of a line, and the cyclic occurrence of the step forms jaggies. The product of the spatial spectrum of 'a' and the characteristics of the human eye's perceiving sensitivity[2] gives the characteristics of the 'perceived' jaggies. Jaggies are recognized the standing factor in the spatial spectrum within the range where we strongly perceive, while the multiple factors or flat (white) spatial spectrum within the range where we strongly perceive would NOT form the clear jaggies, as shown in Fig.5. Here, we define the value of 'Top/Other' as a measure how we strongly perceive the jaggies, which is calculated as the ratio of the strongest factor in the spatial spectrum to the average of the other factors in the calculated spectrum. The value of Top/Other represents how the standing factor is strong in the spatial spectrum, or how we strongly perceive the jaggies, as shown in Fig.6.



(a)



(b)

Figure 5: Examples of the spatial spectrum of the local slope, "a" for the slant line with the angle of 10[deg] with (a)Conventional pixel placement and (b) Pseudorandom pixel placement. (Dotted line: average power except peak, circle indicates: peak factor)

(a) (b) (c)

Figure 6: Examples of the represented slant lines and the value of Top/Other of (a)23.4, (b)6.6, and (c)2.7.

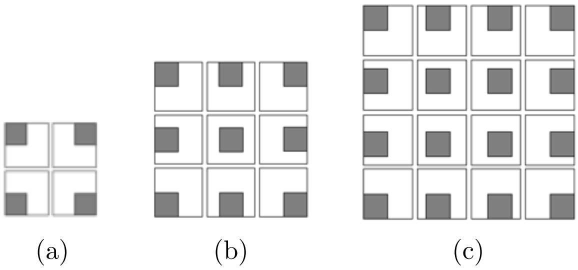


Figure 7: Pixel placement types of (a)4 types, (b)9types, and (c)16 types.

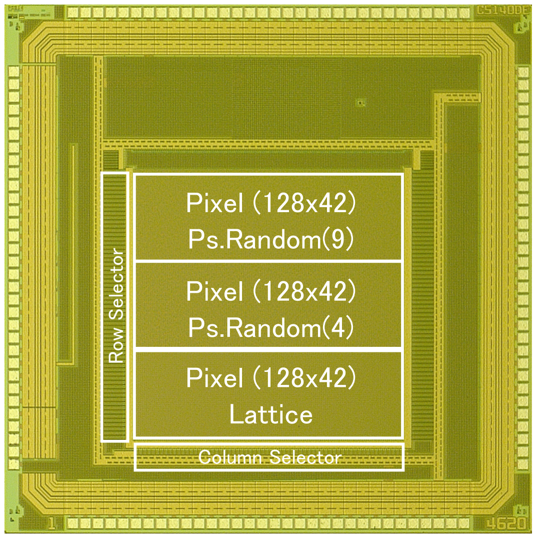


Figure 9: Designed CMOS image sensor with pseudorandom pixel placement

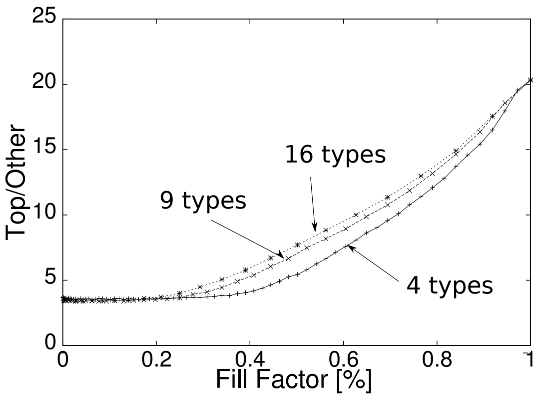
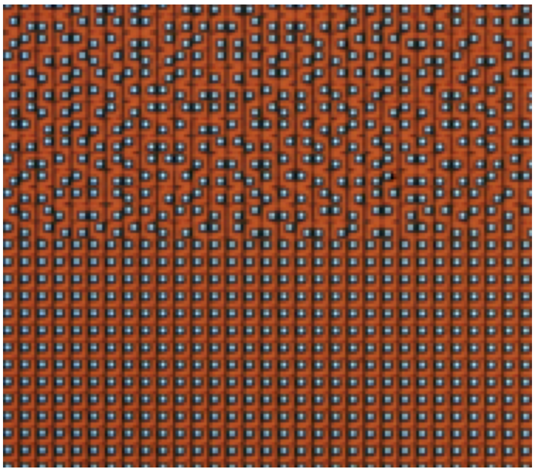


Figure 8: Top/Other for 4, 9, and 16 types pixels

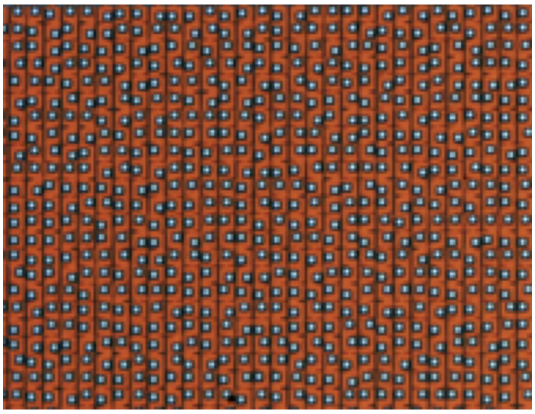
We calculated the Top/Other for three cases of pixel types (4, 9, and 16) for pseudorandom generation selection as shown in Fig.7 for a slant line with various fill factors, using the virtual pixel method[4]. Fig.8 shows the average of Top/Other for all the lines with the slope of 1[deg] to 45[deg], with 10 random number trials, where we obtain the smallest Top/Other, or the least strongly perceived jaggies with pixel types of four, with the fill factor of larger than 0.3.

3 CMOS IMAGE SENSOR DESIGN

Fig.9 and Fig.10 shows the designed CMOS image sensor with pseudorandom pixel placement. The pixel size is 10[μm]x10[μm], with fill factor of 25% using the standard 3-Tr circuit. We designed the nine types of pixels whose photo diode positions are as shown in Fig.7(c), with the identical wiring. We designed three types of pixel placement; the conventional lattice, the pseudorandom using 4 types of pixels, and that using 9 types of pixels.



(a)



(b)

Figure 10: Magnified pixel plan (a)Pseudorandom with 4 type pixels(upper) and lattice (lower), (b)Pseudorandom with 9 type pixels

4 CONCLUTION

In this paper, we discussed the measure how we strongly perceive the jaggies at the edge of the slant line, and the pixel type numbers, as well as the design of CMOS image sensor.

References

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