Programmable sensitivity image sensor with multi-capacitance CMOS pixels

Ryutaro. Oi[†], Kiyoharu. Aizawa[†]

[†]Department of Frontier Informatics, The University of Tokyo

Aizawa Lab. Building #14, 7-3-1 Hongo, Bunkyo-ku Tokyo, 113-0033, Japan

Tel: +81-3-5841-6761 **Fax**: +81-3-5841-6782

Email: ooi@hal.t.u-tokyo.ac.jp

Abstract

Conventional linear response image sensors do not have enough dynamic range to capture wide range of natural scenes. So far, frame-based adaptation methods are widely used (Global adjustment). But, frame-based adaptations are not effective to capture a scene that has both very bright and very dark areas at the same time. We propose a programmable sensitivity image sensor that enables area-based adaptations (local adjustment) in order to remedy this problem. A 200 x 200 pixels of prototype chip was fabricated using 0.6um CMOS technology. Programmable sensitivity feature of the prototype is reported.

I. Introduction

Image sensors are widely used in consumer products such as digital still cameras and TV phone systems. Unfortunately, dynamic range of a single liner-response image sensor is not enough to obtain a wide luminance variation of natural scenes. In order to overcome this problem, conventional camera systems adopt frame-based sensitivity adaptation methods as shown in Figure 1. An IRIS control, a shutter-speed control and an AGC (Automatic Gain Control) have effect on entire pixels globally.

But, these frame-based sensitivity adaptations is not effective to a scene that is composed of very bright areas and dark areas at the same frame.

The method of [1] adopts 4 types of transparent filters in front of photodiodes and then, selects a most sufficient exposure pixel afterwards. Another conventional approach to this problem is exposure time control for each areas/pixels [2]. An area-based sensitivity adaptation method is necessary to get a high dynamic range image that contains both very bright and very dark areas.

II. Programmable sensitivity image sensor

We propose a new image sensor that can contain different-sensitivity pixels in one focal plane. By this local sensitivity adjustment, proposed image sensor prevents saturations at very bright areas. Thus, dynamic range of the image sensor's output can be widened by a circuit side approach.

Figure 2 shows a block diagram of the sensor. Proposed sensor has a sensitivity-flag memory array, a sensitivity-adjustable-pixel array and two readout scanners. The pixel array should have a capability of changing their sensitivities locally at two or more range. The sensitivity is set according to the flag memory value at every reset period of the pixel array. A sensitivity-flag memory should be located on the image sensor chip for storing sensitivity information that is written from external control circuit. Pixel values are readout through vertical and horizontal scanners. While sensitivity-flag memory value can be read and used for farther image processing.

Proposed method doesn't require an additional optical hardware nor an extra photodiode's reset. The method can be combined with an electrical-shutter-control method, because every pixel has a uniform integration time.

III. Sensitivity adjustable pixel

We designed a multi-capacitance CMOS pixel in order to provide a sensitivity adjustable function. Figure 3 shows a schematic of a pixel. C_2 stands for additional capacitances in the pixel circuit.

Here, we assume photocurrent I_p is proportional to light power P. So, the output voltage V can be described as follows.

◆ When C_2 is off

$$V = \frac{Q_1 - \int I_p \cdot dt}{C_1} \qquad (1)$$

Integration of photocurrent is continued until it reaches Q_1. (C_1 stands for parasitic capacitance of a photo diode. Q_1 stands for charge on C_1 right after a photo diode's reset.)

◆ When C_2 is on

$$V = \frac{(Q_1 + Q_2) - \int I_p dt}{(C_1 + C_2)} \qquad (2)$$

Integration of photocurrent is continued until it reaches Q_1+Q_2. (Q_2 stands for charge on C_2 right after a photo diode's reset.)

By adding C_2, equivalent capacitance of the photo diode can be increased. Thus, sensitivity of the pixel is reduced. It prevents a saturation problem of photo diodes at very bright area.

Reduction ratio of sensitivity is determined by a ratio of C_2 and C_1. Unlike other methods of combining multiple exposure images, our approach ensures the uniform-integration-time of photo diodes. Therefore, it doesn't suffer from motion distortions for moving objects.

IV. Prototype design

Figure 4 shows a prototype chip of the programmable sensitivity image sensor. The prototype chip was fabricated in 3-Metal, 2-Poly, 0.6um CMOS process. It has 200 x 200 pixels and has one additional capacitance in each pixel. The ratio of C_1:C_2 = 1:1. It enables twice (6dB) of dynamic range expansion. The floor plan of the chip layout is outlined in Figure 5. For this first prototype, we implemented small memory array beside the vertical scanner. Thus, sensitivity of pixel array can be changed row direction only at this prototype. Table 1 shows the characteristics of the prototype chip.

V. Experimental results

Figure 6 shows an evaluation environment for the prototype image sensor. Lighting is provided by a spotlight and a fixed-iris board lens is arranged in front of the prototype chip. Figure 7 shows the photo-response of a programmable sensitivity pixel, including lens. The prototype pixel has 2800mV of saturation voltage. The pixel saturated at luminance of 538 units as hi-sensitivity, while it saturated at 1060 units as low-sensitivity mode. The pixel is verified to have 0dB/-6dB of sensitivity at linear response region.

Figure 8 shows sample images taken by a prototype. Figure 8 (a) shows the hi-sensitivity output image (0dB) obtained by a prototype. Figure 8 (b) shows the low-sensitivity image (-6dB). Figure 8 (c) shows the mixed sensitivity image (0dB/-6dB) according to the on-chip memory.

VI. Conclusion

Conventional linear response image sensors do not have enough dynamic range to capture wide variety of natural scenes. Thus, frame based adaptation methods are commonly used. But, frame based adaptations are not effective to capture a scene that has both very bright and very dark areas. We propose a programmable sensitivity image sensor that enables area-based adaptations. A 200 x 200 pixels of prototype chip was implemented using standard 0.6um CMOS process. By using a prototype, 0dB/6dB range of programmable sensitivity feature was observed.

References

[1] Shree K. Nayar and Tomoo Mitsunaga, “High Dynamic Range Imaging: Spatially Varying Pixel Exposures,” Proc. IEEE Computer Vision and Pattern Recognition, 2000.

[2] T.Hamamoto and K.Aizawa, "A computational image sensor with adaptive pixel-based integration time," IEEE Journal of Solid State Circuits, Vol.36, No.4, pp.580-585, 2001.

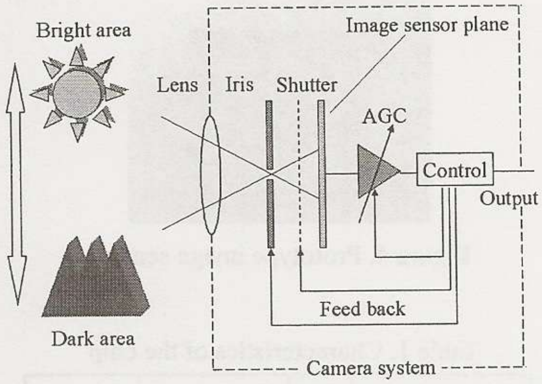


Figure 1. Frame-based sensitivity adaptation methods

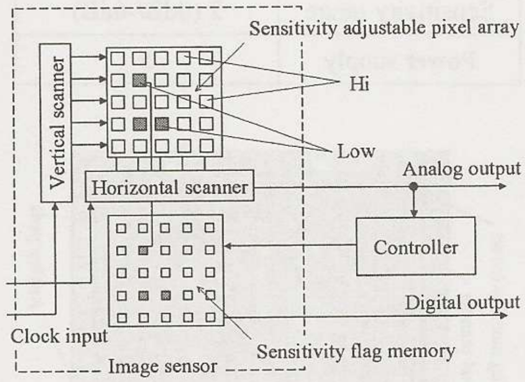


Figure 2. Block diagram of a programmable sensitivity image sensor

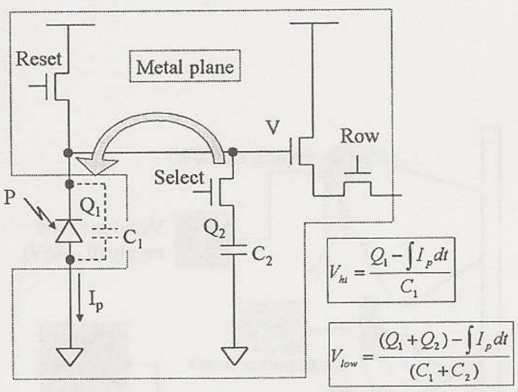


Figure 3. Schematic of a sensitivity adjustable pixel

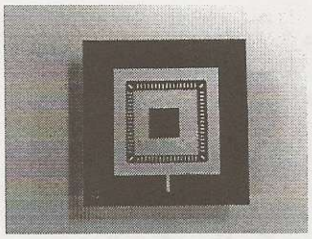


Figure 4. Prototype image sensor

Table 1. Characteristics of the chip

Number of pixels	200 x 200
Process	CMOS 0.6um
Pixel size [um^2]	20 x 20
Number of Tr.	4 transistors / pixel
Fill factor [%]	25
Sensitivity range	2 (0dB/-6dB)
Power supply	5

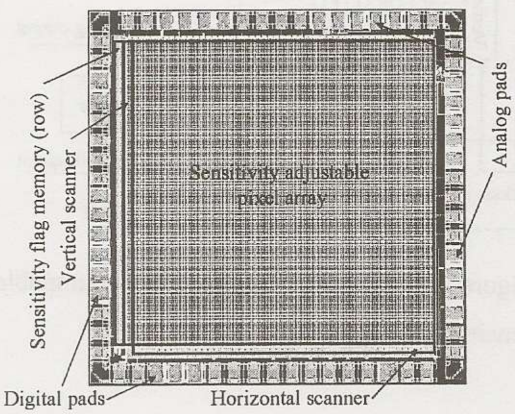


Figure 5. The floorplan of the chip

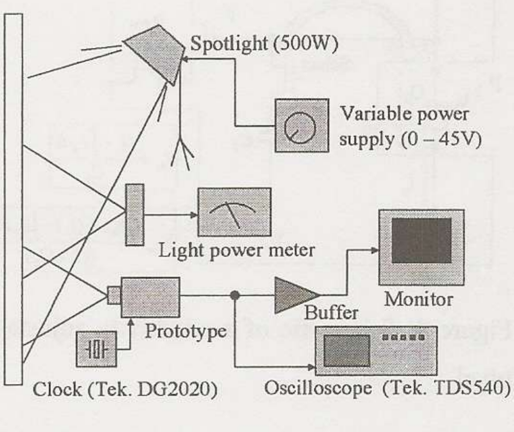


Figure 6. The evaluation environment

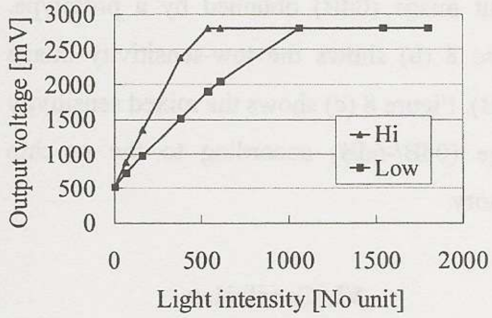
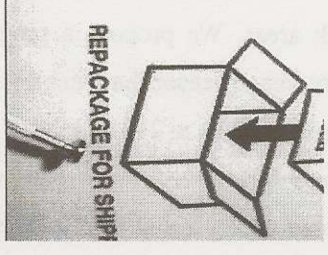
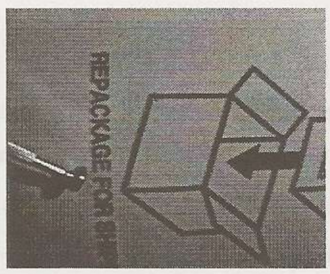


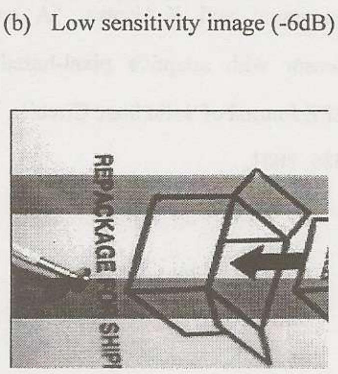
Figure 7. Photoresponse of the chip



(a) Hi sensitivity image (0dB)



(b) Low sensitivity image (-6dB)



(c) Mixed sensitivity image (0dB / -6dB)

Figure 8. Sample images taken by a prototype