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Analog and 15-b digital Output Image Sensor for Wide Dynamic Range

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1. Introduction

By using multiple-readout schemes with some different integration times, an intra-scene dynamic range can be improved [1]-[4]. We have been investigating adaptive-integration-time image sensors which control the integration time pixel by pixel [1][2]. The integration time is controlled by the method based on detection of motion or saturation [1] and image reconstruction can be done on the sensor by analog processing in real time [2].

In this paper, our new adaptive-image sensor based on two different methods is proposed. It outputs analog or 15 bits digital image data. The integration time of each pixel is selected among several lengths by comparing an intermediate pixel value with a threshold at any timing. For one of the two methods, the timings and the threshold are incorporated into the method of A/D conversion. Image reconstruction can be achieved easily by using simple bit shift on the sensor, the proposed sensor outputs 15 bits image data. Therefore the dynamic range of the pixel value is much more widened.

In the following sections, we describe two methods of imaging and the design of new image sensor on which the functions of controlling integration time and reconstructing image data are integrated.

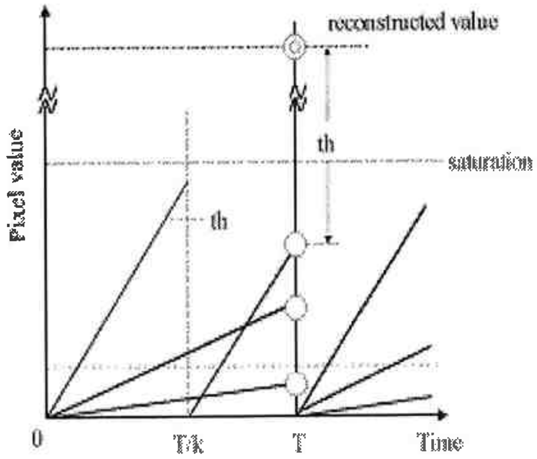


Fig.1 Integration process of pixel values (method A)

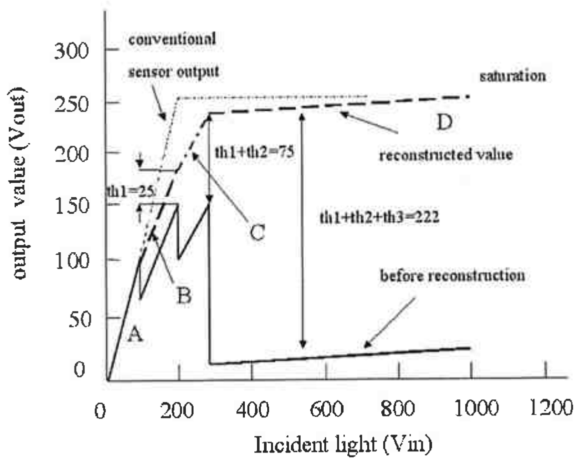


Fig.2 I/O characteristic (method A)

2. Wide dynamic range by controlling integration time of each pixel

2.1 Method A: nonlinear reconstruction and analog output

Method A is almost same method in [2]. We use the intermediate pixel values of each pixel to extend dynamic range. Fig.1 shows an example of an integrating pixel value based on method A. T is the maximum integration time and frame rate is decided by 1/T. At the intermediate of integration (T/k), the photodiode (PD) value is compared to a threshold (th). If the PD value exceeds the threshold, the PD value is selectively reset. Therefore, the integration time of a bright pixel is shorter than that of the other pixel. Because of the variable integration time, the pixel intensity needs to be reconstructed later. We can control both the comparison timing (k) and the threshold (th).

Fig.2 shows the I/O characteristic when the number of the comparison to the threshold is three. Only when the PD value exceeds the threshold, the PD value is reset and a flag signal is stored in a memory. At the end of the integration, the simple analog circuits for reconstruction could add the thresholds to the final PD value when the corresponding flag signals are high. Therefore the image can be reconstructed nonlinearly as shown in Fig.2.

2.2 Method B: linear reconstruction and digital output

Method B is entire new method. Fig.3 shows an example of an integrating pixel value based on method B. Although the timings of the detection-reset processing are varied and the different thresholds are used for each detection in method A, the timings are fixed and a common threshold is used for all detections in method B.

The intermediate PD value is compared to the threshold at T/2, 3T/4, 7T/8, ・・・. The interval of the detection-reset processing is gradually halved. Only when the PD value exceeds the threshold, the corresponding PD value is reset. Therefore the integration time for each pixel is selected from T, T/2, T/4, T/8,・・・, and the widen pixel value is reconstructed by using the final PD value and the length of the integration.

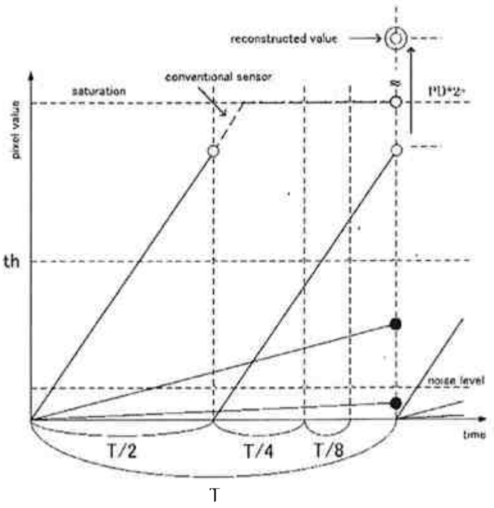


Fig.3 Integration process of pixel values (method B)

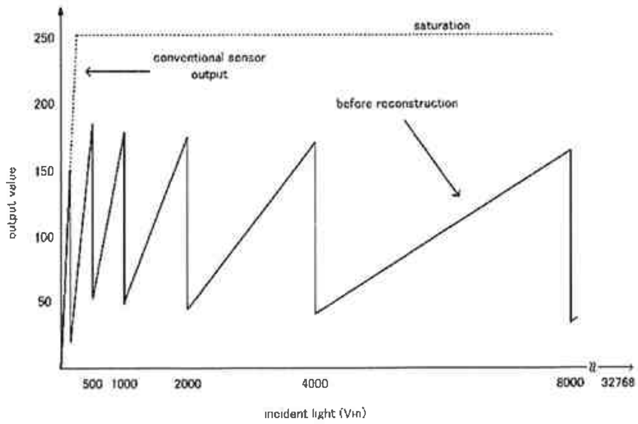


Fig.4 I/O characteristic (method B)

Fig.4 shows the I/O characteristic when 128 is set for the threshold. As shown in Fig.4, the inclination of the polygonal line for brighter pixel values decreases by half gradually.

Our new image sensor can set T/128 for the minimum interval of the detection-reset processing and 8 bits A/D conversion circuits are implemented on the sensor. By using the length of integration and the digitized final PD value, 15 bits linear images can be obtained on the sensor after reconstruction. Table 1 shows the relationship between the integration time and the digitized final PD value for reconstruction when 128 is set for the threshold. In Table 1, T to T/128 show the integration time of final PD values and the symbol "*" shows the position in which the digitized PD value is embedded. The table shows that the linear reconstruction can be done by the following.

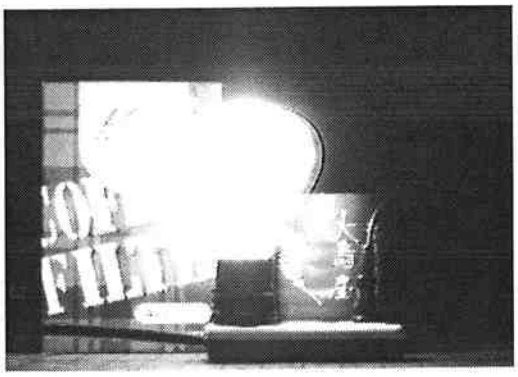
Final PD value x 2^n

where n is number of reset processing.

3. Computer simulation

Fig.5 shows the results of computer simulation using the still images of various integration times. Fig.5 (a) shows the conventional output image. Fig.5 (b) shows the reconstructed image obtained by method A. Fig.5 (c) shows the reconstructed image obtained by method B.

Although the center of the conventional image is saturated, the characters written in the peripheral part of a light bulb are much clear in the case of the proposed images. It appears that the proposed methods can widen the intra-scene dynamic range regardless of linear or nonlinear reconstruction.



(a) Conventional output image

(b) Proposed output image (method A)

(c) Proposed output image (method B)

Fig.5 Results of computer simulation

Table 1 Example of reconstruction by method B

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
T	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*
T/2	0	0	0	0	0	0	1	*	*	*	*	*	*	*	0
T/4	0	0	0	0	0	1	*	*	*	*	*	*	*	0	0
T/8	0	0	0	0	1	*	*	*	*	*	*	*	0	0	0
T/16	0	0	0	1	*	*	*	*	*	*	*	0	0	0	0
T/32	0	0	1	*	*	*	*	*	*	*	0	0	0	0	0
T/64	0	1	*	*	*	*	*	*	*	0	0	0	0	0	0
T/128	1	*	*	*	*	*	*	*	0	0	0	0	0	0	0

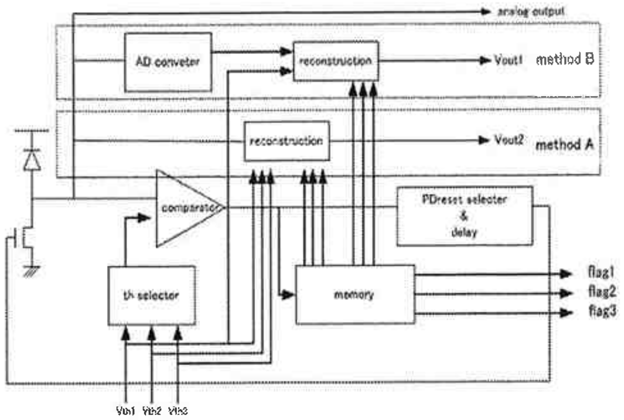


Fig.6 Processing scheme of a pixel

Table 2 Outline of the prototype

Number of pixel (pixels)	64×48
Chip size (mm^2)	3.55×8.45
pixel size (μm^2/pixel)	32×32
Transducer (Tr./pixel)	5
Memory (Tr./pixel,3bit)	15
Processing (Tr./column)	416
Fill factor (%)	29.6
Power (V)	5

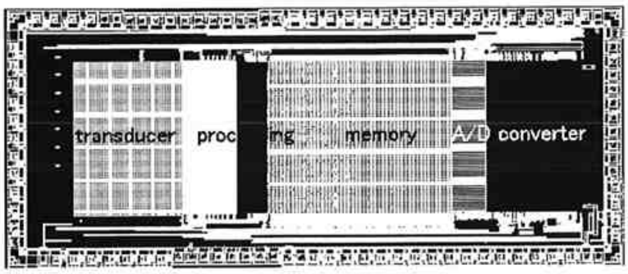


Fig.7 Prototype chip

4. Design and implementation of new smart image sensor

Fig.6 shows the processing scheme in each pixel of the wide dynamic range image sensor. It has processing circuits for the comparison to threshold and real time reconstruction, and 3 bit memory. Transducer, processing circuits, memory and A/D converter are implemented on the sensor separately.

The maximum number of the comparison to threshold during a frame is three for method A and seven for method B. The integrating PD value is compared to one of three different thresholds Vth1, Vth2 and Vth3 for method A, and Vth1 for method B.

We have fabricated prototyped sensor by using 2-poly 2-metal 0.8μm CMOS process. Fig.7 shows the layout of the prototype. We adopt a column parallel architecture for the circuits of processing and A/D converter. The test circuits are also implemented on the same chip. The outline of the prototype is listed in Table 2.

5. Conclusion

In this paper, we introduce a new wide-dynamic-range image sensor. The proposed sensor has the circuits for controlling integration time pixel by pixel and reconstructing nonlinear analog image and linear 15 bits digital image.

The prototype is now under further evaluation.

References

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