Motion Adaptive Image Sensor

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Abstract

We propose a motion adaptive sensor for image enhancement and wide dynamic range. The motion adaptive sensor is able to control suitable storage time pixel by pixel. Storage time of each pixel is controlled by saturation and temporal changes of detected incident light. The proposed sensor has computational elements on the focal plane that detects motion and saturation of the stored charge on photo diode in each pixel. By controlling storage time, it is expected to have high temporal resolution in the moving area, high SNR in the static area and wide dynamic range.

1 Introduction

In general, total quality of an image processing system is determined by image sensors. The performance of image enhancement by post processing is limited by the quality of original pictures.

Among the limitations of the image sensors, temporal resolution is one of the most serious to imaging quality. Conventional image sensor is operated at the fixed frame rate, such as 30 frames/second. In this paradigm, when an object is moving at higher speed more than the frame rate, motion blur is observed around moving object. Furthermore, saturation of dynamic range is also important to image quality. When object is partially very bright, the conventional sensor can not acquire entire scene from dark to bright region because of limited dynamic range. It is substantially difficult for post-processing to recover motion blur and saturation.

We have been investigating novel integration of sensing and processing to enhance the performance of image sensing by making use of temporal redundancy of image information [1]-[4]. In this paper, we present a motion adaptive sensor which controls storage time in each pixel. The proposed sensor not only operates at high frequency but also detects motion and saturation. The motion adaptive sensor is able to control the suitable storage time in each pixel, which results in no motion blur and no saturation. It is expected to have high temporal resolution in the moving area, high SNR and wide dynamic range in the static area.

2 Principle of the Motion Adaptive Storage Time

Figure 1 shows processing scheme in each pixel of the motion adaptive sensor. It is based on detection of motion and saturation. Each pixel keeps integrating charge on photo diode (PD) and is not reset until it detects motion or saturation. As shown in Figure 1, photo diode stores $\int_{t-n\Delta}^{t} I\,dt\ (= I_{PD})$, and the capacitance C_{st} keeps a delayed value of I_{PD}, $\int_{t-n\Delta}^{t-\Delta} I\,dt\ (= I_{Cst})$. Minimum storage interval Δ is very small because the proposed sensor operates at high frequency.

I_t, that is an increase of I_{PD} in last Δ, is calculated by the difference between I_{PD} and I_{Cst}. If the magnitude of the difference between I_t and I_{Cm} is larger than an adjustable threshold, the pixel is detected as moving. (I_{Cm} is the last I_t when the pixel was detected.) On the other hand, when I_{PD} exceeds a fixed limitation, then the pixel is detected as saturated.

If the pixel is detected as moving or saturated, flag signal is activated and I_{PD} and I_{Cst} are output. Then I_{Cm} is replenished by the new I_t, and I_{PD} is cleared. If the pixel is not detected as moving or saturated, I_{PD} is not cleared and keeps integration.

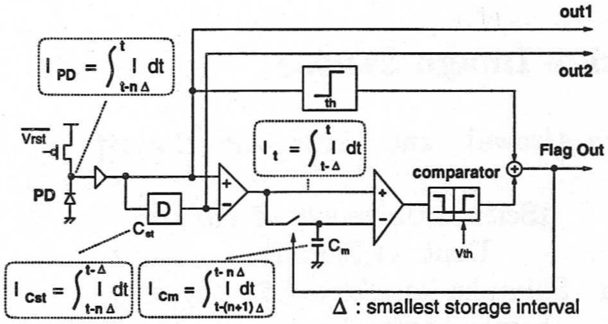


Figure 1: Description of processing in each pixel

3 Design of Computational Elements of the Motion Adaptive Sensor

Figure 2 shows the block diagram of the motion adaptive sensor based on column parallel architecture. This architecture separates transducer, memory and processing elements, and each column shares a processing element. Fill factor and power dissipation are comparable to an ordinary CMOS sensor.

Two vertical shift registers for transducers and memories select the line in order. It has two horizontal shift registers: they are a normal and a smart shift register, and one of the two is selected. In case of the smart shift register, only the pixels detected as moving or saturated are selectively read out and non-detected pixels are skipped without reading. The flag signals sequentially are output by the bottom horizontal shift register at the rate higher than output rate of pixel value. Reconstructed image is calculated by making use of the PD value of the detected pixels and flag signals.

Figure 3 shows the circuit designed for each pixel based on column parallel architecture. Each pixel has a transducer element that consists PD and C_{st}, and a separate memory C_m. The processing element is shared by the pixels of each column and consists of a circuits of computing absolute difference, MOS inverters which detect the saturation and a flag generation circuit.

Prototype has been fabricated by using 1-poly 2-metal CMOS $1\mu m$ process. It has 32 $\times$ 32 pixels. As shown in Table 1, the prototype is able to keep fill factor as high as the normal MOS imager and it has low power dissipation.

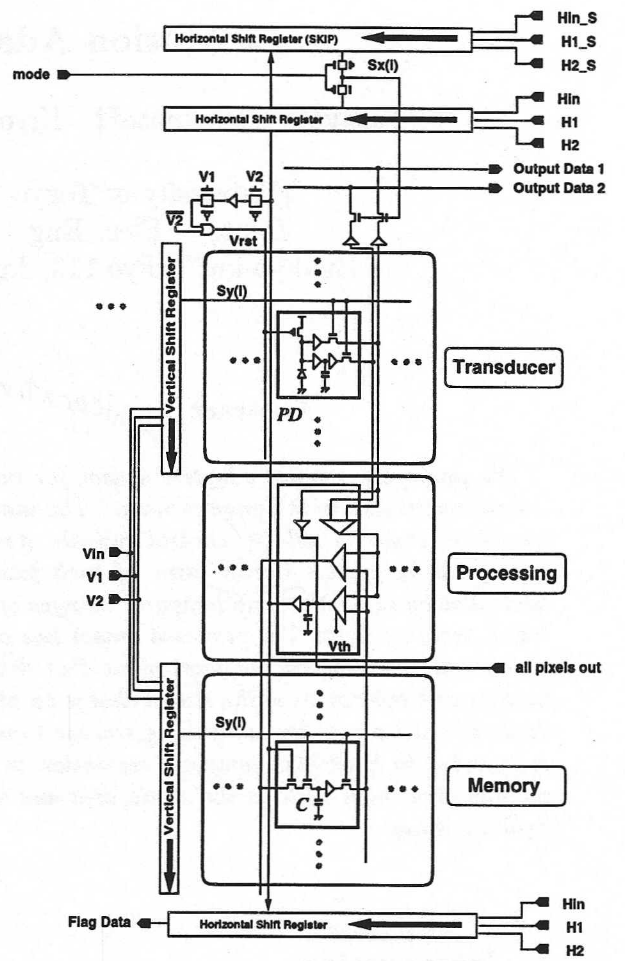


Figure 2: Block diagram of the motion adaptive sensor

Table 1: Outline of prototype

number of pixels	32 $\times$ 32 pixels
die size	4.0 $\times$ 6.1 mm^2
pixel size	transducer : 85 $\times$ 85 μm^2 memory : 85 $\times$ 46 μm^2 processing : 85 $\times$ 191 μm^2
number of transistor	transducer : 17 trs. / pixel memory : 10 trs. / pixel processing : 64 trs. / column
fill factor	14 %
power dissipation	150mW / chip Vdd = 5V
processing rate	≥ 2 μs / row

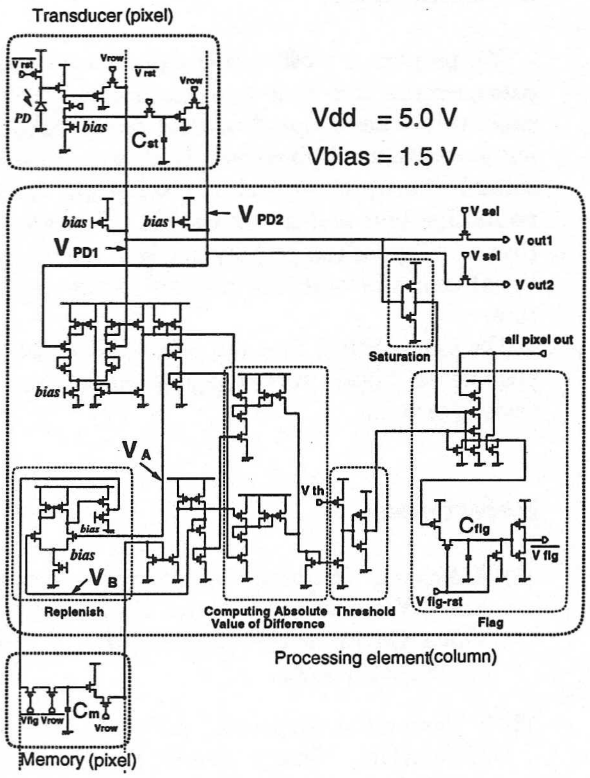


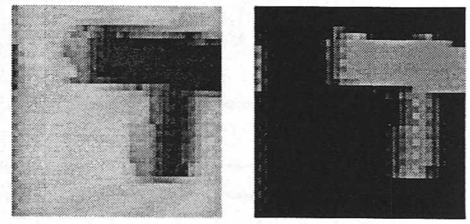
Figure 3: An analog circuit designed for a pixel

4 Experiments

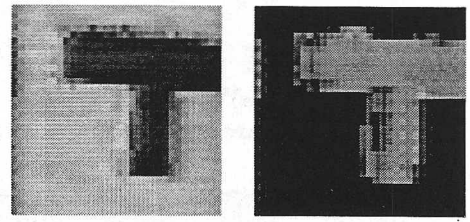
Figure 4 shows images from the prototype when "T" is projected onto the focal plane. When motion detection circuit is invalidated, motion blur is observed on the left side of moving "T". When motion detection circuit is active, the motion blur is effectively removed.

Figure 5 shows the images obtained by prototype when storage time is fixed or adapted. The scene of these images is partially very bright so that the sensor can not clearly acquire entire scene by the fixed storage time because of the limited dynamic range. On the other hand, it is verified that the image obtained by the adaptive storage time is clear from dark to bright region.

Figure 6 shows the responce of a single pixel circuit when a LED driven by a sinusoidal wave is used as a light source. It is observed that motion and saturation are reasonably detected by the computational elements of the proposed sensor.

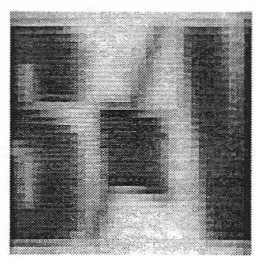


(a)without motion detection ($V_{th} = 0.0V$)

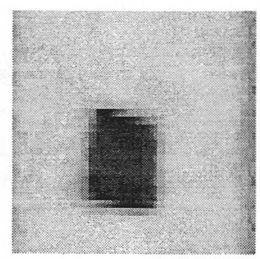


(b)with motion detection ($V_{th} = 2.0V$)

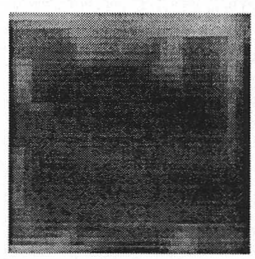
Figure 4: Images obtained by the prototype. (T is moving horizontally.); From left to right: reconstructed image and flag signal (When V_{th} is 0.0V, all pixels are detected as not moving.)



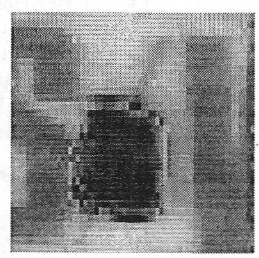
(a)imaging object used in experiments



(b)fixed storage time adjusted to center opening.

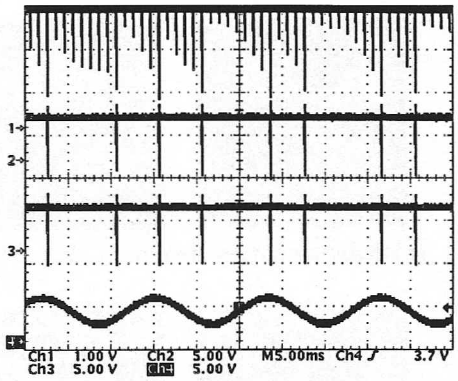


(c)fixed storage time adjusted to the background.

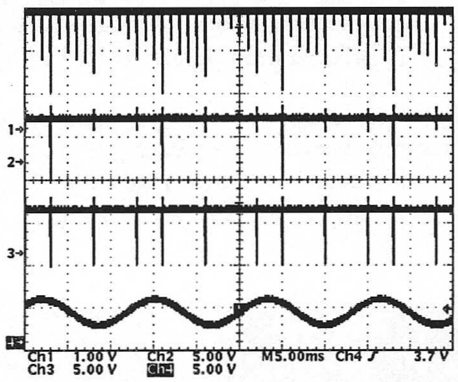


(d)proposed adaptive storage time

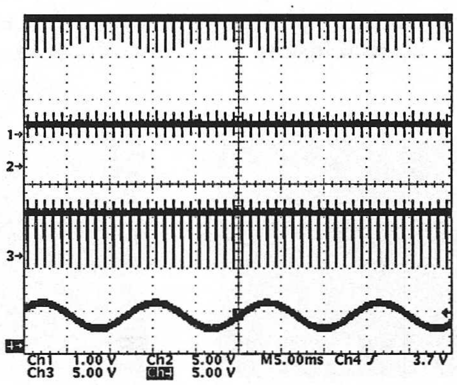
Figure 5: Output images when storage time is fixed or adapted. (In the experiments of fig.(b)(c)(d), incident light through the center opening is very bright. Brighter area of image is in black due to inverse output)



(a)Vth=1.5V
(All flag signals are activated by saturation.)



(b)Vth=2.0V
(When incident light is high or low, flag signals are activated by motion. The other signals are by saturation.)



(c)Vth=2.5V
(All flag signals are activated by motion.)

Figure 6: Response of a single pixel circuit under various thresholds for motion detection. : From top to bottom waves in (a)(b)(c); I_{PD}, saturation detection, saturation and motion detection, LED driving voltage, respectively. (Detection signals are inverse output.)

5 Conclusion

We propose a motion adaptive sensor for image enhancement and wide dynamic range. The proposed sensor has simple functions for detecting moving and saturated pixels and is able to control the suitable storage time pixel by pixel, which results in no motion blur and no saturation. We present the circuit design of the prototype which has computational elements based on column parallel architecture.

We have verified that the proposed sensor is applicable to higher rate imaging more than 1475 frames/second.

References

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