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Video Enhancement Sensor Using Motion Adaptive Storage Time

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Abstract

We propose a video enhancement sensor for smoothing random noise and getting wide dynamic range. The sensor has computational elements based on a column-parallel architecture. It detects motion and saturation of the stored charge on photo diode independently pixel by pixel. By operation at high frame rate, the motion adaptive sensor is able to control the suitable storage time in each pixel which results in no motion-blur and no saturation so that it is expected to have high temporal resolution in the moving area, high SNR in the static area and wide dynamic range. In this paper, we discuss the principle, circuit design and layout of motion adaptive sensor.

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. This paradigm of fixed frame rate imaging significantly degrades imaging quality by motion blur when imaging an object that is moving at high speed. Furthermore, saturation of dynamic range is also important to image quality when object is partially very bright. It is substantially difficult for post-processing to recover these degradations.

A CCD sensor with electronic shutter[1] is capable of imaging at variable storage time. However, read out rate is fixed by timing of 30 frames/second and the storage time is constant for all pixels (Individual variation is not possible). On the other hand, imaging at high frame rate causes degradation of image quality because of the decrease of incident light for each pixel.

In this paper, we propose novel approach to enhance the performance of image sensing by integrating processing element with an image sensor on the same chip. We present a motion adaptive sensor which controls storage time independently pixel by 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 the processing scheme in each pixel of motion adaptive enhancement sensor. It is based on detection of motion and saturation. As shown in Figure 1, photo diode (PD) store $\int_{t-n\Delta}^{t} I\,dt$ $(= I_{PD})$, and the capacitance C_{st} keeps $\int_{t-n\Delta}^{t-\Delta} I\,dt$ $(= I_{C_{st}})$. The current pixel value I_t is given by the difference between I_{PD} and $I_{C_{st}}$. If the magnitude of the difference between I_t and I_{Cm} is larger than a threshold, the pixel is detected as moving. When I_{PD} exceeds a fixed limitation determined by property of MOS inverter, then the pixel is detected as saturated.

If the pixel is detected as moving or saturated, flag signal is activated and I_{PD} and $I_{C_{st}}$ are output. Then I_{Cm} is replenished by the current pixel value I_t and I_{PD} is cleared. On the other hand, if the pixel is not detected as moving or saturated, I_{PD} is not cleared. Output timing is adjusted by post processing outside the motion adaptive sensor.

Improvement in image enhancement of the motion adaptive sensor is investigated by simulation. Figure 2 shows a test sequence used in experiments. The sequence consists of 60 frames and each frame has 256×240 pixels of 256 intensity levels. In Figure 3, the left picture shows the Y-T cross section image of the sequence at $x = 85$ and the right picture illustrates length of the storage time when the dynamic range of PD is assumed 256×5 because the operation frequency is five times as high as the usual. In the right picture of Figure 3, the brighter value shows the longer storage time. When the white or gray changes to black, the pixel is detected as moving or saturated. It is verified that the proposed sensor has high temporal resolution in the moving area. The pixel value in the static area is smoothed until the stored charge exceeds the threshold. Figure

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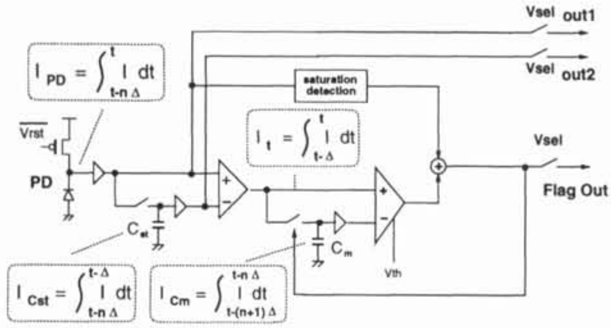

Figure 1: Description of processing in each pixel of the motion adaptive enhancement sensor

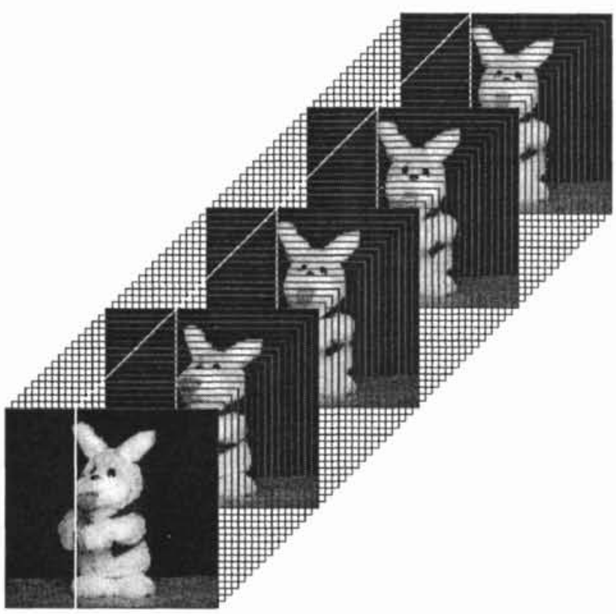

Figure 2: A test sequence in experiments: white line corresponds to the pixels at $x = 85$

4 shows a frame of the test sequence Figure 2. The left picture is an original image and the right picture is an image simulated by the principle of the motion adaptive enhancement sensor. It appears that the random noise in the back ground is significantly reduced and the moving object in the center of the image is not blurred.

Figure 5 shows still pictures acquired by CCD sensor using electronic shutter on the condition of different storage times from $\frac{1}{250}$ to $\frac{1}{6}$ seconds. The scene of these pictures is partially very bright so that ordinary CCD sensor is not able to clearly acquire the entire scene because of the limited dynamic range. On the other hand, it is verified that the picture of the proposed sensor is very clear from dark to bright region.

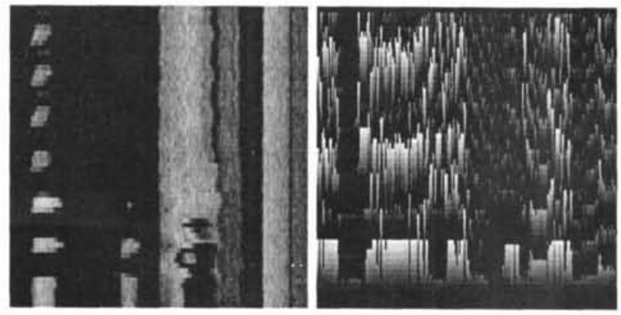

Figure 3: Y-Time cross section images of Figure 2 at $x = 85$; left : original image and right : illustrating picture of the storage time (The brighter pixel values shows the longer storage time.)

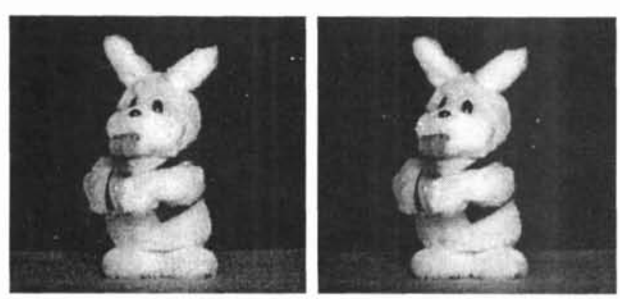

Figure 4: An example of simulation result used in the test sequence; left : an image used for experiments and right : an image acquired by the proposed sensor

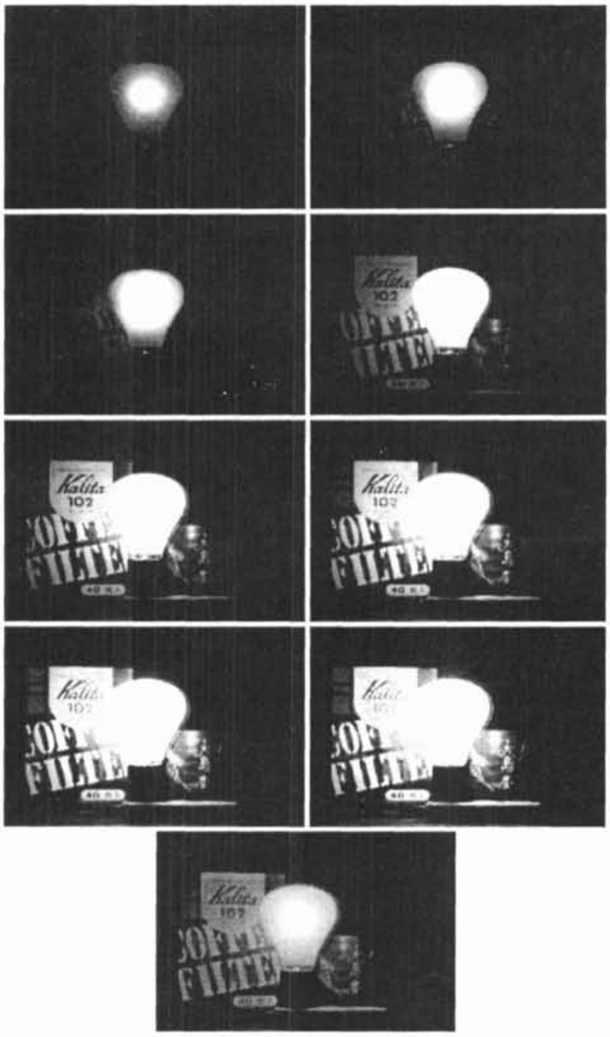

Figure 5: Still pictures in experiments acquired by CCD with electronic shutter; From left to right, top to bottom (4th row): storage time is 1/250, 1/125, 1/100, 1/30, 1/15, 1/10, 1/7.5 and 1/6 second, respectively. Bottom most: simulation of the picture by the motion adaptive image sensor

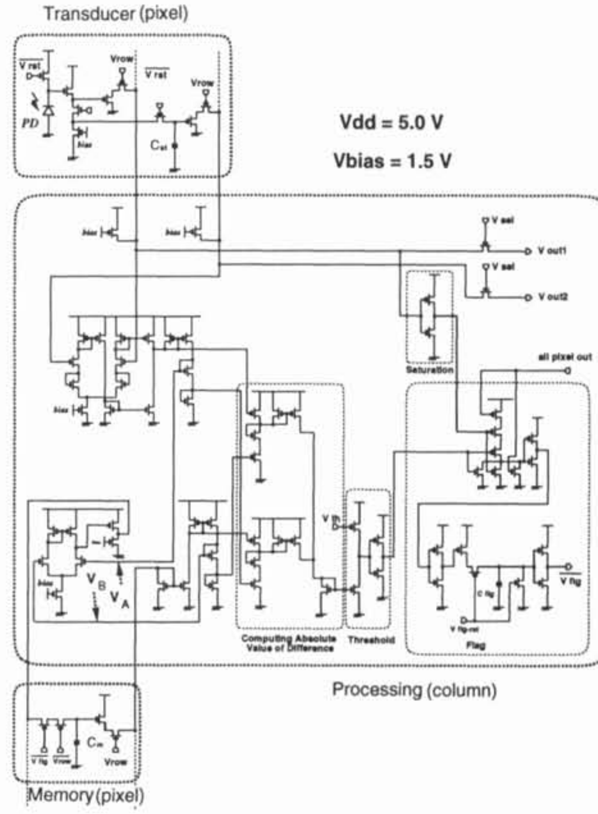

Figure 6: An analog circuit designed for a pixel of the motion adaptive enhancement sensor

3 Design of Computational Elements of the Motion Adaptive Image Sensor

Figure 6 shows the circuit designed for each pixel of the motion adaptive sensor based on column-parallel architecture. Each pixel has a transducer element and a separate memory. The processing element is shared by the pixels of each column and consists of two differential amplifiers, a circuits of computing absolute difference, MOS inverters which detect the saturation and a flag generation circuit.

Figure 7 shows the block diagram of the motion adaptive image sensor. 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. Proposed sensor has two horizontal shift registers: they are normal and smart shift register, and one of the two is selected by the mode signal. 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 are output sequentially by the bottom horizontal shift register at the rate higher than output rate of pixel value.

Figure 8 shows the layout of the prototype which we designed under 1-poly 2-metal CMOS $1\mu m$ rule. It has 32×32 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 in spite of relatively big computational element.

4 Conclusion

In this paper, we propose a video enhancement sensor. 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. It is verified that the motion adaptive sensor is able to

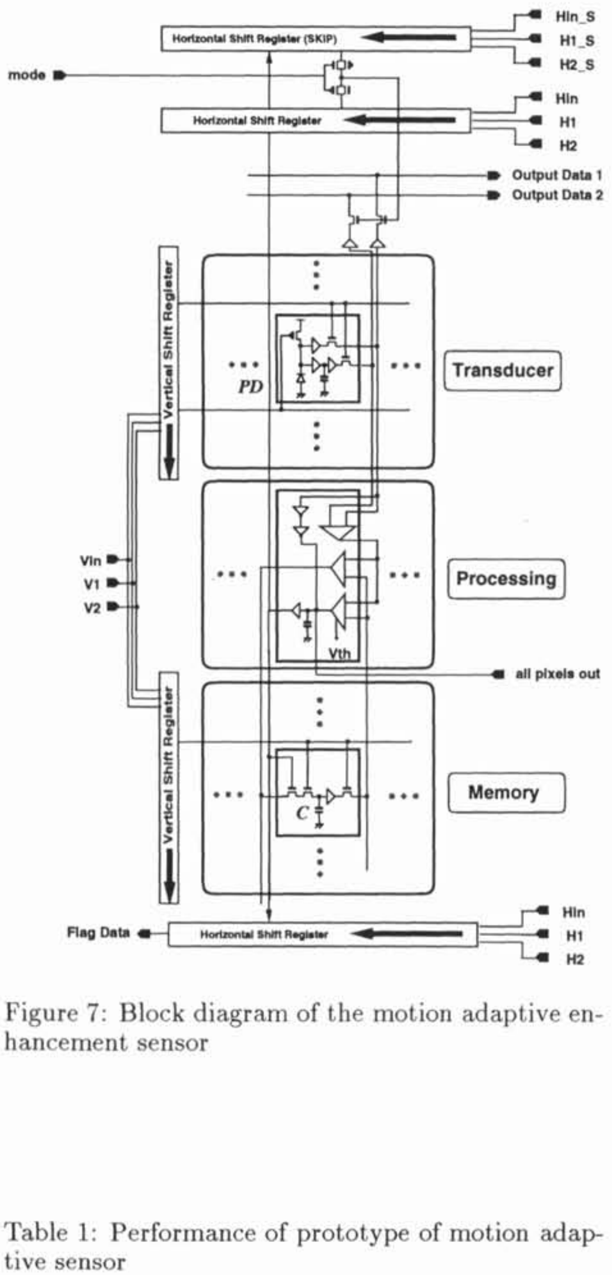

Figure 7: Block diagram of the motion adaptive enhancement sensor

Table 1: Performance of prototype of motion adaptive sensor

number of pixels	32 × 32 pixels
die size	4.0 × 6.1 mm^2
pixel size	transducer : 85 × 85 μm^2
	memory : 85 × 46 μm^2
	processing : 85 × 191 μm^2
number of transistors	transducer : 17 trs. / pixel
	memory : 10 trs. / pixel
	processing : 64 trs. / column
fill factor	14 %
power dissipation	1.5mW / column
processing rate	$\geq$ 2 μs / row (hspice)

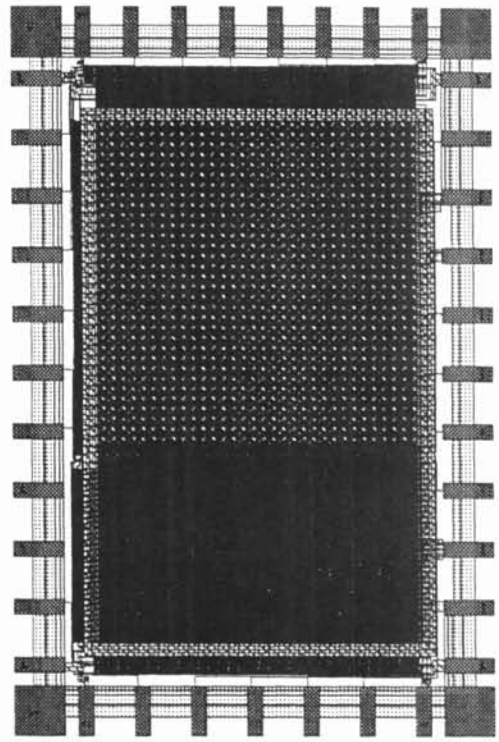

Figure 8: Layout of the motion adaptive enhancement sensor

enhance the dynamic range, temporal resolution in the moving area and SNR in the static area by computer simulation. We present the circuit design and layout of the prototype which has computational elements based on column-parallel architecture.

The prototype is now under fabricating using CMOS 1.0μm process.

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