Image Sensor Architecture for Arbitrarily Directional Motion Detection Using Spatial Propagation Delay of Excitation Signal

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1 Introduction

Various researches are reported on the motion detection image sensor [1, 2, 3, 4], which are mainly categorised into according to their model; one is aiming at considering the correlation of neighbouring pixels and the other is aiming at solving Euler-Lagrange equation by analog circuits.

A model of motion detection on the retina often assumes the types of signals propagating on neural networks, that is, excitation signal and suppression signal.

We proposed a biological model of motion detection which is performed on the lower animals' retina using only excitation signal's propagation delay[8] based on biological model [7], and designed the circuit element for motion detection image sensor using only excitation signal.

We also proposed the possibility of the arbitrarily directional motion detection image sensor using randomly placed pixels.

2 Motion Detection Algorithm

It is known that there are signal processing cells, such as horizontal cells as well as two types of photo receptor cells; rods and cones on the retina, and they form complex networks which give the retina to have the function not only to acquire images, but also to carry out early vision processing[9].

One of the most important functions of the retina is to detect motions, directions and speeds, of moving lights. Although the mechanism, so called 'directional selectivity,' has not been completely clarified yet, in the mechanism of motion detection, two types of signals (i.e., excitation signal and suppression signal), have been regarded as important factors[5, 6]. Recently some researches revealed that only the excitation signal may implement the motion detection in the retina of some creatures', such as a turtle.

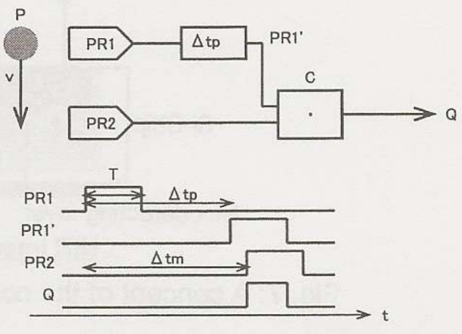

Figure 1: Motion detection model using excitation signal

Takayasu *et al.* have reported the simplified numerical model of motion detection using only excitation signal as well as its electro physiologic characteristics as follows[8]. Assuming that there are two photo receptors, PR1 and PR2 as shown in Fig.1 that make excitation pulse of width T when exposed, the time delay of exposure by moving light will be Δt_m. Δt_m is expressed as L/v, where L is the distance of two photo receptors and v is the velocity of moving light.

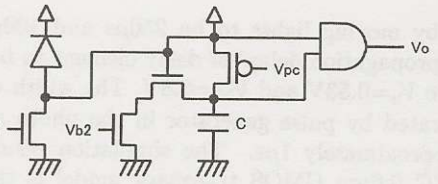

Figure 2: Circuit of photo receptor

The excitation signal generated by PR1 reaches the connecting cell, C after Δt_p by delay element. The connecting cell C excites its output Q only when two pulses have reached simultaneously. The condition of Q generation is expressed as follows.

$$|\Delta t_m - \Delta t_p| < T \quad (1)$$

In other words, if we can observe the excitation of Q, it means that there was a motion from PR1 to PR2 with velocity of $v = L/\Delta t_p$. (Δt_m is assumed to be almost equal to Δt_p.) Above-mentioned two factors determining its motion, L and Δt_p are decided by spatial locations of two photo receptors, PR1 and PR2, and characteristic of delay element, and observing Q may show us various types of motions (i.e., directions and speeds).

3 Design of Motion Detection Image Sensor

We designed circuit elements for the motion detection image sensor using excitation signals as described above.

3.1 Photo receptor

Figure 2 shows the circuit photo receptor including the pulse generator. The capacitor, C of approximately 1pF, is pre-charged by V_{PC} at reset sequence, and the photo current generated by photo diode discharges its charge through the MOS transistor. Excitation pulse whose width is approximately $T \sim 1\mu s$ is generated when exposed.

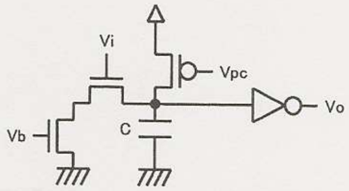

Figure 3: Circuit of delay element

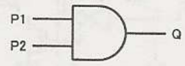

Figure 4: Circuit of pulse detector

3.2 Delay element

Figure 3 shows the designed delay element that produces a long delay comparable to speed of moving lights, approximately 1ms. Assuming that the capacitance of C is 1pF which may be realistic in conventional LSI fabrication processes, the discharging resistance of approximately $10^9\Omega$ is required in order to produce approximately 1ms delay. The MOS transistor in subthreshould region is suitable for such a large resistance. The output of this delay element will be connected to the pulse generator which is mounted on the right half of photo receptor circuit shown in Fig.2 in order to create $T = 1\mu s$ pulse with delay of $\Delta t_p \sim 1$ms.

3.3 Pulse detector

The above-mentioned two pulses, which are delayed by delay element and generated later by moving lights, should be connected to one pulse detector which detects such pulses simultaneously. This pulse detector can be implemented as an AND gate shown in Fig.4.

3.4 Whole structure and simulation

Figure 5 shows the whole structure of the motion detection image sensor for one pair of pixels that can detect a single motion, that is a direction and a speed.

Circuit simulation result using HSPICE is carried out with the condition of 'expose delay' from PD1 to

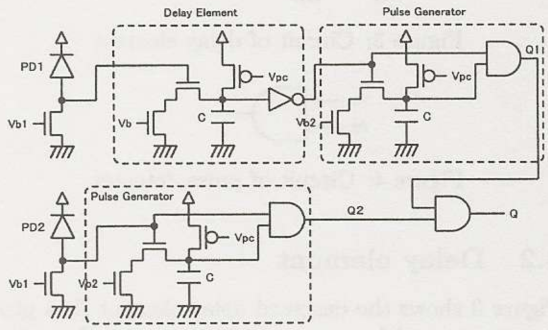

Figure 5: Whole structure of motion detection image sensor

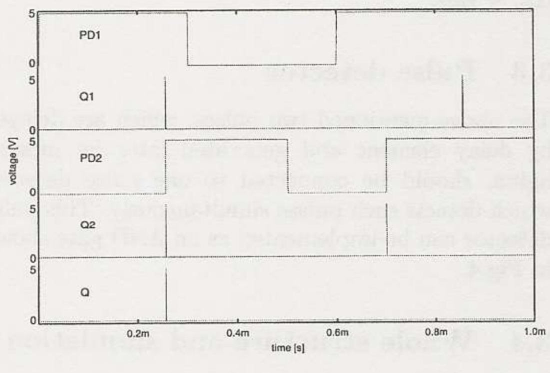

Figure 6: Circuit simulation result

PD2 by moving lights to be 250μs and 100μs, and the 'propagation delay' of delay element to be 250μs where V_b=0.53V and V_{b2}=0.8V. The width of pulse generated by pulse generator in the photo receptor is approximately 1μs. The simulation result using VDEC 0.6μm CMOS transistor model is shown in Fig.6.

The light exposes PD1 at $t = 0$, and output pulse of 1μs is generated at Q1 after 250μs. This moving light exposes PD2 250μs after PD1 is exposed, and the pulse is generated at Q2. Q1 and Q2 are connected to the pulse detector, and the output of the pulse detector, Q, becomes 1 since Q1 and Q2 have generated pulses simultaneously. This result indicates that a motion of light has been detected, whose direction is PD1 to PD2 and speed is $L/250\mu s$, where L is the spatial distance of PD1 and PD2.

At $t = 600\mu s$, another light exposes PD1 and generates pulse at Q1, but its speed is so quick that it exposes PD2 just after 100μs at $t = 700\mu s$. Such two pulses don't reach the pulse detector simultaneously, and it results in no output of Q, which means "there were no motions from PD1 to PD2 with speed of $L/250\mu s$."

3.5 Designed Test Circuit

We also designed the test circuit element (TEG) in the 2.4mm square die using CMOS 0.35μm as shown in Fig.7[1].

This fabricated chip is currently under measurement and evaluation.

4 The Possibility of Arbitrarily Directional Motion Detection

The direction and velocity of motion detected by the model we proposed are determined by two factors (i.e., the photo receptors' spatial relation, and Δt_p

[1]The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo with the collaboration by Rohm Corporation and Toppan Printing Corporation.

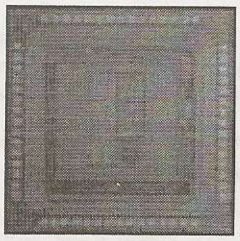

Figure 7: Photograph of fabricated chip

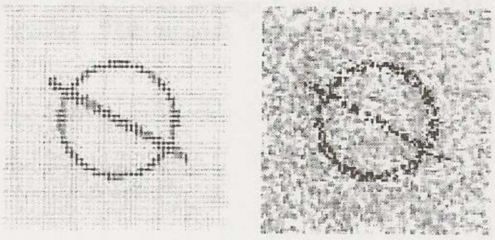

Figure 8: (a)Square placed pixels and (b)randomly placed pixels

by the delay element). This implies the possibility of the arbitrarily directional motion detection image sensor implemented by randomly placed pixels.

Since the pixels are usually placed on square or hexagonal matrix in conventional image sensors, specificity of directional expression has been caused; the vertical and horizontal lines are clearly expressed, but the slant line is expressed by jaggy sequence of pixels. Figure 8 shows examples of a figure expressed by two types of pixel placement; (a)square placement

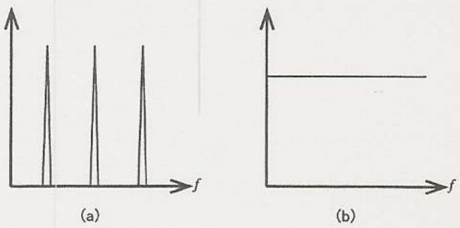

Figure 9: Spatial spectrum of pixel placement; (a)matrix placement and (b)random placement

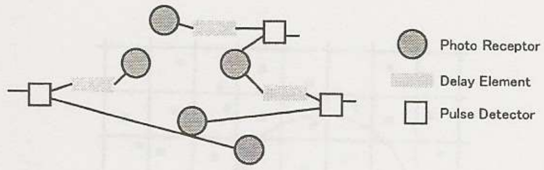

Figure 10: Architecture of arbitrarily directional motion detection image sensor

and (b)random placement. In case of square placement, the slant line and the circle are expressed by square pixel approximation, while those are expressed clearly in average by randomly placed pixels. Random placement pixels have the white noise spatial spectrum that contains all the possible spatial frequency components as shown in Fig.9, which can express an arbitrary spatial pattern.

The motion detection model we proposed has the possibility of the image sensor which has randomly placed pixels as shown in Fig.10, since it is much more flexible in pixel placement, the pixel placement is restricted by two factors; the photo receptors' spatial relation, and Δt_p by the delay element, that are independent from the other pixels.

The most important points, the output read-out strategy and design method will be discussed in our future work. One possible implementation of random pixel placement is to move pixels randomly from matrix placement, which has been studied in the area of cell automata[10, 11].

5 Summary

We proposed the motion detection model using only excitation signals based on biological model. We also designed and fabricated the circuit elements of the motion detection image sensor using our model, and the fabricated chip is currently under measurement and evaluation. We also proposed the possibility of the arbitrarily directional motion detection image sensor, but its detailed implementation will be discussed in our future work.

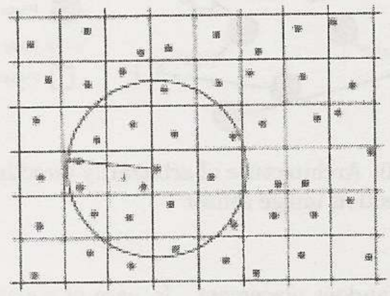

Figure 11: Cell model for solving directional singularity[10]

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