Analog LSI for Motion Detection of Approaching Object with Simple-Shape Recognition Based on Lower Animal Vision

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Abstract - An analog integrated circuit for approach detection with simple-shape recognition was proposed and fabricated based on the lower animal vision. It was clarified that the approaching direction and velocity can be detected by using the fabricated chip. Moreover, it was able to recognize the simple shape such as a circle, square, rectangle and triangle.

I. Introduction

Real time image-processing such as motion detection is difficult in typical image-processing systems using digital computers since the information processing is achieved in a time-sequential way. This is easily in biological systems since the process is performed in massively parallel nerve networks. The integrated circuit based on the biological vision can realize the real time image-processing.

It is necessary to develop the circuit for three-dimensional motion detection. Recently, the integrated circuit for detection of object approach [1], which is the most basic three-dimensional motion detection, was proposed based on the locust visual systems [2]. However, the circuit could not detect object approach when the velocity was fast. The circuit could not detect the approaching direction. The shape recognition is needed to discriminate the moving object. The chip, which has the two functions of motion detection and shape recognition, has not been proposed since the circuit structure becomes complex.

We tried to develop an analog approach detection chip with simple-shape recognition based on lower animal vision.

II. Biological Model

The relationship between an approaching object with a velocity v and the eye is shown in Figs. 1(a) and (b). The angles $\theta_{dir,x}$ and $\theta_{dir,y}$ are the approaching directions. Figure 1(c) shows the image projected on the retina. The image angular velocity (edge velocity) and the angle θ_x increase rapidly just before collision. Locusts can detect object approach by using the signals in the descending contralateral movement detector (DCMD)[2]. The signals are given by

$$I_{left} = |\dot{\theta}_{left}(t)|\exp(-\theta_x(t)) , \quad (1)$$

$$I_{right} = |\dot{\theta}_{right}(t)|\exp(-\theta_x(t)). \quad (2)$$

These signals show the peak values just before collision. $\theta_{dir,x}$ can be detected by using peak value $I_{dir,xp}$ of $I_{dir,x}$ (=I_{left} - I_{right}) [3]. $\theta_{dir,y}$ can be detected by applying this function to y-axis. The signal for detecting $\theta_{dir,y}$ is $I_{dir,y}$. The peak value $I_{vel,p}$ of I_{vel} (=I_{right} + I_{left}) is proportional to v [3].

The model for simple-shape recognition based on the frog vision [3] is shown in Fig. 2. I_x and I_y generated from the edge signals are proportional to θ_x and θ_y, respectively. The object extending laterally and vertically is discriminated from I_E. I_{area} and I_{peri} are signals of the area and perimeter, respectively. The simple shape is recognized from I_M.

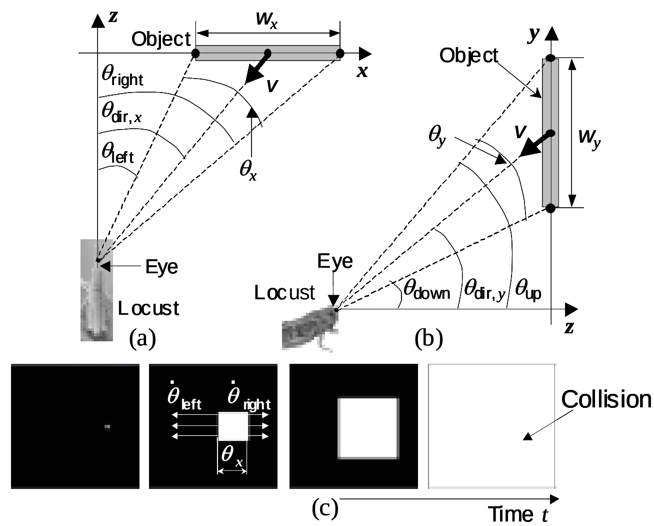

Fig. 1 Approach detection model. (a)Approaching object from the right front. (b)Approaching object from the upper front. (c)Projected image (white square) on the retina.

III. Experimental Results

An approach detection chip with simple-shape recognition was fabricated with 1.2µm CMOS process. Figure 3 shows the photograph of the chip. Edge detection circuits (EDC) with photodiode (PD) [3] are inserted at the first stage. Digitization circuits (DG) [3] arranged to x- and y-axes generate I_x and I_y, respectively. Velocity sensing circuits (VSC) [3] arranged to x-axis generate the signals of the image angular velocity (right and left). DCMD circuit which inputs I_x and the signal of image angular velocity (right) outputs I_{right} in eq. (2) [3]. Thus, four DCMD circuits are contained. EWC and PFC are simple division circuits [3]. The area of each circuit is shown in Table I.

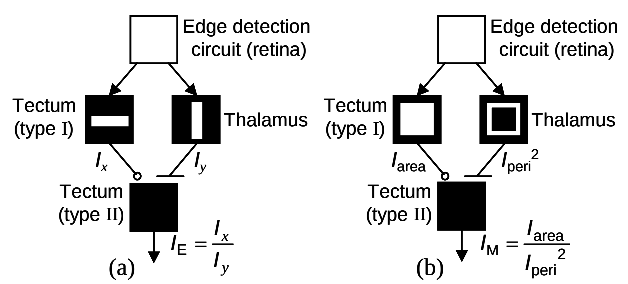

Fig. 2 Model for recognizing the simple shape. (a)Ewert von Seelen model (EWC). (b)Model for discriminating the simple shape such as circle, square and triangle (PFC).

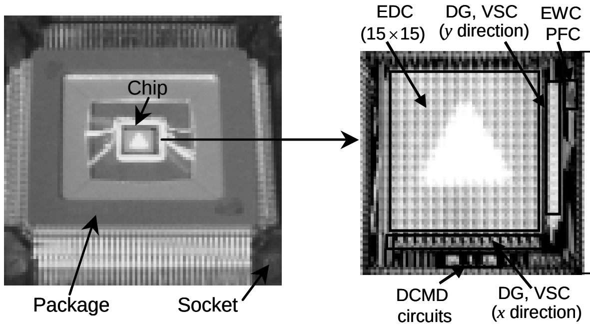

Fig. 3 Micrograph of the chip. The image (triangle) is projected on the chip.

The image which approaches from the upper right front was projected on the chip (Fig. 4(a)). Figure 4(b) shows the output current I_{vel} and $I_{\mathrm{dir},x}$. I_{vel} and $I_{\mathrm{dir},x}$ showed peak values $I_{\mathrm{vel,p}}$ and $I_{\mathrm{dir},x\mathrm{p}}$ just before collision, respectively. $I_{\mathrm{vel,p}}$ was approximately proportional to v up to 60m/s. The absolute value of $I_{\mathrm{dir},x\mathrm{p}}$ was proportional to that of $\theta_{\mathrm{dir},x}$. The absolute value of the peak current $I_{\mathrm{dir},y\mathrm{p}}$ of $I_{\mathrm{dir},y}$ was also proportional to that of $\theta_{\mathrm{dir},y}$. In the measurement of EWC and PFC, the object moved toward the right-hand side. Output current I_{E} was proportional to w_x/w_y. Figure 5 shows the measured results of PFC. It was clarified that the simple shape can be recognized from I_{M}. The power of each circuit was evaluated with the simulation program with integrated circuit emphasis (SPICE), as shown in Table I.

IV. Discussion

Our circuits realized new functions for detection of the approaching direction and simple-shape recognition. The chip can perform at a high speed (60m/s) since each unit circuit operates in parallel. When the capacitor of VSC was set to 0.1pF, the detectable velocity was 600m/s with SPICE. The chip can discriminate among a car, person and ball from the signals of velocity, direction and simple shape.

The chip contained EDC of large area. In EDC, one extra circuit (1/2 of total area) was contained for test chip. The metal wiring occupied the large area (1/3 of total area) since the rule of double-metal was used. We think that the area of EDC is $80 \times 80\,\mu\mathrm{m}^2$ by fabricating with the rule above triple-metal. Since 100×100 EDC can be arranged in $1 \times 1\,\mathrm{cm}^2$, more advanced image processing is expected.

The circuit was characterized by low-power consumption since the circuits operate in a subthreshold region. We hope that the circuit operates with smaller current (pA). Then, there are the problems of the noise and devise mismatch. Although there are the variations of the signals in the biological systems, the signals are processed correctly. This is due to contain the mechanism such as feedback and the averaging the signals [3]. The chip of the lower power is expected by basing on the biological signal processing.

TABLE I
Size and maximum power consumption of unit circuits

	Size of unit circuit	Maximum power
EDC	$200\times200\mu\mathrm{m}^2$ (PD : $2500\mu\mathrm{m}^2$)	0.71μW
DG	$70\times80\mu\mathrm{m}^2$	0.61μW
VSC	$50\times150\mu\mathrm{m}^2$ (C=1pF)	0.42μW
DCMD	$160\times330\mu\mathrm{m}^2$ (C=50pF)	0.91μW
EWC	$60\times45\mu\mathrm{m}^2$	0.33μW
PFC	$110\times120\mu\mathrm{m}^2$	0.85μW

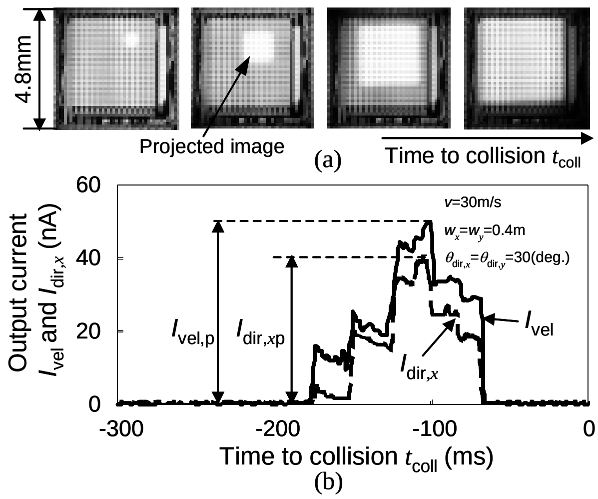

Fig. 4 Measured results of the circuit for approach detection. (a)Relationship between the chip and the projected image (square). (b)Output currents. The supply voltage was 3V.

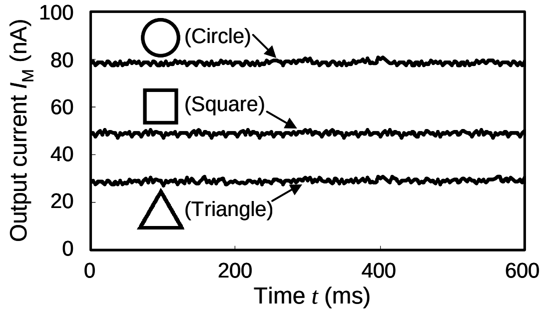

Fig. 5 Measured results of PFC.

V. Conclusion

An analog approach detection chip with simple-shape recognition was fabricated based on the lower animal vision. The chip could detect the approaching direction and velocity. Moreover, it was able to recognize the simple shape such as a circle, square and triangle. The chip can be applied to the system such as robotics vision and collision avoidance.

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