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Analog Circuit for Motion Detection Applied to Target Tracking System

Kimihiro Nishio
Tsuyama National College of Technology
Japan

1. Introduction

It is necessary for the system such as the robotics vision and the monitoring camera to detect the motion of the object and recognize the target in real time. However, this is difficult in conventional image processing systems constructed with a charge coupled device (CCD) camera and Neumann-type computer since information processing in this setup is accomplished in a time-sequential way. On the other hand, real-time image processing is easily performed in biological systems constructed with the retina and the brain since information processing is achieved in massively parallel nerve networks which have a hierarchical structure.
The biological vision system constructed with the retina and brain can detect the motion of the object in real time and judge the target instantly. The complementary metal oxide semiconductor (CMOS) circuits based on the biological vision system can be expected to realize the high speed processing system since each unit circuit operates in parallel as well as the signal processing of the biological vision system. Many researchers proposed the CMOS circuits for edge detection and motion detection based on the biological vision system (Mead, 1989.; Moini, 1999.; Asai et al., 1999b.; Liu., 2000.; Yamada et al. 2001.; Nishio et al. 2003). These circuits are characterized by the high speed processing.
Particularly, there are neurons for tracking the target in the superior colliculus of the brain. The simple target tracking model was proposed based on the signal processing of the brain. The cells for generating the motion signal were introduced at the first stage of the model. The motor for tracking the target was controlled by the motion signal.
Recently, analog CMOS circuits were proposed based on the model for tracking the target (Asai et al., 1999a.; Liu et al., 2001.; Moini, 1999). At the first stage of the circuits, analog motion detection CMOS circuits (Asai et al., 1999b.; Liu., 2000.) based on the biological vision system were introduced for generating the motion signal.
Recently, we proposed simple analog CMOS circuits for generating the motion signal based on the biological vision system (Nishio et al. 2004.; Nishio et al. 2007). The circuit consists of the half of the number of transistors utilized to previous proposed motion detection circuit, which is used at the first stage of the tracking system. The realization of the simple system for tracking the target can be expected by using our circuits to the first stage of the tracking system.
In this study, simple analog CMOS circuit for motion detection was proposed based on the biological vision system. And, I tried to develop the test system for tracking the target based

on the biological vision system. The system was constructed with the analog CMOS circuit for motion detection.
The analog motion detection circuit is characterized by high speed processing because the unit circuits process in parallel as well as the information processing of the retina and brain.
The analog motion detection circuit is characterized by compact structure. The unit circuit is constructed with about 17 MOS transistors by using analog technology.
In this chapter, the following topics (1)-(4) are described.

1. Motion detection model based on the biological vision system
2. Simple analog CMOS circuit for motion detection
3. Target tracking model based on the biological vision system
4. Test system for tracking the target using analog motion detection circuit

2. Motion detection model based on the biological vision system

Figure 1 shows the unit model for motion detection (Reichardt, 1961). We call the model the correlation model. The motion direction and velocity of the target can be detected by the output signal generated by the model. In this section, I describe the details of the model.
The model (elementary motion detector; EMD) is constructed with the large monopolar cell L, the delay neuron D and the correlator C. The photoreceptor P is the input part.
The transient response of each cell when the target (object) moves toward the right side is shown in Fig. 1(b). The P outputs the signal which is proportional to light intensity. The signal of P_1 is input to L_1. When the target moves on P_1, L_1 outputs the pulsed signal. The pulsed signal of L_1 is input to D. Then, the signal of D shows the maximum value. After the target moves away from P_1, the signal of D decreases. When the target moves on P_2, L_2 generates the pulsed signal by inputting the signal of P_2. The signal V_E which is proportional to the signal of D is output when the pulsed signal of L_2 is input to C. The time between the generation of the pulsed signal of L_1 and that of L_2 is equal to the time that the target moves from P_1 to P_2. The time is inversely proportional to the velocity of the target. Thus, V_E is proportional to the velocity of the target.
When the target moves toward the left side, V_E is 0. When the target moves toward the right side, the model generate the signal V_E. This model can detect the motion of the right direction. Thus, it is able to detect the various motion direction by using the model.

3. Simple analog CMOS circuit for motion detection

Figure 2 shows the unit analog motion detection circuit. The circuit was proposed by mimicking EMD in Fig. 1. The circuit can generate the signals for detecting the motion direction and velocity. The operation principles of the circuit are described in this section.
The functions of D and C in Fig. 1 are added to our simple circuit (Nishio et al. 2004.; Nishio et al. 2007). The proposed circuit is simple structure, which consists of 17 MOS transistors and 3 capacitors. The photodiode PD is utilized to the input part. When the target (light) moves on PD_1, the voltage V_{L1} shows about the supply voltage V_{DD}. After the time t_L, the voltage V_{LD} becomes about V_{DD} by the capacitor C_L. Since the pMOS transistor MP_1 and nMOS transistor MN_1 used as the switches turn on for t_L, the current I_{L1} flows into MP_1 and MN_1. Then, the voltage V_D shows the maximum value by the integration circuit constructed with the capacitor C_D and the nMOS transistor MN_2 where the voltage V_{G1} is set to constant value. V_D is converted to the current I_D by the nMOS transistor MN_3. After t_L, MP_1 turns off

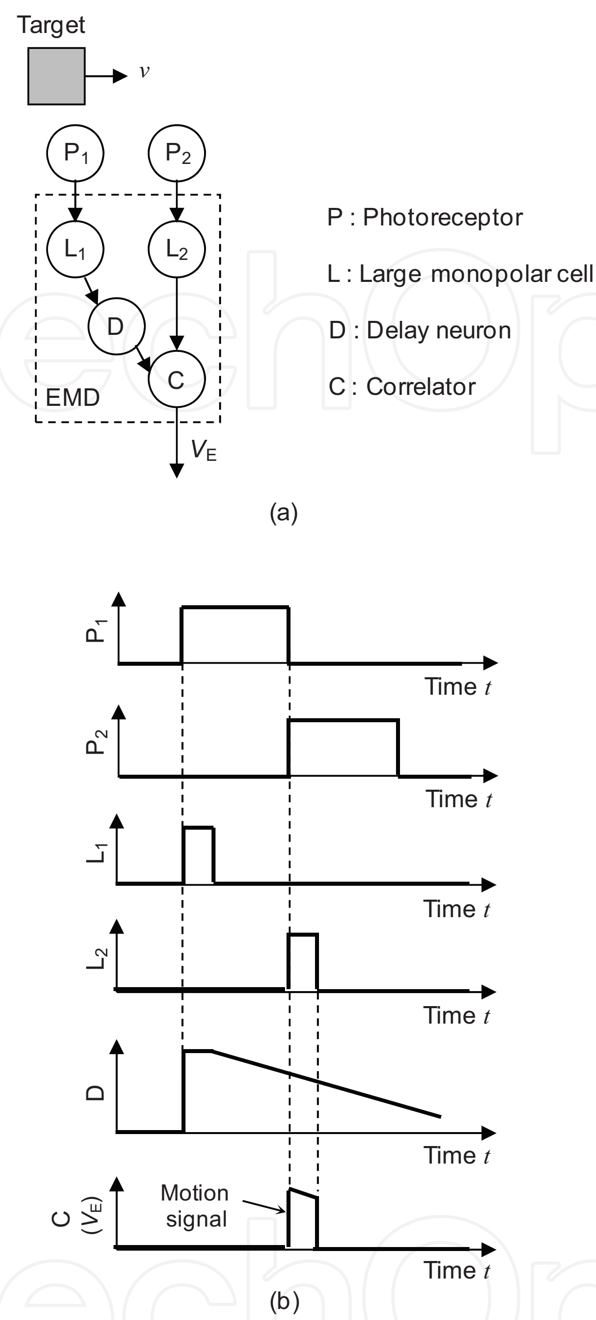

Fig. 1. Unit model for motion detection. (a) Model. (b) Transient response of each cell.

and V_D and I_D are decreased by MN_2. The current I_C is 0 since the nMOS transistor MN_4 turns off when the target is not projected on PD_2.

The target moves toward the right side, and the target projected on PD_2. Then, the voltage V_{L2} becomes about V_{DD} and I_C is equal to I_D since MN_4 turns on. I_C is converted to the output voltage V_E by the integration circuit constructed with the capacitor C_O and the nMOS transistor MN_5 where the voltage V_{G2} is set to the constant value. V_E is proportional to the velocity of the target.

In the case that the circuit is applied to the target tracking system, the voltage V_{center} described in section 4 is generated by the PD located on the center of the array. When the target locates on the center of the input part, V_E shows about 0 by the nMOS transistor MN_6.

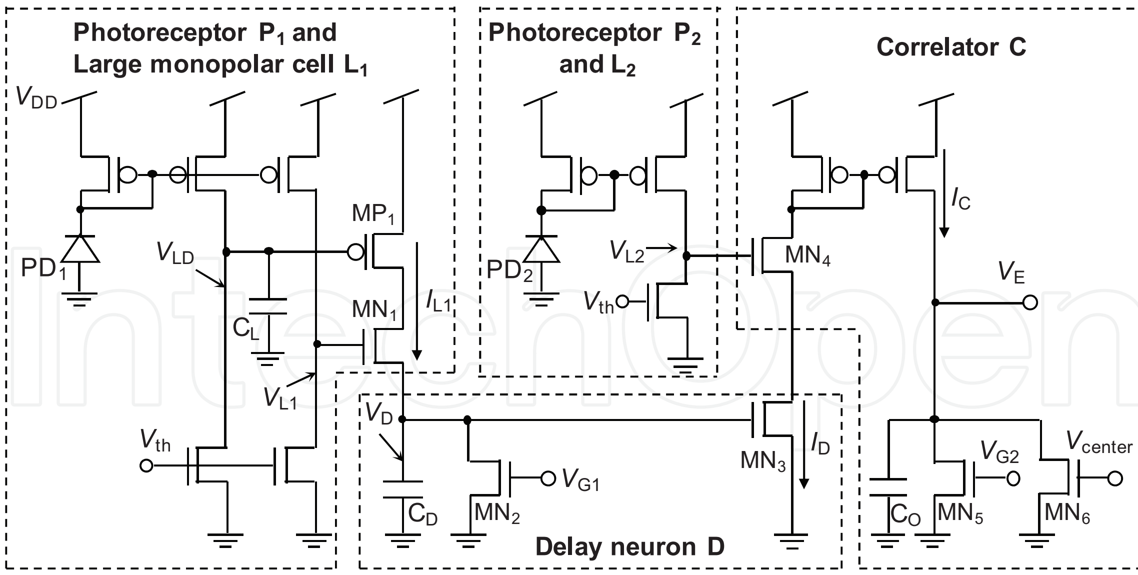

Fig. 2. Unit analog motion detection circuit.

4. Target tracking model based on the biological vision system

Figure 3 shows the model for tracking the target based on the biological vision system. The unit model EMD in Fig. 1 are arrayed in one-dimensionally. By using this model, it is able to track the target and capture the target in the center of the input parts. In this section, I will describe the details of the model.

The input part of the model is the photoreceptor P array. P generates the signal which is proportional to light intensity. The signal of P is input to each EMD. EMD_R generates the signal V_{ER} when the target moves toward the right side. EMD_L generates the signal V_{EL} when the target moves toward the left side.

I describe about the model in Fig. 3 in the case that the target moves toward the right side. When the target moves toward the right side, V_{EL1} and V_{EL2} are not generated, and V_{ER1} and V_{ER2} are sequentially generated. The signal V_{right} is generated by summing V_{ER1} and V_{ER2}. V_{right} and V_{left} are signals for controlling the motor M. Since V_{left} is generated by summing V_{EL1} and V_{EL2}, V_{left} is not generated in this case. Table 1 shows the method for controlling the motor. In this table, V_{DD} means that the signal is generated and 0 means that the signal is not generated. When the target moves toward the right side, V_{right} is V_{DD} and V_{left} is 0. Then, the motor normally rotates for tracking the target. The visual area (P array) turns to the target by the rotation of the motor. When the target is captured on the center of the input array, P_C located on the center of the array generates the signal V_{center}. V_{right} and V_{left} are decreased by V_{center}. Then, V_{right} and V_{left} become 0 and the motor stops. The model repeats the tracking toward the right (rotation of the motor) and the capture of the target (stop of the motor). When the target moves toward the right side, the model can track the target well.

When the target moves toward the left side, V_{ER1} and V_{ER2} are not generated, and V_{EL1} and V_{EL2} are sequentially generated. Then, V_{left} is V_{DD} and V_{right} is 0, and the motor rotates inversely for tracking the target. When the target is captured on the center of the input array, V_{PC} is generated. V_{right} and V_{left} become 0 and the motor stops. The model repeats the tracking toward the left (rotation of the motor) and the capture of the target (stop of the motor). When the target moves toward the left side, the model can track the target well.

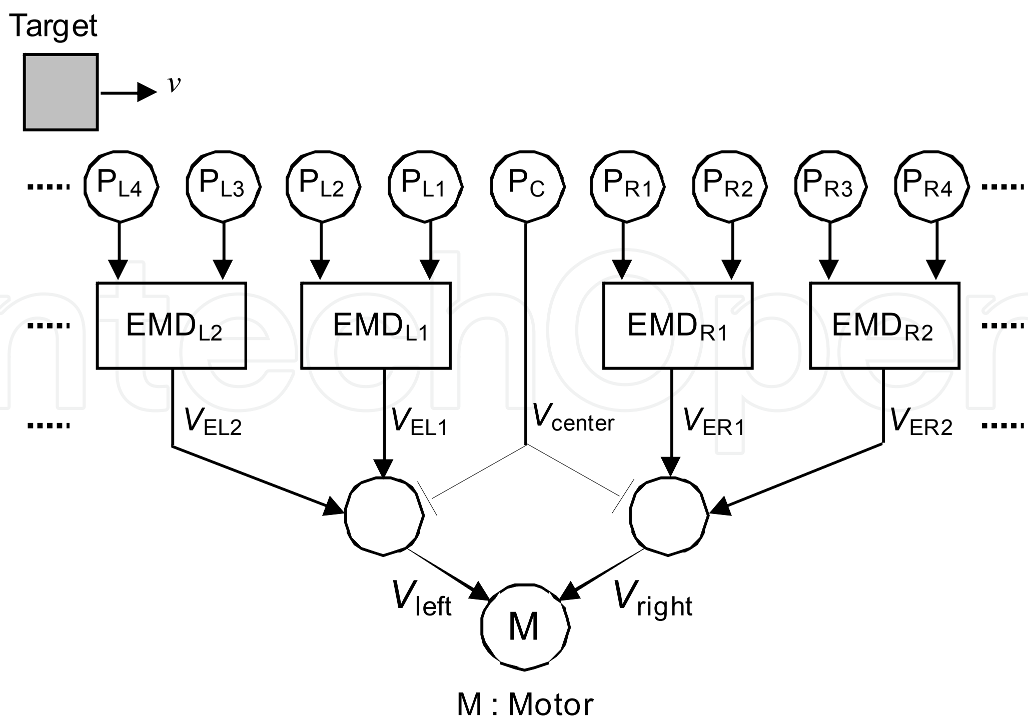

Fig. 3. Model for tracking the target based on the biological vision system.

V_{left}	V_{right}	Motor
0	0	Stop
0	V_{DD}	Normal rotation (track toward the right side)
V_{DD}	0	Reverse rotation (track toward the left side)
V_{DD}	V_{DD}	Stop

Table 1. Method for controlling the motor.

5. Test system for tracking the target using analog motion detection circuit

The test system for tracking the target was fabricated based on the model in Fig. 3. Figure 4 shows the photograph of the fabricated test system for tracking the target. It is able to track the target by arranging the unit circuits in Fig. 2 in one-dimensionally. The PD array fabricated on the printed board was placed on the rotating table which rotates with 360 degrees.

I describe the test system for tracking the target in this section. In the subsection 5.1, the measured results of the test circuit for motion detection are described. The operation principle of the circuit for controlling the motor is also described in the subsection 5.2. The measured results of the test system are shown in subsection 5.3.

5.1 Motion detection circuit

The test circuits of Fig. 2 were fabricated on the printed board by using discrete MOS transistors (nMOS:2SK1398, pMOS:2SJ184, NEC). I measured the test circuit based on EMD applied to the tracking system. The supply voltage V_{DD} was set to 5 V. V_{th}, V_{G1} and V_{G2} were set to 1 V, 0.8 V and 2 V, respectively.

The relationship between PD and the target (light) is shown in Fig. 5(a). The light is provided as the object. The light was moved toward the right side, i.e., the light moved on PD_1 and PD_2 sequentially. The output voltage V_E was monitored by the oscilloscope. The measured result of the output voltage of the motion detection circuit is shown in Fig. 5(b). When the light moved on PD_2, V_E showed about 4.3 V. The test circuit could generate the motion signal. Thus, it is clarified from the results that the proposed circuit can operate normally.

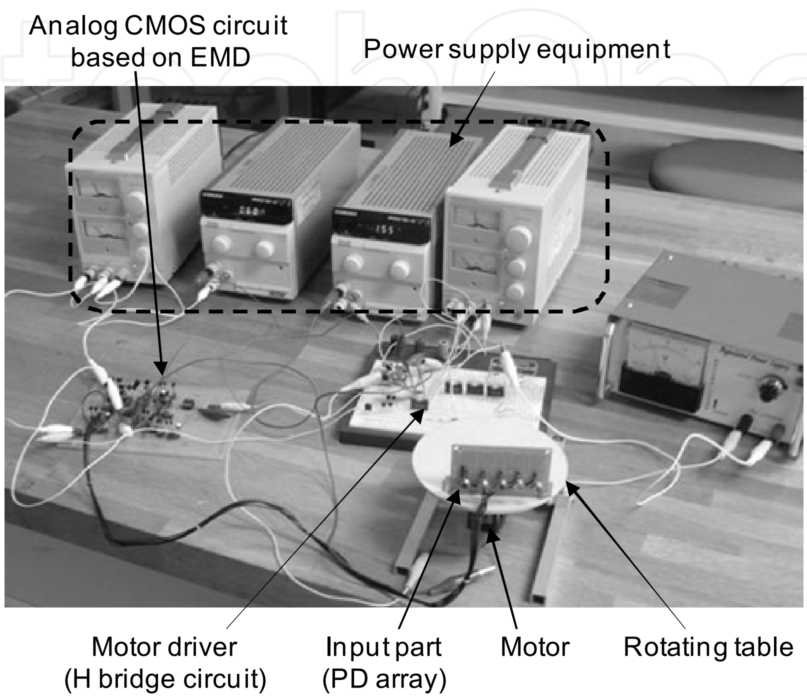

Fig. 4. Photograph of the fabricated test system for tracking the target.

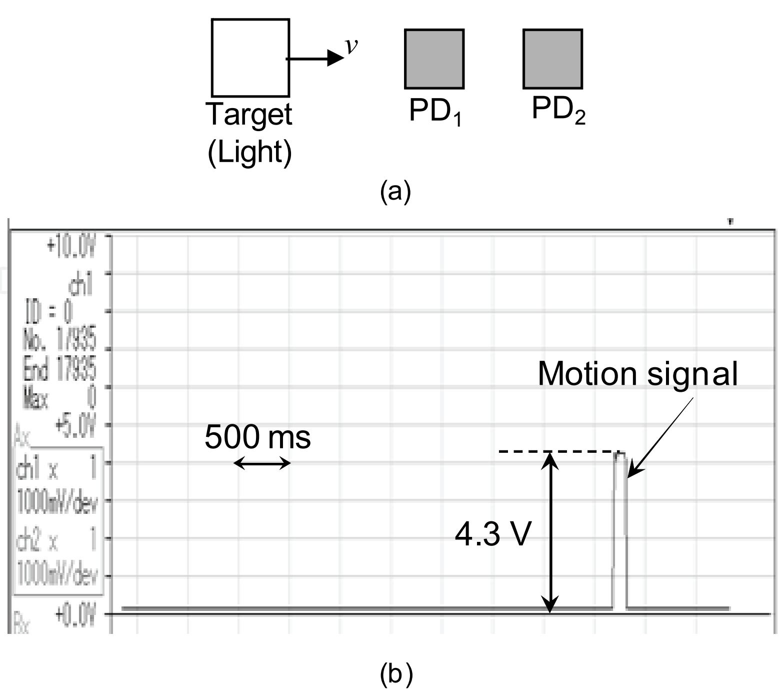

Fig. 5. Measured result of the test circuit for motion detection. (a) Relationship between PD and the target. (b) Result.

5.2 Motor driver

The motor driver (TA7257P, TOSHIBA) was used as the H bridge circuit, which was connected with the DC motor, as shown in Fig. 4. The H bridge circuit is used to control the motor by the voltages V_{left} and V_{right} genenrated by the tracking system in Fig. 3. Figure 6 shows the H bridge circuit. This circuit can control the normal rotation, inverse rotation and stop of the motor.

The motor rotates normally when the switches SW_1 and SW_4 turn on and SW_2 and SW_3 turn off, as shown in Fig. 6(a). When the SW_1 and SW_4 turn off and SW_2 and SW_3 turn on, as shown in Fig. 6(b), the motor rotates inversely. The motor stops when all switches turn off or turn on, as shown in Figs. 6(c) and (d).

To realize the condition table 1, V_{right} controls SW_1 and SW_4. And V_{left} controls SW_2 and SW_3. When V_{right} is about V_{DD} and V_{left} is 0, SW_1 and SW_4 turn on and the motor rotates normally. When V_{left} is about V_{DD} and V_{right} is 0, SW_2 and SW_3 turn on the motor rotates inversely.

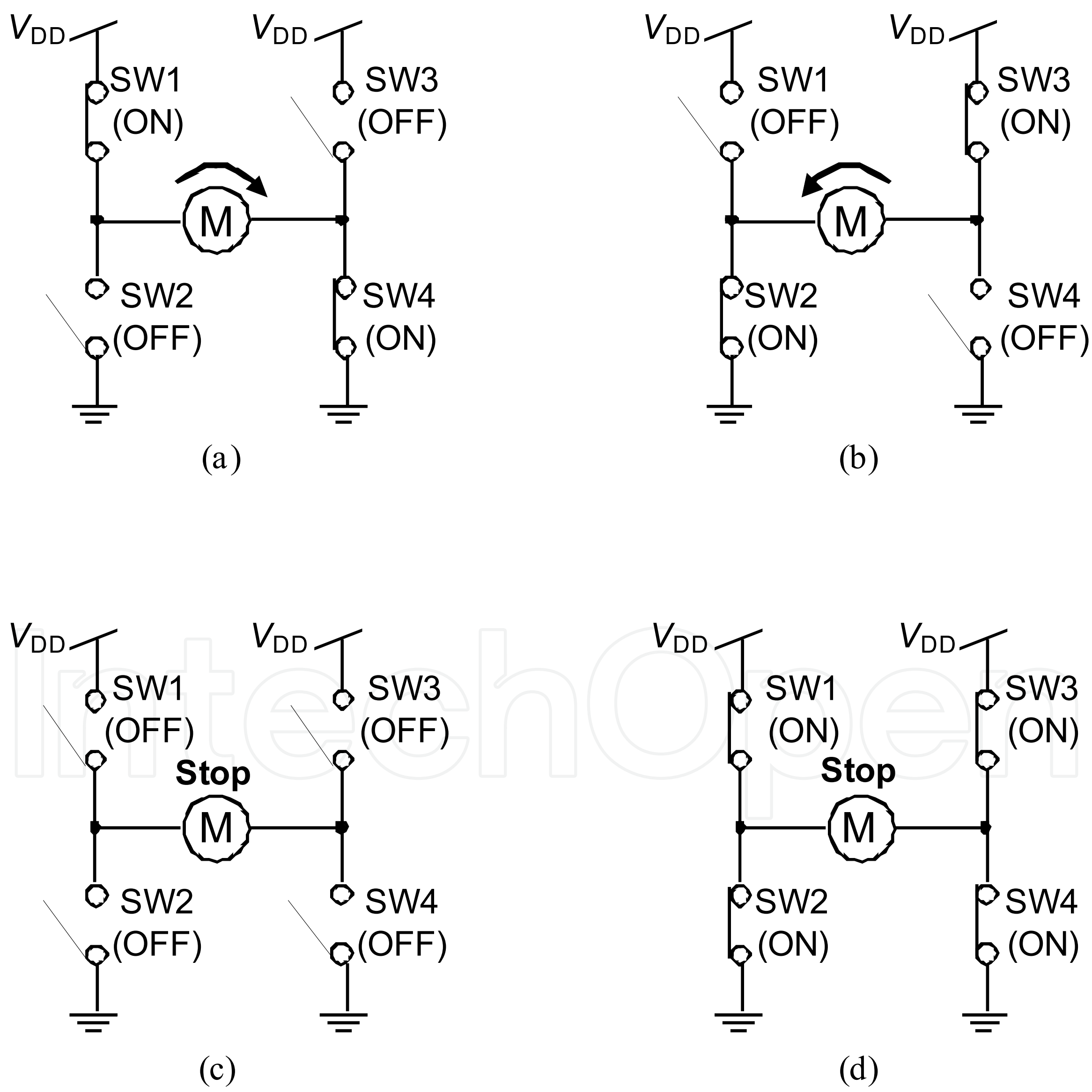

Fig. 6. H bridge circuit. (a) Normal rotation. (b) Inverse rotation. (c) Stop. (d) Stop.

5.3 Measured results of the test system

The fabricated test system for tracking the target in Fig. 4 was measured. Bias voltages set in subsection 5.1 were provided to the circuits based on EMD. As the target, the light was projected on PD array.

The measured results of the test system, when the target moves toward the left side, are shown in Fig. 7. The light was moved toward the left side until *t*=5 s from *t*=0 s. At *t*=5 s, the light was stopped. The system tracked the light, as shown in images at *t*=4 and 5 s. At *t*=6 s, the motor of the system stopped, and the system could capture the target on the center of the PD array.

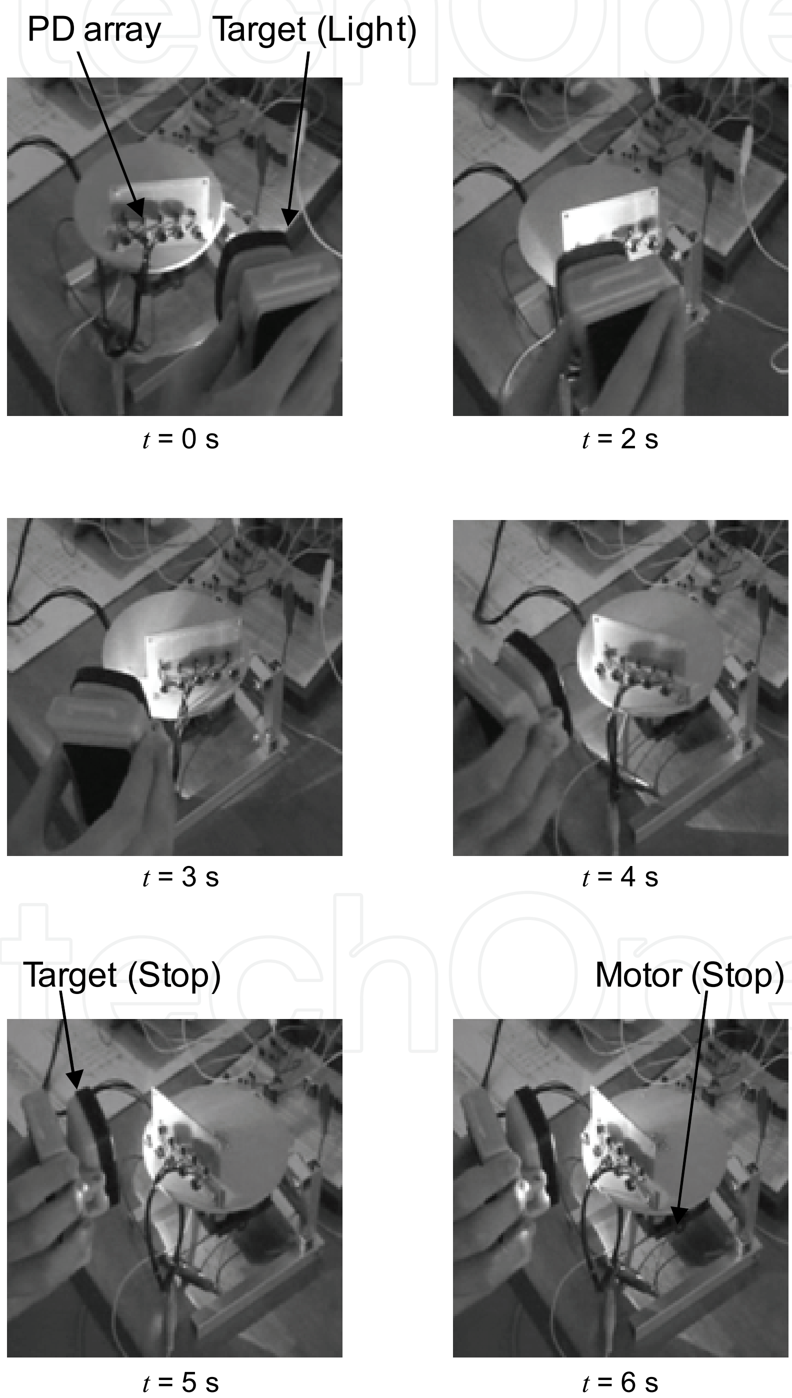

Fig. 7. Measured results of the test system when the target moves toward the left side.

The measured results of the test system, when the target moves toward the right side, are shown in Fig. 8. The light was moved toward the right side until about 3 s. The light was stopped at about 3 s. The system tracked the light toward the right side, as shown in images between *t*=0.5 s and *t*=3 s. As shown in the image at *t*=4 s, the motor stopped and the system could capture the target. Thus, it was clarified from the results that the fabricated system can track the target and capture the target on the center of the PD array.

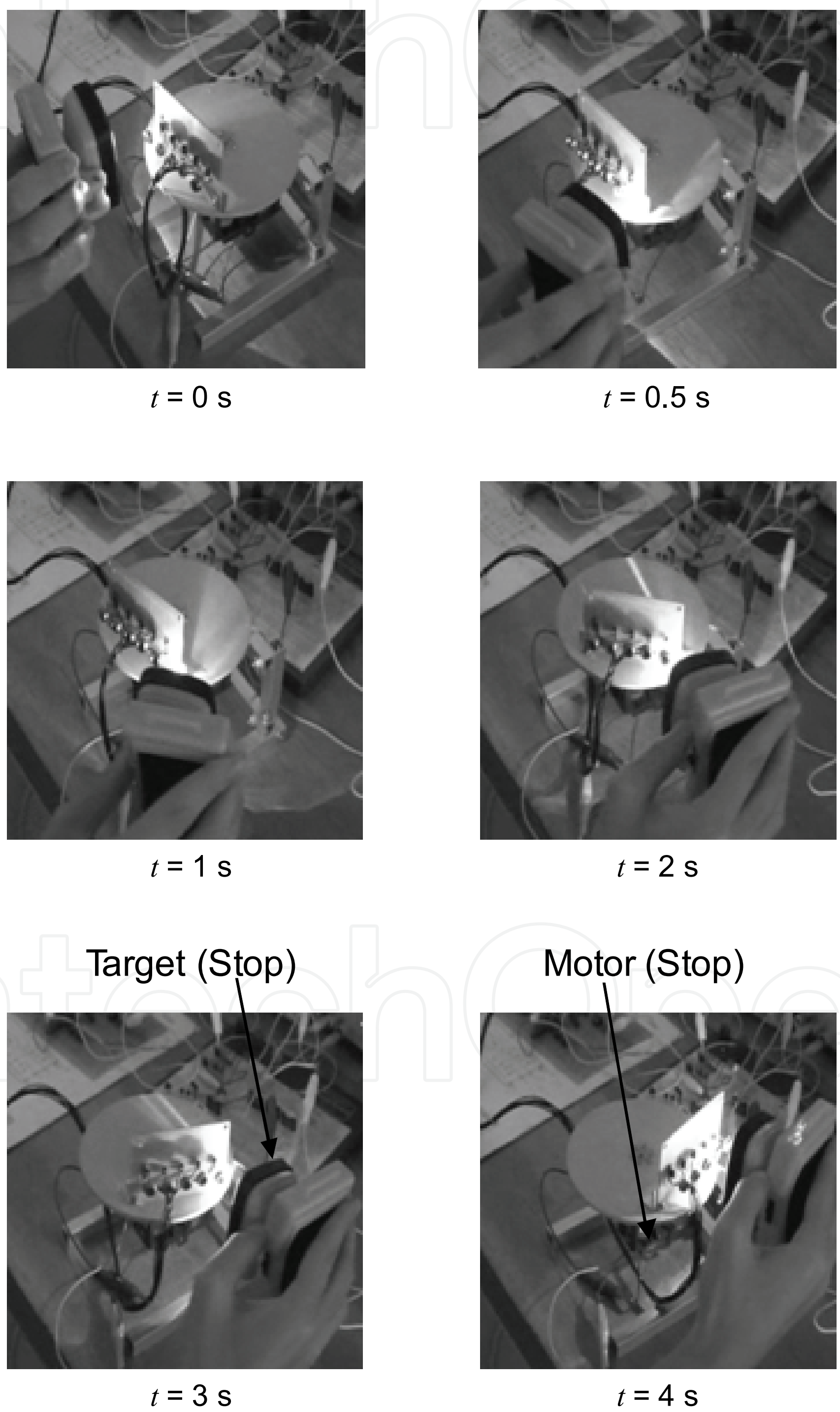

Fig. 8. Measured results of the test system when the target moves toward the right side.

6. Conclusion

In this study, the simple analog CMOS motion detection circuit was proposed based on the biological vision system. The simple circuits for motion detection were applied to the first stage of the target tracking system. The test circuit for motion detection was fabricated on the printed board by using discrete MOS transistors. The test system for tracking the target was fabricated by using the test circuit. The test circuit could generate the motion signal for controlling the motor of the system. The test system could track the target and capture the target on the center of the input part. By using proposed basic circuits and system for tracking the target, we can expect to realize the novel visual sensor for robotics system, monitoring system and others.

7. References

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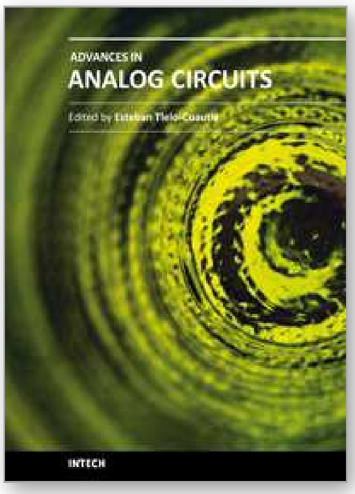

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This book highlights key design issues and challenges to guarantee the development of successful applications of analog circuits. Researchers around the world share acquired experience and insights to develop advances in analog circuit design, modeling and simulation. The key contributions of the sixteen chapters focus on recent advances in analog circuits to accomplish academic or industrial target specifications.