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Determinate the Time to Contact Using Compound Eye Sensor

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Abstract: Recently, many control methods for autonomous robot that are based on biological mechanism have been studied. In particular, a concept of time to contact called tau-margin that is studied in ecological psychology is attracting much attention. In conventional works, various approaches to acquire tau-margin have been studied and are applied for timing control of mobile robots. However, in those studies, robot has a light bulb, and direct light from the light bulb is required for acquiring tau-margin. Thus, it is impossible to apply the conventional method for the robots that use in-direct light for acquiring tau-margin. For that purpose, we develop compound eye sensor which is configured by photodiodes. We employ the framework of optical flow to detect objects and we acquire tau-margin from apparent size of the detected objects and their temporal changes. To demonstrate the effectiveness of the proposed compound eye sensor, we employ a mobile robot controlled with this sensor and conduct a fleeing task. The aim of the fleeing task is to flee an obstacle which approaches, and the timing to flee is controlled by using the tau-margin. Experiments have been conducted by using an actual robot, and as a result, fleeing task has been completed successfully. We can conclude that it is possible to estimate tau-margin by using proposed compound eye sensor.

Keywords: time to contact, ecological psychology, compound eye sensor, optical flow

I. INTRODUCTION

Recently robots that operate in unknown environment have attracted much attention, and various robots have been developed. To behave autonomously, the robots have to acquire information of distance from obstacles to construct three dimensional internal models of the environment. So, usually robot has some sensors that measures distance among the robots and obstacles, for example ultrasonic sensors, the infrared distance sensors and so on.

On the other hand, animals and insects can behave adaptively in the unknown environment without distance sensors. In ecological psychology, the mechanism has been studied, and it is considered that animals and insects employ information that means time to contact instead of information of distance [1]. This time to contact is called "tau-margin", and animals and insects perceive it from apparent size of objects and temporal changes of them.

In conventional works, various approaches to acquire tau-margin have been studied, and are applied for timing control of mobile robots. However, in the conventional studies, robot has a light bulb, and direct light from the light bulb is required for acquiring tau-margin [2]. Thus, it is impossible to apply the conventional method for the robots that use in-direct light for acquiring tau-margin.

In this paper, we propose a method for acquiring time to contact under in-direct light condition. To realize this method, we develop compound eye sensor which is configured by photodiodes. In this sensor, we apply the framework of optical flow to acquire tau-margin. We mount this sensor to a mobile robot, and experiments of fleeing task are conducted by using this mobile robot.

II. TAU-MARGIN IN ECOLOGICAL PSYCHOLOGY

1. Problem of the binocular parallax

It is generally known that many animals and insects can perceive distance by using the binocular parallax. However, as distance becomes far, it is difficult to perceive distance with accuracy, because error between perceived distance and actual distance increases. Fig.1 shows the difference of error of distance with the binocular parallax.

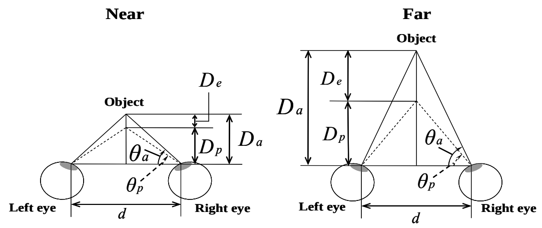


Fig.1. The difference of error of distance

In this figure, the actual distance from the object is described by D_a, and the distance which is recognized visually is described by D_p. θ_a is angular direction to the actual object, and θ_p is angular direction to the perceived object. The error of distance D_e is described by following equation.

$$D_e = \frac{d}{2}(\tan\theta_a - \tan\theta_p) \qquad (1)$$

As the angle of θ_a approaches 90 degrees, D_e diverges to the infinite value. So, this equation means that error of distance becomes larger with increasing actual distance.

2. Perception of tau-margin

It is considered that the binocular parallax is not useful for perceiving long distance. So, in addition to the binocular parallax, animals employ another mechanism to perceive relation between own body and environment. In ecological psychology, this mechanism is studied, and these studies have indicated that animals can perceive visual information which means time to contact. This visual information is called tau-margin, and animals perceive it from apparent size of object and its temporal change. Fig.2 shows visual perception of an object.

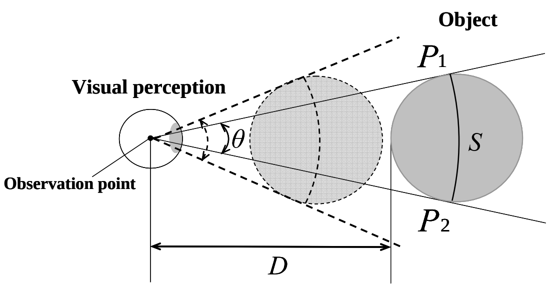


Fig.2. Visual perception of an object

In this figure, S means actual size of the object D means distance between object and visual perception. The apparent size of the object which is represented by θ is described by the equation (2) with S and D.

$$\theta = \frac{S}{D} \qquad (2)$$

The temporal change of θ is shown by the equation (3).

$$\dot{\theta} = -\frac{S}{D^2}\dot{D} \qquad (3)$$

τ means the tau-margin. It is described by the equation (4).

$$\tau = -\frac{\theta}{\dot{\theta}} = \frac{D}{\dot{D}} \qquad (4)$$

This equation means that tau-margin can be perceived directly from the apparent size of object and its temporal change without information of distance or relative velocity to the object.

III. PROPSAL MESTHOD

1. Optical flow

We employ optical flow [3] [4] to acquire apparent size of objects.

Optical flow is one of the popular motion estimate method. It is possible to represent the object motion with velocity vector by analysis of changes in luminance on each pixel. Also, it is possible to estimate direction of the object motion by using the temporal luminance gradient and the spatial luminance gradient.

2. The acquisition method for tau-margin

Fig.3 shows acquisition method for apparent size of object with the compound eye sensor that we propose. In this sensor, each ommatidium is configured by photodiode, and can detect optical flow from optical information of the object.

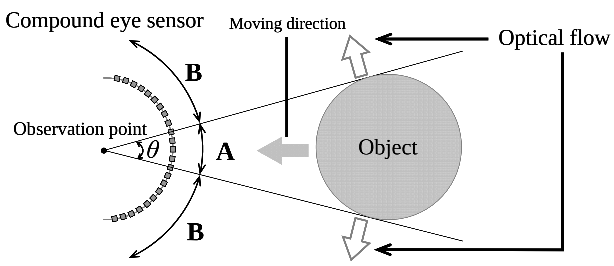


Fig.3 Acquisition method for apparent size of object

As the object approaches to this compound eye sensor, outward optical flow is generated at the region A. And, on the region B, optical flow becomes irregularity. So, it is possible to obtain apparent size of object θ by the outward optical flow.

The temporal change of θ is calculated by an electrical circuit. From these values, tau-margin shown by equation (4) is acquired. Fig. 4 shows processing flow of calculating tau-margin.

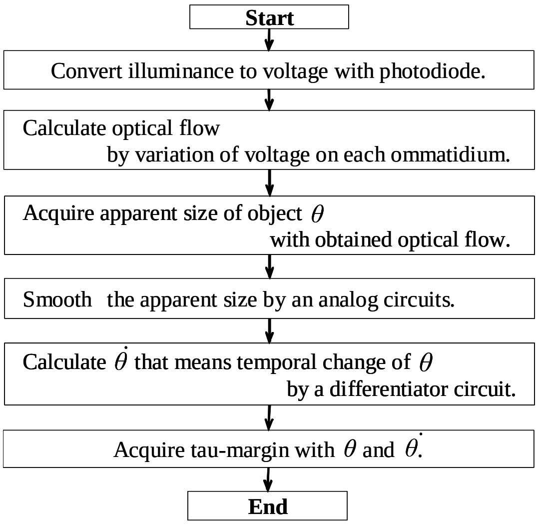


Fig. 4 The processing flow of calculating tau-margin

IV. EXPERIMENTS

1. Compound eye sensor

Fig. 5 and Fig. 6 show the developed compound eye sensor. Fig. 5 is a top view and Fig. 6 is a front view. This sensor is designed so that it can obtain the tau-margin by using some analog circuits which employ 30 photodiode devices. To improve the directivity of the photodiode, a cylinder of black rubber (Fig. 7c) is applied to the photodiode (Fig. 7b). Viewing angle of this sensor is about 160 degrees.

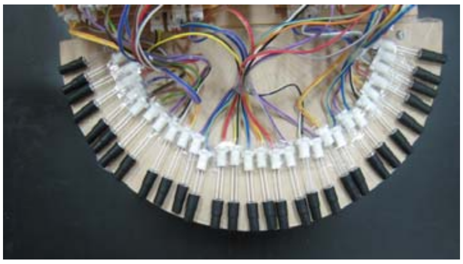


Fig. 5 compound eye sensor (Top view)

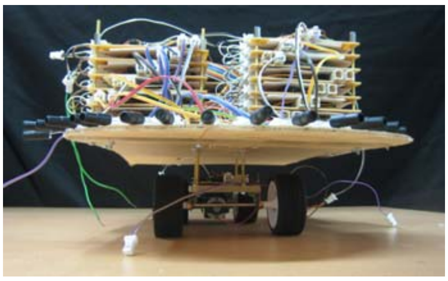
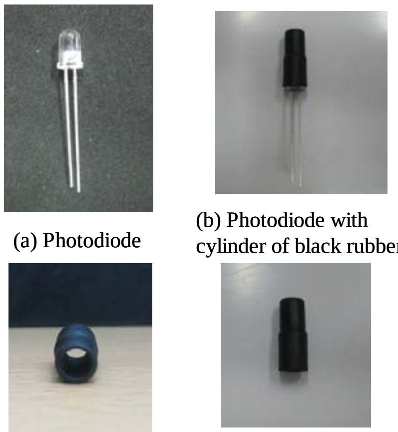


Fig. 6 Compound eye sensor (Front view)



(a) Photodiode

(b) Photodiode with cylinder of black rubber

Side view

Top view

(c) Cylinder of black rubber

Fig. 7 Photodiode

2. Preliminary experiment

As a preliminary experiment, we obtain the tau-margin with the compound eye sensor when object approaches. Fig. 8 shows the experiment environment. There are white boards around the compound eye sensor. The object is a black board, and it approaches to the compound eye sensor.

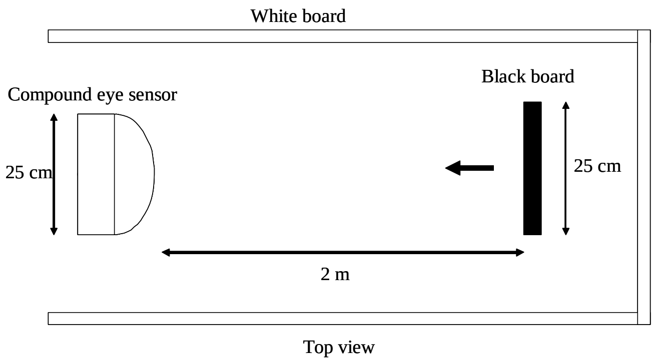


Fig. 8 Experimentation environment

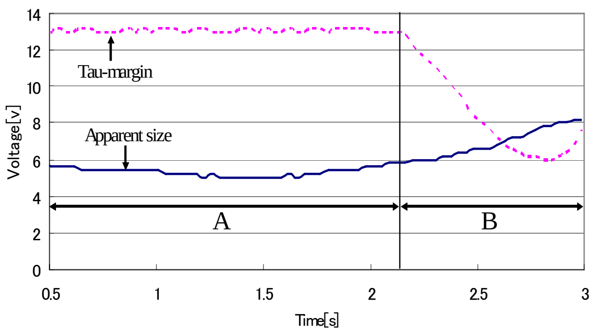


Fig. 9 Apparent size of object and tau-margin

Fig. 9 shows the result. The solid line is the obtained apparent size of the object and dotted line is the tau-margin. In area B, the apparent size of the object increases and the tau-margin decreases. It means that compound eye sensor can obtain the tau-margin from the apparent size.

3. Fleeing task

To demonstrate the effectiveness of the proposed compound eye sensor, we apply it to timing control of a mobile robot. We conduct fleeing task using real robot. The aim of the fleeing task is to flee from the object when it approaches. In this case, the timing of the mobile robot is controlled by the tau-margin.

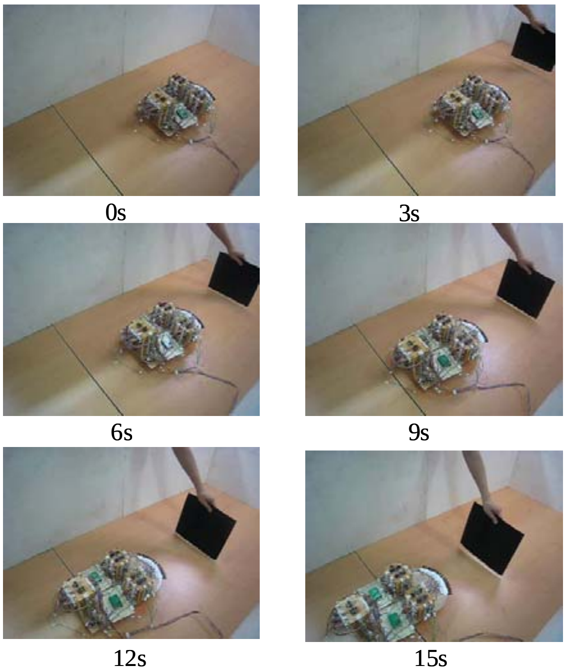


Fig. 10 Fleeing task

Fig. 10 shows a realized motion of the mobile robot in fleeing task. When the object approaches, the robot can operate at the timing to flee. We can consider that the robots behave effectively by using the tau-margin.

4. Discussion

In those experiments, the compound eye sensor does not measure any distance or velocity. However, the fleeing task was able to be achieved by applying the tau-margin. The sensors have obtained the tau-margin in direct light condition. We can confirm that timing control of the mobile robot is realized by the proposed compound eye sensor.

V. CONCLUSION

In this paper, we have considered timing control of a mobile robot and applied the framework of ecological psychology to the robot. We have developed a prototype of the compound eye sensor for obtaining the tau-margin.

We have conducted experiments with the compound eye sensor. As the result, the experiments have been completed successfully. We have confirmed that the compound eye sensor obtained the tau-margin and the robot can operate autonomously by using the tau-margin without any distance or velocity sensors. We can conclude that the proposed compound eye sensor is effective for timing control of the mobile robots.

REFERENCES

[1] Lee DN (1985), Visual timing of interceptive action. Brain mechanisms and spatial vision: 1-30

[2] Tomonori Kai, Yasuhiro Shimada, Kazuyuki Ito (2007), Timing control of the mobile robot using tau-margin. Proceedings of the 13th International Symposium on Artificial Life and Robotics, pp. 907-910

[3] Takashi Fuse, Eihan Shimizu, Morito Tsutsumi (2000), A Comparative Study on Gradient-Based Approaches for Optical Flow Estimation (in Japanese). Proceedings of Applied Survey Technology, Vol. 11, pp. 45-52

[4]Horn B.K.P. and Schunk B.G., Determining optical flow(1981), Artif. Intell. 17, pp.185-203

[5] Kazunori Hoshino (2005), Visual System Inspired by the Insect Compound Eye (in Japanese). Journal of the Robotics Society of Japan, Vol.23, No.1: 32-35

[6] Kazunori Hoshino, Fabrizio Mura, Isao Shimoyama (2001), Fabrication and Performance of Compound Eye Sensors with Scanning Receptor Arrays (in Japanese). Journal of the Robotics Society of Japan, Vol.19, No.3: 408-414

[7] Michiaki SEKINE, Kazunori UMEDA (2001), Construction of compound-eye-type micro vision sensor with simple structure (in Japanese). Journal of the Horological Institute of Japan, Vol.45, No.2: 54-62

[8] Kazunori Hoshino, Fabrizio Mura, Isao Shimoyama (2001), A One-Chip Scanning Retina With an Integrated Micromechanical Scanning Actuator. Journal of Microelectromechanical systems, Vol.10, No.4:492-497