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Timing Control of the Mobile Robot Using Tau-Margin

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Abstract: Recently, autonomous robots which are designed on the basis of biological mechanism have attracted much attention. In this paper, we focus on the mechanism of timing control studied by ecological psychology, and apply the framework to timing control of mobile robots. Experiments using real robots have been conducted and effective behaviors have been realized.

Keywords: Timing control, Mobile robot, Ecological psychology, Tau-margin.

I. INTRODUCTION

Recently, robots that can operate autonomously in unknown environment have attracted much attention, and various robots have been developed. To operate a robot in unknown environment, the robot has to acquire various information of the environment and has to create its model. Therefore, it is necessary for conventional robots to measure the distance between them and obstacles with some sensors such as laser radar, ultrasonic sensor, or binocular vision. However, lots of computational cost is required for creating the model of the environment, and it causes lack of agility of the robots.

On the other hand, animals can behave adaptively in unknown environment without distance sensors. According to ecological psychology, they do not obtain precise models of the environment using distance sensors, but they utilize optical information called tau-margin that represents time to contact, instead of precise distance information. In ecological psychology, how animals perceive the environment has been studied, and it has been confirmed that the tau-margin has been used for various timing control of animals[1]-[8].

In this paper, we consider timing control of mobile robots and apply the framework of ecological psychology to the robots. To demonstrate effectiveness of the proposed method, experiments of pursuit task and fleeing task using real robots are conducted.

II. TAU-MARGIN IN ECOLOGICAL PSYCHOLOGY

In ecological psychology, it is considered that optical information called tau-margin enables animals to specify time to contact directly, and animals time their action by utilizing it. Fig. 1 shows how tau-margin is specified optically. l [m] is the size of an object, Z [m] is the distance between the observer and the object, and ϕ [sr] is the solid angle for the object.

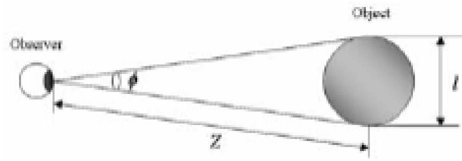


Fig. 1 Tau-margin

And the following equation represents the tau-margin.

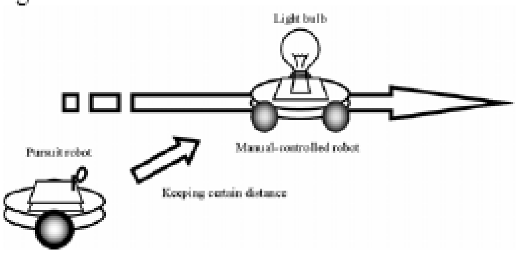
$$\tau = \frac{\phi}{\dot{\phi}} = \frac{\pi l^2 / 4Z^2}{-\pi l^2 \dot{Z} / 2Z^3} = -\frac{1}{2} \cdot \frac{Z}{\dot{Z}} \qquad (1)$$

This equation indicates that the tau-margin represents remaining time to contact. From this equation, we can find that animals can perceive remaining time to contact directly from ϕ and $\dot{\phi}$ without measuring distance Z and velocity $\dot{Z}$.

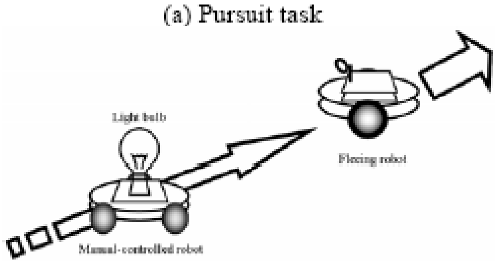
III. PROPOSED SYSTEM

1. Tasks

In this paper, we consider timing control of a mobile robot and apply the framework of the ecological psychology. To verify the proposed system, we conduct pursuit task and fleeing task using real robots. The aim of the pursuit task is to chase the robot that has light bulb with keeping certain distance, and the aim of fleeing task is to flee from the robot that has light bulb when it approaches. In either case, the timing of the mobile robots is controlled by the tau-margin obtained from analog circuits. Fig. 2 shows pursuit task and fleeing task.



(a) Pursuit task



(b) Fleeing task

Fig. 2 Pursuit task and fleeing task

2. Proposed robots

Fig. 3 shows the proposed mobile robot. This mobile robot is designed so that it can obtain the tau-margin by using some analog circuits which employ three CdS cells.

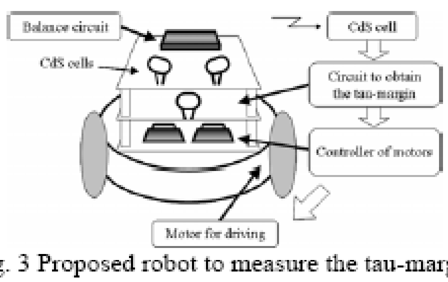


Fig. 3 Proposed robot to measure the tau-margin

We employ the inverse-square law of illuminance (equation (2)) to obtain the tau-margin.

$$E = \frac{I}{x^2} \tag{2}$$

where E [lx] is the illuminace, I [cd] is the luminous intensity of the light source, and x [m] is the distance to the light bulb. The tau-margin can be realized by using the optical properties instead of the optical flow of physical objects.

Secondly, we prepare an analog circuit shown by Fig 3 for converting the light intensity into the voltage. Its output voltage P [V] is given by equation (3). Where R_{CdS} [Ω] is the resistance of a CdS cell, R [Ω] is the resistance, and V_t [V] is reference voltage.

$$P = -\frac{R}{R_{Cds}} \cdot V_t \tag{3}$$

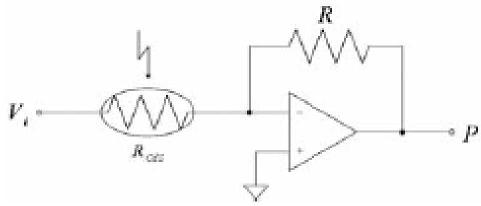


Fig. 4 Circuit to convert light intensity into voltage

We assume that the relationship between the distance to the light bulb and the resistance of the CdS cell is given by the equation (4).

$$r = ax^2 \tag{4}$$

where r [Ω] is the resistance of a CdS cell, and x [m] is the distance to a light bulb.

Equation (5) shows the relation between the P and the tau-margin. From the equation (5), we can find that the tau-margin can be given by using the P.

$$\frac{P}{\dot{P}} = \frac{-\frac{R}{R_{CdS}}V_t}{\frac{d}{dt}\left(-\frac{R}{R_{CdS}}V_t\right)} = -\frac{R_{CdS}}{\dot{R}_{CdS}} = \frac{ax^2}{2ax\dot{x}} = -\frac{1}{2}\cdot\frac{x}{\dot{x}} = \tau \tag{5}$$

In this paper, we obtain the tau-margin by using the P without using information of distance. In the tasks written in subsection III-1, we employ various light bulbs and their intensities are unknown, so we can not obtain the distance from the resistance of the CdS cell.

3. Setting of pursuit robot

The impellent force of the pursuit robot is given by the equation (6).

$$F = -k_p \frac{1}{\tau} \tag{6}$$

where $k_p (k_p > 0)$ is proportional constant.

The direction of the impellent force is controlled by the balance circuit which is composed of two CdS cells. Fig. 5 shows the balance circuit.

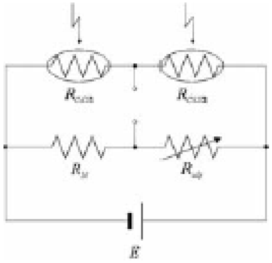


Fig. 5 Balance circuit of light intensity

This circuit compares R_{CdS1} with R_{CdS2}, and R_{adj} is the variable resistance to compensate the dispersion of them.

4. Setting of the fleeing robot

The impellent force of the fleeing robot is determined by the equation (7).

$$F = \begin{cases} k & (\tau < T) \\ 0 & (\tau \geq T) \end{cases} \tag{7}$$

where T [s] is the timing to flee, and k [N· m] is a constant. The fleeing robot compares the tau-margin with the reference time to flee. If the tau-margin falls below the reference, the robot is given certain force enough to flee. The direction of the impellent force is controlled by the balance circuit indicated by Fig. 5.

5. Manual-controlled robot

To lead the pursuit robot and to chase the fleeing robot, we prepare a manual-controlled robot which has light bulb. The mobile robot is controlled manually with a joystick. In pursuit task, this robot leads the pursuit robot. In fleeing task, it chases the fleeing robot manually with the joystick. And, we operate the manual-controlled robot so that it can drive at the same speed as the pursuit robot and the fleeing robot.

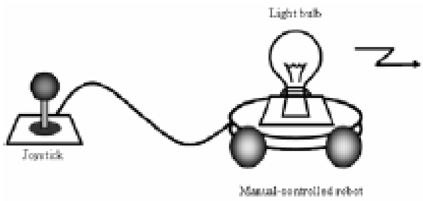


Fig. 6 Manual-controlled robot

IV. Experiments

1. Preliminary experiment

As a preliminary experiment, we confirmed the relationship between the resistance of a CdS cell and the distance to a light bulb. We employ a ten-watt bulb as the light source and investigate the resistance of the CdS cell. Fig. 7 shows the result.

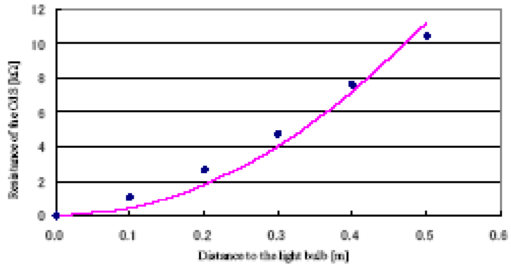


Fig. 7 Approximated curve by least-squares method

We can find that the relationship between resistance of the CdS cell and the distance to the light bulb can be approximated by equation (4) as far as the distance is smaller than 0.5m. This approximation is adequate for obtaining the tau-margin because the timing is required in closer range.

2. Pursuit task

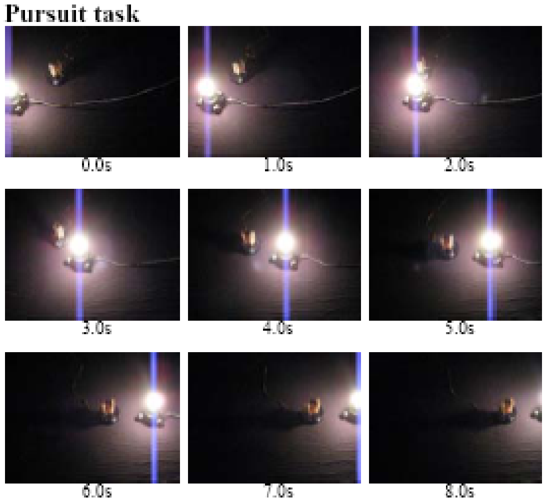


Fig. 8 Pursuit task with a 30-watt bulb

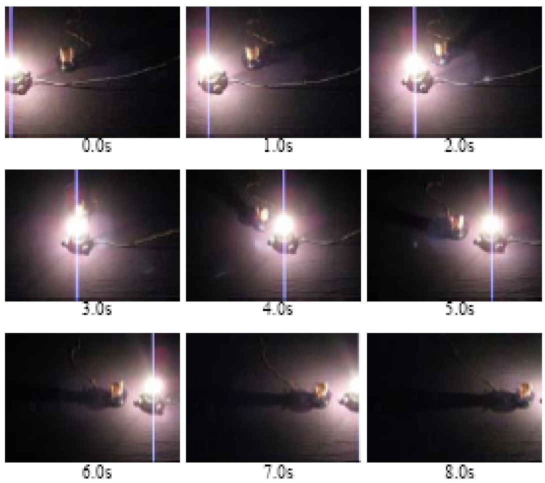


Fig. 9 Pursuit task with a 60-watt bulb

Fig. 8 and Fig. 9 show the realized motion of the mobile robot in pursuit task. The former shows the pursuit task with a thirty-watt bulb and the latter shows that with a sixty-watt bulb. From both figures, we can find that the pursuit robot can follow the leading robot in spite of the fact that the leading robot has different light bulbs.

3. Fleeing task

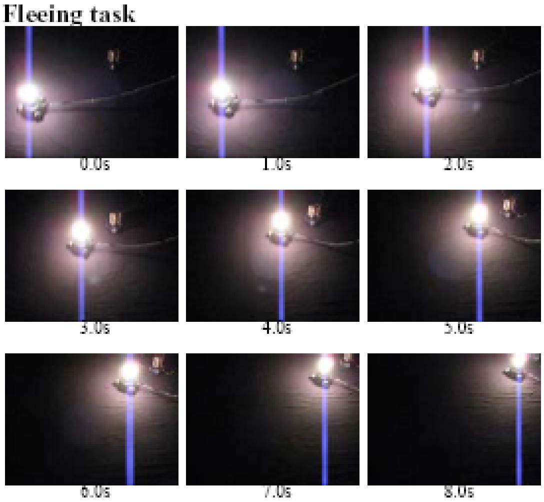


Fig. 10 Fleeing task with a 30-watt bulb

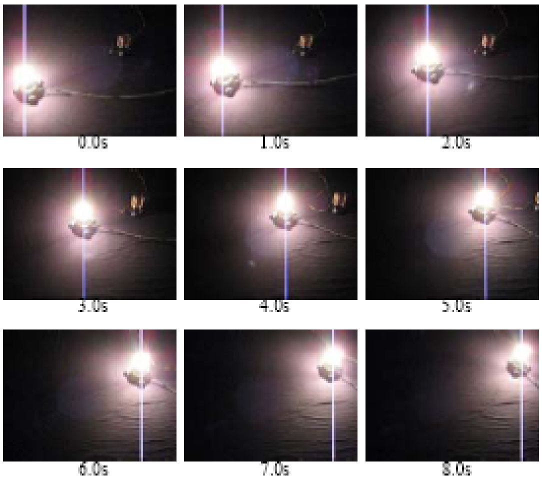


Fig. 11 Fleeing task with a 60-watt bulb

Fig. 10 and Fig. 11 show the realized motion of the mobile robot in fleeing task. The former shows the fleeing task with a thirty-watt bulb and the latter shows that with a sixty-watt bulb. When the chasing robot approaches, the fleeing robot can operate at the timing to flee. From both figure, we can also find that the fleeing robot can flee from the chasing robot at almost the same timing in spite of the fact that the chasing robot has different light bulbs. We can consider that the robots behave effectively by using the tau-margin.

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 conducted the experiments of two tasks. As a result, both tasks have been completed successfully. We have confirmed that the robot can operate autonomously by using the tau-margin without any distance or velocity sensors. Therefore, we can conclude that the framework of tau-margin is effective for timing control of the mobile robots.

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