A reconstruction method of projection image on worker honeybees' compound eye

Hidetoshi Ikeno [a]

[a] *School of Humanities for Environmental Policy and Technology, Himeji Institute of Technology,1-1-12, Shinzaike-Honcho, Himeji, HYOGO, 670-0092, Japan*

Abstract

Visual perception by insect compound eyes is of interest in visual science for revealing neuronal principals of vision, and applying their small and simple structures to artificial vision systems. In order to investigate how animal behavior is related to sensory stimuli, it is important to take into account real input signals to the nervous system. In the case of an insect with compound eyes, sceneries projected onto compound eye are the basic signals for visual information processing. In this paper, a method to reconstruct the projected images on the honeybee compound eyes is presented. This method estimates the illuminance change of a single ommatidium surface. It may be applied to analyze the correspondence between input images and retinal responses.

Keywords: compound eye, ommatidium, honeybee, vision

1 Introduction

Flying insects like bees can not only control their posture, but also navigate to the target based on time-varying image signals during their flight. Insect visual mechanisms are of interest for revealing neuronal principals of image processing and applying their simple structure to artificial vision. It is well known that capabilities of scenery recognition differ across species, so insects with compound eyes are living in a different visual world from mammals. However, only a few experiments take into consideration the difference in

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[2] Corresponding author. phone: +81-792-92-1515; fax: +81-792-93-5710; e-mail: ikeno@hept.himeji-tech.ac.jp

image perception by compound eyes[3]. It tends to be assumed that the same characteristics or information are used for recognition and behavioral control even in the insect brain. But if we want to reveal neural mechanisms for image processing in insect brains, it is essential to analyze and model based on real input signals into the photoreceptors.

In the case of honeybee flight, sceneries of her outside world are projected onto her compound eyes and received by photoreceptors in the ommatidium. Photoreceptor responses are processed through the visual signal pathway from retina to brain for detection of information and control of her behavior. Even though the projected images on her eyes are distorted by her position and posture, she can navigate easily with discrimination of patterns, recognition of shapes, and estimation of depth and distance. In my laboratory, we are building a mathematical model of image processing and flight control in the honeybee based on neural and behavioral properties. As a first step in the analysis of flight behavior to the visual stimulus, it is important to know real inputs to their eyes, that is, illuminance changes on the ommatidium surface. In this paper, a method to calculate the projection image on the honeybee compound eye is presented. A sequence of acquisition images through the flight path can be reconstructed by this method.

2 Model

A method to calculate the projection image on the compound eye of honeybees is presented and demonstrated by Giger[2]. In this method, a projection image of outside scenery was reconstructed by geometrical transformation, but I present a new method which is calculated based on illuminance changes on ommatidium lens surfaces.

2.1 Geometrical properties

Geometrical properties of compound eyes of worker honeybees were measured by Seidl and Kaiser[5]. In a frontal view of the honeybee head (Fig.1(a)), a horizontal base plane (XY) was determined by the widest part of the head capsule. The boundaries of the visual receptive field based on the XY plane are 105.5° ventrally and 119.0° dorsally in vertical directions. The Z axis is determined to pass through a point central to a virtual circle for approximating the horizontal arrangement of ommatidia (Fig.1(b)). Boundaries of the horizontal receptive field are reported at 104.5° forward and 71.5° backward from the Y axis.

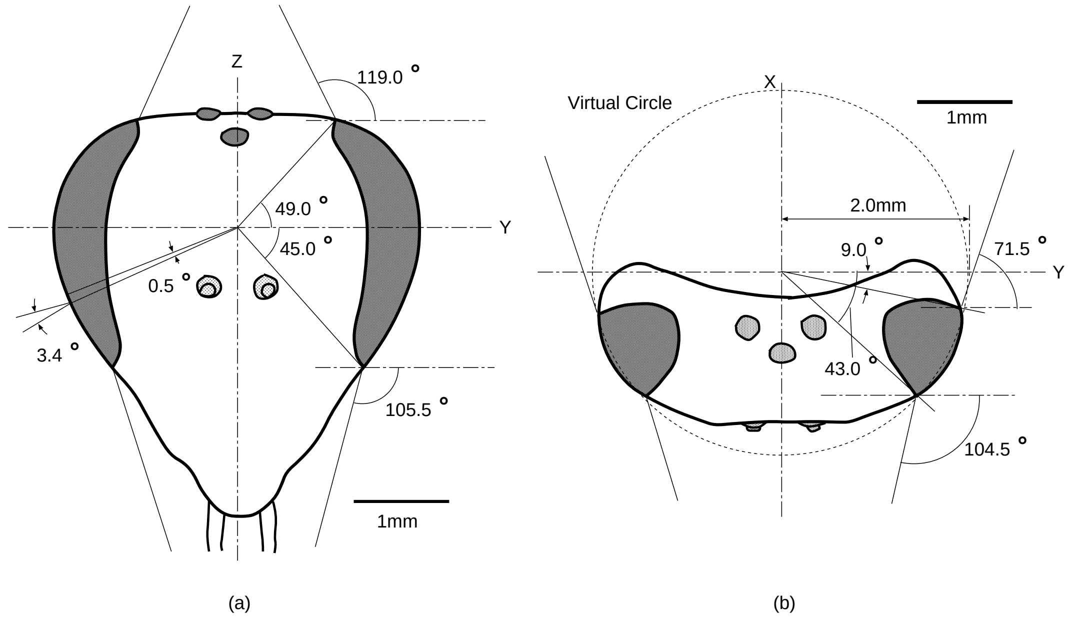

Fig. 1. Geometrical parameters of honeybees' compound eye, (a) frontal view, (b) dorsal view.

In the illuminance change method, a projected image on the compound eye is reconstructed based on the calculation of illuminance changes on each ommatidium surface. For the calculation, it is necessary to determine the coordinates and the direction of view for each ommatidium. Ommatidia are arranged vertically from the ventral boundary at 45° to the dorsal one the 49° and horizontally from 9° to 43° on the virtual circle as shown in Fig.1(b). Ommatidium are allocated along the circumference of radius 2mm on YZ plane. Numbers of horizontally allocated ommatidia were decreased from 38° both ventrally and dorsally. The number of ommatidia in each compound eye is known to be about 5,000. Ommatidia were assigned at regularl interval as 0.5°, within the boundaries. The assignment was staggered by half of interval, 0.25°, in horizontal arrangement.

2.2 Calculation of projection image

The direction of visual field vector (perpendicular line to the lens) for each ommatidium was determined by equally dividing the whole receptive field of the compound eye. The response sensitivity of each ommatidium was approximated by a Gaussian function with $mean = 0$, $standard\ deviation = 1.77°$.

The image presented to the honeybee was composed of black and white pixels as shown in Fig.2. The illuminance change on each ommatidium lens due to

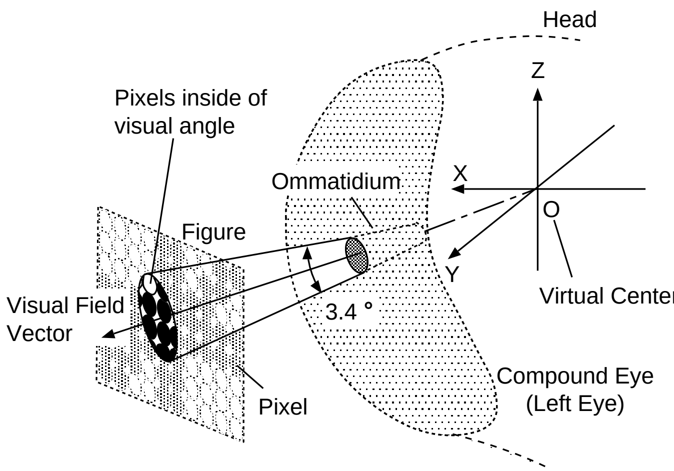

Fig. 2. Acquisition of light in the ommatidium

each image pixel was calculated as follows;

$$\Delta l_i = L_i \cdot \frac{S_i}{S_o} \cdot \frac{1}{r_i^2} \cdot cos\theta_i \qquad (1)$$

In this equation, Δl_i is the illuminance produced change by one image pixel i. S_i/S_o is the ratio of image pixel size within a receptive field to the receptive field size of the ommatidium. L_i is the brightness of the image pixel, and r_i is the distance between the pixel and the ommatidium. θ_i is the angle between the visual field vector and a line perpendicular to the image pixel. For each ommatidium, the total illuminance change caused by all image pixels is described by the sum of Δl_i.

3 Simulation results

Sceneries reconstructed by this illuminance change method were compared with the results of B-EYE[2]. It was confirmed that the illuminance change method also reconstructed a projection image on honeybee eyes. This method required a long time for calculations, because it estimated the illuminance for each ommatidia surface. However, it corresponded well to the photoreceptor model [1], since the presented method can produce real input stimuli for the photoreceptor.

An image compound of vertical, horizontal and diagonal lines with 100mm length and 10mm width was presented as a target in front of the honeybee flight path (Fig.3(a)). Projection images were calculated on the compound eye in the case of approaching toward the target through five UVW coordinate points (a: 80, 0, 10), (b: 70, -30, 30), (c: 60, 0, 10), (d: 50, 30, -30), (e: 40, 0 10) (unit: mm) as shown in Fig. 3(b). In this simulation, posture was kept

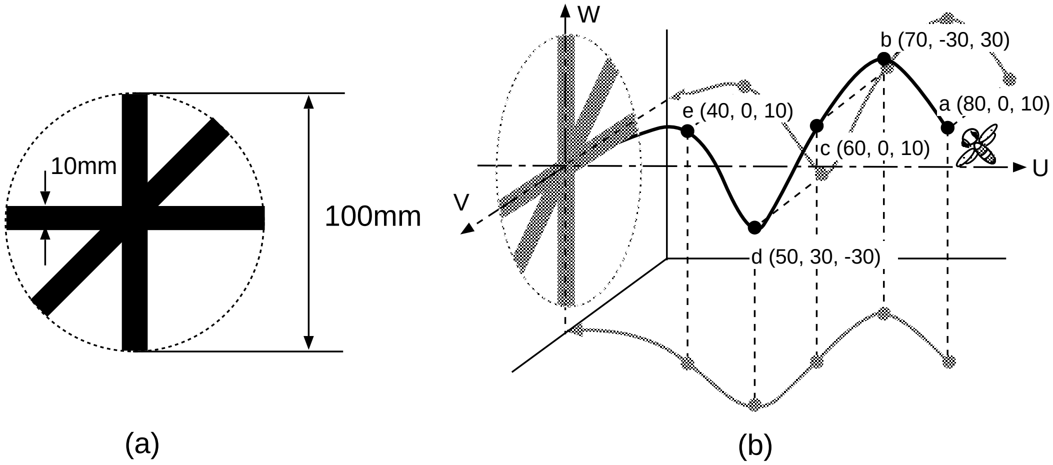

Fig. 3. Target pattern and flight route for simulation, (a) Target pattern, (b) flight route

constant at 30 degrees tilt to the vertical target plane. In the results of the simulation in Fig. 4, each picture is presenting the right side view of right eye, front views of both eyes and left side view of left eye. Numbers in the center show the UVW coordinates of bee positions.

At point (a) which is 80mm from the target, a small image of the target was projected on both eyes, but the illuminance differed little from ommatidia receiving background light. When the bee flew in the upper right direction, to point (b), most of the image moved onto the left eye, but a small part of the target in the binocular visual field still remained on the right eye. At this point, the image of the line was curved and the target was asymmetric. At point (c), the image was more clear than at point (a), but vertical line was thicker in the lower part. The image became more distorted as the bee moved down to the left direction, point (d), and closer to the target, point (e).

4 Remarks

In this paper, a method was presented for reconstructing images projected onto the compound eye of worker honeybees. As shown in the simulation results, honeybees uses strongly distorted images whose distortion depends on the distance and direction from the target, but the honeybee shows skillful navigation based on this uncertain information. Presently, we are using a CCD camera to measure flight trajectories in the Y-shaped maze, which is used for conditioning honeybee[6]. Input images to the visual nervous system during the flight can be calculated by using this new method, which will be useful for analysis of behavioral control mechanisms based on visual stimuli and memory.

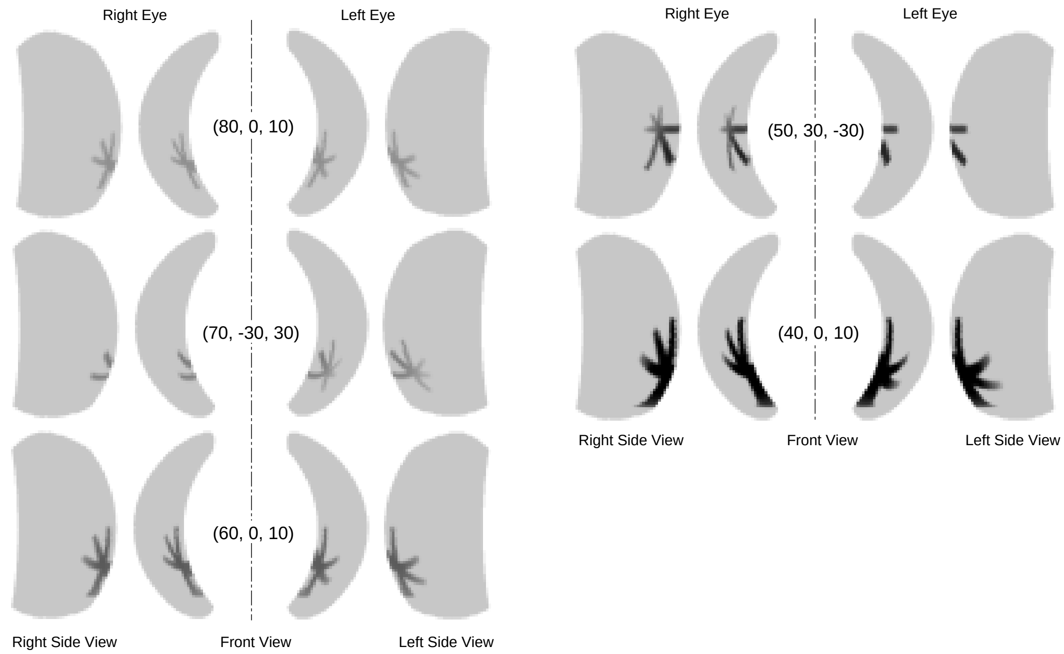

Fig. 4. Projected target pattern on compound eye

References

[1] K. Becker and W. Backhaus, A physiological model of dark-adapted and light-adapted photoreceptors of the honeybee, Biol. Cybern., 82, 153–160, 2000.

[2] B-EYE, http://cvs.anu.edu.au/andy/beye/beyehome.html.

[3] D. Efler and B. Ronacher, Evidence against a Retinotopic-template Matching in Honeybees' Pattern Recognition, Vision Res., 40, 3391–3403, 2000.

[4] S.B. Laughlin and G.A. Horridge, Angular Sensitivity of the Retinula Cells of Dark Adapted Worker Honey bee, Z. vergl. Physiol., 74, 329–335, 1971.

[5] R. Seidl and W. Kaiser, Visual Field Size, Binocular Domain and the Ommatidial Array of the Compound Eyes in Worker Honey Bee, J. Comp. Physiol. A, 143, 17–26, 1981.

[6] A. Horridge, Seven experiments on pattern vision of the honeybee, with a model, Vision Research, 40, 2589-2603, 2000.

Hidetoshi Ikeno He received the B.Eng., M.Eng. and D.Eng. degree from the Toyohashi University of Technology in 1983, 1985 and 1993, respectively. 1985–1989: Research Associate; 1989–1992: Assistant Professor; 1994–1998: Associate Professor at Maizuru National College of Technology. Assistant Professor at Toyohashi University of Technology, 1992–1994. Since April 1998, he has been an Associate Professor at Himeji Institute of Technology.