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

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Abstract

Visual perception by insect compound eyes have been interested in visual science fields for revealing neuronal principals of vision, and applying their small and simple structures to the artificial vision system. In order to investigate the animal behavior which related with sensory stimuli, it is important to take account into real input signals for nervous system. In the case of insect with compound eye, the projected scenery on compound eye is basic signal for visual information processing. In this paper, it is presented a reconstruction method of projected image on honeybee compound eye. This method can be estimated illuminance change of a single ommatidium surface. It would be applied to analysis of relevance between input images and retinal responses.

Keywords: compound eye, ommatidium, honeybee, model, vision

1 Introduction

Insects like bee can not only control their posture, but also detect their target based on image data during the flight. It have been interested in the insect visual system for revealing neuronal principals of image processing and applying to the artificial vision. It have been well known that capability of scenery recognition is differed by animals, so insects with compound eye are living in the different visual worlds from us. However, only a few experiments take

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account into considerations about difference of visual system between insects and us [3]. It tend to be assumed that same characteristics or information could be used for recognition and behavioral control even in the insect brain. But if we want to reveal the neural mechanisms for image processing of insect visual system, it is demanded to analyze based on real input signal into the photoreceptor.

In the case of flight honeybee, time varying sceneries are projected on their compound eye and received by photoreceptor in the an ommatidium. Photoreceptor responses are processed through the visual signal pathway from retina to brain for detection of information and control of her behavior. Even the projected images on her eye would be distorted by her position and posture, she seems to be handling them easily to discriminate the patterns, recognize the shapes, estimate the depth and measure the distance. We are currently going to build a mathematical model for the image processing and flight control of honeybee based on her neural and behavioral properties. In that study, it is important to know real input signal, that is, illuminance to the photoreceptor. In this paper, projection images on the honeybee compound eye during flight were reconstructed based on illuminance changes of single ommatidium.

2 Model

A method to calculate the projection image on the compound eye of honeybee is presented and demonstrated by Giger[2] on the Web site. In this method, outside scenery of honeybee was modulated by geometrical transformation, but I presented a method based on the illuminance on the surface of ommatidium lens in order to correspond to the photoreceptor response and image stimuli.

2.1 Geometrical properties

Geometrical properties of compound eyes about worker honeybee had been measured by Seidl and Kaiser[5]. In a front view of honeybee head (Fig.1(a)), a horizontal base plane (XY) was determined by the widest part of head capsule. The boundaries of visual receptive field based on the XY plane are 105.5 ventrally and 119.0 degrees dorsally in vertical directions. Z axis is determined to pass trough a point which can draw a virtual circle for approximating the horizontal arrangement of ommatidia (Fig.1(b)). Boundaries of horizontal receptive field are reported 104.5 and 71.5 degrees from Y axis.

In presented method, projection image on the compound eye is reconstructed

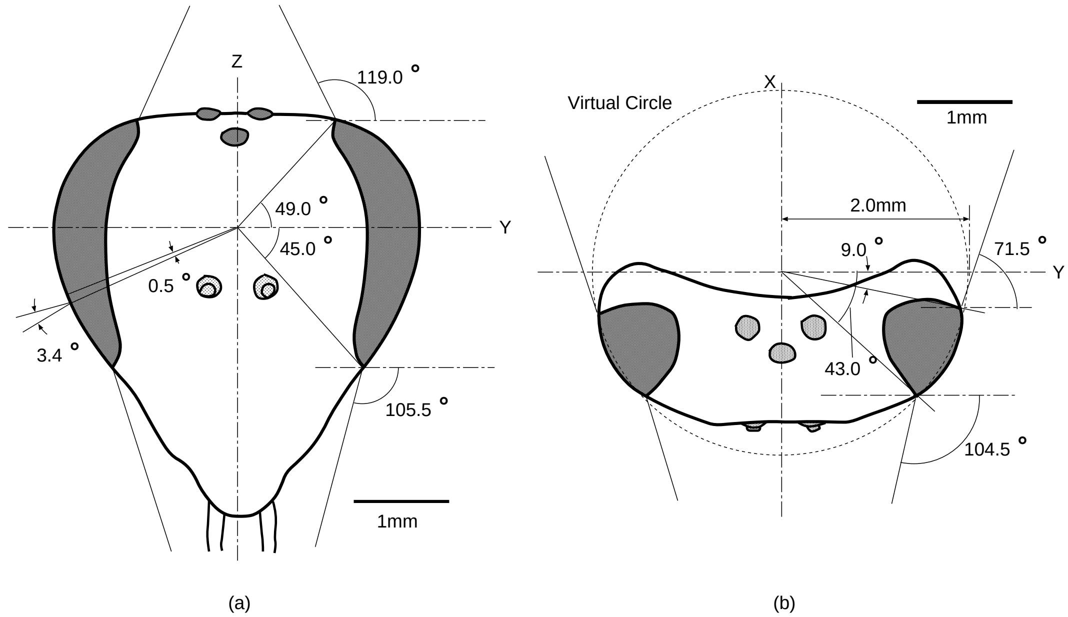

Fig. 1. Geometrical parameters of honeybees' compound eye, (a) vertical view, (b) horizontal view.

based on the calculation of brightness of each ommatidium surface lens. It is need to determine the coordinate of each ommatidium and direction view field vector. Ommatidia were arranged vertically from ventral boundary 45 degree to dorsal one 49 degree. Z coordinates for ommatidia are determined by circle on YZ plane with radius 2mm. Arrangements of ommatidia was started horizontally from 9 degree to 43 degree on the virtual circle as shown in Fig.1(b). Decreasing of number of horizontal ommatidia was started at 38 degrees both ventrally and dorsally. The characteristics of decreasing was approximated by 2nd order function.

2.2 Calculation of projection image

Number of ommatidia in each compound eye is known about 5,000. From this number, each ommatidia was separated by 0.6 degree horizontally and 0.5 degree vertically. Direction of view field vector (perpendicular line to the lens) for each ommatidium was demanded by equally divided whole receptive field of compound eye. Sensitivity of light acquisition was approximated by the Gaussian function.

Image presented to the honeybee was composed by black and white pixel as shown in Fig.2. Illuminance change on each ommatidium lens was calculated by light reflection of each image pixel;

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

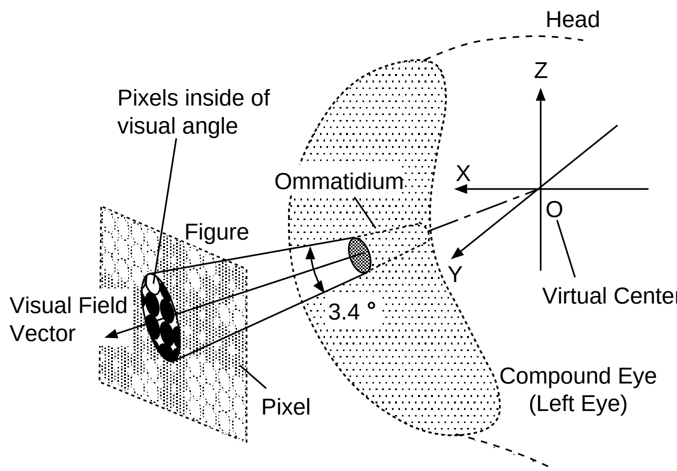

Fig. 2. Acquisition of light in the ommatidium

In this equation, l_i is illuminance change by one image pixel i. S_i/S_o is a ratio of image pixel size within a receptive field to the receptive field size of ommatidium. L_i is brightness of image pixel, and r_i is distance between pixel and ommatidium. $theta_i$ is a angle between view field vector and perpendicular line of image pixel. For each ommatidium, illuminance change caused by all image pixel is described by sum of I_i.

3 Simulation results

Sceneries reconstructed by presented method are compared with the results of B-EYE[2]. It was confirmed that presented method also reconstructs a projection image on honeybee eyes. New method take a long time to calculation, because it estimates the illuminance for each ommatidia surface. However, it would be well corresponded 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 is presented as target in front of honeybee flight path (Fig.3(a)). It was calculated projection images on compound eye in the case for approaching toward the target through the 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, it was assumed posture was kept constant at tilting in 30 degrees to the vertical target plane. In the results of the simulation Fig. 4, each raw is presenting the right side view of right eye, front views of both eyes and left side view of left eye. Numbers in center are shown the UVW coordinates of bee existing.

At the point (a) where is in 80mm from target, small image of target was projected on both eyes, but difference of illuminance was little from ommatidia

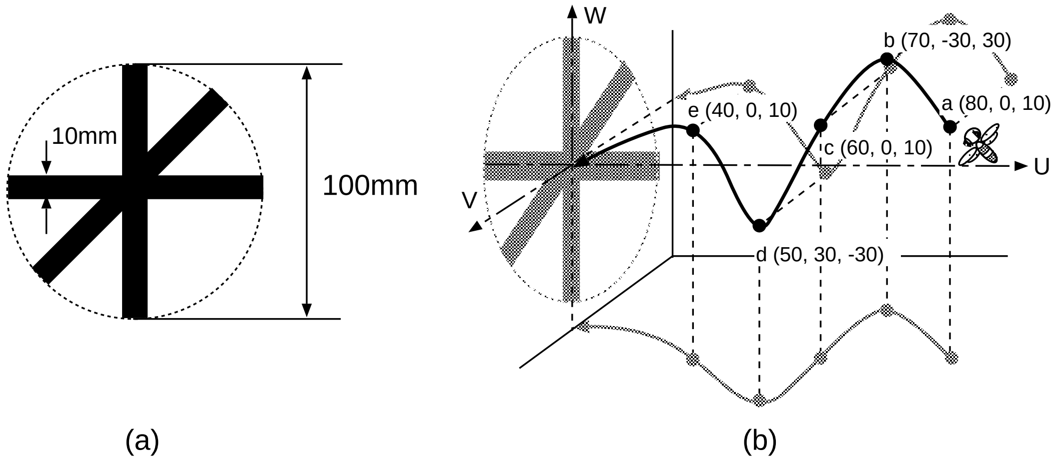

Fig. 3. Target pattern and flight route for simulation, (a) Target pattern, (b) flight route

which receiving background light. When the bee went upper right direction, point (b), almost all image was moved onto the left eye, but small part of target in binocular visual field was still remain on the right eye. At this point, image of line was curved and broken the symmetry. At point (c), image became more clear than one at point (a), but vertical line became thicker in lower part. Furthermore, image got heavy distortions by moving down to the left direction, point (d), and closing to the target, point (e).

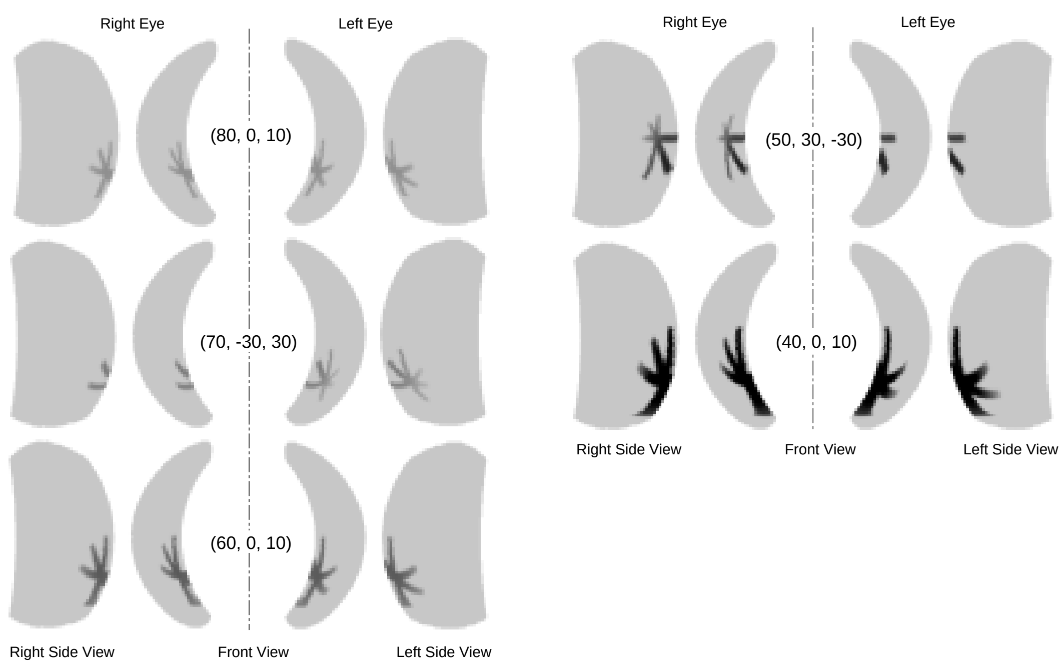

Fig. 4. Projected target pattern on compound eye

4 Remarks

In this paper, it was presented a method for reconstructing the image projected on the compound eye of worker honeybee. As shown in the simulation results, honeybee uses image signals with distortions depended on the distance and direction of target, but she shows skillful flight based on that uncertain information. Now, it is measuring flight trajectories in the restricted area by CCD cameras. From that results, input image to the visual nervous system will be calculated by this method, and analyzed the relation between input image and behavioral control.

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