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Small brains, smart computations: Vision and navigation in honeybees, and applications to robotics

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Abstract. Flying insects provide a clear demonstration that living organisms can display surprisingly competent mechanisms of guidance and navigation, despite possessing relatively small brains and simple nervous systems. Consequently, they are proving to be excellent organisms in which to investigate how visual information is exploited to guide locomotion and navigation. Three illustrative examples are described here, in the context of navigation to a destination. Bees negotiate narrow gaps by balancing the speeds of the images in the two eyes. The flight speed is regulated by holding constant the average image velocity as seen by the two eyes. Smooth landings on a horizontal surface are achieved by holding image velocity constant as the surface is approached, thus automatically ensuring that the flight speed is close to zero at touchdown. Tests of the feasibility of some of these navigational strategies, by implementation in robots, are described. © 2006 Elsevier B.V. All rights reserved.

Keywords: Insect vision; Flight; Optic flow; Landing; Terrain following

1. Introduction

Insect eyes differ from vertebrate or human eyes in a number of ways. Unlike vertebrates, insects have immobile eyes with fixed-focus optics. Therefore, they cannot infer the distances to objects or surfaces from the extent to which the directions of gaze must converge to view the object, or by monitoring the refractive power that is required to bring the image of the object into focus on the retina. Furthermore, compared with human eyes, insects eyes are positioned much closer together and possess inferior spatial acuity

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[1]. Therefore, the precision with which insects could estimate range through binocular stereopsis would be much poorer and restricted to relatively small distances, even if they possessed the requisite neural apparatus [2]. Not surprisingly, then, insects have evolved alternative strategies for dealing with the problems of visually guided flight. Many of these strategies rely on using image motion, generated by the insect's own motion, to infer the distances to obstacles and to control various manoeuvres [2–4]. Here, we describe three ways in which flying insects—specifically, honeybees-use vision for guidance. The specific navigational problems considered are: (i) negotiating narrow gaps and avoiding obstacles, (ii) regulating flight speed and (iii) performing smooth landings. We also briefly describe tests of the effectiveness of some of these strategies by implementation in robots.

2. Negotiating narrow gaps and avoiding obstacles

When a bee flies through a hole in a wall, it tends to fly through its centre, without colliding with the rims. How does she gauge and balance the distances to the two rims?

One possibility is that the bee does not measure distances at all, but simply balances the speeds of image motion on the two eyes, as she flies through the opening. To investigate this possibility, Kirchner and Srinivasan [5] trained bees to enter an apparatus that offered a reward of sugar solution at the end of a tunnel. Each side wall carried a pattern consisting of a vertical black-and-white grating (Fig. 1). The grating on one wall could be moved horizontally at any desired speed, either towards the reward or away from it. After the bees had received several rewards with the gratings stationary, they were filmed from above as they flew along the tunnel. When both gratings were stationary, the bees tended to fly along the midline of the tunnel, i.e. equidistant from the two walls (Fig. 1a). However, when one of the gratings was moved at a constant speed in the direction of the bees' flight–thereby reducing the speed of retinal image motion on that eye relative to the other eye–the bees' trajectories shifted towards the side of the moving grating (Fig. 1b). When the grating moved in a direction opposite to that of the bees' flight–thereby increasing the

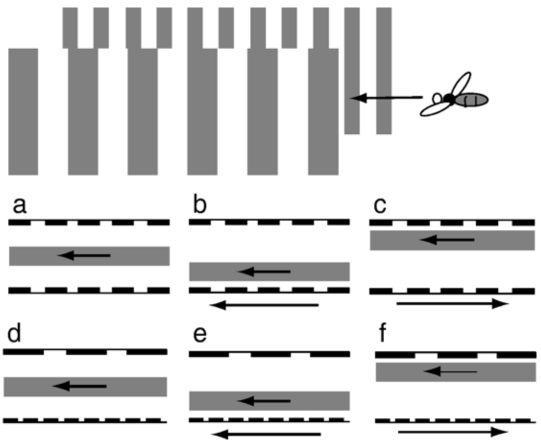

Fig. 1. Illustration of an experiment which demonstrates that flying bees infer range from apparent image speed. The shaded areas represent the means and standard deviations of the positions of the flight trajectories, analysed from video recordings of several hundred flights. Reproduced with permission from [4].