Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 1, Number 10; October, 2014 pp. 110-113

http://www.krishisanskriti.org/jbaer.html

Sturdy Closed Loopshaping Flight Dynamics of A Bio-Mimetic Flapping Wing Micro Air Vehicle

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Abstract: **Birds exhibit incredibly the sturdy closed loop flight dynamics in the face of dilemma. The underlying principle bestow to this unparalleled response is rapid processing and convergence of visual sensory to flight motor commands via spatial wide -field integration , competent by retinal motion pattern sensitive interneurons (LPTCs) in the lobulo plate portion of the visual ganglia [1] . Inside a control-theoretic framework, an inner product model for wide-field integration of retinal image flow is developed, delineating the spatial decompositions performed by LPTCs in the bird visuomotor system .This LPTCs act as wide field optic flow sensors and are involved, in particular, in visual guidance. A rigid signalization of the information available from this visuomotor convergence approach for motion within environments initiating disparate spatial distributions is pulled off, establishing the connection between retinal motion sensitivity shape and closed loop Behavior. Hence, the global optic flow cues extracted by LPTCs, which are generalized combinations of speed/depth, provide control-relevant information, as well as a novel methodology for utilizing optic flow sensory information in autonomous robotic navigation and control applications. Accordingly, extraction of global retinal motion cues through computationally efficient wide-field integration processing provides a novel and promising methodology for utilizing visual sensory information in autonomous robotics navigation and flight control applications [5]. The initiated output feedback methodology is shown to be adequate to give rise to experimentally observed bird navigational heuristics, counting forward speech regulation, obstacle avoidance, hovering and terrain following behaviors.**

1. INTRODUCTION

Flying insects, in particular, are microminiaturized packages competent of efficient and productive visual-based navigation. In spite of the size and intelligibility of their nervous systems, they illustrate the highest standard for performance and robustness in flight control and navigation of uncertain environments. On the other hand, local maneuvering and obstacle avoidance in cluttered environments poses a significant challenge for autonomous, unmanned aerial vehicles (UAVs) in operational scenarios. With the current limitations, agile, near-ground flight is impractical. Simple, robust, and lightweight solutions are required for autonomous behavior to be achievable within the power, weight, and size constraints of a miniature UAV. Despite these challenges, artificial vision-based systems appear to be essential to the development of truly autonomous UAVs, especially for near-ground flight.

A characteristic of typical vision sensors is that they provide a vast amount of information at any given time instant. Hence, any successful vision-based navigation algorithm must be able to rapidly and intelligently parse this information to provide appropriate motor control signals at required servo rates. The fundamental principles inherent to insect navigation are both elusive and promising candidates for closing the considerably large gap in performance and robustness that exists between biological systems and their robotic counterparts [5].

2. DELINEATION OF INSECT VISUOMOTOR SYSTEM

Insect visual systems encode optic flow by combining motion estimates from arrays of local movement detectors in a way that preserves the spatial layout of the retina. This spatially preserved motion information is parsed by wide-field motion sensitive interneurons in the lobula plate section of the visual ganglia (called tangential cells, or LPTCs for short). The output of these neurons is communicated via decending neurons to the motor control centers, creating a sensory processing front end that spatially integrates the optic flow. This visuomotor convergence technique, spatial wide-field integration, is presumed to be used by insects to extract behaviorally relevant information from optic flow patterns to modulate the kinematics of flight. Also, the patterns that form on the retina are time dependent and are a function of the particular kinematics of the motion as well as the spatial layout of the environment and therefore contain critical information useful for stabilization and navigation tasks.

2.1 Wide-Field Motion Sensitive Tangential Neurons

Descending cells, which receive dendritic input from LPTCs, drive motor neurons controlling the steering muscles of the mechanosensory halteres, which provide input to neurons controlling wing kinematics.

Early studies of these neurons focused on structure, arrangement, and synaptic connectivity; however, recent developments in experimental capabilities have provided various classifications based on response characteristics [4]. Due to their receptive field structure, which is similar to the equivalent projected velocity fields for certain cases of rotary self motion, these neurons are thought to contribute to stabilization and course control.

2.2 The Matched Filter Concept

Biological matched filter, where the neural images formed from sensory inputs are compared with pre-determined templates, presumably to assist in determination of behavioral responses [3]. Investigations comparing VS neuron receptive field organizations and matched filter models based on rotary optic flow fields have been performed. In order to perform these calculations, knowledge about the distance statistics of the environment, self-motion, and EMD noise had to be assumed.

To compute the weights used in the estimator, prior knowledge about the particular environmental distance distribution and about the noise and egomotion statistics of the sensor were used. In order to compute the distance statistics, a robot was sent around the environment along prescribed trajectories recording the distance information [3]. From the measurements, an average distance and covariance were computed. There are several points that should be noted regarding the performance of these types of matched filter implementations. Firstly, optic flow is inherently a relative measurement; that is to say, it is a measure of effective angular image velocity or speed/depth. The implementations described above are attempting to estimate absolute quantities (rotational and translational velocities) that would presumably be utilized in a closed feedback loop. The difficulty is evident when you consider utilizing the approach above for estimating the same egomotion for a robot that is translating through two distinct environments. Secondly, detailed statistics regarding the particular environment as well as the noise and egomotion of the sensor were required in order to achieve the results obtained. Presuming that birds do collect this information, as evidenced by the fact that LPTC receptive field organization does not depend on visual experience, the navigational robustness of insects with respect to different environments suggests other principles might be at work.

2.3 Global Optic Flow Cues for Navigation

While there had been extensive research efforts focused on understanding the function of this complex sensory and control system from a behavioral point of view. In this context, LPTCs are interpreted as an intermediate processing layer that extracts specific global cues from the complicated patterns of retinal motion that presumably are useful for navigational and stabilization tasks.

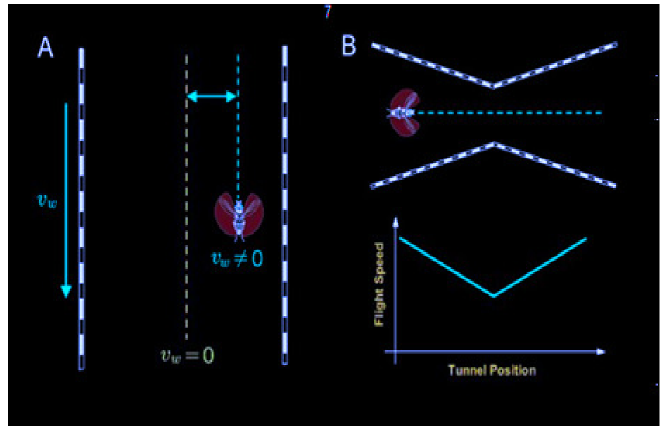


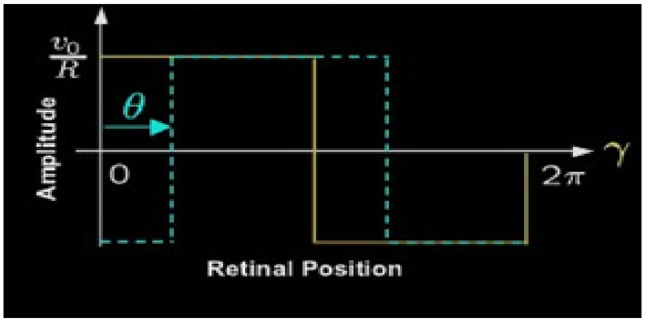
Fig. 1: Navigation with global optic flow cues. (A) The centering response; insects adjust their flight path in order to balance the effective angular velocity induced by wall motion. (B) The forward speed regulation response; insects modulate forward speed based on the average global image velocity.

In these investigations it was found that the visuomotor systems of tethered flies robustly generate torques to minimize large-field rotational motion on their retinas. These reflexive behaviors are different from the optomotor response in a very fundamental way; the optomotor response attempts to regulate a retinal equilibrium of zero image velocity, whereas the centering and forward speed responses regulate nonzero retinal image motion patterns [2]. The centering response states that in order to negotiate a narrow gap, an insect must balance the speed of the image velocity on each retina. In these investigations it was found that the visuomotor systems of tethered flies robustly generate torques to minimize large-field rotational motion on their retinas.

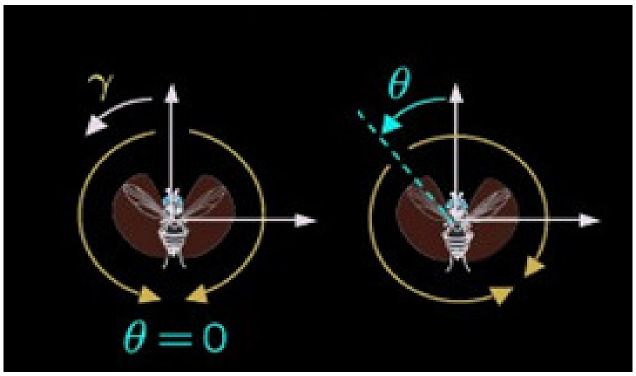
In experiments with flies, navigating a cylindrical tunnel were held stationary by rotating the walls of the cylinder, and hence inducing backward pattern motion indicative of forward flight [2]. The flies were also observed to modulate thrust to compensate for wind in order to hold the angular velocity of the image constant [1]. If same experiment done with the narrow tunnel, as more narrow tunnel dictates a reduced speed. The conclusion was that the flies were holding the apparent angular velocity of the retinal image induced by the walls at 320deg/s.

3. VISUALLY CONCILIATE WIND DISTURBANCE REBUFF

Recent experimental results demonstrate that flies posses a robust tendency to orient towards the frontally-centered focus of the visual motion field that typically occurs during upwind flight. These data suggest that a control algorithm based on feedback of the movement of the visual focus of contraction could be used to detect wind direction, since upwind flight induces a frontally centered focus of the visual motion field.



(a)



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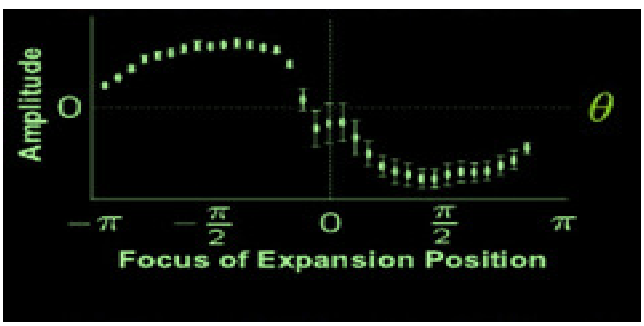
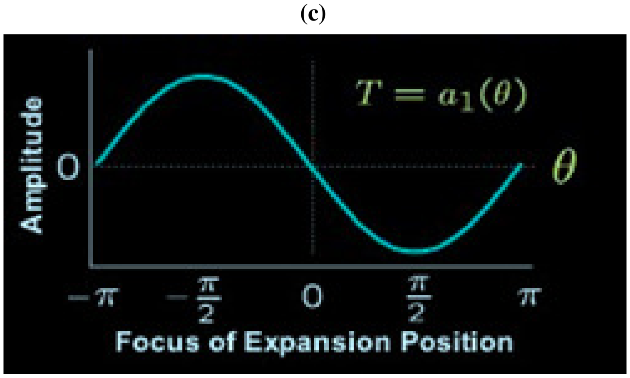


(c)



(d)

Fig. 2: Open loop visuomotor reflexes in Insect. (A) Open loop visual stimulus pattern as a function of the retinal viewing angle. (B) Open loop response as a function of the position of the focus of expansion on the retina of tethered animals. The quantity plotted on the vertical axis is the difference between the right and left wing beat amplitudes measured by an optical sensor. (C) Open loop response of the visual turning model as a function of the focus of expansion position.

Since, LPTCs perform a spatial decomposition of the retinal motion field. Mathematically, this operation can be represented by an inner product between the instantaneous optic flow field and a set of spatially defined functions representing the visual motion pattern sensitivity of each specific LPTC. Under a planar model assumption, both the optic flow stimulus 'P' and the pattern sensitivity Q, representing a left and right hemispherical pair of LPTCs, are 2π-periodic functions of the body-fixed retinal viewing angle β. The open loop optic flow stimulus presented in the experiment depends on radius of the arena r, the magnitude of optic flow $\frac{\vartheta_0}{r}$, and the location of the focus of expansion on the retina $'\theta'$ Described as a spatial Fourier series expansion in terms of β,

$$P(\beta,\theta) = \frac{4\vartheta_0}{\pi r}\sum_{n=1,3,5..}^{\infty}\left(\frac{\cos n\theta}{n} sin n\beta - \frac{\sin n\theta}{n}\cos n\beta\right), \qquad (1)$$

with amplitudes of the cosine and sine spatial harmonics

$$a_n(\theta) = \frac{1}{\pi}\int_0^{2\pi} P(\beta,\theta).\cos n\beta d\beta = -\frac{4\vartheta_0}{\pi r n}\sin n\theta$$

$$b_n(\theta) = \frac{1}{\pi}\int_0^{2\pi} P(\beta,\theta).\sin n\beta d\beta = \frac{4\vartheta_0}{\pi r n}\cos n\theta \quad \ldots (2)$$

If we assume the following visuomotor control model for yaw torque

$$R(\theta) = [P(\beta,\theta), Q(\beta)], \qquad (3)$$

along with a LPTC motion pattern sensitivity

$$Q(\beta) = \cos\beta, \qquad (4)$$

then the open loop turning response is

$$R(\theta) = -\frac{4\vartheta_0}{\pi r}\sin\theta \qquad (5)$$

which corresponds to the first spatial harmonic of optic flow $a_1(\theta)$ from (2). Open loop turning response experiments were performed earlier, whose data is replotted in Figure (2)c, along with the open loop model response (5) in Figure(2)c. The simple model of open loop visual response is shown to be in remarkable agreement with the behavioral data from the falcon bird.

Based on these results, a closed loop planar Insect flight model was constructed, with a control algorithm based on feedback of the location of the visual focus of contraction [4].

4. RESULT

The experiments and modeling effort provide an initial step in the verification of the hypothesis that LPTCs extract global optic flow cues for use in navigation and stabilization, in contrast to more traditional suggestions that LPTCs might be used as direct estimators of kinematic states. However, these efforts have assumed that the environment has a homogeneous and uniform spatial distribution of objects. In order to generalize the conclusions to free flight behavior, as well as develop optic flow based methodologies for autonomous robotic guidance and navigation, we must relax the uniformity and homogeneity assumptions on the environment.

5. CONCLUSION

With a general overview, from the set of all possible wide-field integration outputs is characterized by the spatial Fourier coefficients of the planar optic flows. In addition, these Fourier coefficients are characterized in terms of the body frame linear and angular velocity and the spatial harmonics of the nearness function. Interpretations of these wide-field integration outputs for arbitrary environments are presented, which suggest a general methodology for stabilization of various navigational tasks. Essentially, by balancing various spatial harmonics of optic flow, we can obtain generalized feedback terms in relative units of speed/depth that are functions of rotational and lateral stiffness with respect to flight trajectories that avoid objects in the environment, as well as terms that contain rotational, lateral, and forward velocities, which are useful for closed loop stabilization and performance.

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