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Vision-based bio-inspired guidance law for small aerial vehicle

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Abstract During predation, a flying insect can form a stealth flight path. This behavior is called motion camouflage. Based on the study results of this behavior, the perception and neurology of flying insects, a novel bio-inspired guidance law is proposed for the terminal guidance for small aerial vehicle with charge-coupled device imaging seekers. The kinematics relationship between a small aerial vehicle and target is analyzed, and a two-dimensional guidance law model is established by using artificial neural networks. To compare with the proportional guidance law, the numerical simulations are carried out in the vertical plane and in the horizontal plane respectively. The simulation results show that the ballistic of the small aerial vehicle is straighter and the normal acceleration is smaller by using the bio-inspired guidance law than by using the proportional guidance law. That is to say, the bio-inspired guidance law just uses the information of the target from the imaging seeker, but the performance of it can be better than that of the proportional guidance law.

1. Introduction

The biologists discover that a series of continuously changing images is formed on the retina from the ambient brightness when insect flies. And this series of changing information continuously flows through the retina, which seems like a flow of light. So the apparent motion of this image brightness is called optical flow.[1,2] When flying insect flies to prey the target insect, it can keep itself always on the line connecting the target insect and the fixed point. Then the optical flow about the movement of predator will not be formed on the retina of prey. The prey would think predator is stationary at the fixed point, so that predator can easily capture prey. This is because the eyes of insects gather bearing only information from the environment, and, under some conditions, depth cannot be derived from motion.[2–4] The fixed point is defined as any selected point on the line connecting the initial positions of prey and predator. It can be chosen at the finite place or at the infinity place. The dragonflies take advantage of this "motion camouflage" to capture the moving targets.

Motion camouflage was firstly suggested by Srinivasan and Davey[4] to interpret a series of hoverflies' behaviors, such as the

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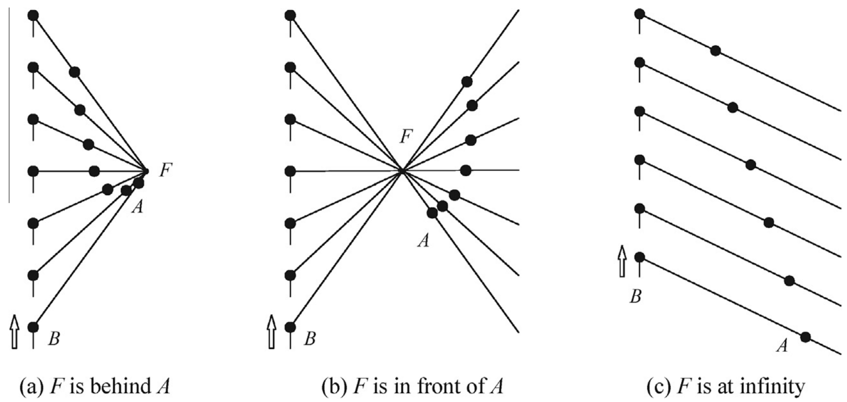
tactical maneuvers in territory fighting and mating.[5,6] They introduced the concept of camouflage line and gave an equation that motion camouflage needs to follow, which is defined by $\Delta\lambda/\Delta\theta = r$, where $\Delta\lambda$ is the shortest flight distance for the insect to maintain camouflaging motion, $\Delta\theta$ is the angle that the insect turns around the fixed point F, and r is the distance between the insect and the fixed point. However, they did not establish a complete mathematical model for motion camouflage in their article. In 2002–2003, with respect to the case that the fixed point is within finite distance and only the target azimuth information is known, Anderson and McOwan established a guidance system model with a three-part algorithm structure by using the Artificial Neural Network and a brief introduction to the neural network training process was given.[7–9] However the detailed kinematics modeling between the small aerial vehicle (SAV) and the target was not mentioned, and the model is not reproducible without this part. In 2004, with respect to the two-dimensional navigation cases that the fixed point is at the finite distance or at the infinite distance from the insect, Carey, Ford and Chahl constructed a linear quadratic Gaussian equation for motion camouflage by using the conventional optimal control theory and the energy required was controlled to be optimal.[10] But the target position in the inertial frame needs to be known at every moment and a very complex matrix equation for the two-point boundary value problem needs to be solved, which are difficult to achieve in actual implementation. In 2006–2009, Reddy, Galloway et al. built a camouflaging kinematic vector model in the polar coordinates for the fixed point at infinity distance and deduced the control equation for the predator through the geometric relationship between the predator and the target.[11–14] However, the line-of-sight (LOS) angle, the direction and the value of target's speed are needed in this model, which are difficult to obtain. Traditional proportional guidance law (PGL) is widely used in guided weapons. However, to make the small aerial vehicle capable of capturing and tracking the mobile targets as flying creatures is a huge challenge for the design of guidance law. Biologists at Cornell University conducted experiments on flies tracking the targets and proposed a guidance law design method that is completely different from the traditional ones.[15]

When designing an aircraft guidance system, there is no need to make the small aerial vehicle seem stationary to the target, which is quite different from the predation behavior in nature. After observing the trajectory of predator with the fixed point at finite place, it is discovered that the trajectory features are similar to the trajectory features when the guidance law is derived by the traditional three-point method.[16] The trajectory features of predator with the fixed point at infinity place are similar to the ideal trajectory features when the guidance law is derived by the parallel navigation.[17] In the traditional guidance approaches, the trajectory guided by the parallel navigation is the straightest one, and the required normal load factor is the smallest. This makes omnidirectional attack possible. Although the parallel navigation is considered to be the best navigation method, it has not been widely used so far. As it raise strict requirements for the guidance system. It requires accurately measuring the aerial vehicle velocity and the target velocity at every moment. And it needs to strictly maintain the motion relationship in parallel navigation, in order to keep the direction of relative speed always pointing to the target. Due to the limitations of the sensor, it is hard to satisfy the requirements above. In nature, no matter the eyes of flying insects are monocular eye or compound eyes, they have limited information about the target, but they can rely on the vision system to capture prey[18] and can form a similar trajectory guided by the parallel approach method or by the three-point method. This inspired the authors to do the research on the bio-inspired guidance law (BGL) in this paper.

This paper aims to present a new guidance law inspired by the motion camouflage, which uses the artificial neural network algorithm to make its model and it can be used in the small aerial vehicle. We use neural network mainly because it has the ability to gain an adequate concept of target depth from their inputs[4] and the depth information of target is the necessity of the model (we will explain it in Section 3.2 in detail), According to the simulation results, the normal acceleration of the small aerial vehicle can be smaller by using the bio-inspired guidance law than by using the traditional proportional guidance law. The bio-inspired guidance law just uses the angular information of the target from the imaging seeker, but it can make the small aerial vehicle perform approaching the parallel navigation, which is considered as the best navigation method.

2. Problem description

Fig. 1 shows the trajectory when flying insect preys target, where A is predator, B is prey, and F is the fixed point. F can be chosen at the finite place (Fig. 1(a)) or at the infinity place (Fig. 1(b)), but in this paper, we just have done the research on the situation that Fig. 1(a) shows.



(a) F is behind A (b) F is in front of A (c) F is at infinity

Fig. 1 Flight paths with camouflage effect.