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Measuring the Wing Kinematics of a Moth (*Helicoverpa Armigera*) by a Two-Dimensional Fringe Projection Method

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Abstract

We describe a two-dimensional (2-D) fringe projection method, projecting two groups of comb-fringe patterns with high intensity and sharpness onto the flapping wings of a moth (*Helicoverpa armigera*) from two directions. The images of distorted fringes are caught by two high speed cameras from two orthogonal views. By three-dimensional reconstruction of the wing, we obtain the wing kinematics of the moth including the flapping angle, torsion angle and camber deformation.

Keywords: fringe projection, wing kinematics, moth, three-dimensional reconstruction

1 Introduction

Details of the body and wing kinematics are the fundamental to a biomechanical analysis of insect flight. The body kinematics includes body position and attitude; the wing kinematics includes flapping angle, torsion angle and wing deformation. Comparing to the study of body motions, quantitative analysis of flapping insect wings requires substantially more complicated experimental methodology.

In the past twenty years, a number of studies have been focused on the wing kinematics of insects. Most of the investigators use high speed cameras to catch images of the flapping wings of insects[1–8], and then reconstruct three-dimensional (3-D) motions of the wings by using various methods including the symmetry method[1–3], the planes method[4–5], the strips method[6–7] and the landmarks method[8]. However, these methods are not applicable to insects whose wing deformation (such as camber deformation) is significant. Fringe projection method has been demonstrated to be a suitable way to measure the wing deformation of flying insects[9–10]. But when such a one-dimensional (1-D) fringe projection method is applied to the insects with large flapping angle (such as a moth), data could not be gathered for the whole flapping cycle due to the large variation in wing orientation with respect to the projected fringes[11].

In this paper, we utilized a two-dimensional (2-D) fringe projection method, projecting two groups of comb-fringe patterns with high intensity and sharpness onto the flapping wings of a moth (*Helicoverpa armigera*) from two directions. Images of the wings with distorted fringes were then recorded by two high-speed cameras in orthogonal directions. Based on the distorted fringe patterns, we reconstructed wing shape and obtained the wing kinematic parameters for the whole flapping cycle.

2 Material and method

2.1 Insects and experimental setup

Moths of the species *Helicoverpa armigera* were collected for the experiments. They were obtained as pupae from a population maintained at the Department of Entomology in China Agricultural University.

Fig. 1a shows the experimental setup. A moth was tethered with adhesive at the head to a rigid stick. Two fringe pattern projectors (FPP-A and FPP-B in Fig. 1a) with inter-beam fringe angles of 0.77˚ are used to project

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two groups of sharp comb fringes onto the moth from different directions. The two FPPs are adjusted to make sure that at least one group of fringes on the right wing is clear and dense enough for measurement during the whole wing flapping cycle. The images of distorted fringes are caught by two high speed cameras (HSC-A and HSC-B in Fig. 1) with 248 by 248 pixels at 1600 frame per second (fps) from two orthogonal views. The two cameras were synchronized by external signals and the image data were transferred to the computer (PC in Fig. 1a) memory instantly. Figs. 1b and 1c show the image samples of HSC-A and HSC-B, respectively. The fringes in Fig. 1b is projected by FPP-A; the fringes in Fig. 1c is projected by FPP-B.

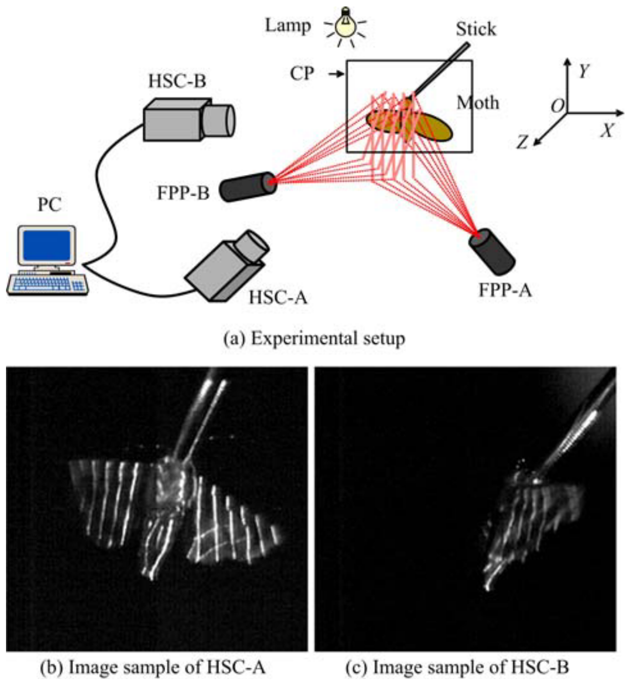

Fig. 1 Experimental setup and the image samples of two high speed cameras.

2.2 Calibration and deduction of global coordinates

A calibration plane (CP in Fig. 1a) perpendicular to the optical axis of HSC-A is used to calibrate the system, which can move vertically along its normal direction by using a stage with a micro-screw. The global coordinates (see Fig. 1a) are defined as follows: the *XOY*-plane is on the CP at its farthest position from HSC-A; the *Z*-axis is the optical axis of HSC-A; the *X*-axis is parallel to the optical axis of HSC-B and the *Y*-axis perpendicular to the optical axis of HSC-B.

The calibration procedure of a 1-D fringe projection measurement system and the method for determining the coordinates of the point on the wing was described in detail by Wang *et al.*[10]. 3-D coordinates of points on the distorted fringes were calculated by spatial analytic geometry. Interpolation was used to calculate the spatial position of points of interest not on the fringes. Our measurement system consists of two 1-D fringe projection measurement systems. The two systems were treated separately, and the calibration and calculation for each system were done following Wang *et al.* did[10]. Finally, the 3-D coordinates obtained from the two systems were unified by coordinate transformation.

2.3 Wing kinematics

In order to describe the wing kinematics, we set up a new coordinate system based on the stroke plane (see Fig. 2a). In this coordinate system, the origin *O*' is situated at the wing base, and the stroke plane *Y*'*O*'*Z*' is defined by three points: the wing base, and the wingtip at the maximum and minimum angular positions in a flapping cycle. The *Y*'-axis is defined as the line that joins the left and right wing bases projected onto the plane *Y*'*O*'*Z*'.

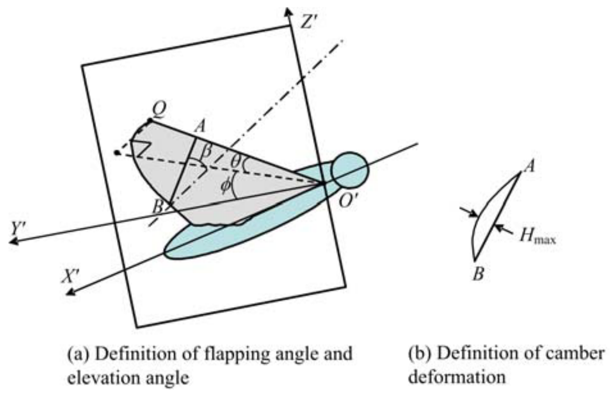

Fig. 2 Definition of wing kinematic parameters.

The flapping angle is defined as the angle between the *Y*'-axis and the line *O*'*Q* (*Q* is the wing tip on leading edge), projected on the stroke plane (Fig. 2a). During the flapping cycle, the leading edge does not always move in