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DEFORMATION MEASUREMENT OF A FLEXIBLE BIRDLIKE AIRFOIL WITH OPTICAL FLOW

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Optical flow determines the velocity field of two dimensional image intensity motions with single-pixel resolution. There are two main methods: global intensity smoothing methods based on Horn-Schunck scheme (Horn, Schunck, 1981), and local methods based on Lucas-Kanade scheme (Lucas, Kanade, 1981). Since the Lucas-Kanade optical flow method was first proposed in 1981, it has been developed into numerous variants and the most widely used technique in computer vision (Baker et al., 2004). The application of such a method has seen a huge success in a wide variety of fields. This paper applies the pyramidal Lucas-Kanade (Bouguet, 2000) in the measurement of the deformation of a flexible birdlike airfoil due to steady aerodynamic loads at transitional low Reynolds-numbers. Inter alia, the influence of angle-of-attack on the airfoil deformation is measured. The investigation of deformation is important to validate numerical schemes, which incorporate the simulation of fluid-structure interaction.

The flexible airfoil used in this paper is the birdlike airfoil SG04 (Bansmer et al. 2010), see Fig. 1. It has been designed as a birdlike airfoil with two-dimensional behavior to study the coupled problem where the deformation of airfoil surface caused by aerodynamic and inertial loads. The dot pattern on the upper surface is stochastic ink spray for easy capture of airfoil motion by camera. The movement of this stochastic dot pattern and so the airfoil deformation is computed with optical flow.

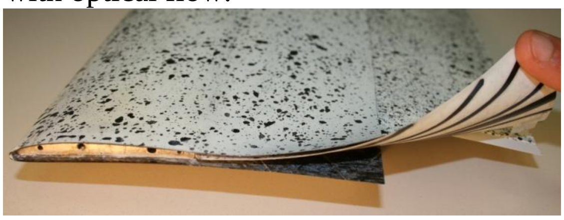

Fig. 1 Flexible airfoil

Let $I_1(x,y,t)$ denote 2D image intensity, where x and y is the location of local intensity and t is the present time. Let $I_2(x+dx,y+dy,t+dt)$ denote local intensity after short time duration dt. dx, dy is the displacement of local intensity. The goal of Lucas-Kanade is to minimize the sum of squared error between $I_1(x,y,t)$ and $I_2(x+dx,y+dy,t+dt)$ in an integration window *w*:

$$min \sum_{x,y\in w} [I_1(x,y,t) - I_2(x+dx,y+dy,t+dt)]^2 \quad (1)$$

After performing first order Taylor expansion on $I_2(x+dx,y+dy,t+dt)$, Equation (1) is simplified to:

$$min \sum_{x,y\in w} \left(I_x dx + I_y dy + I_t dt\right)^2 \quad (2)$$

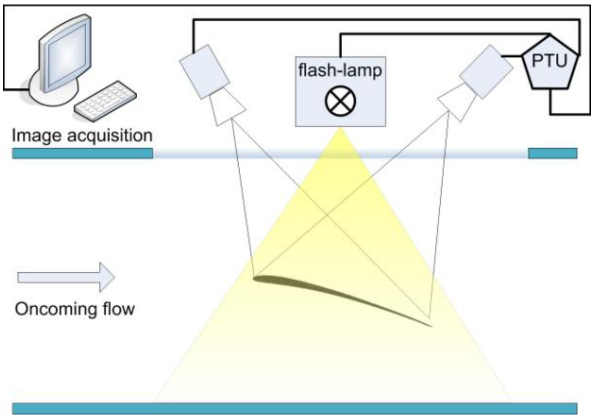

Fig. 2 Setup of the custom made deformation measurement system

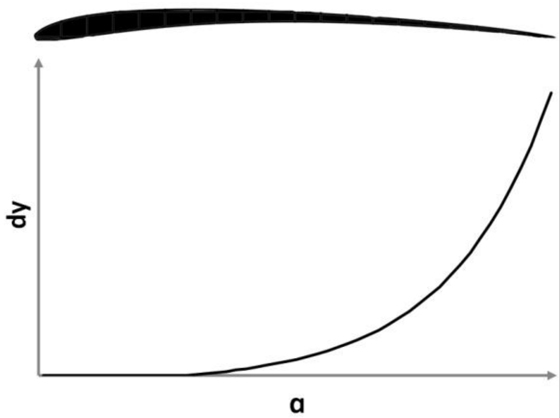

Fig. 3 Vertical deformation of airfoil along the air flow

However, this simplification maintains proper accuracy only for quite small displacement, say around one pixel. With larger motions, Pyramidal Lucas-Kanade gives out reasonable result. It downsamples original image with the factor 0.5 on each level and starts at the coarsest image. The coarse solution is used as initialization for solving a refined image until step by step the full-resolution image is solved (Bouguet, 2000).

The experiment will be carried out in the low noise, low speed wind tunnel (LNB). The detailed setup is sketched in Fig. 2 as a side view of the wind-tunnel test section.

The left oncoming air flows over the flexible airfoil with certain angle of attack. When the oncoming air flow is stable, the airfoil will be deformed. The PTU (Programmable Timing Unit) is used to control a flash lamp to illuminate the airfoil, and two cameras in stereoscopic setup to photograph the ink pattern on the upper surface of the airfoil. This procedure is repeated with gradually increasing angle of attack, and then we get two image series of the ink pattern for both cameras. After that we apply the pyramidal Lucas-Kanade optical flow algorithm to the two image series respectively to calculate two optical flow fields, i.e. the displacement of ink patterns. Combined with a calibration, it’s possible to transform optical flow information to the three-dimensional deformation of the airfoil. Fig. 3 shows the expected result of the vertical deformation of the airfoil along the air flow. Apart from this, the deformation along the wingspan and the vertical displacement of trailing edge with respect to angle of attack is studied.

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