High spatial resolution optical flow velocimetry verification and application

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Abstract Now particle image velocimetry can provide accurate velocity vector fields which contain more and more information than measurement result of traditional single point test technique. Unfortunately, the vectors' resolution of particle image velocimetry depends on image interpretation area and could not be improved.The optical flow technique possesses the advantages of high space resolution and velocity field smoothness, and could acquire velocity vector by pixel scale from particle image. The differential method is the basic solution of optical flow velocity measurement. Based on optical flow constraint equation combined with smoothness constraint condition and spatial and temporal gradients of grayscale, the movement information of each point would be extracted from optical flow field. In the paper, optical flow calculation method was introduced and optical flow velocity test was programmed. Through artificial displacement image, the program was verified and analyzed to obtain a reasonable measurement range and the optimal weighted value by which to guide how to gain optical flow velocity field of high precision in practical application. A backward facing step internal flow verification experiment was carried out in a small wind tunnel, by tracer particle as measurement carrier, and the velocity vector field with a resolution of pixel scale was calculated out. The objective of this paper is to develop full flow field measurement technology based on optical flow, improve the spatial resolution and avoid the velocity gradient effect. It is expected that optical flow can contribute to understanding the dynamics space structure of complex flow and acquiring more dynamics information. Recently, an optical flow velocity field test on NACA0012 airfoil model trailing edge Karman vortex street was carried out, which velocity field result showed excellent resolution and more details compared with PIV result.
Keywords: optical flow; velocity measurement; particle image; motion estimation; variation

1 Introduction

In recent decades, depending on particle image and cross correlation method to acquire velocity vector field, the Particle Image Velocimetry had achieved considerable development and hold application advantages of non-invasive measurement, global measurement and high accuracy. The velocity vector obtained by PIV is the average velocity of interpretation window, so the variation of velocity field in the interpretation window is ignored. During the exposure interval, the displacement of particle, which follows the nyquist criterion, should be less than half of the size of interpretation window so that the spatial resolution of PIV is limited by certain restrictions. The accuracy of velocity vector field obtained by PIV is also restricted in the region with large velocity gradient.Horn and Schunck creatively studied optical flow in 1980s. Horn et al thought that the optical flow field caused by moving object should be continuous and smooth, namely the grayscale variation projected on the image should be smooth because velocities of adjacent points on the same object should be similar. Based on this idea, additional velocity smoothness constraint, i.e. global smoothness constraint can be added to optical flow field, so the calculation problem of optical flow field could be translated into the calculus problem of variation and the motion estimation of pixel scale would be obtained.

2 Wind tunnel test

The difficulty in this experiment is to guarantee the experiment conditions satisfying the constraint equation of optical flow velocimetry. For effective calculation of optical flow velocity field, this algorithm requires identical illumination condition for each image of continuous shooting and tiny displacement of corresponding pixels on adjacent images.

(1) Backward facing step interval flow test. The experiment was conducted in a small low-speed wind tunnel system which was set up temporarily in the laboratory. The whole system was composed of wind tunnel and flow control sub system, tracer particles generation and seeding sub system, laser illumination and optical path sub system, image acquisition sub system and computer processing sub system. The flow speed of wind tunnel test section is controlled by a controllable turbo fan motor and within the range of 1m/s to 20 m/s by regulating the frequency converter. The wind tunnel inhaled air flow mixed with tracer particles coming from three seeding tubes, and after passing through the cellular, the air and the tracer particles mixed uniformly. An Argon ion continuous laser, beam expander lens and cylindrical lens were applied in this experiment to achieve identical illumination condition. A high-speed camera with maximum frequency of 1500HZ was used to capture images and ensure tiny displacement at scale of pixel between adjacent images.

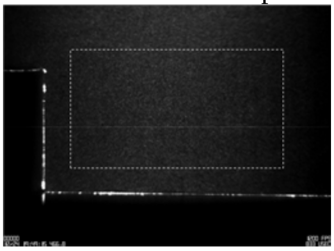

Fig. 1 BFS particle image

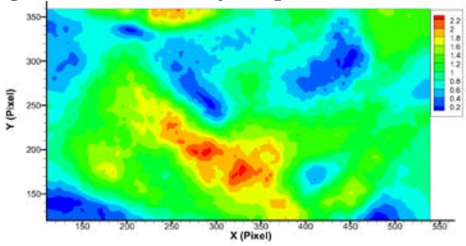

Fig. 1 High resolution optical flow field

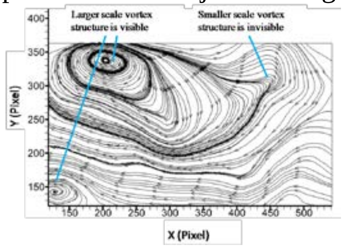

Fig. 3 Flow structure of Optical flow

(2) NACA0012 airfoil test. The experiment was conducted in the same wind tunnel, in which the model has chord of 100mm and spanwise of 100mm. The velocity of freestream was set to 2m/s, and a Photron SA5 high speed camera was used with 10kHz frame rate.

Fig. 4 NACA0012 airfoil Model and particle image

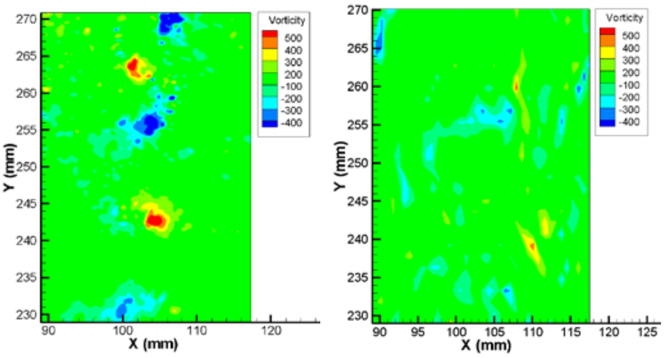

Fig. 5 Optical flow field(L) and PIV field(R)

3 Conclusion

Through the analysis of optical flow algorithm, the experiment requirement of optical flow velocimetry was studied and the test platform was successfully set up.By comparison between optical flow result and PIV result, it can be concluded that the optical flow algorithm could obtain a smoother velocity field than PIV in the conditions of pixel scale and is more suitable for velocity field measurement of complex flow. The optical flow result, in which there is a velocity vector on each pixel, can show a more detailed flow field structure. The PIV result with a resolution of 8×8 pixel has an obstacle on viewing fine flow field structure.

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