CONTROL OF THE DEPTH OF CORRELATION IN MICRO-PIV USING A NOVEL POST-PROCESSING METHOD

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Summary In micro PIV, volume illumination affects significantly the depth of the images that contribute to the correlation. Consequently, the measurement is a weighted average of the flow within the depth of correlation. For relatively large correlation depths this may result in distortion of the correlation peak and large measurement errors. It is therefore desirable to reduce the depth of correlation. We present a novel application of image overlapping to effectively reduce the depth of correlation and improve the measurement accuracy. This technique is particularly effective in boundary flows where velocity gradients are large. This short paper will present results of image overlapping applied to synthetic data.

INTRODUCTION

Micro particle image velocimetry (micro PIV) is an extension of PIV to measure flows in micro channels. Meinhart et al [3] first described a micro PIV system consisting of a microscope connected to a camera and using fluorescent particles as flow tracers. Due to the small measuring region, it is impossible to create a laser sheet to capture a slice of of the flow as traditionally done in macro PIV. Instead the laser beam illuminates all particles within the viewing volume. Consequently both in-focus and out-of-focus particles appear in the image.

PIV measurement relies on the correlation between consecutive images to determine flow velocities. Thus the accurate detection of the correlation peak is vital. The depth of correlation [2, 4, 6] is the image depth over which particles can affect significantly the image correlation and therefore the measurement result. The calculated velocity is a weighted average over the depth of correlation. In regions of high velocity gradient, contributions from out-of-focus particles can result in significant bias errors. To reduce measurement errors, it is desirable to reduce the depth of correlation. The depth of correlation depends on the optical system and changing depth of correlation of a system requires changing important optical properties such as numerical aperture and magnification. An alternative option is to change the depth of correlation using image processing. Bourdon et al [1] proposed a power-filter method to modify the depth of correlation in micro PIV by raising the image intensity to a chosen power. Their method can effectively reduce or increase the depth of correlation by a factor up to two. In this paper we present an alternative method to reduce the effect of depth of correlation by applying image overlapping.

Image overlapping

Image overlapping was introduced by Wereley et al [5] to artificially increase particle density in PIV images with steady flow. This is carried out by producing a maximal image from a set of images, where each pixel is the maximal value of the pixels at the same position. This is equivalent to collecting the brightest particles from the image set. The correlation of the maximal, or overlapped image, produces an increased number of valid velocity vectors in low particle-seeding regions. When image overlapping is applied to micro PIV images, a secondary effect has been discovered. The brightest particles in the image are the ones in focus while the out-of-focus particles produce weaker, less bright images. By applying image overlapping, the brighter particles are selected and they dominate the resulting image, thereby effectively reducing the depth of correlation. A disadvantage of image overlapping is that the shape of the particles are distorted when they are close to one another. This can be considered as loss of information. Therefore excessive image overlapping can introduce errors. Image overlapping is also a time-averaging technique.

METHOD

Image overlapping can be used with correlation averaging[5] to provide optimal results from a set of images. A subset of the image pairs are overlapped to produce a single overlapped image pair. For each subset, a single correlation peak is calculated. The final result is obtained by correlation averaging these peaks. The overlapping ratio is defined as the number of images in the subset. The higher the overlapping ratio, the smaller the depth of correlation.

RESULT

To validate the effect of image overlapping, tests with synthetic data sets of 600 image pairs were carried out. The image pairs contain 30 particles scattered within a channel with a depth (H) of $100\mu m$. The images are generated for focal planes between 0.1 to 0.5 times the channel height. The $0.5\mu m$ particles are displaced by a parabolic velocity profile between the top and bottom walls, with a maximum displacement of 64.5 pixels and a wall shear gradient of 0.4. The particles are projected, in wall-normal direction, through a lens system with a magnification of 30 and a numerical aperture of 0.2,

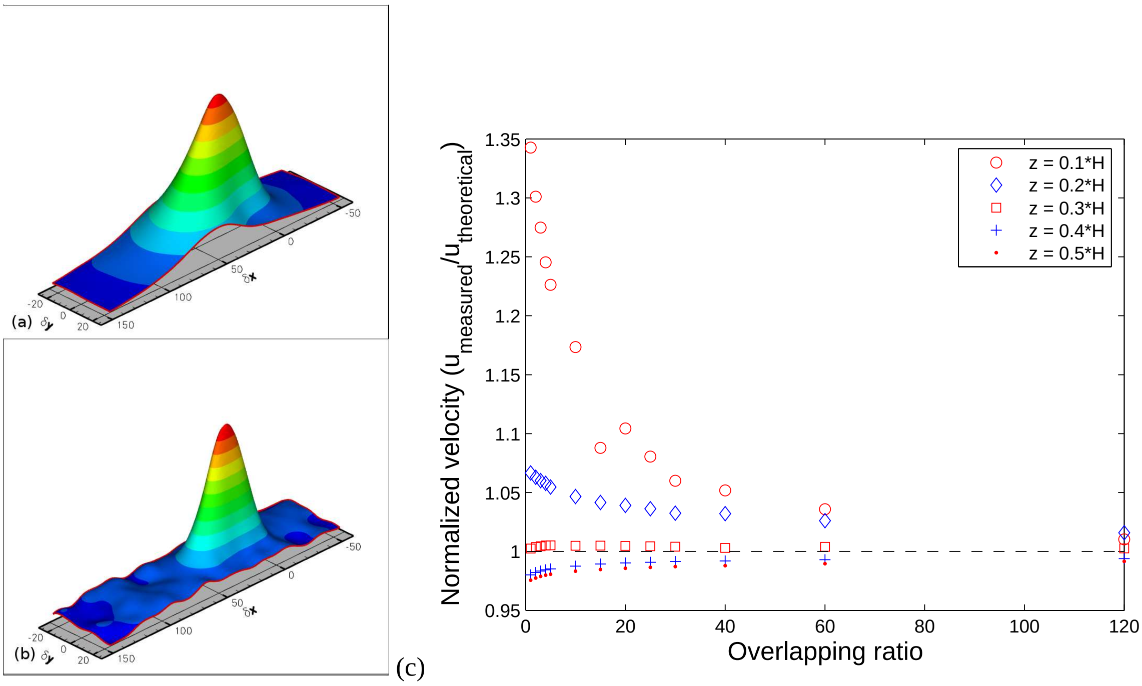

Figure 1. (a) Averaged correlation map without applying image overlapping. (b) Averaged correlation map with an overlapping ratio of 30. The base of the correlation for the image with overlapping is smaller than without overlapping, indicating that the contribution of the out-of-focus particles is reduced. There is also a shift in the position of the correlation peak. (c) Effect of image overlapping for velocity measurement at different focal planes (z = 0.1H to 0.5H). Measured velocity is normalized by theoretical value. Without overlapping, velocity measurements close to the wall may overestimate the velocity by up to 35%. In the center of the flow the velocity measurements underestimate the true value. However the image overlapping can reduce the bias drastically.

using the formulas by Olsen and Adrian [4]. The camera pixel size is $4.65\mu m \times 4.65\mu m$ and the image size is 646×323 pixels. The peak intensity of in-focus particles is 50 in 8-bit gray scale. No background noise is added to the images.

The effect of image overlapping applied to synthetic micro-PIV images is shown in figure 1. The whole image is used as a single image window for the PIV correlation. The averaged correlation map obtained from the original images is shown in figure 1(a). The averaged correlation map obtained from overlapped images with an overlapping ratio of 30 is shown in figure 1(b). The base of the correlation peak for the image with overlapping is smaller. This indicates that the contribution of the out-of-focus particles is smaller for image overlapping. Importantly, there is also a shift in the position of the correlation peak.

The position of the correlation peak (or the particle displacement) obtained from images with varying overlapping ratios is shown in figure 1(c). The position was obtained using 3-point Gaussian fitting. The overlapping ratio was varied from 1 (no image overlapping) to 120. The measured displacement is normalized by the theoretical value at the focal plane position. Figure 1(c) shows that without overlapping, velocity measurement close to the wall may overestimate the velocity by up to 35% In the center of the flow the velocity measurements underestimate the true value. However the image overlapping can reduce the bias drastically and the measurement converges towards the theoretical value.

CONCLUSIONS

This work shows that the accuracy of micro PIV measurement can be improved greatly by applying a simple image overlapping technique. These improvements are greatest close to the wall. The effect of the depth of correlation is effectively decreased with increasing image overlapping ratio.

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