PIV STANDARD IMAGE COMPRESSION BASED ON WAVELET TRANSFORM

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ABSTRACT

In this paper the wavelet-based image compression technique is applied to PIV processing for reducing noise in images and reducing the physical storage. To determine the effect of the choice of the wavelet bases, the standard PIV images are compressed by some known wavelet families, Daubechies, Coifman, and baylkin families. It was found that high order wavelet bases provides good compression performance for compressing PIV Images, because they have good frequency localization that in turn increases the energy compaction. The reconstructed PIV image with lower compression ratio may emphasize particle edges at a relatively high spatial resolution, and the reconstructed PIV image with higher compression ratio may display the large-scale motion of particles and may deduce noisy. In this study, higher compression ratio, from 25% to 6.25%, can be realized without losing significant flow information in PIV processing. It can say that the wavelet image compression technique is effective in PIV system.

Key Words: Digital Particle Image Velocimetry, Discrete Wavelet Transform, Wavelet Image Compression

1. INTRODUCTION

It is well known that Particle Image Velocimetry (PIV) is now firmly established as a powerful fluid dynamics tool to measure instantaneous full-field flow velocity in the area of fluid mechanics. The evaluation of a PIV technique is often characterized by its accuracy and its spatial resolution. However, a certain number of erroneous vectors in the vector fields may generate with the use of PIV. One of factors may be related to poor quality of images. Therefore, it is becoming significant attention to improve spatial resolution and reliability in PIV technique.

The International Standard Organization (ISO) has proposed the JPEG standard for still image compression and MPEG standards for video compression. These standards employ discrete cosine transform (DCT) to reduce the spatial redundancy present in the images or video frames. We note that DCT has the drawbacks of blocking artifacts, mosquito noise and aliasing distortions at high compression ratios. However, the method of image compression that was often used in PIV is only to eliminate the low intensity pixels of image file. Because the low intensity pixels contribute little information about particle displacement, this type of image compression has very little effect on the accuracy of PIV. Recently, Hart (1998)[(1)] employed sparse array image correlation to realize compression ratios of 30:1 or greater and high processing speed of PIV.

Over the past decade discrete wavelet transform (DWT) has emerged as a popular technique for image processing. A wide variety of wavelet-based image processing has been reported in the literature, however, few applications can be found in the area of fluid mechanics. Our motive of this study is to develop an application of wavelet technique to PIV for improving spatial resolution and reliability. In this paper, we apply the wavelet image compression technique to PIV for *simultaneously* suppressing random noise in images and compressing the images. The higher spatial resolution can be obtained by reducing noise in images, and the economy in storing, transmitting or further processing with high speed can be realized based on compressing the images, i.e., we try to "kill two birds with one stone".

2. WAVELET COMPRESSION TECHNIQUE

It is well known that black-and-white images are often used in PIV, and are expressed in a discrete numerical form as a function $f(x_1, x_2)$ over two dimensions in which the function value $f(x_1^0, x_2^0)$ represents the “gray scale” value of the image at the position or pixel values (x_0, y_0). Therefore, we must considered to use the discrete type of wavelet transform.

The two-dimensional discrete wavelet transform of a function $f(x_1, x_2)$ is given by

$$Wf_{m_1,n_1;m_2,n_2} = \sum_i \sum_j f(x_1^i, x_2^j)\Psi_{m_1,n_1;m_2,n_2}(x_1^i, x_2^j). \quad (1)$$

where $Wf_{m_1,n_1;m_2,n_2}$ is the wavelet transform coefficients, and the $\Psi_{m_1,n_1;m_2,n_2}(x_1, x_2)$ is a two-dimensional orthonormal wavelet basis and is defined as

$$\Psi_{m_1,n_1;m_2,n_2}(x_1, x_2) = 2^{-(m_1+m_2)/2}\psi\left(2^{-m_1}x_1 - n_1\right)\psi\left(2^{-m_2}x_2 - n_2\right), \quad (2)$$

which is simply to take the tensor product functions generated by two one-dimensional wavelet bases. The oldest example an orthogonal basis is the Haar function, constructed long before the term “wavelet” was coined. In the last ten years, various orthogonal wavelet bases, e.g., Meyer basis, Daubechies basis, Coifman basis, Battle-Lemarie basis, Baylkin basis, spline basis, and others, have been constructed. They provide excellent localization properties in both physical and frequency spaces. In this study, we have used the following sets of compactly supported orthonormal wavelets.

(1) Daubechies wavelet with orders 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20;
(2) Coiflets wavelet with orders 6, 12, 18, 24 and 30;
(3) Baylkin wavelet with orders 6, 12 and 18.

The reconstruction of the original scalar field can be achieved by using

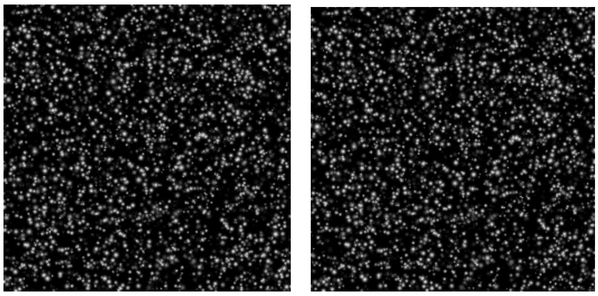
$$f(x_1, x_2) = \sum_{m_1}\sum_{m_2}\sum_{n_1}\sum_{n_2} Wf_{m_1,n_1;m_2,n_2}\Psi_{m_1,n_1;m_2,n_2}(x_1, x_2). \quad (3)$$

In general, the image compression is defined as the representation of image using fewer basis function coefficients than were originally given, either with or without loss of information. There are several methods to compress the image based on wavelets. The approach of wavelet image compression we employed in this paper is to setting wavelet coefficients of modes with insignificant energy to zero. The procedure of this compressed method can be summarized in three steps:

(1) Compute wavelet coefficients $Wf_{m_1,n_1;m_2,n_2}$ representing an image in orthonormal wavelets basis.
(2) Specify the number of wavelet coefficients M to retain, that is, fix the compression ratio M/N where N is the total number of wavelet coefficients before compression and delete all other wavelet coefficients.
(3) Reconstructed the image from compressed wavelet coefficients using inverse wavelet transform.

We can then adjust the number of wavelet coefficients M to vary the compression ratio and reduce the noise in images. For evaluating the compressed feature, the correlation coefficients between the original image and compressed image is employed in this paper.

The PIV standard images of the two-dimensional wall shear flow, which were proposed by The Visualization Society of Japan, are used in this paper. Figure 1 shows two successive PIV images (256 by 256 pixels with an-8bit grayscale) within time interval $\Delta t = 0.033s$.



(a) At time T **(b) At time $T + \Delta t$**

Fig.1 PIV standard images

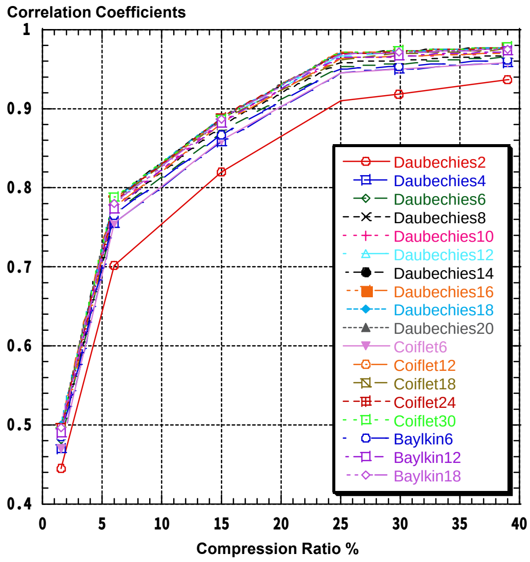
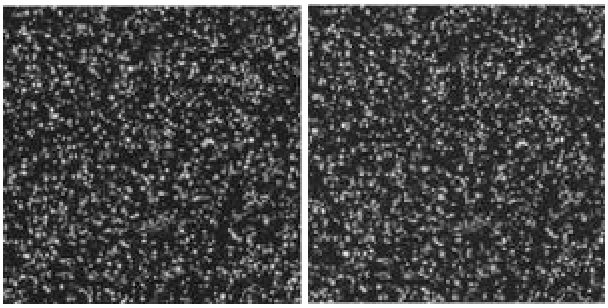


Fig.2 Comparison of compression performance with various wavelet bases

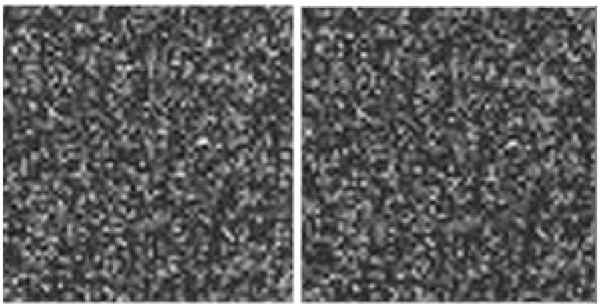
3. RESULTS AND DISCUSSION

The choice of wavelet base and its order is important in achieving good compressed performance. Figure 2 summarizes the performance of various wavelet families’ bases and orders when compressing PIV standard image (Fig.1 (a)) (abscissa: compression ratio, ordinate: correlation coefficients). From Fig.2, it is evident that as increasing compression ratio, the correlation coefficients decreased and dropped quickly near compression ratios 25% and 6.25%. These two points may indicate important compression ratios in PIV images. It can be found in Fig.2 that the best subjective performance was obtained with high order wavelet bases (Daubechies wavelet with orders 16 to 20, Coiflets wavelet with orders 18 to 30, and Baylkin wavelet with orders 12 and 18), because a high order wavelet base can be designed to have good frequency localization that in turn increases the energy compaction. The regularity of wavelet also increases with its order. In addition, more vanishing moments can be obtained with a higher



(a) At time T (b) At time $T+\Delta t$

Fig.3 Reconstructed PIV images with compression ratio 25% and correlation coefficients 0.94 based on wavelet bases Coiflet30



(a) At time T (b) At time $T+\Delta t$

Fig.4 Reconstructed PIV images with compression ratio 6.25% and correlation coefficients 0.69 based on wavelet bases Coiflet30

order wavelet base. On the other hand, although a lower order wavelet base is expected to have a better time localization and therefore preserve the crucial edge information, lower order wavelet bases for compressing PIV images show smaller correlation coefficients than that of higher order wavelet bases at same compression ratios. In this work, the Coiflet base with order 30 provides best compression performance.

In the following, we only discuss the application of the Coiflet base with order 30 to compress PIV image. Figures 3 and 4 show a sequence of reconstructed images that differ in the number of wavelet coefficients that have been kept. These images are reconstructed from the remaining 25% and 6.25% of the 65536 wavelet coefficients, with correlation coefficients 0.94 and 0.69, respectively. The reconstructed images with a lower compress ratio and larger correlation coefficient in Fig.3 emphasizes particle edges at a relatively high spatial resolution, while Fig. 4 having higher compression ratio and smaller correlation coefficient give us the image of particle group. Corresponding to the physically intuitive of physics of the flow, Figure 3 indicates the small-scale motion of particles and may keep same spatial resolution as original images, whereas Fig.4 exhibits the large-scale motion of particles and may deduce noisy in original images.

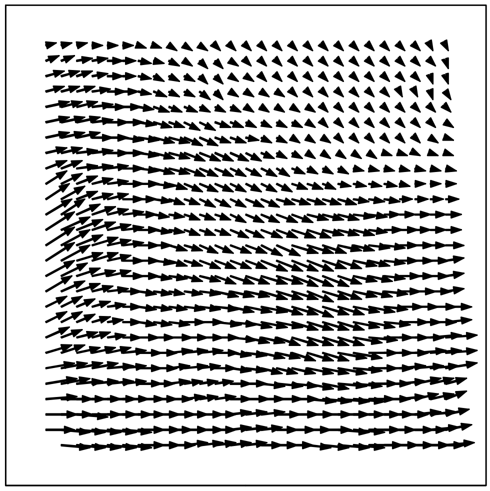


Fig.5 Velocity vector field obtained from Fig.3

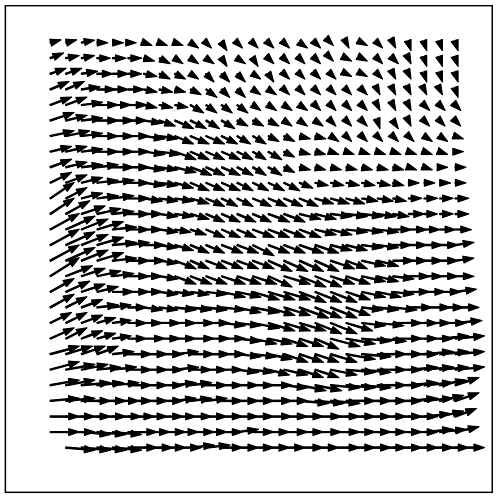


Fig.6 Velocity vector field obtained from Fig.4

Figures 5 and 6 display the velocity vector field that is obtained from Figs.3 and 4 using cross-correlation PIV method. We prefer to present the raw data. It is emphasized that displacement vector of the particles within interrogation window is determined by simply finding the location of the maximum of the cross-correlation coefficient without using any sophisticated algorithms. The velocity vector is then calculated by simple division of the displacement by the time interval between two successive images. The velocity vector field, which was obtained from images with compression ratio 25% in Fig.3 and was interrogated with 12x12 pixels interrogation window, is shown in Fig.5. It is evident that the PIV result of compressed images is agree with that of original images. This indicates that the redundancy of information is contained in PIV image. When increasing compression ratio to 6.25% with 16x16 pixels interrogation window, the velocity vector field plotted in Fig.6 shows almost same result as Fig.5. These compressing images still capture the flow field structure without losing significant correlation information. When increasing compression ratio, the size of the interrogation window in PIV also increases since compressed images describe large-scale motion of particles.

In order to evaluate the performance of wavelet compression technique in PIV, we additive the high frequency to the PIV standard images of Fig.1. For the purpose of comparison, the velocity vector field obtained from the original cross-correlation PIV method is shown in Fig.7, which was interrogated with 8x8 pixels interrogation window and 8x8 pixels grid spacing. A few of erroneous and unreasonable vectors are still appeared in velocity vector filed, although the dynamic mean value method is employ to remove the erroneous vectors.

The images with compression ratio 25% that are realized by the wavelet image compression technique are analyzed by PIV method and the velocity vector field is showed in Fig.8. This result is consistent with the accurate solution. This indicates that the noise in images can be also reduced by the wavelet image compression technique without losing significant correlation information. Therefore, the spatial resolution of PIV can be improved.

From above results, the higher spatial resolution and image compression can be achieved by the wavelet image compression technique with out losing information of flow field structure.

4. SUMMARY

The wavelet compression technique was applied to PIV processing for reducing the noise and physical storage in this study. The following main results are summarized.

(1) A high order wavelet base provides good compression performance for compressing PIV Images, because they have good frequency localization that in turn increases the energy compaction.
(2) The PIV image with lower compression ratio may emphasize particle edges at a relatively high spatial resolution, and the PIV image with higher compression ratio may display the large-scale motion of particles.
(3) A higher compression ratio can be realized without losing significant flow information in PIV processing.
(4) The higher spatial resolution can be realized by reducing noise in images based on compressing the images.

REFERENCES

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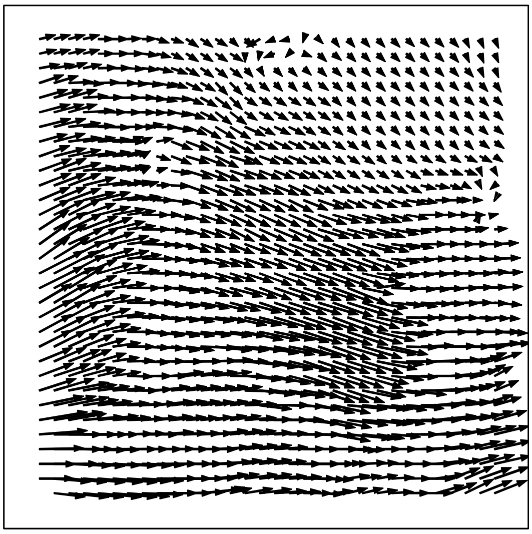

Fig.7 Velocity vector field based on original PIV

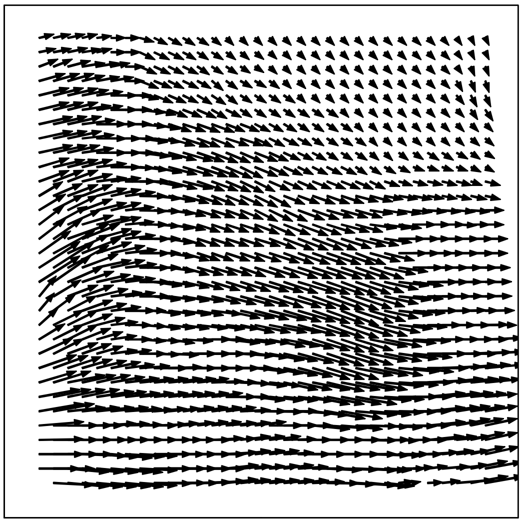

Fig.8 Velocity vector field based on wavelet image compression with compression ratio 25% and correlation coefficients 0.78