PIV: Direct Cross-Correlation compared with FFT-based Cross-Correlation

Oliver Pust

Department of Fluid Mechanics, Faculty of Mechanical Engineering, University of the Federal Armed Forces, D–22039 Hamburg

Abstract

PIV has become widely accepted as a reliable field measurement technique for the determination of velocity fields in the recent years. It has spread from research laboratories towards industrial applications. Several companies sell integrated turn-key systems. Almost all algorithms for the estimation of the displacement of a group of tracer particles use cross-correlation techniques. For the sake of computational speed most authors and especially vendors of PIV-systems implement the cross-correlation-function by means of the discrete Fast-Fourier-Transform (FFT). Although this implementation has some drawbacks concerning flexibility and the accuracy of the computed velocity little or nothing is put down in literature about this conflict by the respective authors. The present article wants to draw the attention of developers and users of PIV-systems towards this aspect of image interrogation.

Some aspects of using FFT-based cross-correlation (FFT-CC) instead of direct cross-correlation (D-CC) are not mentioned or neglected too often: while the discrete cross-correlation function is well defined for finite regions and therefore perfectly suited for the interrogation of finite sub-samples of PIV recordings, the FFT is well defined only for infinite domains. For the purpose of comparing the two cross-correlation methods the D-CC is modified in several ways to achieve the qualitatively best possible results:

- the size of the second sub-image is selected in such a way that—even with the maximal offset between the two sub-images applied— the edges of the first sub-image do not extend over the edges of the second sub-image,
- the average intensities of the sub-images $\bar{f}$ and $\bar{g}$ are computed and subtracted from the individual intensity values if these are greater than the average intensity; if the individual intensity values are smaller than the average intensity they are set equal to zero,
- the cross-correlation function is normalized suitably; the result is the cross-correlation coefficient function $\phi_{fg}(m,n)$ as shown in equation 1.

$$\phi_{fg}(m,n) = \frac{\sum_i \sum_j \left[f(i,j) - \bar{f}\right] \times \left[g(i+m, j+n) - \bar{g}(m,n)\right]}{\sqrt{\sum_i \sum_j \left[f(i,j) - \bar{f}\right]^2 \times \sum_i \sum_j \left[g(i+m, j+n) - \bar{g}(m,n)\right]^2}} \qquad (1)$$

The results of the different evaluations are presented in three ways: profiles of the horizontal velocities, scatter plots of all the velocity vectors that have been computed and histograms of the horizontal velocity components. An effect that is often overlooked when viewing vector maps or velocity profiles of turbulent flow fields is the so called *peak locking effect*. The peak locking effect becomes evident in figure 1(left): the dots are clustered at the grid points while in figure 1(right) the dots are distributed more evenly within the velocity domain.

This article shows that representative FFT-CC algorithms perform poorer than an optimized D-CC algorithm. Moreover, there is evidence that peak locking is not only caused by small particle images but also influenced by the algorithm in question. Adaptive FFT-CC schemes, that seem to be promising, may enlarge spatial resolution but do not enhance the quality of the results. Deciding between D-CC and optimized FFT-CC means weighing the advantage of the slightly better results of the D-CC against its disadvantageous higher computational time and the effort to avoid the drawbacks of the FFT-CC while still using the FFT. There are two final recommendations:

1. use direct cross-correlation based algorithms if the results have to be as exact as possible,
2. assess the quality of particle image interrogation methods not only by evaluating synthetic images but also by using images that have been recorded under real conditions in the laboratory.
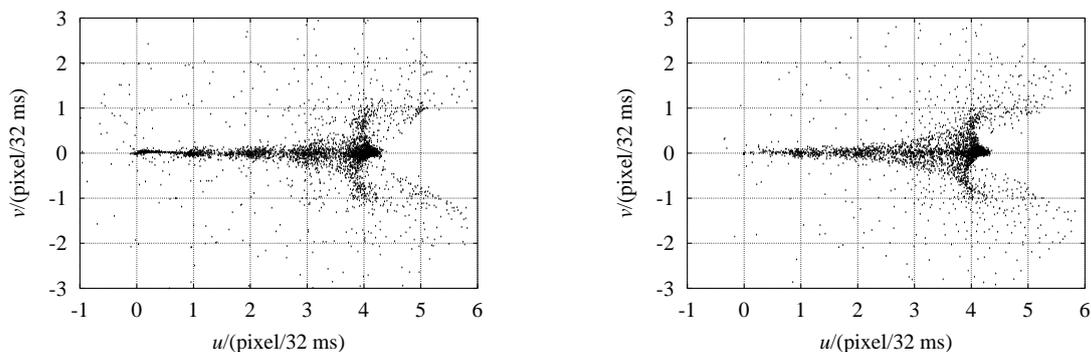

Figure 1: Scatter plot of the velocities: FFT-CC left, D-CC right