Particle Image Velocimetry

A powerful and relatively new tool for flow visualization and velocimetry is the process known as *particle image velocimetry*. This involves digitizing a moving image of a flow seeded with particles of typical dimension, c (Figure 1). Here we describe the two-dimensional or planar procedure though the extension to three-dimensions and to holographic images is quite straightforward though very data intensive. The video or photographic image is first divided up into windows as illustrated by the blue outline boxes shown in Figures 1 and 2; for convenience we define pixel addresses within the window with $j = 0 \rightarrow J$ and $k = 0 \rightarrow K$ as shown in Figure 2. The size of these windows, b, should be small enough so that the fluid velocities do not vary greatly within that window for the procedure described here yields a fluid velocity (actually a particle velocity) within that window and the result is a velocity distribution within the large image that consists of a velocity for each of the windows. The window size, b, should also be large enough so that each window contains at least one particle. The next step is to scan each of the sets of windows

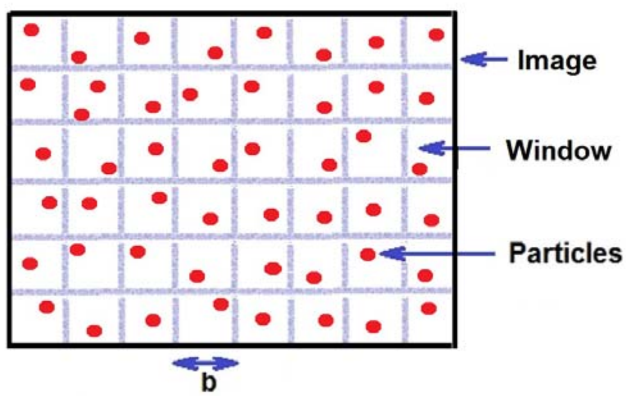

Figure 1: Image divided into windows.

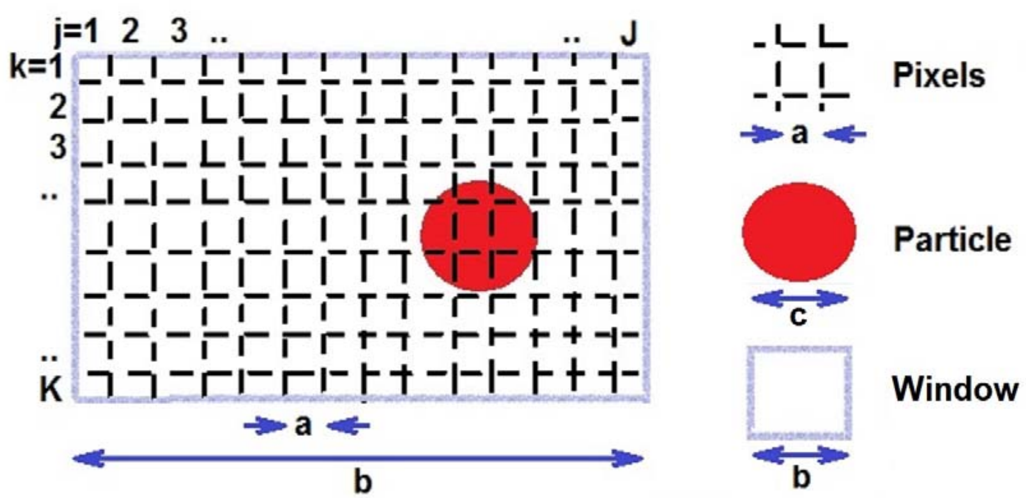

Figure 2: Window digitization.

for at least two moments in time and to record a pixel brightness value for each of the addresses within each window. It is best to utilize high contrast, black and white images and to arrange the lighting of

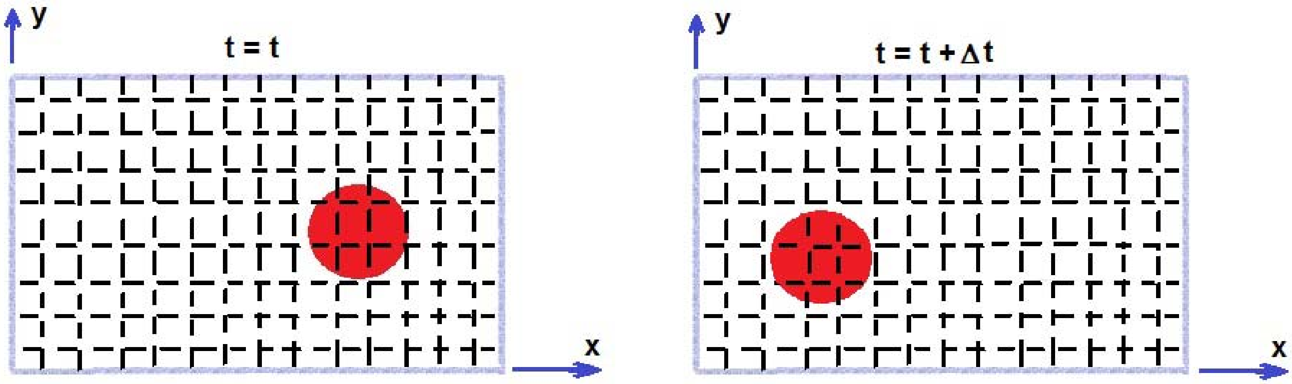

Figure 3: Cross-correlation of windows.

the flow such that the particles are in contrast with the rest of the flow and the background. The scan of each window image should record the digital brightness of each pixel with, say, a zero for a black pixel and a one for a white pixel where we will assume that the presence of a particle yields a black pixel and the absence yields a white pixel. For convenience, we denote those matrices or arrays of ones and zeros by $A(x, y, t)$ where (x, y) are the coordinates within the window as depicted in Figure 3.

Then consider the arrays $A(x, y, t)$ and $A(x, y, t + \Delta t)$ obtained for two adjacent moments in time as

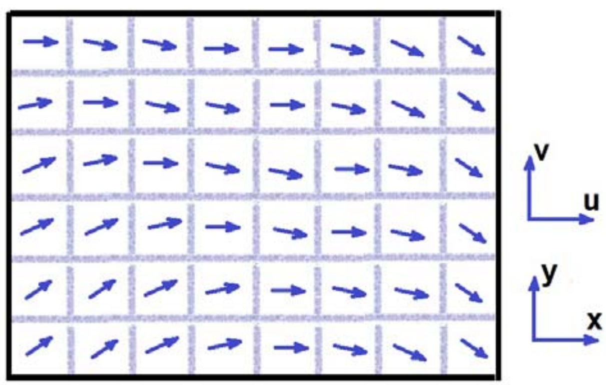

Figure 4: Velocity vectors from the Particle Image Velocimetry.

sketched in Figure 3. These two arrays are processed as follows. The array $A(x, y, t + \Delta t)$ is displaced by Δx in the x direction and Δy in the y direction and the quantity, Q, where

$$Q = \sum_{j=1 \to J} \sum_{k=1 \to K} A(x, y, t) A(x + \Delta x, y + \Delta y, t + \Delta t) \qquad \text{(Kdbc1)}$$

is evaluated for a range of values of Δx and Δy. Note that Q is only increased when a particle is registered both in the original image array $(A(x, y, t))$ and in the displaced image array $(A(x+\Delta x, y+\Delta y, t+\Delta t))$. Finally we search through all these calculated values to find the displacements, Δx_m and Δy_m, that yield the maximum value of Q. Then velocity components of the particle, u and v, in the x and y directions are given by

$$u = -\frac{\Delta x_m}{\Delta t} \quad \text{and} \quad v = -\frac{\Delta y_m}{\Delta t} \qquad \text{(Kdbc2)}$$

This computationally intensive process is then repeated for each of the windows in the video image so as to obtain velocity components for each of the windows as depicted in Figure 4. Once the velocity vectors for each window have been obtained, streamlines of the flow can be constructed and other quantities such as the vorticity can be computed.

It is evident that this process is very computationally intensive especially if a high resolution velocity field is sought. Consequently extension to three-dimensional, holographic particle image velocimetry requires very high powered computational ability. Moreover, the method by which such three-dimensional images are to be viewed, analyzed and used requires considerable forethought.