Water Surface Velocity Measurement Using Pattern Matching Technique

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Abstract – In many cases it is necessary to measure the velocity of water flow whether it is during some installation of scientific research or some natural calamities. But, In surface water studies, it is difficult to measure the velocity of water. Contact Sensors have been used in various examination but they did not execute accurate result. In this paper non-contact velocity measurement technique based on Particle Image Velocimetry (PIV) is implied. For this purpose the video of water surface is taken by a fixed digital camera. The undistorted appearances are collected. Spatial cross correlation method is applied as the pattern matching technique to calculate the displacement. The measurement is done on the hydraulic model of CWPRS and the results are shown.

Keywords – LSPIV; PIV; Ortho-rectification; CMOS Image Sensor; Cross-correlation

I. INTRODUCTION

The well-known research institute CWPRS has been working in the area of water resources since 1916. In initial stages math models were used but they were limited with boundary conditions. So the physical model studies were taken in account because of its efficient and successful implementation. The measurement of velocity of flow is one of the requirements occurring in the physical model area. This paper aims to measure velocity in one of the physical hydraulic models of CWPRS [1]. Now a days the flow velocity have relied on the mechanical methods, which has the disadvantage of mechanical wear, and also on the acoustic and radar method, which are costly and to monitor 100m^2 area minimum of 8 sensors are required. So, in this paper an image based technique is shown which is less intrusive, gives more accuracy and is lesser in cost [1].

The method is an image based technique known as the large scale particle image velocimetry (LSPIV) in which the images i.e. the digital information is captured by digital camera and then it is further processed to obtain the flow detail i.e. displacement between two frames and the time interval between them.

In the early days researchers made the process very easy by observing each particle individually. They split the flow in small "interrogation" areas and analyzed individually the velocity of different particles. In those days recording were done by analog cameras and computation was also harder. But now with powerful CCD camera and computers it becomes a very popular method. So, now-a-days instantaneous frames are recorded and analyzed to determine the whole field's flow by interrogating them through fast computation. Thus this method is advantageous because of its pace and automation. This is why this process gets warm welcome. It is also easy to use computing device instead of a transducer. It is more effective in various fields of engineering and installation of many water based techniques because it is easy to install and hydraulically sound. Figure 1 shows the basic schematic diagram of the image based system.

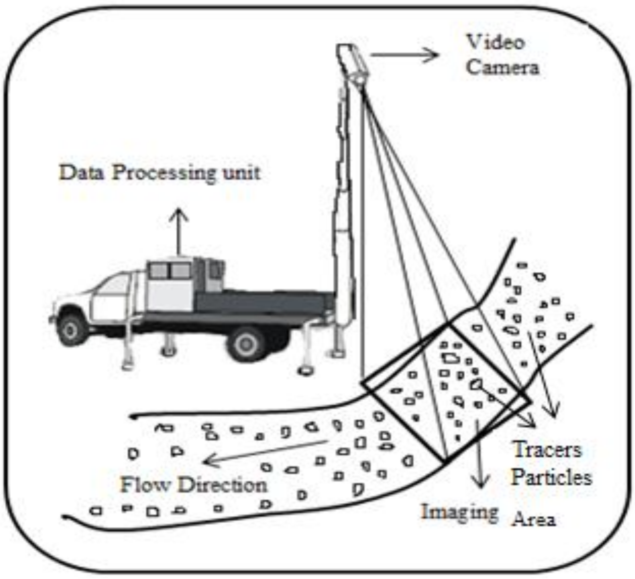


Fig. 1. Schematic Diagram of System [1]

A. Basic Principle

Both directions of displacement in water flow of two-dimensional plane, a function of time t, can be expressed as x(t) and y(t). So, the location point of the tracer particle of the two dimensional flow can be expressed as equation (1, 2) [4]:

$$u = \frac{dx(t)}{dt} = \frac{x(t+\Delta t)-x(t)}{\Delta t} = \bar{u} \quad (1)$$

$$v = \frac{dy(t)}{dt} = \frac{y(t+\Delta t)-y(t)}{\Delta t} = \bar{v} \quad (2)$$

Where, u and v are water points along the direction of instantaneous speed and direction, $\bar{u}$ and $\bar{v}$ is water points along the direction of the average speed and direction, Δt is the measured time interval [4].

II. VELOCITY MEASUREMENT SYSTEM COMPONENTS

A. Light Source:

For obtaining the high quality data, illumination component is the most crucial. For the outdoor setup the light source can be natural light, but if it is an indoor experimental setup then strong illumination is required. So Halogen and sodium-vapor lamp are used. These are to be positioned in order to have uniform illumination of the area and to avoid light reflection on the surface. To obtain the homogenous light intensity distribution over the entire area, the spots must be placed around or on top of the camera [1, 3], [11].

B. Tracer Particles:

For measurement, determining the tracer particle is very important. The tracer particles must be small enough to track accurately the flow but large enough to scatter sufficient light for imaging .Tracer particles should be lighter than the density of water and should also follow with the velocity of water. The tracers need to be cheap, and environmentally acceptable. The particle size, density composition, and concentration are important factors when selecting tracer for s [1], [3], [6], [11].

The tendency of flow of tracer particle with the water flow is the relation time, τ_p , defined as the time required for a particle at rest to be accelerated within about 63% of the fluid velocity, which can be estimated using equation 3 [1], [3]:

$$\tau_p = \frac{\rho_p}{\rho}\frac{d_p^2}{18\nu} \quad (3)$$

Where, ρ_p and d_p are the density and the diameter of the particle, ρ and ν are the fluid density and kinematic viscosity, respectively..

C. Image Recorder:

The video frames of tracer particles in imaging area are recorded using a high speed digital camera. CMOS image sensor is used widely because the function, size, price, and power dissipation are all better than CCD image sensor and also the performance parameter is close to CCD camera. To reduce time interval of two frames, it is necessary to use high frame rate image sensor in order to get real time measurement. The improvement in resolution ratio and sample no. in correlate operation can be done by using high pixel image sensor [1], [5].

III. PROCESSING OF VIDEO IMAGES

The general block diagram of the system is given in figure 2.

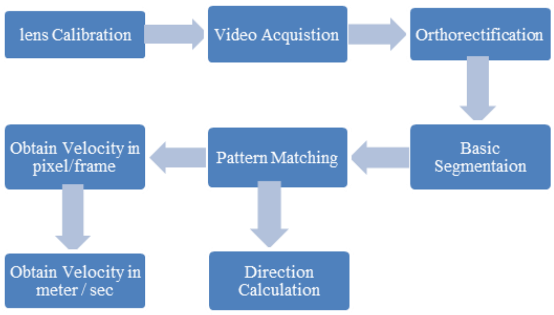


Fig.2. General Block Diagram of the System

The system involves image processing which evaluates the velocity field.

A. Pre-processing:

From the recorded video, frames are extracted and each frame is processed in order to prepare for further calculations. The frames of the video are in distorted form which has to be transformed into the undistorted appearance according to the block diagram given in figure 3.

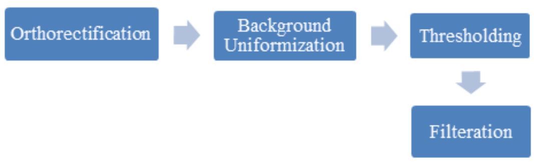


Fig. 3. Block Diagram of Pre-processing

For the large area application, images are taken from oblique angle which does not give the accurate result. So the frames acquired from the video have to be rectified such that the frames are acquired from top of the imaging area. For accurate result orthographic projection is needed [1], [6].

Generally, a Direct Linear Transformation (DLT) is applied to produce ortho-images i.e. the relationship between 3-D real world coordinate (X, Y, and Z) and the 2-D image coordinate (x and y), as shown in Figure 4. The mapping relationships between the two systems are given in Eq. 4 and Eq. 5 [6], [10]:

$$x = \frac{A_1X + A_2Y + A_3Z + A_4}{C_1X + C_2Y + C_3Z + 1} \quad (4)$$

$$y = \frac{B_1X + B_2Y + B_3Z + B_4}{C_1X + C_2Y + C_3Z + 1} \quad (5)$$

Where, A_1 to A_4 , B_1 to B_4 and C_1 to C_3 are the mapping Coefficients which can be determined by the least square method using the known 3-D coordinates. For transformation minimum six 3-D coordinates are needed. The 3-D coordinate point is generally what can be easily accessible out in the field e.g., trees, power line poles, building corners, etc. Before accessing the above equation, the effect of radial lens distortion has to be corrected from the image such that the size of undistorted image as well as the original image should be of same size [1], [6].

After we get ortho-photo, the following steps are carried out for the preprocessing [7]:

- Conversion of RGB video frame into the gray scale.
- The raw image contains the Region of interest (ROI) to be analyzed and also the region surrounding the ROI which is of no use for analysis. This region of no use is masked to increase the computational efficiency and processing accuracy.
- To enhance particle detection, brightness/ contrast level is adjusted.
- To give uniform illumination in frames subtraction of a averaged background image is done.
- To trace the particles, all the particles less than 50 pixels are filtered.

B. Processing:

Some sort of interrogation scheme is needed for the measurement of velocity. The evaluation of video frame is done using particle matching technique i.e. correlation technique, which is performed on the gray level particles present on frames.

Cross-correlation is a double frame single exposure method whose basic concept is to individuate each corresponding particle pattern in image pair by calculating the cross-correlation coefficient. In cross-correlation the direction of flow can be easily found i.e. there is no directional ambiguity and displacement can be calculated with more accuracy. The cross-correlation can be discretely represented as given Eq. 6 [1], [3], [6], [7]:

$$c = \frac{\sum_{\substack{0 \le i \le M_i \\ 0<j<M_j}} (A_{ij} - \overline{A_{ij}})(B_{ij} - \overline{B_{ij}})}{\left[\sum_{\substack{0 \le i \le M_i \\ 0<j<M_j}} (A_{ij} - \overline{A_{ij}})^2 \sum_{\substack{0 \le i \le M_i \\ 0<j<M_j}} (B_{ij} - \overline{B_{ij}})^2\right]^{1/2}} \quad (6)$$

Where, M_i and M_j are the respective sizes of the interrogation areas in pixels. A_{ij} and B_{ij} are the respective distributions of grey-scale intensity in the two images. A_{ij} and B_{ij} are the mean intensities in that interrogation area, used to normalize the intensities.

Direct cross-correlation gives the mean particle displacement for the interrogation area and the computations are of $O[M^4]$. Thus the reduction of computational process can be done by cross-correlation using fast Fourier transforms. The computation through this procedure is reduced to $O[M^2 \log_2 M]$ [7]. Figure 4 shows the steps for cross correlation using fast Fourier transform.

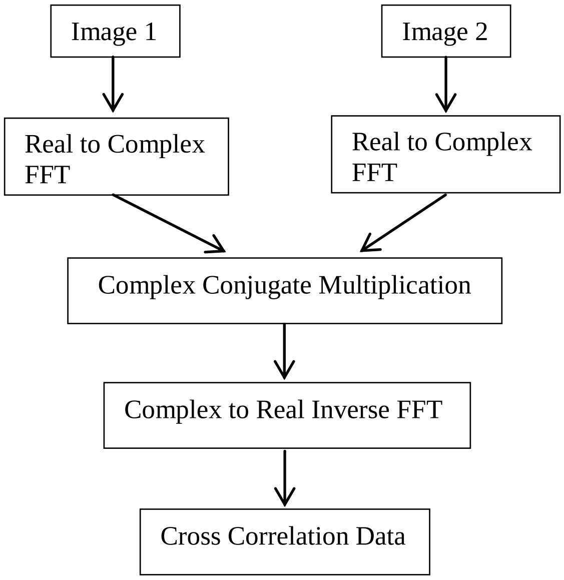


Fig. 4. Steps for Cross Correlation using Fast Fourier Transform

The image based method uses cross-correlation as the similarity index, which is calculated for patterns enclosed in a small interrogation area (IA) which is equal to ROI in the first frame and for the same sized window in larger searching area in the second frame. The window pair having the maximum cross-correlation value is the pattern's most probable displacement between two consecutive frames [4]. When the displacement is obtained, velocity can be calculated by dividing it with the time difference between two consecutive frames. The size of interrogation area can be considered such that it contains at least 6 particles per window on an average. The whole concept of image processing is shown in figure 5 [1].

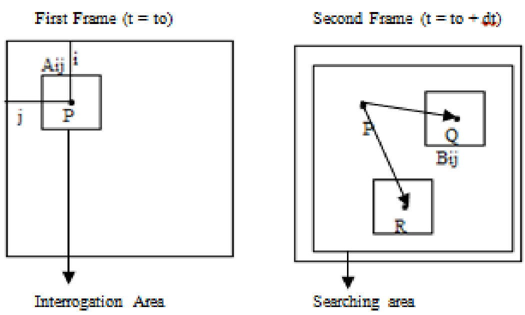


Fig. 5. Concept of Pattern Matching

A. Calibration

After the processing all results are in the unit of pixel and frames, which has no use in real world. So convert it in meter per second calibration has to be done.The calibration of the time is easily done by taking the time difference between two frames. This time difference however is not constant for all images. So, the average time difference of all frames in the series is calculated and the whole series is used. For the calibration of the distance, a reference with known distance has to be present in the photos. This distance on the photo in pixels can be related then to a real distance as given in Eq. 7 [1], [8]:

$$u = \frac{x\ \text{pixels}}{y\ \text{frames}} = \frac{xC_{distance}}{yC_{time}} \frac{m}{s} \quad (7)$$

B. Vector Validation and Interpolation

Sometimes due to the uneven illumination of tracer particles and many other factors lead to the noise in the frame, which results in invalid velocity vector. Therefore, it is necessary to remove the error vector manually. This makes the wrong location as a blank vector. So, the point on the blank flow is interpolated [7]. The interpolation can be done using Kriging method, which is based on variation of function space analysis based on the limited value of regional variables with in the region to conduct an unbiased optimal estimation method [4]. A series of the sampling points in the observation value are the variable for the regional flow field. The estimated value of a grid point in the flow region is the linear combination of the estimates and is given as equation 8[4].

$$v(x_0) = \sum_{i=1}^{n} \lambda_i v(x_i) \quad (8)$$

Where : λ_i is weighting coefficient. The kriging equations is given as equation 9:

$$\sum_{j=1}^{n} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0), i = 1, 2, \ldots, n \quad (9)$$

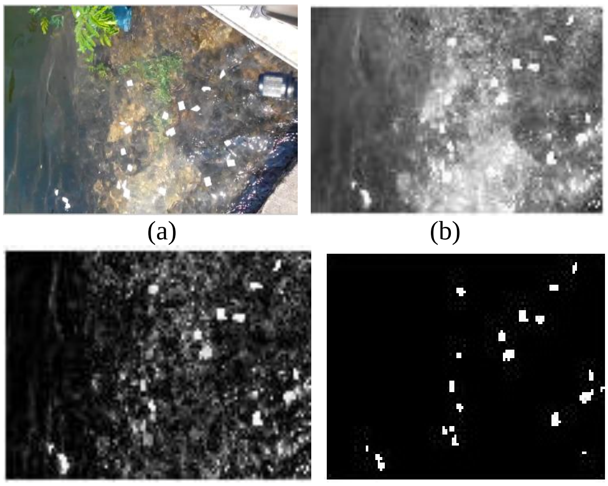
$$\sum_{i=1}^{n} \lambda_i = 1$$

Where, $\gamma(x_i, x_j)$ is sampling point, xi, xj is variate function value, μ is lagrange constant.

IV. IMPLEMENTATION AND RESULTS

Using a 8 MP camera with resolution 1280x720 and 24 bits per pixel, we took the video at Bombay airport model at CWPRS, Pune. It has a duration of 3.1360 secs and frame rate was 29. We used intel dual core processor for computation. We introduced some additional paper particles as tracer particles on the flow. We accessed the following sequence of frame: 1-2, 2-3, 3-4 and so on.

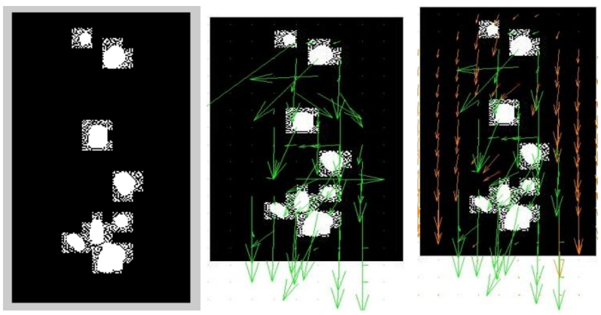
The preprocessed image of video frames is given in figure 6 (a) Shows the actual frame, (b) Gray scale frame, (c) shows the background uniform frame and (d) shows the preprocessed image.



(a) (b) (c) (d)

Fig. 6. (a) Actual Frame, (b) Gray scale image, (c) Uniform Background frame, (d) Preprocessed Frame

The interrogation area is selected as 64 pixels with the step of 32 pixels i.e 50 percent of overlapping. The ROI of the frame is given in figure 7(a) after applying the pattern matching technique the velocity vectors are given in figure 7(b) and 7(c) shows the frame after vector validation and interpolation is applied. Figure 8 shows the scatter plot of the velocity in (u,v) i.e horizontal and vertical direction respectively.



(a) (b) (c)

Fig. 7. (a) ROI of the frames, (b) Velocity vectors of frame and (c) Frame after vector validation and interpolation

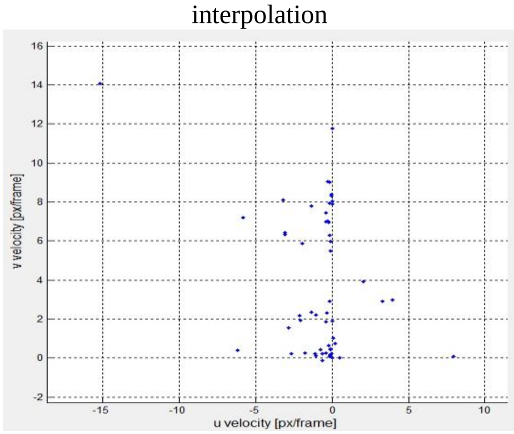


Fig. 8 Scatter Plot of Velocity Vectors

The velocity in pixel/frame is calculated as u = -2.3635 px/fr and v = 0.7073 px/fr.

V. CONCLUSION

From the above discussions we can understand that image based technique is a reliable, accurate and instantaneous measurement approach. During devastating flood and superficial flow, this technique can be used effectively and it can produce prolific results.

In our chosen method we generated ortho-images to obtain accurate through ortho-rectification. To suppress the bed effect segmentation of the Tacer particles was done. By using pattern matching technique we determined the displacement of trace particles and by dividing this by the time interval between two frames we got the velocity. For all these, highly sensitive and high speed CMOS camera was preferred. The results are found accurately using the given system.

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