ISSN 2278-3083
Volume 3, No.4, July - August 2014
International Journal of Science and Applied Information Technology
Available Online at http://warse.org/pdfs/2014/ijsait02342014.pdf

A novel method for measurement of an open-stream water flow for a hydrologicalmodel with multiple tracers using image processing

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ABSTRACT
Fluid velocity measurement is done by various methods which include mechanical sensors, but these techniques fail in the long run due to wear and tear of the instruments. PIV is a technique which is based on image processing but due to the complexity of the initial setups, they cannot be used for open stream applications. ADCP is also an instrument, but it cannot be used by everyone since it is not a cost efficient solution. A need for developing a low cost and a non-contact solution aroused and a technique for velocity profiling using punch holes and a colored dye was developed which used tracking of these tracers using image processing. The technique and the algorithm was tested in CWPRS and accurate results were obtained.

Key words:ADCP, mechanical sensors, PIV, tracer

1. INTRODUCTION

Flow measurement is quantification of the bulk movement of the fluid. Flow measurement is used in different applications, like it can be used in selecting the best source of a drinking water supply. Usually it is done at the end of the end of the dry season when the flow is the lowest to assess whether the source is able to provide sufficient water all year around.

Several techniques have been developed in the field of fluid dynamics for measuring the flow-rate and direction of the flow. Mechanical flow meters like oval gear meter [1], turbine flow meter [2], jet meters are extensively used in measuring the flow rate, but due to several reasons like mechanical wear and tear of these instruments because of repeatable use makes them unreliable in the long run. Also these instruments give the idea of the flow at that place where the strobe is inserted and one cannot the idea of the general flow nature of stream.Electromagnetic sensors[3] which rely on the Faraday principle, that works with Emf which generated by changing on magnetic flux density. The magnetic field produces by exciting wire in two kinds of DC and AC excitation systems. Therefore, induced voltage between electrodes calculated by simple equation,$E = B.d.v_m$, that illustrate the operation of an electromagnetic flow meter that based on the Faraday's law. In above equation, B is magnetic flux density, d is length of conductive which is equal to diameter of the pipe and v_m is mean flow velocity.[4]-[6] The system require a great deal of initial setup and cannot be used for open channel flow measurement and are susceptible to external electromagnetic interference. Ultrasonic flow meters work on the concept of Doppler shift which prove to be a very viable solution, but due to its huge cost and limitation of the field of measurement, it cannot be used as and when needed. These all techniques do not use a tracer for tracking the fluid motion and hence no image processing techniques can be applied on them. Another technique called Particle Image Velocimetry [7]-[9] is adopted which uses micro tracer particles which mass the density of water and hence travel according to the flow of the fluid. The flow is illuminated by a collimated laser beam in order to illuminate the tracer particles so that they can easily be tracked. Tracking of the tracer particles can be 2 dimensional or 3 dimensional with the use of stereoscopy, which require 2 cameras or at times maximum of 4 cameras to correctly track the particle. The disadvantage is that it cannot be used practically in a field because of the complex assembly required. Commercial research grade PIV system includes a class IV laser high speed/resolution camera that makes the system potentially unsafe and very expensive.

In this paper we have modified the technique of PIV and developed our own technique/algorithm using tracer objects like paper punch holes, which can easily float on water and for detecting fluid velocity below the water surface, a tracer fluid having the density same as water was injected inside water and by tracking these punch holes/ fluid, water velocity was accurately being determined. The whole system requires no prerequisites of complex setups and hence can prove a cost-effective, reliable solution for fluid velocity profiling and measurement.

2. METHODOLOGY

The experimental setup can be as shown in figure 1. Figure 1 shows an overhead camera which will be placed at the top of the stream and tracer particle like punch holes or fluid will be introduced in the water. The camera will continuously take a video of the stream. Area ABCD is the field of view of the camera for the stream. The camera will be connected to a laptop, which will then process the acquired frames and give the velocity profiling based on tracking the tracer.

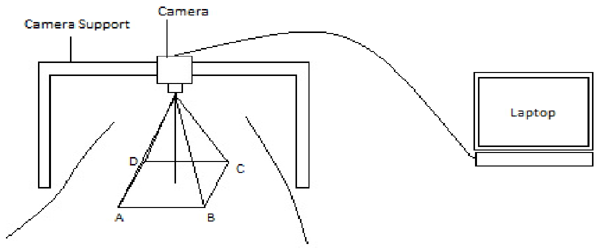

Figure 1: Schematic assembly for flow measurement

Based on the type of tracer there will be 2 different algorithms for tracking them.

2.1 Punch Holes

Punch holes of paper were administered in flowing water and a video was captured of it. The video was then processed in MATLAB 2012. A Graphical User Interface is made asking the users to record or stop it and also the frame rate at which the video can be recorded.

A detailed algorithm of the velocity calculation is shown in figure 2.

The Process is divided into 3 parts

1. Pre Processing
2. Object detection and tracking
3. Post Processing/Velocity Calculation

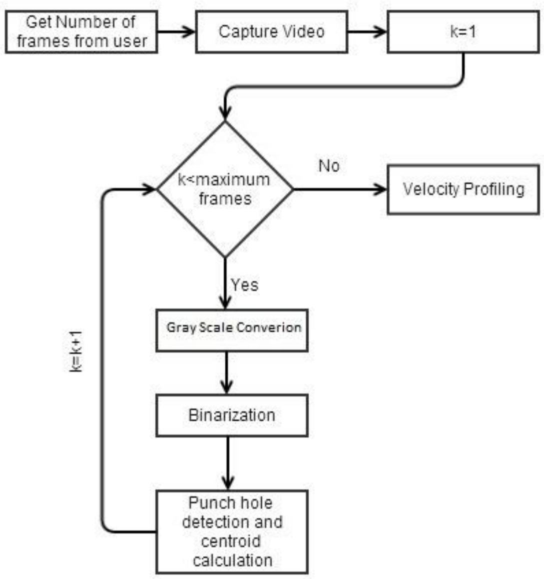

Figure 2: Schematic flow of Velocity Profiling using Punch holes

2.1.1 Pre Processing

Video is nothing but the series of images played at a faster rate. Framing is a very important part of the video processing. Framing means breaking the video into that series of images. Itmakes the video analysis easy and fast. Each frame will be analyzed and processed individually.

A video is a series of frames. Framing was done to get each frame and then each frame was independently being processed. After getting the frame, the image was in RGB format and hence it was then converted into grayscale.

Let $A(x, y, :)$ be the RGB image. It is a three dimension matrix, where $A(x, y, 1)$ represents the Red colour matrix, $A(x, y, 2)$ represent the Green colour matrix and $A(x, y, 3)$ represents the Blue colour matrix. Let $G(x, y)$ be the greyscale image having 256 levels, 0 being black and 255 being white. G(x,y) can be calculated with the help of 'Luminosity Equation'.

$$G(x, y) = 0.21 * A(x, y, 1) + 0.71 * A(x, y, 2) + 0.07 * A(x, y, 3) \quad (1)$$

$G(x, y)$Is the image obtained after grayscale conversion which is then binarized with a threshold (T) of 178 was used and this threshold may vary depending upon the background and ambient conditions.

Let $B(x, y)$ be the binarized image. Let T be the threshold for binarization.

$$B(x, y) = 1 \ where\ 0 \leq G(x, y) \leq T \ and B(x, y) = 0 \ where T < G(x, y) \leq 255 \quad (2)$$

2.1.2 Object Detection

After Binarization, the components having similar pixel value were connected using a flood fill algorithm[10] and after that components having pixel count similar to the punch holes were filtered. Their respective centroids were calculated and now we just have single point location of all the punch holes, for a single frame. Similar operations needs to be done on the next frame and based on the previous frame's point the angle and distance travelled can be calculated.

2.1.3 Post Processing

The respective centroids of the punch holes in all the frames of the video is stored in an array and this will be used for angle and distance calculation.

The angle can be calculated as below,

$$\theta_l^i = \tan^{-1}\frac{y^{(i)}(k)-y^{(i)}(k-n)}{x^{(i)}(k)-x^{(i)}(k-n)}, n=1,2,3 \ldots \quad (3)$$

$\theta_l^i$is the angle of the vector for i^{th}punch holes for frame range l which is $(k - n)$.

For distance similarly the equation will be,

$$D_l^i = \sqrt{\left(x^{(i)}(k) - x^{(i)}(k-n)\right)^2 + \left(y^{(i)}(k) - y^{(i)}(k-n)\right)^2}, n=1, 2, 3\ldots \quad (4)$$

$D_l^i$is the length of the vector in terms of pixels for i^{th}punch holes for frame range l which is $(k - n)$.

$y^{(i)}(k)$is the y-coordinate for i^{th} punch hole in k^{th} frame and $x^{(i)}(k)$ is the x-coordinate for i^{th} punch hole in k^{th} frame.$(k - n)$indicates the n^{th} previous frame from frame k.

For calculating the velocity the equation will be,

$$V_l^i = \frac{D_l^i}{l/n} \quad (5)$$

Where n is the frame rate(frames/second) at which the camera is capturing the video and V_l^i is the velocity of i^{th}punch-hole between frames k and n in pixels/sec.

For getting the velocity in m/sec, the image should be properly geo-referenced, which can be done by referencing known points in the image with a map of the same area and by using 3rd degree polynomial affine transformation, the image can be scaled, rotated or skewed based upon the coefficients obtained after solving the equations.

The disadvantage of this method is that it will only give the surface water velocity since the paper punch-holes will float on water. So a different approach was adopted for calculating the velocity of water below it's surface.

2.2 Colored Dye

A known color dye was administered in water using an injector and with the same camera and software setup, video was captured and processed.

A detailed algorithm is shown in figure 3. The process is again similarly divided into 3 parts,

1. Pre Processing
2. Fluid Detection and tracking
3. Post Processing

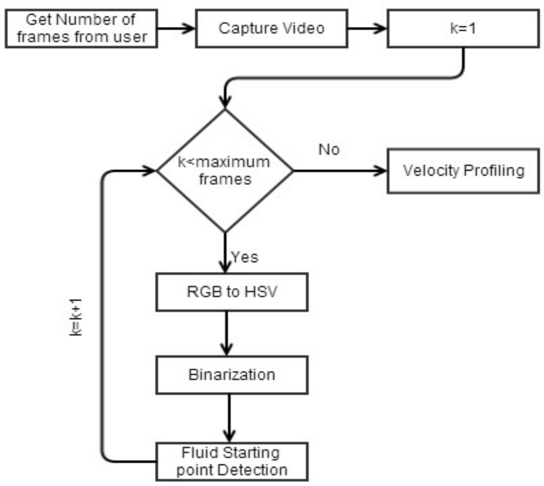

Figure 3: Schematic flow of Velocity Profiling using Dye

2.2.1 Pre Processing

Similar to the punch holes framing is done to the video and then the RGB image is converted into a HSV model image.Let $A(x,y,:)$ be the RGB image; $A(x,y,1)$ being the R component, $A(x,y,2)$ being the G component and $A(x,y,3)$ being the B component. Let $P(x,y,:)$ be the HSV modelled image; $P(x,y,1)$ being the Hue component, $P(x,y,2)$ being the saturation component and $P(x,y,3)$ being the Intensity Value component.

$$R' = \frac{A(x,y,1)}{255} G' = \frac{A(x,y,2)}{255} B' = \frac{A(x,y,3)}{255} \quad (6)$$

$$Cmax = \max(R',G',B') \quad Cmin = \min(R',G',B')$$

$$\Delta = Cmax - Cmin \quad (7)$$

For Hue, the equation is,

$$H = P(x,y,1) = 60° * \left(\frac{G' - B'}{\Delta} mod6\right), \quad Cmax = R'$$

$$H = P(x,y,1) = 60° * \left(\frac{B' - R'}{\Delta} + 2\right), Cmax = G'$$

$$H = P(x,y,1) = 60° * \left(\frac{R' - G'}{\Delta} + 4\right), Cmax = B' \quad (8)$$

For Saturation, the equation is,

$$S = P(x,y,2) = 0 \; if \; \Delta = 0 \; else \; S = \frac{\Delta}{Cmax} \quad (9)$$

For Value, the equation is,

$$V = P(x,y,3) = Cmax \quad (10)$$

Where H, S and V are the respective Hue, Saturation and Value components.

Here only the saturation component is of our interest and the binarization will be based on the saturation value.

$P(x,y)$ Is the image obtained after RGB to HSV conversion which is then binarized with a threshold (T) of 128 was used and this threshold may vary depending upon the background and ambient conditions. A monocolored uniform background is chosen having a color different than the dye, which made it possible to segregate the dye from the background.

Let $B(x,y)$ be the binarized image. Let T be the threshold for binarization.

$$B(x,y) = 1 \; where \; 0 \le P(x,y) \le T$$

$$and B(x,y) = 0 \; where T < P(x,y) \le 255 \quad (11)$$

2.2.2 Dye detection and tracking

After binarization the image only had dye whose pixels had value 1 while the rest background had value 0. By using a simple search algorithm the starting point of the fluid was detected and this was used as the reference point for the first frame.

2.2.3 Post Processing

The starting point of the dye can be used as a tracer, since it will be difficult to keep track of multiple points in a fluid in coming frames. The starting point of the dye will follow the same trajectory as that of the flowing water. For getting the starting point of the dye a searching algorithm was made which finds the first point scanning column wise in the image from left to right and stops as soon as it gets one point which has a value of 1 and records its x and y co-ordinates. The location of the respective starting point of the fluid from each frames was recorded and based on the equation 3, 4 and 5 their respective angle, position and velocities were calculated.

The difference is for punch-holes we got velocities for multiple locations in a stream, while dye gave us only the velocity of the starting point, which is single velocity.

3. RESULTS

The experiment was performed at the Bombay Port model in Central Water and Power Research Station (CWPRS), Khadakwasla with proper calibration and setup.A constant velocity water flow was made in the model and a video was recorded using the camera for punch holes and then similarly using dye. A schematic setup of the arrangement can be seen in figure 1. A mechanical support carrying the camera on the top of the stream was connected via a USB to a laptop. The laptop controlled the frame rate and video capturing time. At the same time, using a mechanical rotor velocity sensor corresponding readings were taken at the points where punch holes were present and then compared with the results got using our image processing technique. Table 1 shows the results obtained using Image processing using punch holes and mechanical sensor.

Table 1: Velocities obtained using punch holes

Image Processing		Mechanical sensor(m/sec)	Relative Error (%)
Velocity (m/sec)	Angle (°)		
0.93	4.45	0.94	-1.06
0.73	4.21	0.72	1.39
1.30	5.33	1.29	0.78
1.22	6.12	1.21	0.83

The results show a very less error compared to the mechanical sensor and in addition to that Image processing gave the direction of flow also. This proves that image processing can be a viable substitute and it gave simultaneously all the four readings while mechanical sensor needed manual insertion of the probe at four different places at different time. Thus we got instantaneous results of all the different sections of the stream at a given time, while mechanical sensor failed in this condition.

The GUI screenshots can be seen in figure 4 and 5 with the respective results.

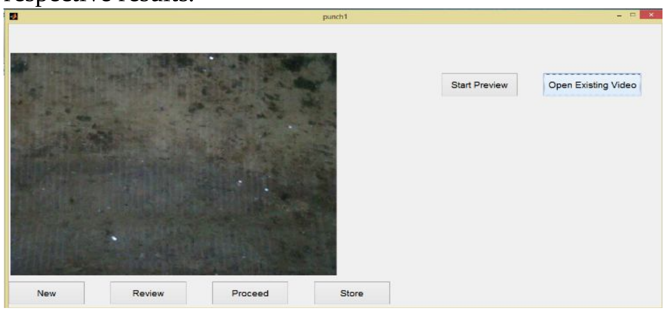

Figure 4: Video Capturing GUI(Punch holes)

As shown in figure 4 white colored punch holes were recorded and the user has the ability to manually start and stop the recording.

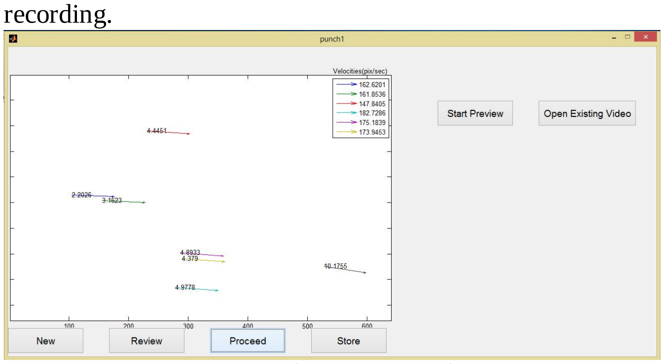

Figure 5: Result obtained after velocity profiling (punch holes)

Figure 5 shows the velocity of 6 tracer punch holes with their respective velocities in pix/sec in legend with the angle and direction of flow. This type of profiling is possible using PIV, but our system requires a minimal amount of setup and is a very low cost solution.

Similarly a colored dye was injected at 10cm below the water surface and velocity was calculated by the algorithms mentioned in 2.2., the velocity profiling was done. A screenshot of the GUI can be seen in figure 6 and the user had the ability to control the camera via the interface.

Figure 6: Video Capturing GUI (Dye)

Figure 6 shows the pink colored dye introduce in water.

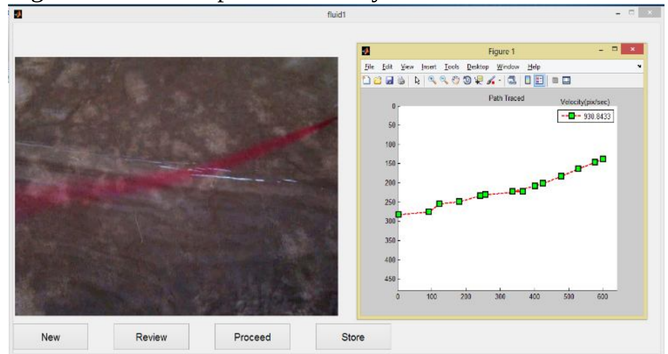

Figure 7: Result obtained after velocity profiling (Dye)

Figure 7 shows the obtained trajectory of the starting point of the dye and the image was sampled at a rate of 6 frames per second.

The green colored squares are the position of the starting point of the dye at different point of time.

Table 2: Velocities obtained using dye

Image Processing		Mechanical sensor(m/sec)	Relative Error (%)
Velocity (m/sec)	Angle (°)		
1.10	2.10	1.15	-4.34
1.16	5.22	1.20	-3.33
1.02	6.20	1.06	-3.77
0.98	3.15	0.95	3.16

Table 2 shows the results obtained for velocities using a dye. Compared to the punch holes, dye show a high relative error.

4. CONCLUSION

Both of the techniques has its own application with their respective advantages and disadvantages. Punch holes will give velocity of the stream at different location at that instant of time while fluid will only give velocity for a single point at an instances. On the other side punch holes will give surface velocity while fluid will give water velocity at a given depth. Both of the approaches will give a 2 dimensional velocity profile, but an introduction of a second camera will help us to find the velocity profile in the 3rd dimension also. It has been observed that due to the cohesive forces the punch holes stick together amongst themselves and start to rotate along a common axis irrespective of the flow of the media which makes the tracking difficult, in addition to that it will create false reading. Thus it is advised to use only few punch holes to avoid this scenario. For correct detection of dye as well as punch holes it is advised to use a dark background with no inclusions of external factors like reflections and water should be pure enough just to detect the white tracer particles perfectly.

The system requires no use of lasers as in PIV and hence can be easily used in open stream flow condition. The system can be improved further by removing the dependency of external conditions and background color, also an algorithm for tracking multiple points of dye can prove a revolutionary solution.

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