CHAPTER 1

Introduction

1.1 Background

In the beginning of the 20th century, the need for small scale laboratory investigations to study the twin problems of irrigation and drainage was recognized by the Government. The Central Water and Power Research Station (CWPRS), Pune, as it is known today, was established in 1916 by the then Bombay Presidency as a "Special Irrigation Cell" with a limited mandate to modify irrigation practice to meet agricultural requirements. Recognizing its role in the systematic study of various phases of water flow, including floods, the institution was taken over by the Government of India in 1936.

Fig: 1.1 Central Water and Power Research Station, Khadakwasla, Pune

With the dawn of independence and launching of planned development of the nation's water resources, CWPRS became the principal central agency to cater to the R&D needs of projects in the fields of water and energy resources development and water-borne transport. Today, CWPRS, a part of the Union Ministry of Water Resources, is one of the foremost organizations in the world in the field of hydraulics and allied research. CWPRS provides specialized services through physical and mathematical model studies in river training and flood control, hydraulic structures, harbors, coastal protection, foundation engineering, construction materials, pumps and turbines, ship hydrodynamics, hydraulic design of bridges, environmental studies, earth sciences, and cooling water intakes. The studies conducted by CWPRS are able to provide hydraulically sound and economically viable solutions to various problems associated with projects on water resources, energy and water-borne transport including coastal and harbor engineering.

The recent research, in the CWPRS, is being carried out on the Bombay Port Model and Panvel International Airport Model. Mumbai, the economical capital of India, has two airports Chhatrapati Shivaji International Airport and Santacruz Domestic Airport, but are unable to fulfill ever growing needs of Mumbai. So there arose a need of third airport. Panvel, the city and a municipal council in Raigad District, also known as the gateway of Konkan Region, was found to be a suitable place for setting up the Navi Mumbai International Airport, as it is nearer to the Mumbai and less populated than it. It is to come up around the Panvel-Kopra area surrounded by the four rivers Gadhi, Ulna, Kalundre and Kirki. Due to large rains and flooding in Mumbai causes Panvel to go under water because of the rivers carrying out the flood. To avoid any damage and harm to the Airport, river diversion is mandatory. So government also needs a monitoring system to measure and determine the flow. There are systems available, based on water velocity measurement, consisting of Acoustic Doppler Effect Sensors. But these systems are costly and minimum 8 sensors are required to monitor a 100 m^2area. So they are not feasible to implement. Hence the system based on the image processing will be very much cost effective. In addition to this, the sensors are inefficient in plotting flow pattern which is the major part of our project work. So, this system, water flow velocity and flow pattern measurement, will provide a cost effective, illustrative and attractive solution to tackle this problem faced by the Government.

1.2 Relevance

The system, water flow velocity and flow pattern measurement, is instrumentation using image processing (video processing). The field of electronics and telecommunication engineering comprises these subjects. We had Digital Image Processing as our major elective and the subjects like Test & Measurement Techniques, Electronic Instrumentation Techniques, which deal with the instrumentation part.

1.3 Literature Survey

1.3.1 Image Processing

Image processing is any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image[3]. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques to it. An image is defined in the "real world" is considered to be a function of two real variables, for example, $a(x, y)$ with a as the amplitude (e.g. brightness) of the image at the real coordinate position(x, y).

Basic Digital Image Processing System includes the following steps.

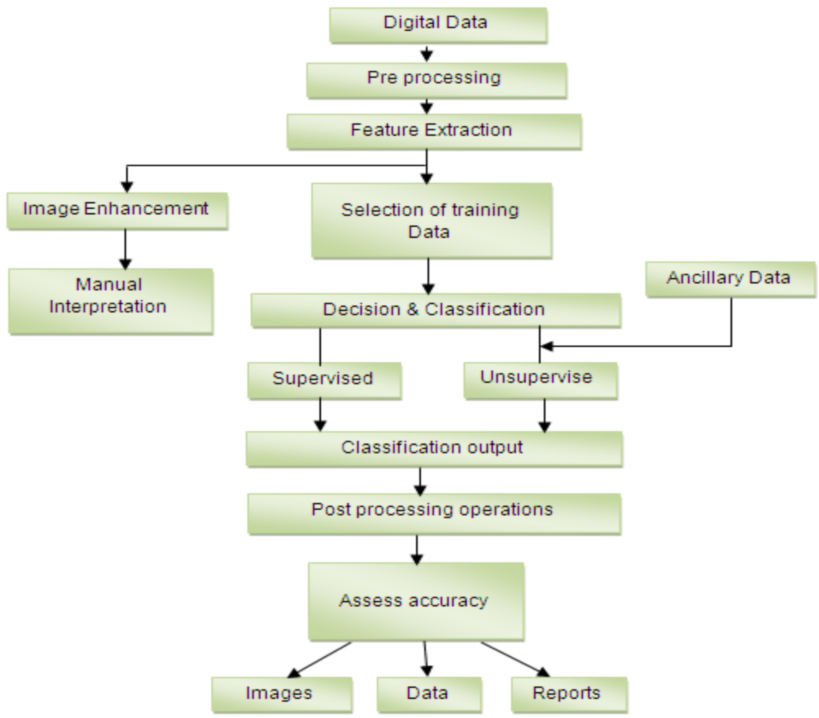


Fig: 1.2 Steps in Digital Image Processing Systems

1.3.2 Particle Image Velocimetry

Several research scientists have developed different techniques based on hardware mechanics. The different technologies include ultrasonic and electromagnetic concepts.

The method traditionally used using image processing is Particle Image Velocimetry (PIV) [2]. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles which, for sufficiently small particles, are assumed to faithfully follow the flow dynamics. The fluid with entrained particles is illuminated so that particles are visible. The motion of the seeding particles is used to calculate speed and direction (the velocity field) of the flow being studied. Typical PIV apparatus consists of a camera (normally a digital camera with a CCD chip in modern systems), a strobe or laser with an optical arrangement to limit the physical region illuminated (normally a cylindrical lens to convert a light beam to a line), a synchronizer to act as an external trigger for control of the camera and laser, the seeding particles and the fluid under investigation. A fiber optic cable or liquid light guide may connect the laser to the lens setup. PIV s/w is used to post-process the optical images.

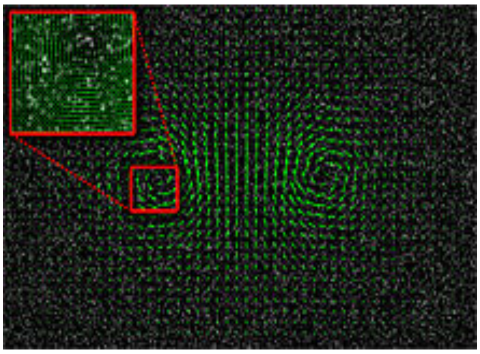


Fig: 1.3 PIV Analysis of Vortex Pair

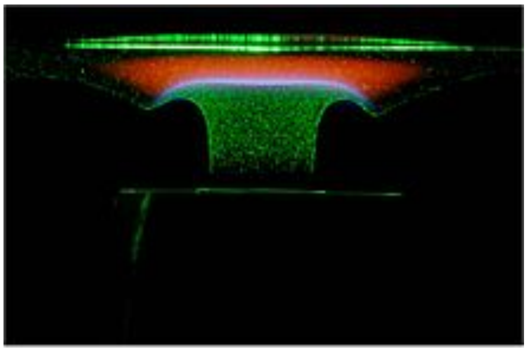


Fig: 1.4 Application of PIV in combustion

Particle image velocimetry methods have lot of drawbacks. PIV techniques will in general not be able to measure components along the z-axis (towards/away from the camera). These components might not only be missed, they might also introduce interference in the data for the x/y-components caused by parallax. These problems do not exist in Stereoscopic PIV, which uses two cameras to measure all three velocity components. Commercial research grade PIV systems include a Class IV laser and high resolution/speed digital camera that make the systems potentially unsafe and very expensive. Commercial systems are prohibitively expensive (at least US$100K).

Because of such drawbacks, implementation of PIV is not possible. But the logic behind tracing the particles and finding out the velocity is quite impressing. So we can use that logic with normal object detection methods.

1.3.3 Object Detection

Object detection is a computer technology related to computer vision and image processing that deals with detecting instances of semantic objects of a certain class.

The object detection can be done with various algorithms. As flow tracers, we are using coloured fluid and paper-punch holes. Paper-punch holes are too small in size and weight though their shape is fixed. Shape and Size of the coloured fluid in water will be stochastic in nature. Most of the object detection algorithms are based on shape and size of the object. But all these were not much useful in this scenario. So we came up with the colour-based object detection.

Image binarization, thresholding, colour modelling-space et-cetera can be used for object detection. So we proceeded in that way. So we will focus on some basic image processing techniques and colour models.

1.3.4 Greyscale Conversion

Fig: 1.5 Greyscale Conversion

A greyscale [4] digital image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. Images of this sort, also known as black-and-white, are composed exclusively of shades of grey, varying from black at the weakest intensity to white at the strongest.

Greyscale images are also called monochromatic, denoting the presence of only one (mono) colour (chrome). Greyscale images are often the result of measuring the intensity of light at each pixel in a single band of the electromagnetic spectrum.

To convert any colour to a Greyscale representation of its luminance, first, one must obtain the values of its red, green, and blue (RGB) primaries in linear intensity encoding.

Greyscale images are commonly stored with 8 bits per sampled pixel, which allows 256 different intensities (i.e., shades of grey) to be recorded, typically on a non-linear scale. The intensity of a pixel is expressed within a given range between a minimum and a maximum, inclusive. This range is represented in an abstract way as a range from 0 (total absence, black) and 1 (total presence, white), with any fractional values in between.

To convert a grey intensity value to RGB, simply set all the three primary colour components red, green and blue to the grey value, correcting to a different gamma if necessary.

Let $A(x, y, :)$ is the RGB image. It is a three dimension matrix, where $A(x, y, 1)$ represents the Red colour matrix, $A(x, y, 2)$ represents 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' [3].

$$\boxed{G(x, y) = 0.21 * A(x, y, 1) + 0.71 * A(x, y, 2) + 0.07 * A(x, y, 3) \qquad (1.1)}$$

1.3.5 Image Binarization

Image binarization [4] converts an image of up to 256 grey levels to a black and white image.

The simplest way to use image binarization is to choose a threshold value, and classify all pixels with values above this threshold as white, and all other pixels as black. The problem then is how to select the correct threshold. In many cases, finding one threshold compatible to the entire image is very difficult, and in many cases even impossible. Therefore, adaptive image binarization is needed where an optimal threshold is chosen for each image area.

Image binarization is a process which is very important in detection of object. The main purpose of binarization is conversion of an image into two sets that is foreground and background.

Fig: 1.6 Image Binarization

The process of binarization can be explained through the following chart.

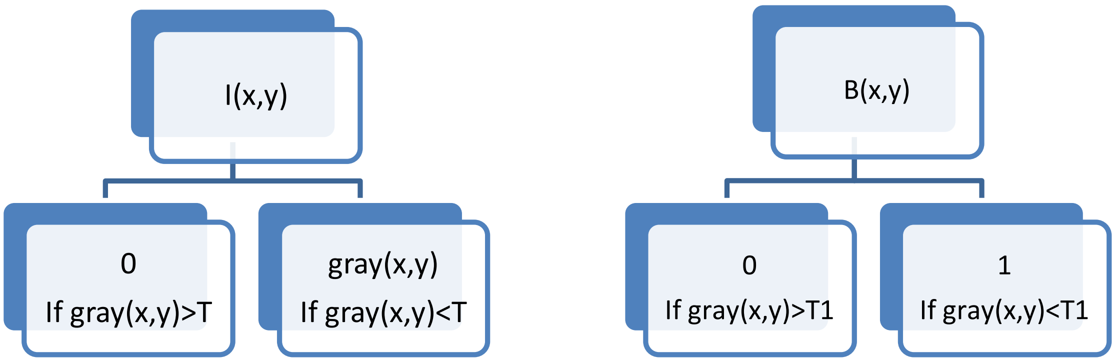


Fig: 1.7 Process of Binarization

In this figure $gray(x,y)$ is the greyscale image, $I(x,y)$ is the intermediate image and $B(x,y)$ is the binarized image.

Binarization can be of two types:

1. Global Binarization
2. Local Binarization.

Global Binarization is a technique in which the threshold is created on the basis of the whole image and using this threshold the image is converted into foreground and background. Global Threshold can be calculated by following equation. Here $rows$ is the number of rows in the image matrix and $cols$ is the number of columns.

$$\mathrm{T} = \left\{\sum_{(k,l)=(1,1)}^{(rows,cols)} \mathrm{gray}_{\mathrm{image}(\mathrm{k,l})}\right\} \div (rows * cols) \tag{1.2}$$

Local Binarization is a process in which the threshold of the image is created based on the neighbouring pixel values. Global binarization is a faster method than local binarization.

$G(x, y)$ is the grey-scaled image we have obtained from RGB to Greyscale conversion. Let $B(x, y)$ be the binarized image. Let $'T'$ be the threshold for binarization [3].

$$B(x,y) = 1 \; where \; 0 \leq G(x,y) \leq \; T \tag{1.3}$$
$$and \; B(x,y) = 0 \; where \; T < G(x,y) \leq 255$$

1.3.6 Colour Models

A colour model [4] is an abstract mathematical model describing the way colours can be represented as tuples of numbers, typically as three or four values or colour components. When this model is associated with a precise description of how the components are to be interpreted (viewing conditions, etc.), the resulting set of colours is called colour space.

The eye seems to be composed of rods and cones. Rods respond only to the intensity of the light falling on them, and are more sensitive to low light levels than are cones. The cones are of three different types and respond differently to different wavelengths. What we perceive as colour seems to depend on characteristics of brightness, hue, and saturation. We generally regard the basic colours as Red, Green, and Blue, and define other colours as a mix of these three.

There are several models viz. RGB, CMYK, YIQ, HSV, used to describe the tri-stimulus colour scheme. Each model was derived for specific purpose and has certain advantages over the others. What computer understands is RGB colour model and what human eye percept is HSV model. Since colour based object detection is to be used, we will convert the RGB image to HSV modelled 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 [3].

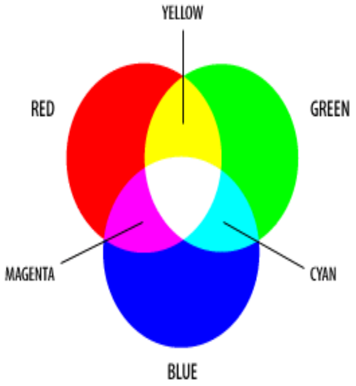


Fig: 1.8 RGB Colour Model

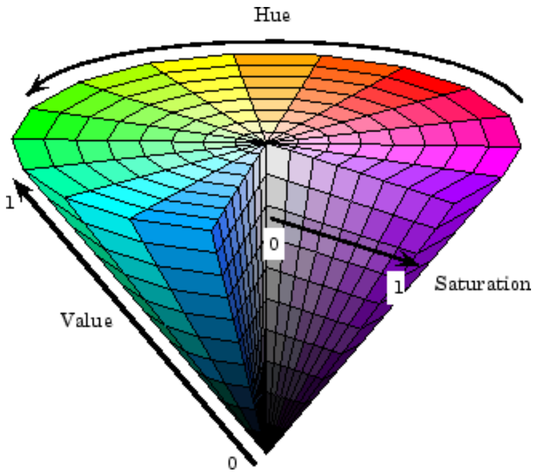


Fig: 1.9 HSV Colour Model

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

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

Hue Calculation:

$$H = P(x,y,1) = 60° * \left(\frac{G'-B'}{\Delta} mod6\right), \qquad Cmax = R' \tag{1.4}$$

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

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

Saturation Calculation:

$$S = P(x,y,2) = 0 \; if \; \Delta = 0 \; else \; S = \frac{\Delta}{Cmax} \tag{1.5}$$

Value Calculation:

$$V = P(x,y,3) = \; Cmax \tag{1.6}$$

Fig: 1.10 RGB to HSV Conversion

1.3.7 Stepper Motor

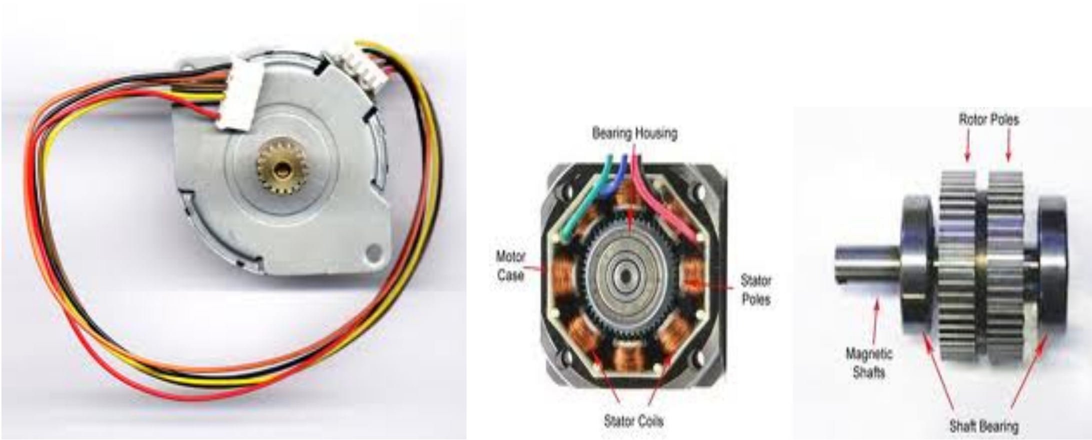


Fig. 1.11 Stepper Motor and its construction

It converts electrical power into mechanical power. The main difference between them and all the other motors is the way they revolve. Unlike other motors, stepper motors does not continuously rotate; instead, they rotate in steps. Each step is a fraction of a full circle. This fraction depends mostly from the mechanical parts of the motor, and from the driving method. The stepper motors also differs in the way they are powered. Instead of an AC or a DC voltage, they are driven (usually) with pulses. Each pulse is translated into a degree of rotation. For example, a 1.8° stepper motor will revolve its shaft 1.8° on every pulse that arrives. Often, due to this characteristic, stepper motors are also called **digital motors.**

A stepper motor works with permanent magnets, which are attached to the output shaft. Around the body of the motor is a series of coils that create a magnetic field that interacts with the permanent magnets. When these coils are turned on and off, the magnetic field causes the rotor to move. The motor will rotate forward or reverse as the coils are turned on and off in sequence.

In a stepper motor, the input command specifies the desired angle of rotation, and the controller provides the corresponding sequence of commutations without the use of any feedback about the position of the system being driven.

As all motors, the stepper motors consists of a stator and a rotor. The rotor carries a set of permanent magnets, and the stator has the coils. There are 4 coils with 90° angle between each other which are fixed on the stator. The way the coils are interconnected, will finally characterize the type of stepper motor connection. In the above drawing, the coils are not connected together. The above motor has 90° rotation steps. The coils are activated in a cyclic order, one by one. The rotation direction of the shaft is determined by the order that the coils are activated. The coils are energized in series, with about 1sec interval. The shaft rotates 90° each time the next coil is activated.

Specifications:

1. Operating Voltage: $12\ V$
2. Current rating: $600\ mA$
3. Step Angle: 1.8°
4. Torque: $3.4\ Kg/cm$

1.3.8 P89V51RD2 – An 8051 Microcontroller

The P89V51RD2 is an 80C51 microcontroller with $64\ kB$ Flash and 1024 bytes of data RAM [9].

Features:

1. 80C51 Central Processing Unit
2. 5 V Operating voltage from 0 to 40 MHz
3. 64 kB of on-chip Flash program memory with ISP (In-System Programming) and IAP (In-Application Programming)
4. Supports 12-clock (default) or 6-clock mode selection via software or ISP
5. SPI (Serial Peripheral Interface) and enhanced UART
6. PCA (Programmable Counter Array) with PWM and Capture/Compare functions
7. Four 8-bit I/O ports with three high-current Port 1 pins (16 mA each)

8. Three 16-bit timers/counters
9. Programmable Watchdog timer (WDT)
10. Eight interrupt sources with four priority levels
11. Second DPTR register
12. Low EMI mode (ALE inhibit)
13. TTL- and CMOS-compatible logic levels
14. Brown-out detection
15. Low power modes

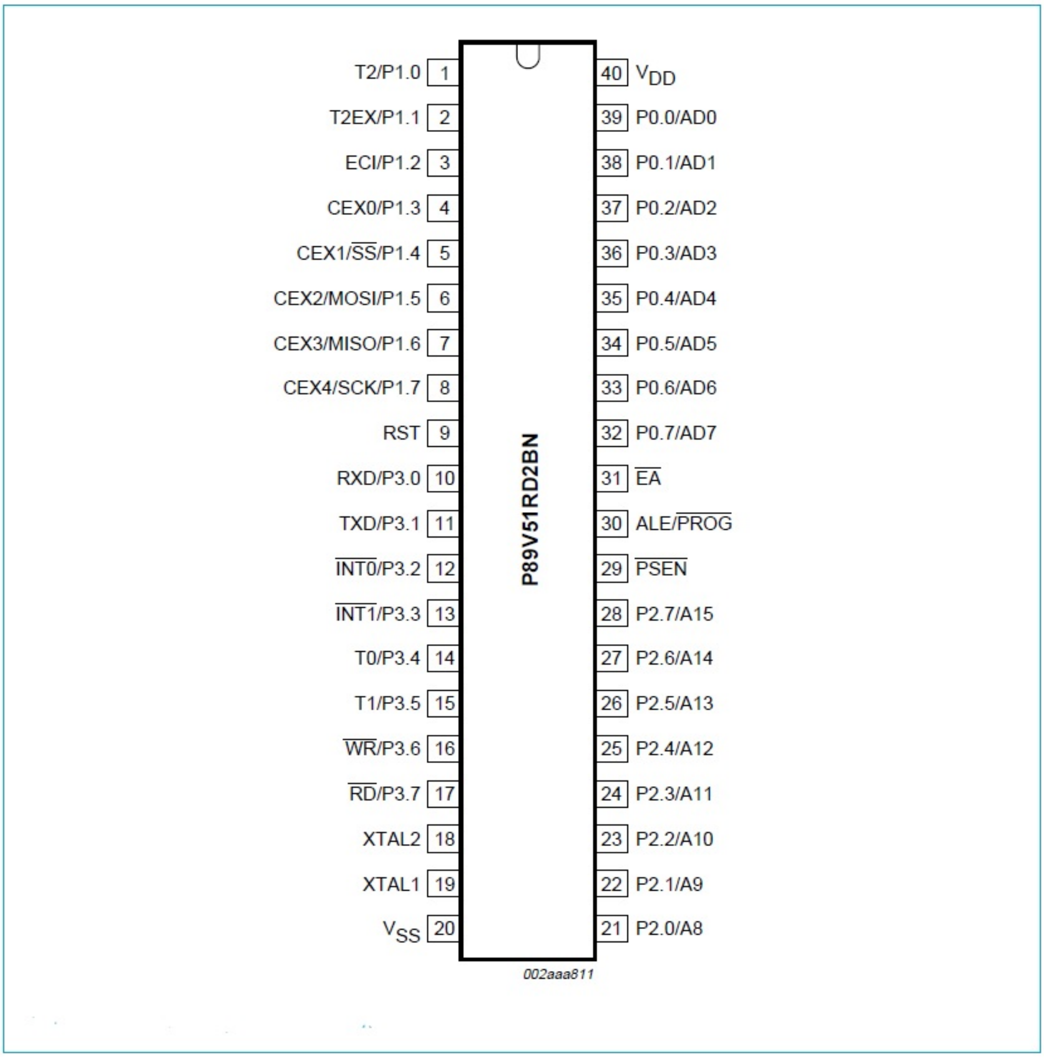


Fig: 1.12 P89V51RD2BN Pin Diagram

1.4 Motivation

We are less aware about the study, research and time it takes, to get the huge structural projects, like Dams, Airports, Power Stations, sanctioned and stood. So it was a huge opportunity for us to work with the Government of India's Research Organization and have a small contribution to the social and real life problem.

In physical models, Vertical Acoustic Doppler Current Profiler Sensors are used for the velocity measurement of the water flow. These sensors give accurate results, but are cost ineffective and fail to generate the flow pattern plot (movement of water current).

So, in order to remove these drawbacks we provide a solution using image processing for velocity measurement and flow profiling, which will be cost effective as only hardware included will be camera and being a software project data logging, data communication and data illustration is possible if needed.

1.5 Aim of the Project

Flow pattern and velocity measurement in a Physical Hydraulic Model using Image Acquiring and Processing System along with the Camera Control through MATLAB

1.6 Scope and Objectives

1.6.1 Objectives

1. Setting the frame rate and camera angle through software.
2. Estimating velocity and direction from captured image with MATLAB image processing toolbox.
3. Stepper Motor Drive for Camera Angle Control

1.6.2 Scope

The software, developed, will be used by the scientist in CWPRS, Khadakwasla for velocity measurement and flow pattern profiling in the Bombay Port model.

The scope of our project only focuses on the programming part and development of a new algorithm for flow pattern measurement.

1.7 Technical Approach

It is difficult to find out the water velocity only with the flowing water. We must introduce some tracer which will flow along with the water and detection of water will be possible. There are two approaches in tracer decision. Tracer can be small objects or particles like Paper Punch Holes or can be colored liquid. So detection of these tracers will lead us to find out the velocity and flow pattern.

A camera is connected to the laptop using USB which is loaded with the latest version of MATLAB. A Graphical User Interface is made asking the video location and also the frame rate.

Frames are then separated from the video and then each frame is binarized or converted to HSV model according to the tracer used and our algorithm.

The processed frames are then used for detection of the fluid and by using various object tracking algorithms and the flow velocity is calculated and also the flow pattern.

CHAPTER 2

Brief Background and Theoretical Details

2.1 Introduction

Flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways. There are various methods available which are used for flow measurement. In some methods, fixed volume of fluid is accumulated and then number of times the volume is filled is counted, to measure flow while, some flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction, to indirectly calculate flow. But in our project, measurement of flow is done by measuring the velocity of fluid over a known area.

2.2 Importance of Flow Measurement

Water flow is measured to assess how much water is available for a supply to check the quantity of water flowing through a system or treatment plant. Flow control is essential in water treatment plants and for effective disinfection of distribution networks. Most water treatment process requires a controlled constant flow of water in order to operate effectively and efficiently. The measurement of water flow is important in selecting the best source for a drinking water supply. The flow of water sources should be measured to access the amount of water they may provide. Though this project deals with the water velocity measurement, the amount of water can be calculated by the continuity principle.

2.3 Importnace of Physical Hydraulic Models

A physical model is a system whose operation can be used to predict the characteristics of a similar system, or prototype, usually more complex or built to a much larger scale. A model is a smaller scaled real entity.

Various studies like determination of various forces, implementation and experimentation of various environmental conditions which will withstand the real life situations, physical changes in case of diversification studies are carried out on these models.

These studies are important because the changes in actual structures or resources cannot be made because of the cost, population dependent on that resources and environmental aspects. So model studies are carried out.

Fig: 2.1 Bombay (Mumbai) Port Model

2.4 Existing Techniques for Water Velocity Measurement

Existing techniques include both image processing based and hardware based systems.

Non-image processing based systems include Mechanical Flow Meters, Pressure Based Meters, Optical Flow Meters, Thermal Mass Flow Meters, Vortex Flow Meters, Electromagnetic Flow Meters, and Ultrasonic Flow Meters etc. But all these have own disadvantages. Mechanical Flow Meters and Pressure Based Meters get jammed because of the dirt particles, gravels the rotary parts in the meters. Optical Flow Meters are only feasible for model studies and the assembly is also costly. For Thermal Mass Flow Meters, hardware cost is more. Vortex Flow Meters are inaccurate for low velocity measurement and in curved flows. Electromagnetic Flow Meters are only useful for flow through pipes, so cannot be used for free flowing waters or model studies.

Image processing based systems include Particle Image Velocimetry (PIV) [2]. PIV is an optical method of flow visualization used in education and research. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles which, for sufficiently small particles, are assumed to faithfully follow the flow dynamics (the degree to which the particles faithfully follow the flow is represented by the Stokes number). The fluid with entrained particles is illuminated so that particles are visible. The motion of the seeding particles is used to calculate speed and direction (the velocity field) of the flow being studied.

2.5 Need of New Technique

The most elite breed of engineers of India, who are working in CWPRS, Khadakwasla are now using ADCP (Acoustic Color Doppler Current Profilers) technique. The sensor which they are using nowadays is Sentinel V. Each sensor costs about ₹ 600000 and for sufficient readings of the whole model, there is a need for at least 8 sensors. CWPRS is a huge division with 30+ hydraulic models. Therefore,

$$Total\ cost = (10 * 30) * 600000 = ₹\ 180000000$$

Fig: 2.2 Sentinel V Sensor

This cost is huge. Image processing will provide a low cost solution for this problem.

Most of the hardware solutions available for flow measurement are contact technologies. Contact with the water reduces the life of sensors. Image processing system is a non-contact technology overcoming the life dependency.

The existing image processing technology PIV is very much costly and can only be used for indoor model studies and laboratory purposes.

To overcome all these drawbacks we have developed a new system based on tracer detection and frame analysis which is much more cost effective and relatively accurate.

CHAPTER 3

Block Diagram and Algorithm

3.1 Block Diagram

Block diagram includes major blocks showing the flow of project. Each block will be explained in detail.

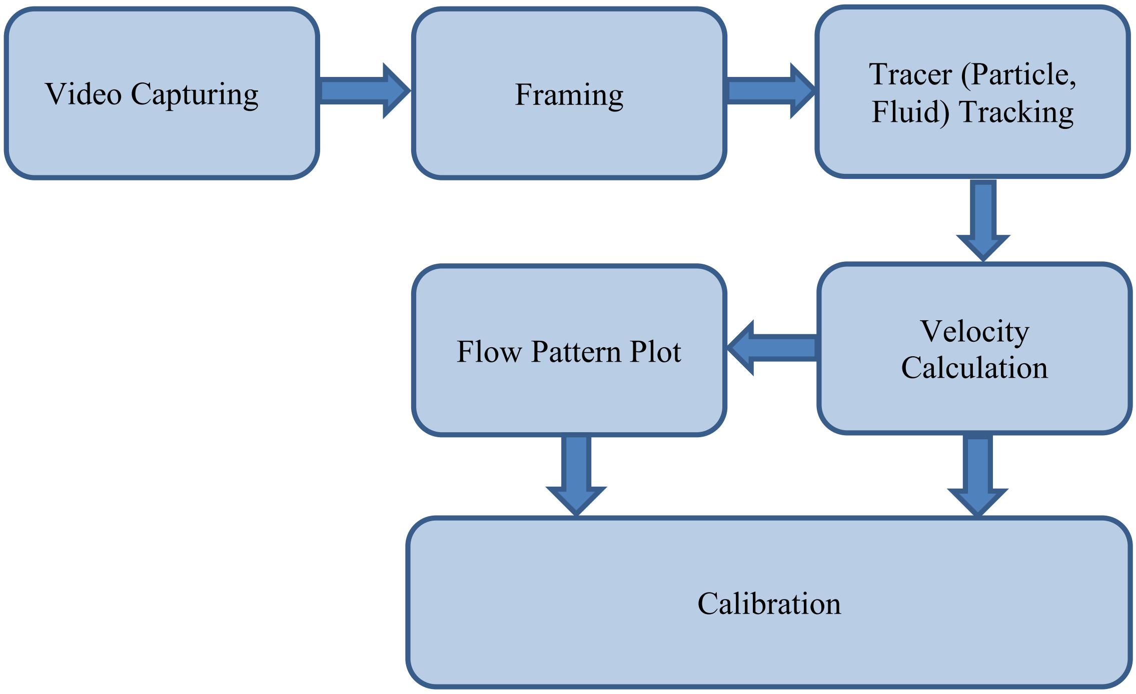


Fig: 3.1 Block Diagram

3.1.1 Video Capturing

Video capturing is done with the help of camera which is interfaced to a laptop computer through USB. MATLAB is used to trigger the camera and capture the videos. A micro-controller based Camera Control Module is used to change the camera angle. The motor is driven by microcontroller which is triggered from the MATLAB. Image Acquisition tool is developed in MATLAB which is provided with facilities such as File Location Browser, Frame Rate selector, Brightness – Contrast Controller etc.

The video will be captured in the ***.mp4*** format. Default frame rate used is ***30 fps*** and will be read and processed in MATLAB.

The MATLAB has inbuilt function ***'VideoReader'*** which is used for reading the video. The variable $video$ will contain the video after reading the video.

$$video = VideoReader('filepath/filename.extension');.$$

3.1.2 Framing

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. It makes the video analysis easy and fast. Each frame will be analyzed and processed individually.

Every video comprises series of images. Since we are dealing with the color video processing, our video will have color images. Color image is nothing but the 3D matrix having R-G-B intensity values. Each color can be represented with the different combinations of Red, Green and Blue values. The header of image also has colormap which gives information about the colors present in the image. So for framing the video and storing each frame we must define a structure which will have a 3D matrix and colormap. This structure will represent one frame. We must define this frame structure for total number of frames in the video for storing every frame.

$$no\_of\_frames = video.NumberOfFrames;$$
$$vid\_height = video.Height;$$
$$vid\_width = video.Width;$$
$$mov(1{:}no\_of\_frames) = struct('cdata', zeros(vid\_height, vid\_width, 3, 'uint8'), 'colormap', []);$$

Each of the $cdata$ matrices of structure mov will represent the individual frame. Now we have to store frames in this structure. A simple loop will work.

$$loop: (index = 1; index \leq no\_of\_frames; index++)$$
$$mov(index).cdata = read(video, index);$$
$$end\ loop;$$

3.1.3 Tracer Tracking

In the object detection approach towards velocity measurement, we have two types of tracers which can be used.

i. Small Circular Objects such as Punch Holes

   Small circular objects such as punch holes are introduced in the water flow and by tracing the punch holes water flow is determined.

The white color dots in the adjacent image are white paper punch holes. These are used as tracer particles.

Fig: 3.2 Punch-Holes as Tracer

ii. Coloured Fluid

   Different colour liquids such as Oil Colours, Ink or Holi Colours are used. Choice of the liquid depends on various factors such as Density of the fluid, Viscosity, Colour and its effect on Environment. The proper flow measurement also depends on the method of dispersion of fluid in water flow. The dispersion can be above the surface of water or inside the water. But results for inside water dispersion are more accurate.

The black colored lump in the adjacent image is the black colored fluid which will be used for tracing.

Fig: 3.3 Coloured-Fluids as Tracer

After the tracing, centroids of punch holes as well as fluid are stored in the form of matrix and flow pattern is plotted.

3.1.4 Velocity Calculation

Consider we have 10 frames. Each frame will be processed and centroids are obtained. And consider the length of video is 1 second. Let us say, $centroid\_x$ are the abscissa of the centroids and $centroid\_y$ are ordinates of the centroids obtained.

$$centroid\_x = [\ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10\ ]$$

$$centroid\_y = [\ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10\ ]$$

The object has moved from (1,1) to (10,10) in 1 sec. Since these are pixel values. The magnitude of velocity will be $pixel/sec$. Distance formula will be used to calculate distance travelled.

$$|velocity| = \frac{\sqrt{(10-1)^2 + (10-1)^2}}{1} = \frac{9\sqrt{2}}{1} = 12.726\, pixels/sec$$

This is the magnitude of velocity. The direction of velocity can be easily found using tangent formula.

$$\theta = \tan^{-1}\frac{(10-1)}{(10-1)} = \tan^{-1} 1 = 45°$$

Therefore the final value of velocity will be,

$$\boxed{velocity = 12.726\, pixels/\sec\ \angle 45°}$$

3.1.5 Flow Pattern Measurement

The matrices obtained are used for plotting the flow pattern.

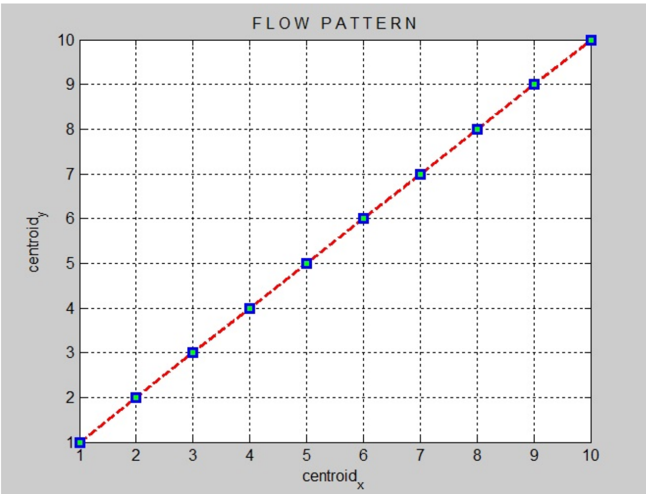


Figure 3.4 Flow Pattern Plot

3.1.6 Calibration

Since all the above calculation and plots are expressed in terms of pixels we must calibrate them to MKS units. For that we must calibrate the system.

3.1.6.1 Camera Axis perpendicular to the surface of Water Flow

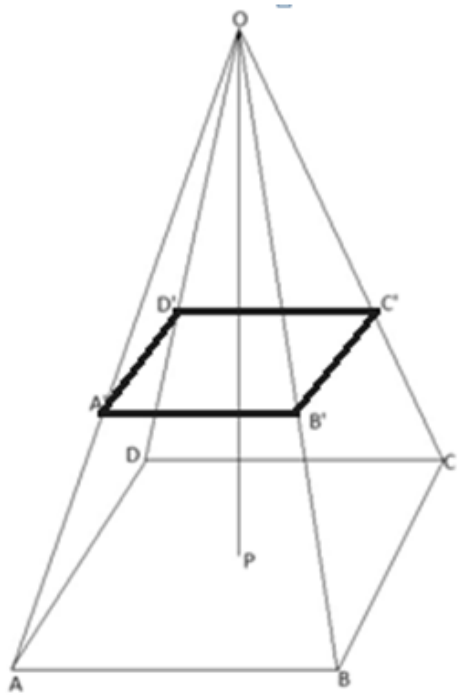


Fig: 3.5 Camera Axis perpendicular to the surface of water flow

In this figure, $ABCD$ is the plane of the water surface and $A'B'C'D'$ is the plane of an image obtained. Here, the image plane as well as the surface plane is rectangular.

For velocity calculation, we must know the real time distance travelled by the tracer. So we must calibrate the Camera Field of View. If adjust the camera view such as the width of image is $0.8m$ and height of image is $0.6m$ then the physical area covered by the image is $0.48m^2$. Consider image resolution be $800\ X\ 600$.

Now if particle has travelled from $(1,1)$ to $(10,10)$ pixels, physically it has travelled $0.009\ m$ in both x and y direction in1 sec. Therefore the actual velocity of the water flow will be,

$$\boxed{velocity = 0.01272\ m/s\ \angle 45° = 1.272\ cm/s\ \angle 45°}$$

3.1.6.1 Camera Axis oblique to the surface of Water Flow

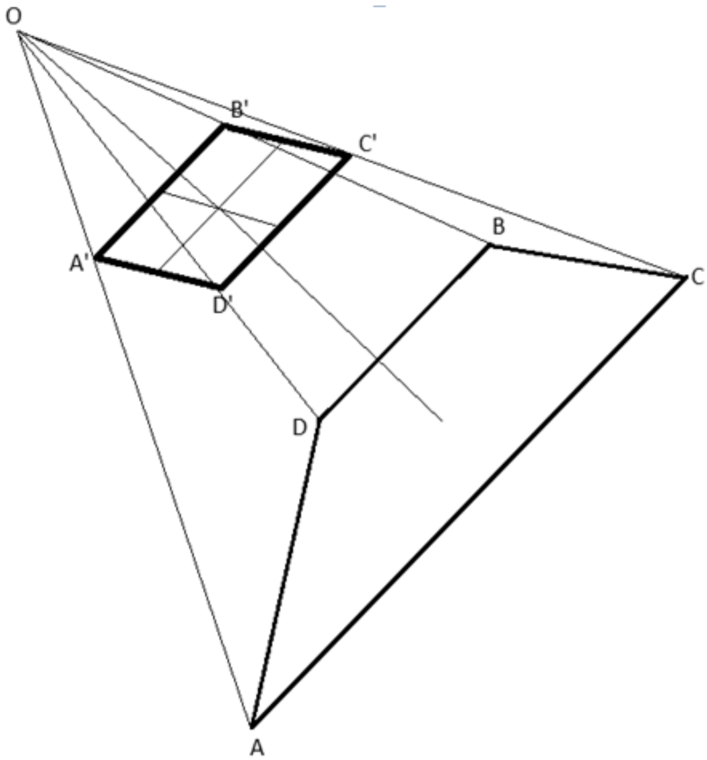


Fig: 3.6 Camera Axis oblique to the surface of water flow

In this figure also, $ABCD$ is the plane of water surface and $A'B'C'D'$ is the image plane obtained. Plane $ABCD$ is rectangular in shape while plane $A'B'C'D'$ is trapezoidal in nature.

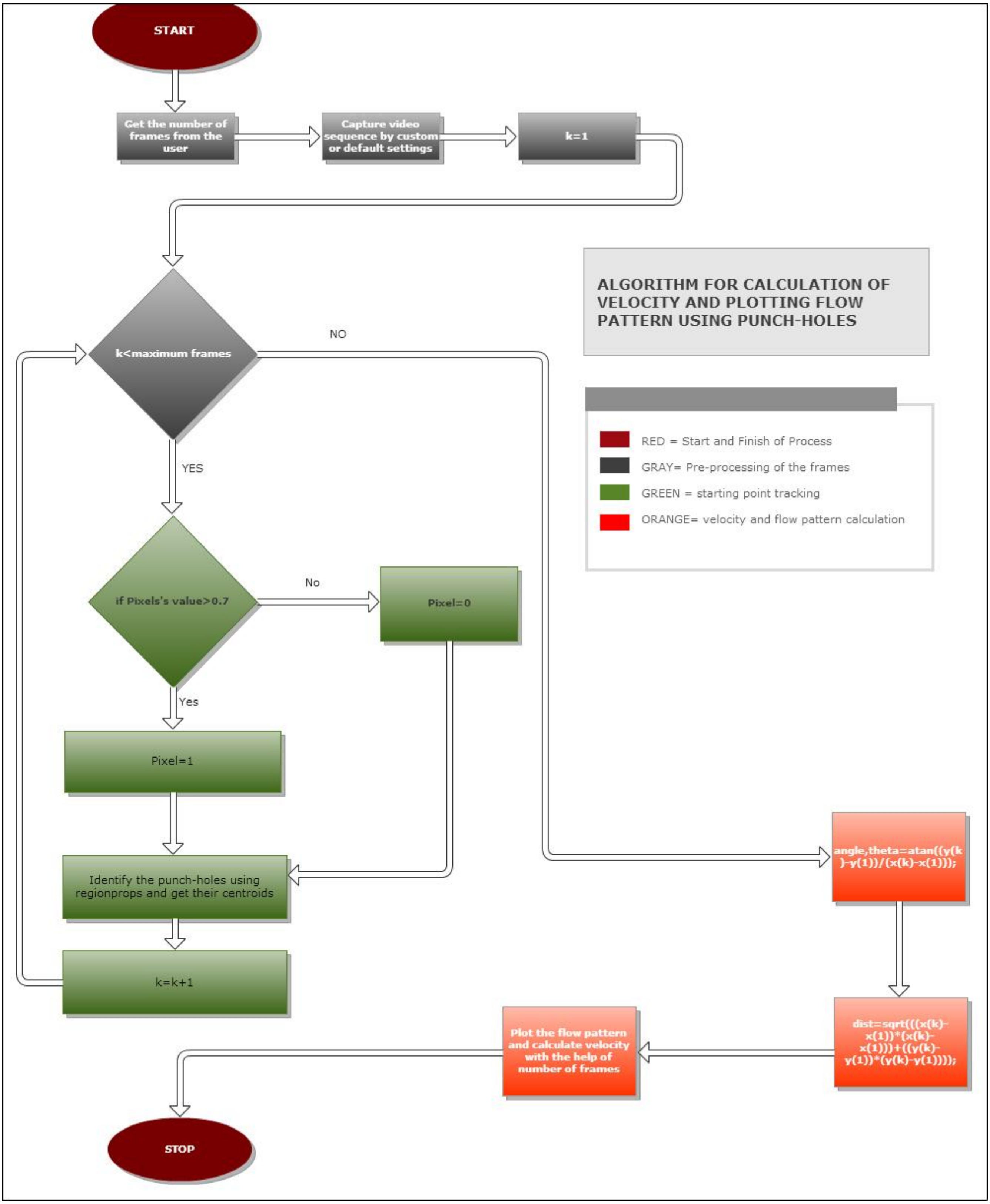
Let the angle between the normal to the water surface and camera axis be angle of tilt. Knowing this angle, with the help of simple trigonometric equations, we can convert the relative velocity values into the actual velocity.

3.2 Algorithm

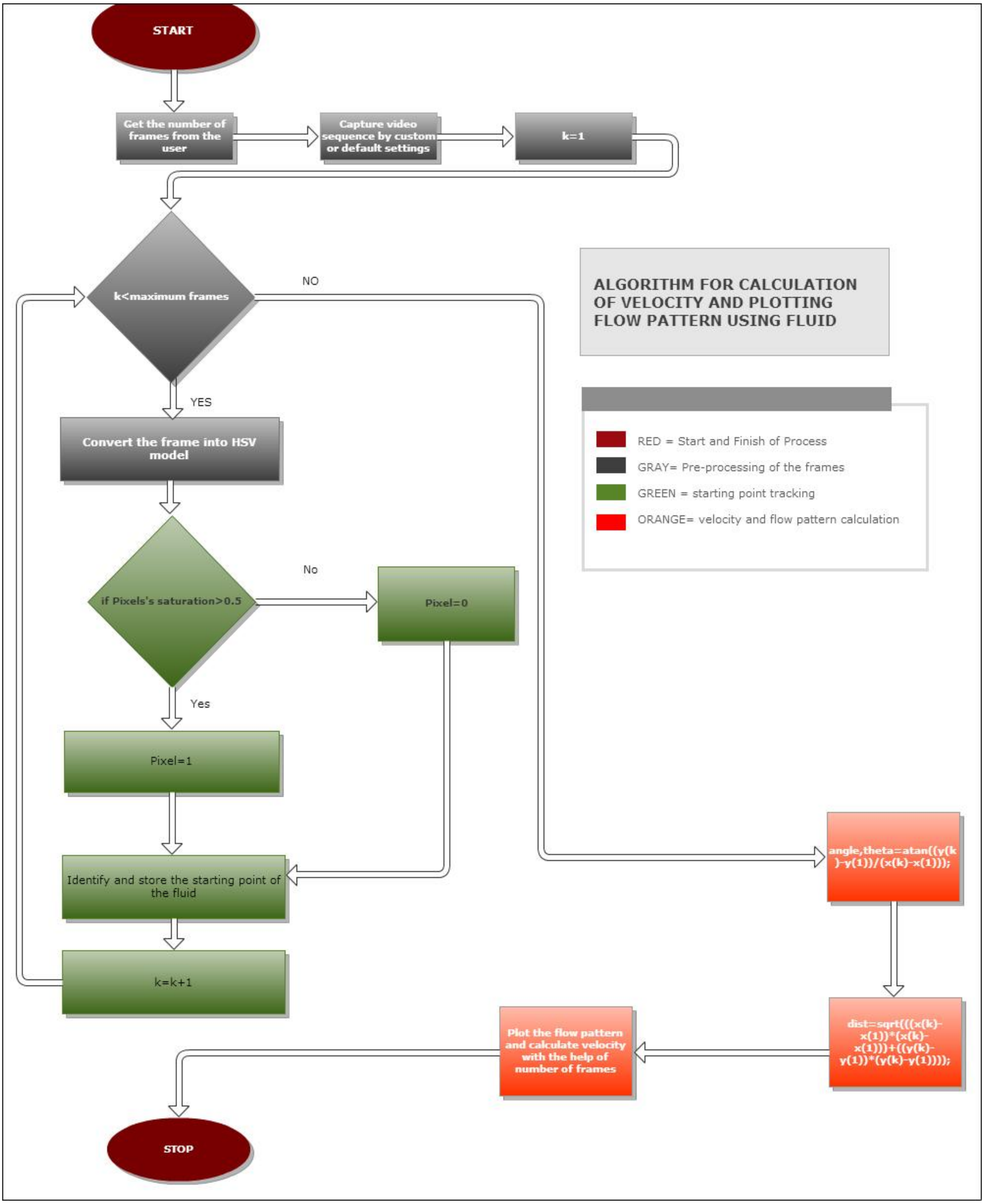
Step by step procedure is described. We are using Punch holes as well as colored fluid. Both have different algorithms for their tracking. The punch hole tracking algorithm is based on the image thresholding and binarization while the fluid tracking algorithm is based on the HSV color modeling.

Algorithms are explained through an illustrative flow chart in section 3.2.1 and 3.2.2.

3.2.1 Punch Holes as Tracer Particles



3.2.2 Coloured-Fluid as Tracer



3.2.3 Image Binarization

The basic image processing technique, image binarization is used in the punch-hole tracking algorithm. The binarized image is a two dimensional array with logical values, 0 being the black and 1 being the white colour. The threshold can be decided according to the colour of the water, colour of the punch holes and impurities present in the water body. Let Y be the binarized image of input image X, where X is an RGB image.

In the algorithm image is nothing but the video frame obtained after the framing process. As already mention, it can be accessed by $cdata$ of the video structure. ***im2bw*** is the inbuilt command in MATLAB used for image binarization.

$$Y(logical) = im2bw(X, threshold)$$

3.2.4 Colour Model Transformation

The colour model transformation, RGB to HSV, is the prime aspect in colored-fluid detection. We have already seen the colour models and how to transform image from one colour model to another. Let Y be the HSV modeled output image and X be the input RGB image.

The image here also concern with the video frame. ***rgb2hsv*** is the inbuilt MATLAB command used.

$$Y(HSV_{modelled}) = rgb2hsv(X(RGB_{modelled}))$$

3.2.5 Camera Angle Control Mechanism

A camera is mounted on a stepper motor. A stepper motor is interfaced with a micro-controller which is serially interfaced with the MATLAB and application software.

Stepper motor is moved in such a way that the capturing angle is changed and we get better output. Since stepper motor, as name suggests, can move in steps, it will be useful for adjusting smaller angles such as1.8°. Stepper motor can be easily controlled with the help of Micro-controller. So stepper motor is chosen. The basic reason behind the 8051 core micro-controller is its simplicity. All the basic requirements are fulfilled by the 8051 and hence chosen.

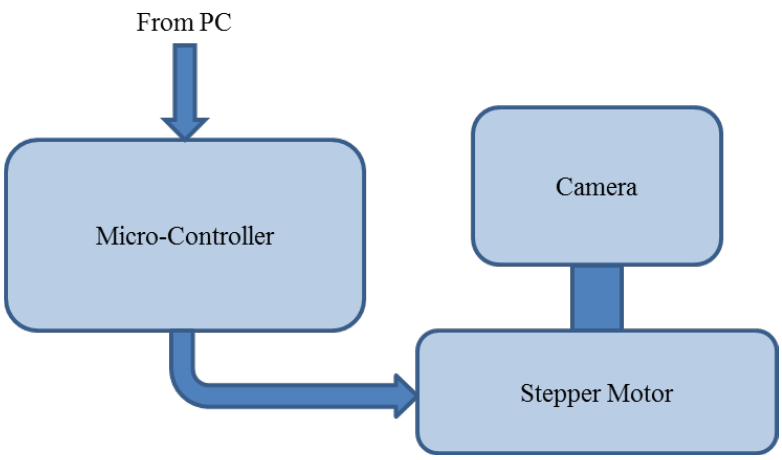


Fig: 3.7 Camera Control Mechanism

The part of concern here is the serial communication with micro-controller through MATLAB.

3.2.6 Serial Communication

Serial Communication is done with various inbuilt commands in MATLAB. First you have to create a serial port object. Then set its baud-rate and mode. Then open the object file, write the data and close the file. Communication is done.

$$serial_{object} = serial('COM\ PORT');$$

$$set(serial_{object}, 'BaudRate', [\,]);$$

$$fopen(serial_{object});$$

$$fprintf(serial_{object}, '\%type', value, 'mode');$$

$$fclose(serial_{object});$$

CHAPTER 4

Results and Discussion

4.1 Results

4.1.1 Velocity Calculation

We have successfully calculated the velocity of the flow by both the methods. Since we are using more than one punch-hole as tracer, we will get velocity of the flow at different places according to the position of the punch-holes. Following are the results obtained at a certain model flow by punch-holes method.

Table 4.1

Result Table: Velocity Calculation – Punch-holes Method

Particle	**Velocity (pixels/sec)**
Blue	$162.6201\angle -2.2026°$
Green	$161.8536\angle -3.1623°$
Red	$147.8405\angle -4.4451°$
Cyan	$182.7826\angle -4.9788°$
Magenta	$175.1839\angle -4.8933°$
Yellow	$173.9453\angle -4.3790°$

Six punch-holes are introduced in the water current. Each punch-hole is tracked and categorized with different colours.

Since we are using single colour fluid in water flow, we will get the velocity of the water by identifying this colour flow. We can use more colour liquids, for the similar analysis like the Punch-holes.

The results obtained by the coloured-fluid method are more accurate than the punch-holes method for the velocity calculation.

4.1.2 Flow Pattern

We have obtained flow patterns by both the methods. Flow pattern is the graph which is obtained by tracing the tracers and gives us the idea about the flow behavior.

The colored fluid gives better results while plotting the flow patterns than the punch-holes methodology; according to the observations.

4.1.3 Hardware implementation at CWPRS

Fig: 4.1 RPM based velocity measurement system

The blue colored tripod stand in the water body has a turbine attached to it. According to the speed of the flow, it starts rotating. On the bank, there is an rpm meter (Revolutions per Minute meter). As per the radius of the dynamo and rpm, velocity of the flow is calculated. This solution gives accurate results in streamlined flows but fail to give the directional analysis of the flow.

When the values for velocity measurement by colored-fluid and hardware solution are compared, they are found to be approximately equal. For a particular flow, the magnitude of velocity by colored-fluid method obtained was $792\ cm/sec$ which is approximately equal to the hardware solution value i.e. $820\ cm/sec$. The error is just 3.414%, which is negligible.

The velocities obtained by punch-hole measurement are more likely to be within the percentage error range of 6 to 7.

But since hardware solution cannot analyze the behavior of flow, image processing methodologies are quite useful for illustrative solutions.

Since software is used for the measurement and analysis, graphical user interface needs to be created which will guide the user through the methodology conveniently.

4.1.4 Comparative Analysis

Table 4.2

Comparative Analysis

Method Vs. Parameter	Punch-hole Tracking Method	Colour Fluid Tracking Method	RPM based measurement
$\lvert velocity \rvert$	$767\ cm/sec$	$792\ cm/sec$	$820\ cm/sec$
error percentage	6.46%	3.414%	---

4.2 GUI Screenshots

4.2.1 Velocity Calculation

We have successfully calculated the value of velocity pixels/sec. After calibration we will get the values in MKS units.

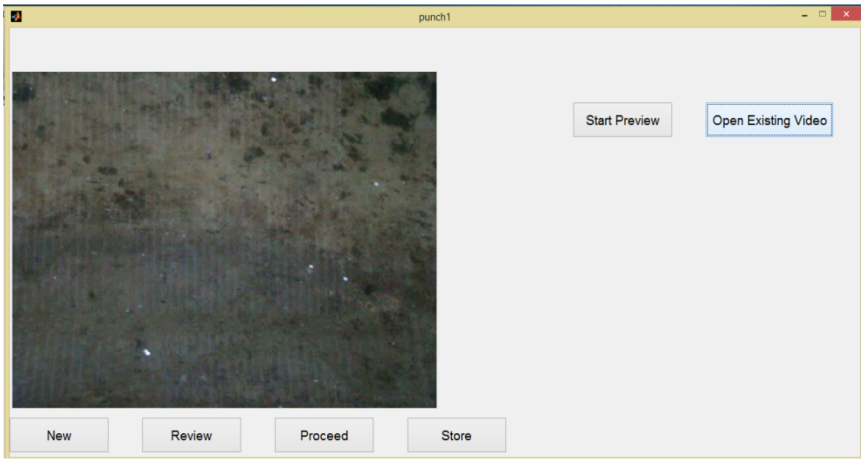


Fig: 4.2 Input Video - Punch Holes GUI Screenshot

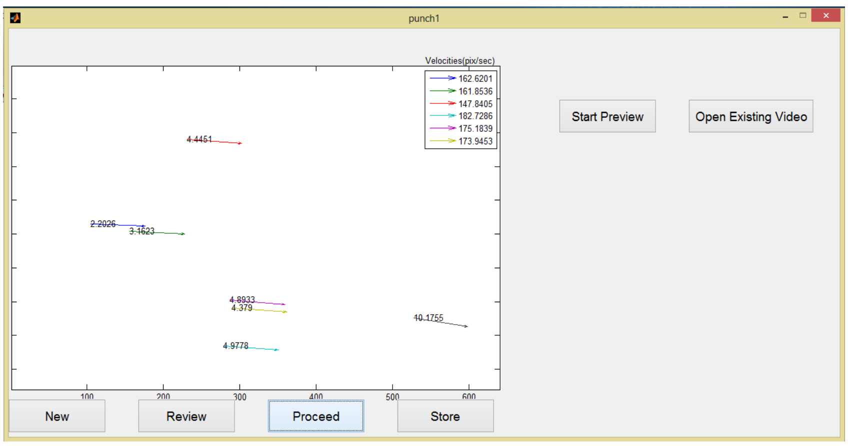


Fig: 4.3 Velocity and Direction of Each Punch Hole is Tracked

4.2.2 Flow Pattern

We have successfully plotted the flow pattern. The flow flow pattern is the prime aspect of flow analysis.

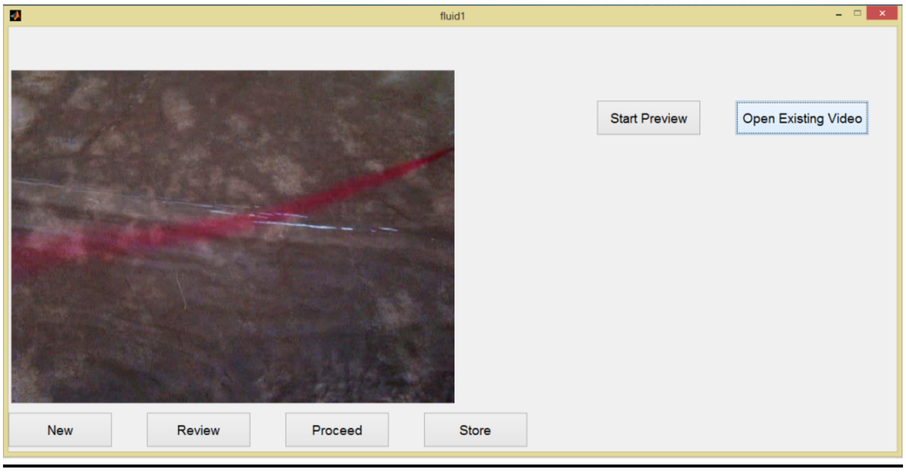


Fig: 4.4 Input Video - Coloured Fluid GUI Screenshot

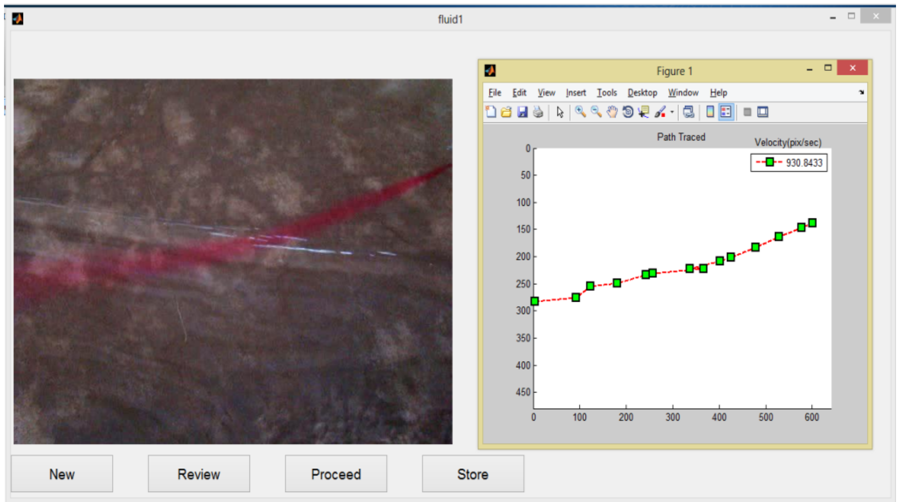


Fig: 4.5 Flow Pattern Plot

4.3 Product Overview: Specifications

- Complete and Illustrative Solution for Water Flow Velocity calculation and Flow Pattern Analysis in a Physical Hydraulic Model
- Image/Video Acquisition Tool:
    - Web Camera interfacing for real time analysis
    - Interfaced camera control assembly
    - Access to the previously stored database : modify and review
    - Contrast, brightness, hue, saturation adjustments.
    - Interactive Region of Interest capturing facility.
    - Real time saving, individual frame capturing, prior initialization of video length
- Flow Velocity Calculation:
    - Individual method based analysis (tracer dependent)
    - Real time as well as Database
    - Velocity in pixels/sec as well as MKS units
    - Error $\pm 6\%$ for velocity<2m/sec
- Flow Pattern:
    - Individual method based analysis (tracer dependent)
    - Real time as well as Database
    - Flow pattern is plotted over defined samples
    - Access to each pixel value on the flow pattern

CHAPTER 5

Conclusions

Successful calculation for the velocity of the water flow in a physical hydraulic model by both Tracer particles as Punch-holes and Tracer as Coloured Fluid methods has been done. We have obtained sufficiently accurate results. We have also plotted the flow pattern for same flow. We have accurately observed the flow and its behavior.

For detecting punch holes normal binarization technique is used. Threshold for binarization is decided according to the environmental conditions such as colour of impurities in water and colour of the water bed.

For detection of Coloured fluid, the HSV colour modeling is used. Hue component gives the colour present in the image. According to the colour of the water bed and atmospheric conditions, we will select the colour of the fluid.

We have also plotted the flow patterns for both the methods. The flow patterns are obtained accurately by starting point tracking algorithms.

A patent for calculation of velocity using fluid is also been filed.

A significant research and implementation has been done in the field of sedimentation and fluid dynamics has been done and papers were published.

CHAPTER 6

Future Scope

The velocity of the water flow and plotting of flow pattern is done in a physical hydraulic model. But real life scenarios are different than the model environment. So in future, work can be done on the actual river flows.

Results obtained through the implemented algorithms are impressive but accuracy can be improved further.

Automatic colour-fluid and punch-holes dispenser systems can be designed which can be controlled remotely.

The processor based embedded system can be designed so there won't be need for computer at remote places. A module can be set up and data can be fetched with wireless technologies.

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