DEVELOPMENT OF AN AUTOMATED FLOW RATE ESTIMATION METHOD

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CERTIFICATION OF APPROVAL

DEVELOPMENT OF AN AUTOMATED FLOW RATE ESTIMATION METHOD

By

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MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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EMALISA BINTI KAMSANI

ABSTRACT

In this project, a flow rate estimation method will be developed using the MATLab algorithm. This method can be use to estimate a volume flow rate of leaking fluid to the environment.

On 2010, there was oil spill in BH Deepwater Horizon. Many assumptions have been made about the total amount of leaking. Few methods have been developed but none of them can be consider as accurate. At the end, different parties has been come out with different conclusion.

The experiment will be based on the Partical Image Velocimetry (PIV) method. An experiment will be set up for this study. A Kinect 3D camera was used to record the flow rate analogy. From the video, few sets of images was taken the analysis. The analysis was completed using the Image Processing Tool.

Based on the analysis, the velocity with highest frequency recorded is 0.708 m/s and the volume flow rate is 3.475 cm^3/s. While the volume flow rate recorded during experiment is 3.333 cm^3/s. Therefore the difference percentage is 4.26%.

ACKNOWLEDGEMENTS

I want to express my appreciation to Universiti Teknologi PETRONAS for providing facilities for me to carry out this project. I am deeply indebted and would like to express my deepest gratitude to my supervisor Mr. Mark Ovinis and my co-supervisor Ms. Rosmawati Bt Mat Zain from Mechanical Engineering Department whose help, stimulating suggestions and encouragement helped me in all the time of my project work and also writing of this thesis. I also would like to express my appreciation to all those who gave me the possibility to complete this thesis.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

On April 20, 2010, a report of an explosion and fire aboard the mobile offshore drilling unit Deepwater Horizon was released [10]. It is informed that the rig was leaking at rate of 8,000 barrels per day (bbls/day). On April 22, 2010, Deepwater Horizon sank, leaving one mile by five mile sheen on the ocean's surface [10]. The leaks were caused by the failure of the blowout preventer equipment to seal the well after the explosion [9].

There were so many flow estimations have been submitted regarding the leak. The national Coast Guard announced during the first week of explosion that the oil spill to the ocean was 8000 bbls/day [2]. The scientists from National Oceanic and Atmospheric Administration (NOAA) estimate that the leak flow was 5000 bbls/day [2]. At the mean time, the independent researcher and founder of SkyTruth.org estimate the flow was 5000 to 20 000 bbls/day while Dr. Ian MacDonald from Florida State University estimate 26 500 bbls/day [2]. However as has been announced by BP, "there is no way to estimate the flow coming out of the pipe accurately" [7].

This has cause difficulty in deciding the penalty that the company should pay to the government. It is because the penalty was based on total amount of oil spill. Under the BP claims program, the company has paid $ 1,374,295,819 to the government due to this incident [9].

1.2 Problem Statement

Although BP has announced that there still no reliable methods to estimate the oil flow accurately, scientists say there are actually many proven techniques for doing just that [7]. BP's conclusion might be cause by the limited information about the leakage at that time. The most common data that can be used in this case are satellite image of the sea surface and the video of the leakage captured by the underwater remotely operated vehicle (ROV). Therefore there is always a need to develop a new estimation method that can gives at least close to the exact flow rate.

There are few technique has been used to estimate flow rate. One of it is "Bonn Convention". However this technique cannot be considered as accurate because it judges the volume of the oil only base on the appearance at the water surface and as been said by Admiral Landry from NOAA that estimating surface volume from visual appearance of an oil slick was highly unreliable [2]. This has left us with another choice of estimation method which is by using the video of the leakage.

1.3 Objective

i. To acquire 3D image from Kinect 3D-camera.
ii. To develop an automated three-dimensional measurement that estimates the flow rate using an image based technique.
iii. To verify the accuracy of the automated measurement by comparing the results with the experimental results.

1.4 Scope of Study

The study is about measuring the flow rate using the Image Velocimetry technique. This technique is an optical method of flow visualization used to obtain instantaneous velocity measurements and related properties in fluids [11]. The local fluid velocity can be measured by measuring the fluid displacement from multiple particle images and dividing that displacement by the time interval between the exposures. To get an accurate instantaneous flow velocity, the time between exposures should be small compared to the time scales in the flow, and the spatial resolution of the PIV sensor should be small compared to the length scales in the flow [4].

An experiment will be set up to get the visual data of the flow volume. Kinect 3D- camera will be use to obtain the image. The camera will be connected to the desktop using MATlab Image Acquisition Tool. Few image frames will be taken for image analysis. This analysis will be done using MATlab Image Processing Tool.

From this analysis, a graphical user interface (GUI) will used together with MATlab Image Processing Tool to get the velocity of the flow [8]. Then from the data gathered, the flow rate algorithm can be governed using MATlab. This flow rate result will be compared later using the experimental value.

CHAPTER 2

LITERATURE REVIEW

2.1 National Commission on the BP Deepwater Horizon and Offshore Drilling

The paper work has discussed the estimation made by various people. It gives the figure of the estimated flow rate and also the technique used to come out with the number. Although this paper only state the basic of the technique used, it can present the possible techniques to estimate the flow rate for future development.

Admiral Landry from NOAA has derived an estimation using "Bonn Convention" and satellite imagery [2]. Bonn Convention involves using aerial data to measure the extent of spill. By using the surface's color they will estimate the thickness of various parts of spill, and then calculate the volume of oil. However, he noted that estimating surface volume from visual appearance of an oil slick was "a highly unreliable process" [2]. This cannot be consider as accurate because there might be some oil from the spill that has been burned out during the explosion and fire at the surface.

By using the satellite imagery, John Amos, the founder of SkyTruth.org has come out with his own estimation [2]. He multiplies the surface area of the spill by the minimum thickness for the oil to be visible on the surface of 1 micron to get the low number. For the high number, he multiplies with the significant thicker which is 100 micron [2]. This seems like more complicated because the thickness might be varies from 1 micron to 100 micron.

In other hand, Dr. Eugene Chiang estimated use the angle of flow and the rate of which oil would naturally rise through sea water to estimate the velocity of the oil coming out of the riser. Then he estimates the diameter of the riser to come out with his final amount of oil leaks [2].

Dr. Timothy Crone, used a technique called Optical Plume Velocimetry (OPV), which involves temporal cross-correlation of the visual intensity of two pixels in a video. This technique was recognized as the one that is close to accurate estimation [3]. The prolonged of this technique has been discussed by himself and his team in his research paper, Optical Plume Velocimetry: A New Flow Measurement Technique for Use in Seafloor Hydrothermal System.

Dr. Steve Wereley from Purdue University has used Particle Image Velocimetry (PIV) technique to come out with his estimation of 36 090 bbls/day [2]. This technique identifies and tract the distinct "flow structure" that moves across screen in term of pixel. Then he factors it in scale and volume to determine the flow rate [2]. This method has been said to be accurate to a degree of plus or minus 20 percent [7].

Based on the techniques discussed in this paper, it can be conclude the estimation can be done by using two types of source data. First is using the satellite image of the surface area. Nevertheless, the experts note that such methods are not reliable for large spills, due in part of the difficulty to determine the oil thickness [2]. The second source is the video data. This technique has the possibility to be more accurate as the estimation is base on the flow from the riser and proved to be significant more accurate than the official estimates [2]. Unfortunately, BP still chooses the lowest number from the Coast Guard as their official flow leakage [7].

2.2 Optical Plume Velocimetry: A New Flow Measurement Technique for Use in Seafloor Hydrothermal System

This paper has discussed about the research and study done by Dr. Timothy Crone and his team. The paper has discussed the basic theory for his research, the laboratory simulation, computational methods used for analysis, result and discussion and also the implication of this study for seafloor system.

Crone wrote about Theory of Turbulent Buoyant Jets and Plumes and states that a key consideration for the development of and image-based flow measurement technique is the evolution of constrained nozzle flow into a fully-developed free turbulent flow. McDuff has come out with the parameter in case of pure jets which is the specific momentum flux at the nozzle, M [3].

$$M = QW = AW^2$$
$$Q = AW$$

Q is the nozzle flow rate, W is the mean nozzle velocity, and A is the area of the nozzle opening.

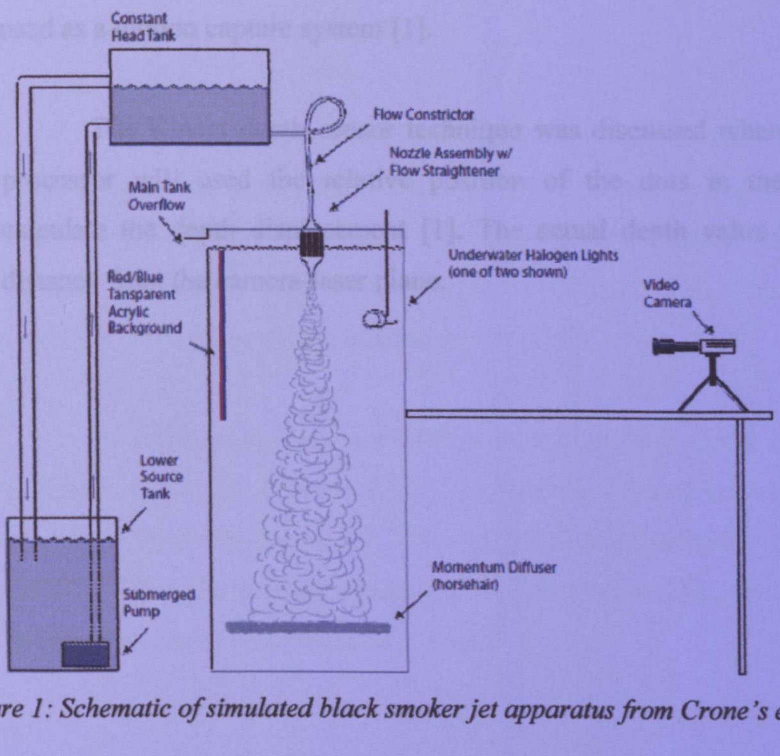

Figure 1: Schematic of simulated black smoker jet apparatus from Crone's experiment

Based on the figure above, fluid from the constant-head tank passed through a flow straightener and downward into a main tank through a nozzle. The jet fluid consisted of tap water with _0.5 wt% NaCl to provide buoyancy flux, and colloidal graphite particles to simulate black smoker particulates. The main tank was filled with plain tap water. The nozzle flow rate was adjusted by varying diameter and changing the constant-head tank overflow height [3].

This article can be a good start in developing the basic concept of Velocimetry technique. Crone did review others work in order to develop his study. The analysis methods proposed in his research can ease other researcher for future development in other area.

2.3 Kinect Depth Sensor Evaluation for Computer Vision Applications

This paper work was done by Anderson M.R, Jensen T., and Lisouski P. from Department of Electrical and Computer Engineering, Aarhus University. This paper describes the evaluation done by the team for the depth sensor (Kinect sensor) at the 3D- camera. This sensor basically was used as a motion capture system [1].

The Kinect depth sensor technique was discussed where the image processor will used the relative position of the dots in the pattern to calculate the depth displacement [1]. The actual depth value is the same distance from the camera-laser plane.

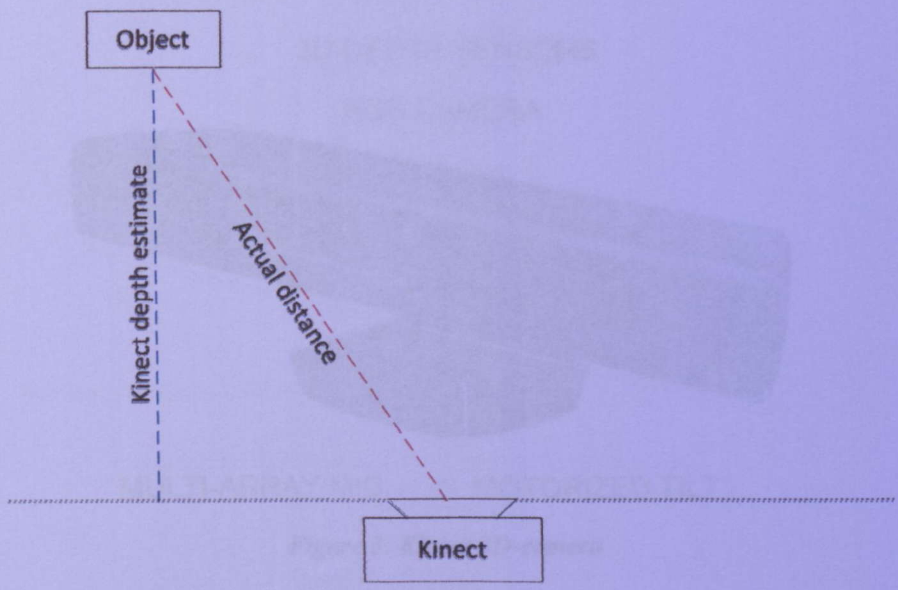

Figure 2: Description on how the Kinect depth estimates should be interpreted

There are several software frameworks that can be used to complete Kinect sensor analysis such like Microsoft Software development Kit (SDK), OpenNI, and OpenKinect. These three software were discussed in term of the depth resolution and noise resistance. However the paper state that the team chooses to use OpenNI framework since it has the smallest dept difference measurement [1].

The properties of the sensor were elaborated in term of linearity, depth resolution, depth accuracy and precision, spatial precision, structural noise, multi-camera setup and also few general considerations. Other consideration for Kinect 3D camera application was the lens distortion, calibration and also shadow indepth image [1].

In overall, this paper gives better view in understanding the concept of Kinect depth sensor. Since this 3D-camera is not a well known use before other than for computer games. Although the authors did not mention any possible future usage or development, the information discussed can be a gateway for many possible developments.

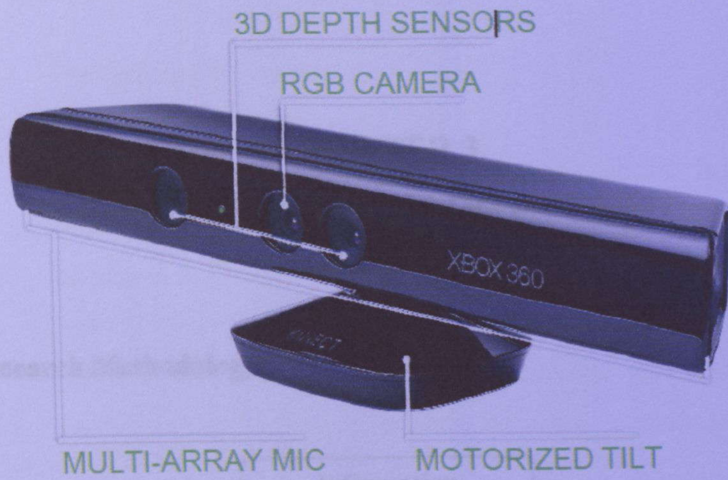

Figure 3: Kinect 3D-camera

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

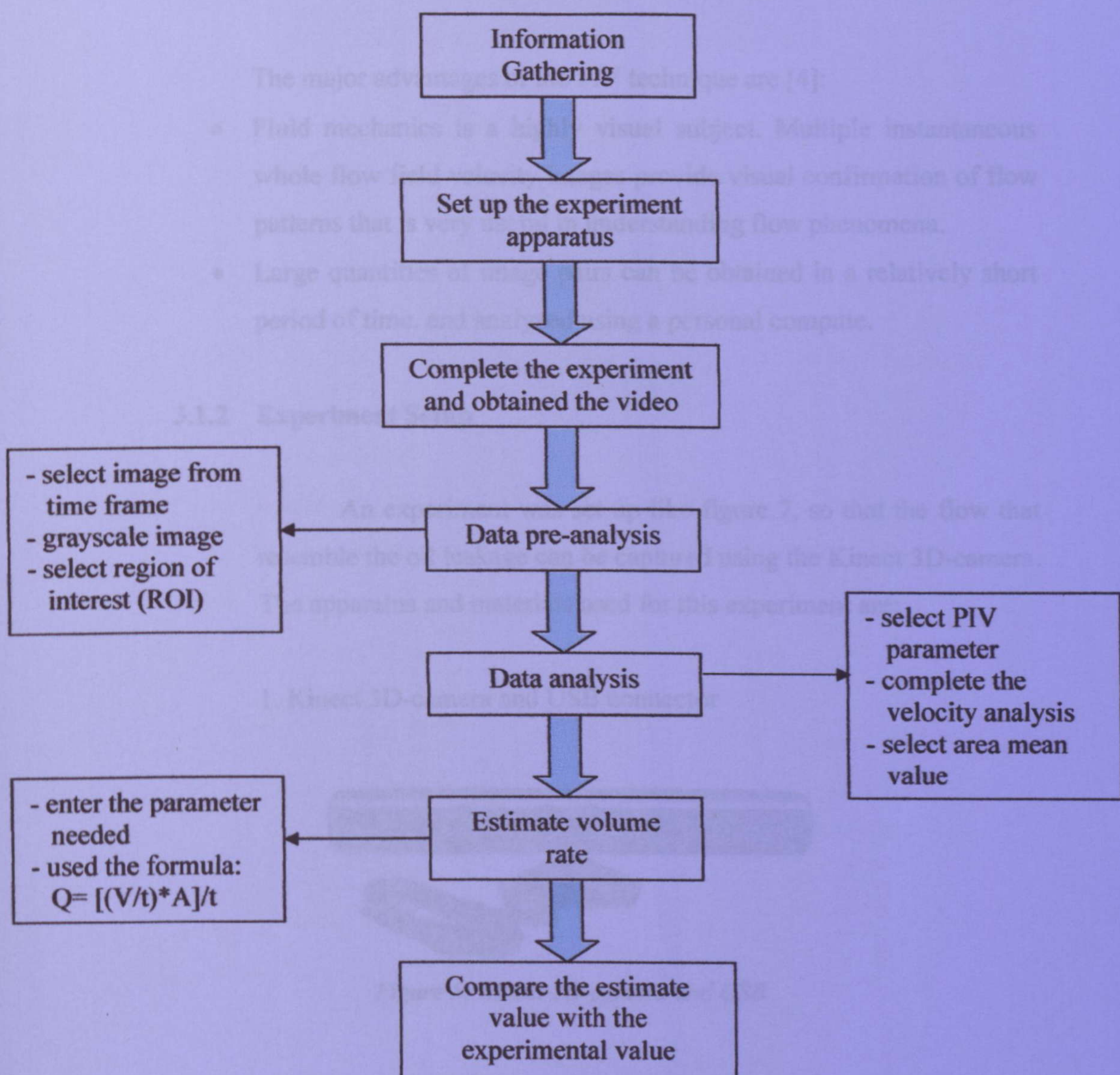

Figure 4: Research methodology flow chart

3.2 Project Activities

3.1.1 Preliminary Research

PIV has become one of the most popular instrument flow measurement in many field of study. Modern developments of camera and laser technology, as well as PIV software, continue to improve the performance of the PIV systems and their capability to difficult flow measurement [4]. The studies and finding from the previous work can be a revision in developing my study.

The major advantages of the PIV technique are [4]:

- Fluid mechanics is a highly visual subject. Multiple instantaneous whole flow field velocity images provide visual confirmation of flow patterns that is very useful in understanding flow phenomena.
- Large quantities of image pairs can be obtained in a relatively short period of time, and analyzed using a personal compute.

3.1.2 Experiment Setup

An experiment was set up like figure 7, so that the flow that resemble the oil leakage can be captured using the Kinect 3D-camera. The apparatus and materials used for this experiment are:

1. Kinect 3D-camera and USB connector

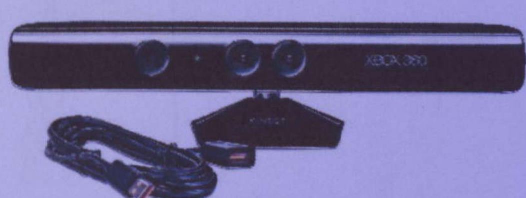

Figure 5: Kinect 3D-camera and USB

2. Water tank

Figure 6: Water tank

3. 20 ml Syringe

Figure 7: 20 ml Syringe

4. Water

5. Known amount of cooking oil as penetrate

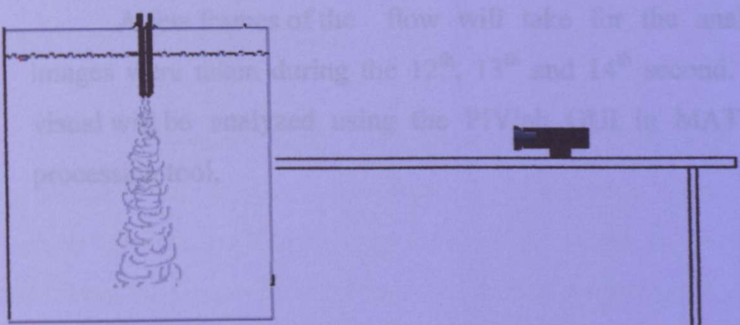

Figure 8: Illustration for the experiment setup

3.1.3 Obtain the Flow Image

For the experiment set up, the tank need to be fill with the clear water until ¾ of the full depth. The camera was placed perpendicular with the oil flow. It is important to make sure that this experiment was take place at the bright area to avoid any shadow for this experiment. This to make sure that the video recorded was in good quality. The flow of the oil was created using the syringe as nozzle.

The camera need to be connected with the computer first. The camera will be installed as Image Acquisition Device. The camera will record the oil flow into the water.

3.1.4 Data Analysis

During the experiment, the flow rate needs to be calculated first. The value will be compared later with the MATlab value. Since the amount of oil use is known, the flow rate can be easily calculated by dividing it with the time taken.

$$\text{Volume rate, } Q = \frac{\underline{\text{Volume, } V}}{\text{Time, } t}$$

A few frames of the flow will take for the analysis. The images were taken during the 12^{th}, 13^{th} and 14^{th} second. Later this visual will be analyzed using the PIVlab GUI in MATlab image processing tool.

3.2 Gantt Chart

FYP 1 – Semester January 2012

No.	Detail/Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research														
3	Set up the apparatus														
4	Flow observation experiment														
5	Obtain single best video/image for analysis														
6	Experiment improvement and Retake video for stereo analysis														
7	Matching stereo images														

Table 1: Gantt chart for FYP 1

FYP 2 – Semester May 2012

No.	Detail/Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experiment improvement and Retake video														
2	Velocity analysis														
3	Flow rate analysis														
4	Flow rate estimation analysis/comparison														
5	Report writing														

Table 2: Gantt chart for FYP 2

Complete task   Ongoing task

Table 1 shows the Gantt chart during FYP 1. During the first three weeks, the time was allocated for project topic selection conducted by the Mechanical Engineering Department. In week 3 to week 6, the preliminary research about the topic selected was done. At this stage, frequent discussion was done with the main supervisor. The study continues with the experiment setup and the image requisition until week 9. Some improvements have been done to the experiment setup and the video need to be taken again in week 11.

The improvements done in this phase is adding from using single camera to two camera position in 45° from the parallel line. The liquid us as penetrate used also was change from printer ink to cooking oil. From week 12 to week 14 was spent for matching the stereo image captured from the cameras.

Table 2 shows the Gantt chart for FYP 2. For the first two weeks, some improvement has been done to the experiment setup by using the Kinect 3D camera that was equipped with sensor for movement detection. The flow was recorded again using this camera. Week 3 until week 8 was used for data analysis. At first, the analysis was done using by programming in MATlab. Since the programming become more complicated, a graphical user interface (GUI) was modified for the analysis. From week 9 to week 11, the flow rate from the analysis was compared with the experiment value. Some changes were done to the GUI to improve the accuracy based on the experiment.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Pre-analysis

The color images from the video need to convert into grayscale because the MATlab tool cannot process the color image for velocimetry analysis. The image can be converted one-by-one using MATlab Image Processing Tool.

The coding to convert color image to grayscale image [8]:

```
>> I = imread('image_name.jpg');
>> J = rgb2gray(I);
>> figure, imshow(J);
```

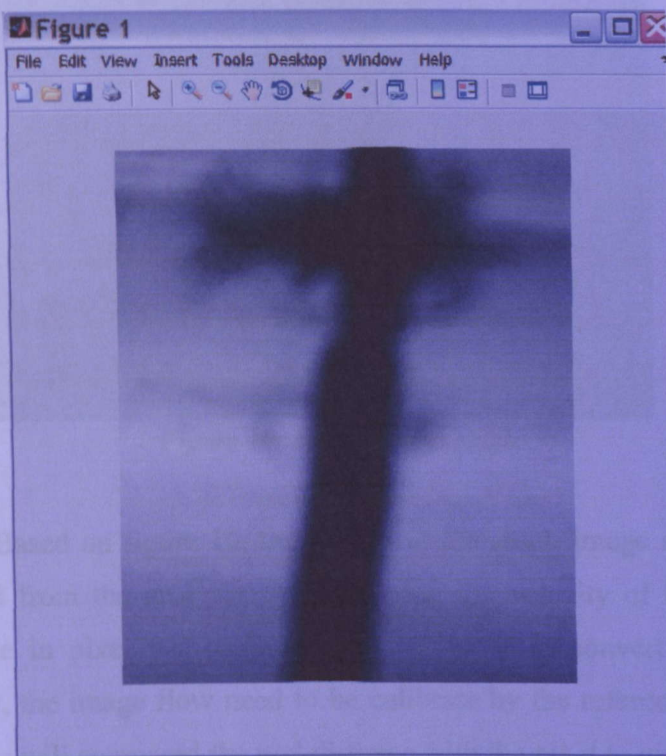

Figure 9: Flow at 12th second

Before start to analyze the image, one small area nearest to the nozzle was selected as the region of interest (ROI). It is to make sure the result is the instantaneous velocity of the oil flow from the nozzle.

4.2 Velocity Analysis

Fast Fourier transform (FFT) analysis will give more accurate estimation due to multi pass using window deformation. This also may cause the time taken for the analysis slightly longer compare to Direct Cross Correlation (DCC).

Figure 10: FFT analysis result

Based on figure 10, the arrows at the result image shows the vector detected from the analysis. At this point, the velocity of the flow already available in pixel per second (px/s). In order to convert the unit of the velocity, the image flow need to be calibrate by the reference distance. The interface will compared the real distance with the pixel to give the velocity in meter per second (m/s).

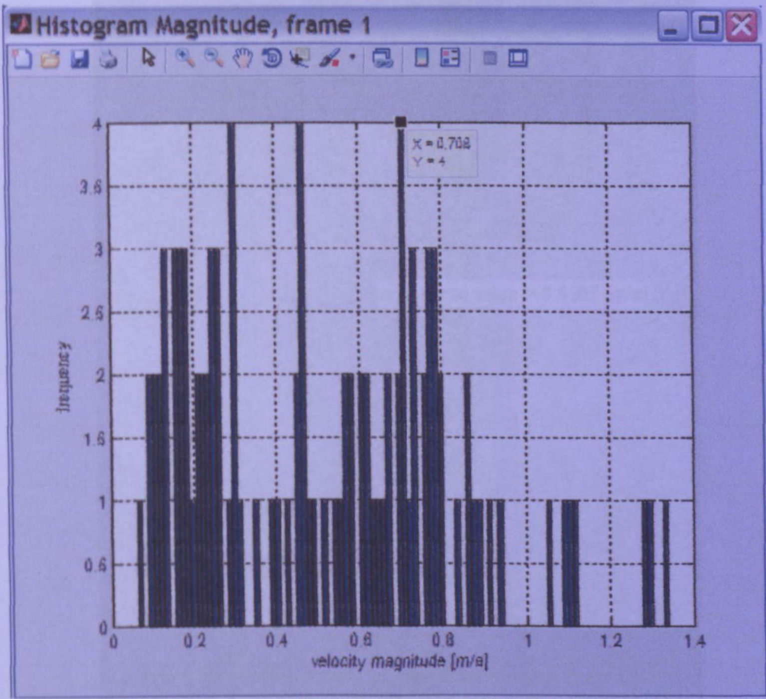

Figure 11: Histogram of Frequency vs Velocity Magnitude (m/s)

From the histogram we can see few velocities recorded with less frequency. There are three velocities with highest frequency recorded. The velocities are 0.279 m/s, 0.427 m/s and 0.708 m/s. Since there is more than one dominant velocity, the area mean value will be used for volume rate estimation. Which means through out the calculation, the flow was assumed having a constant flow rate.

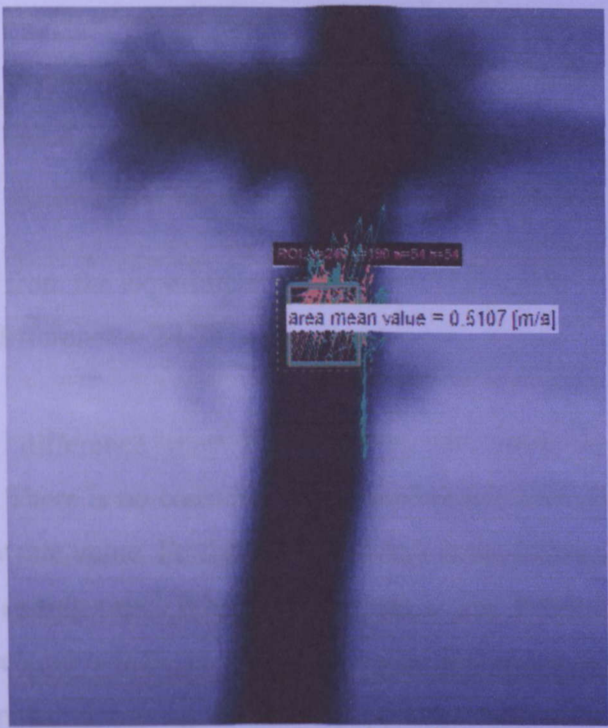

Figure 12: Extract parameter from the area

4.3 Volumetric Flow Rate Calculation

By assuming that the flow rate is constant, we can develop our study to find the volumetric rate.

MATlab coding to find the volumetric flow rate:

```
>> clear all

>> % volumetric flow rate
>> D = 0.5    % diameter in cm

D =

 0.5000

>> t = 2    % time frame for the analysis

t = 2

>> V = 0.5107     % velocity from PIV analysis in m/s

V =

0.5107

>> V = V*100     % velocity from PIV analysis in cm/s

V =

 51.0700

>> A = pi*((D/2)^2)     % nozzle outlet area in cm^2
```

A =

0.1963

>> Q = ((V/t)*A)/t   % volume rate in cm^3/s

Q =

2.5069

The volume from the experiment is Q(exp) = 3.333 cm^3/s

Percentage difference = 24.78 %

This difference may be cause by the error in conducting the experiment. There is no constant pressure in the oil flow. This may cause the error in flow rate value. Furthermore, Q (exp) is the total rate from the initial time to the ending time. While the analysis is just between the 12^{th} second until 14^{th} second which is only 2 second. In calculating the Q, V was assumed constant by taking the velocity of area mean value.

If another velocity with high frequency was selected in determine the volume rate, the difference percentage will be difference too.

For example if the velocity of 0.708 m/s was taken as the flow velocity, the volume rate will be 3.475 cm^3/s. Therefore the percentage will be only 4.26%.

CHAPTER 5

CONCLUSION AND RECOMENDATION

A Kinect 3-D Camera can use laboratory work despite the initial purpose of it as game console. By using this camera, few steps in matching the images can be skipped. The camera was connected with computer and MATLab Image Acquisition Tool as the framework.

By using MATlAb Image Processing Tool, the images were analyzed. The flow was assumed having a constant flow rate. Based on the analysis, the velocity with highest frequency recorded is 0.708 m/s and the volume flow rate is 3.475 cm^3/s and the volume flow rate recorded during experiment is 3.333 cm^3/s. So, the difference percentage between the two values is 4.26%.

The flow cannot be easily assumed as having the constant flow rate. Therefore, to make sure that the flow rate is constant, the experiment setup must be improved. The motor should be include and connect to the nozzle. This is to make sure that the oil has a constant pressure and constant flow rate.

Another GUI can be developed to calculate the volume flow rate from the velocity resulted in PIV analysis. The GUI can be developed using the MATLAB Graphical User Interface Development Environment (GUIDE).

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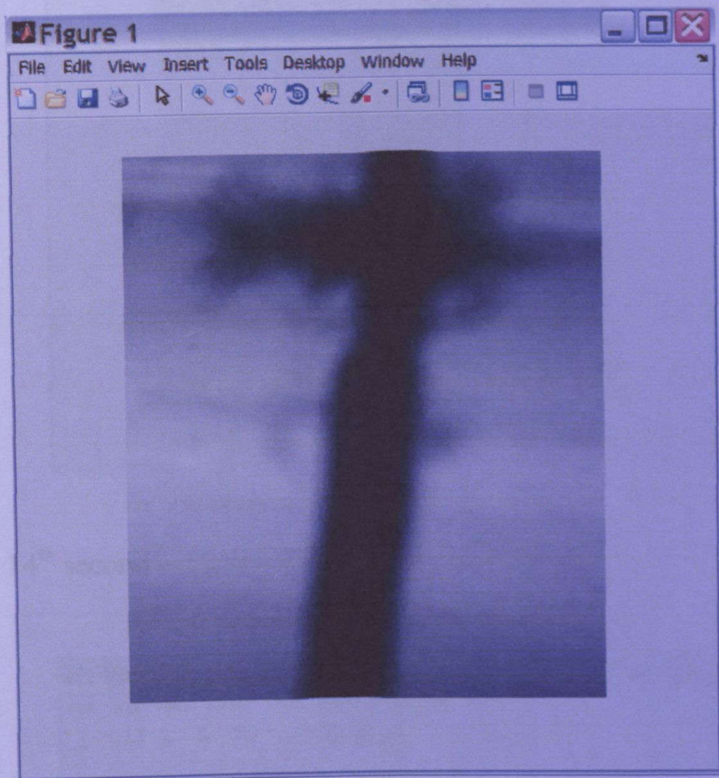
APPENDICES

7a) Flow at 12th second



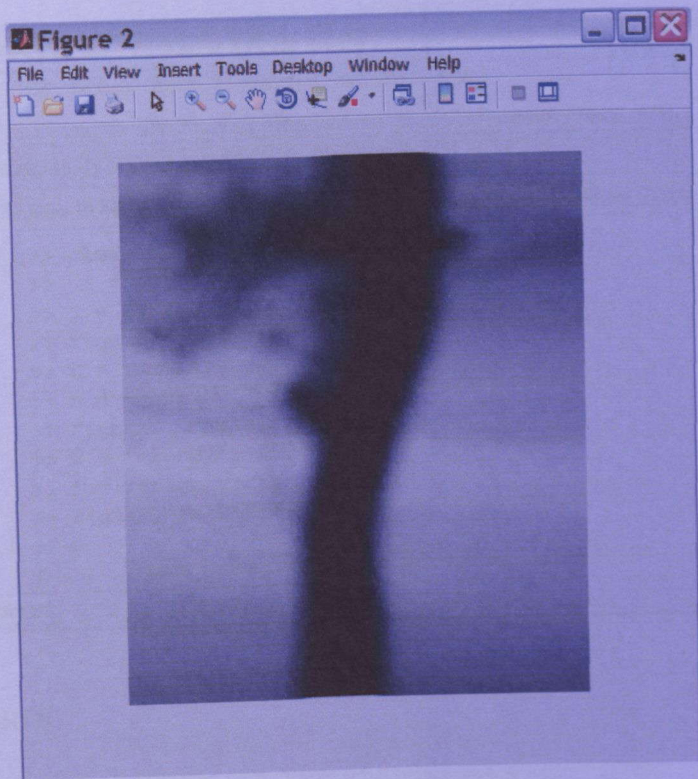
[8] William Thielicke, Eize J Stamhuis, *PIVlab - Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB,* pivlab.blogspot.com retrieved on 20th June 2012

[9] *Deepwater Horizon Accident*, retrieved on February 21, 2012 from http://www.bp.com/sectiongenericarticle800.do?categoryId=9036575&contentId=7067541

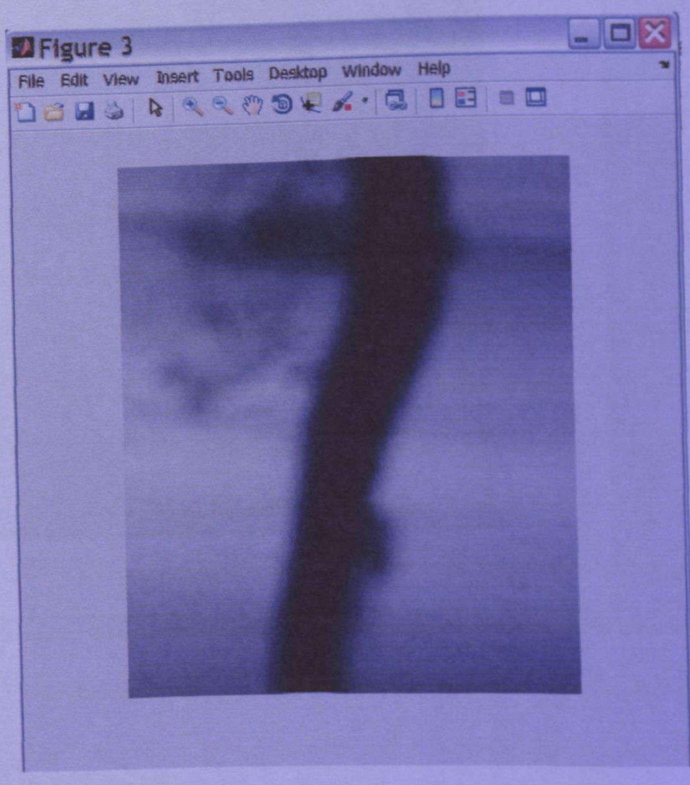
[10] *Deepwater Horizon Explosion*, retrieved on February 21, 2012, from http://en.wikipedia.org/wiki/Deepwater_Horizon_explosion

[11] Wikipedia: Particle image velocimetry , retrieved on February 21, 2012, from http://en.wikipedia.org/wiki/Particle_image_velocimetry

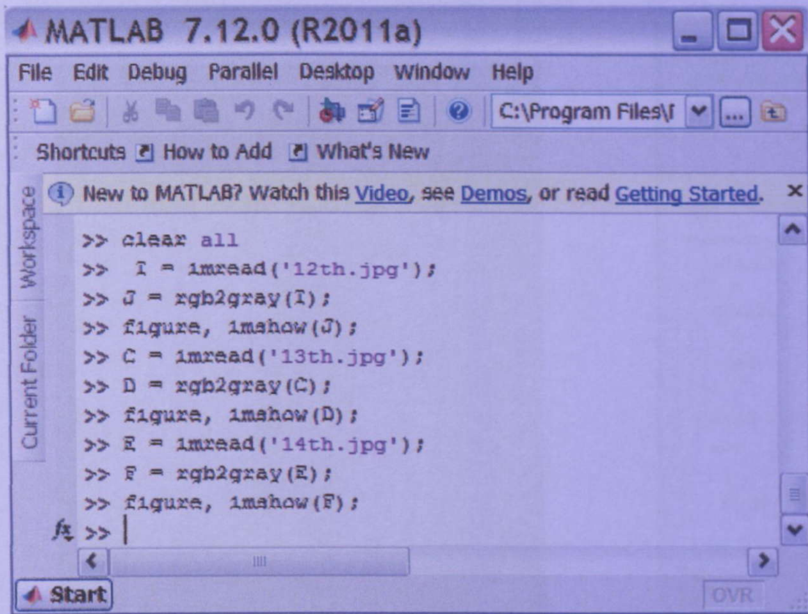
7b) Flow at 13th second



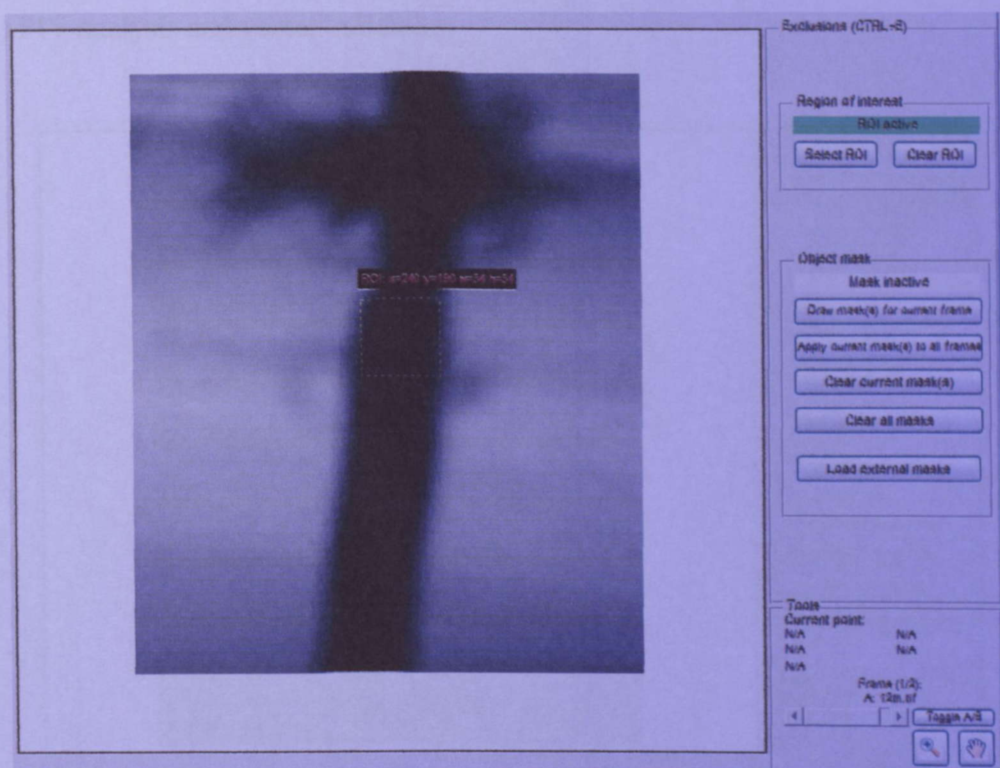
7c) Flow at 14th second



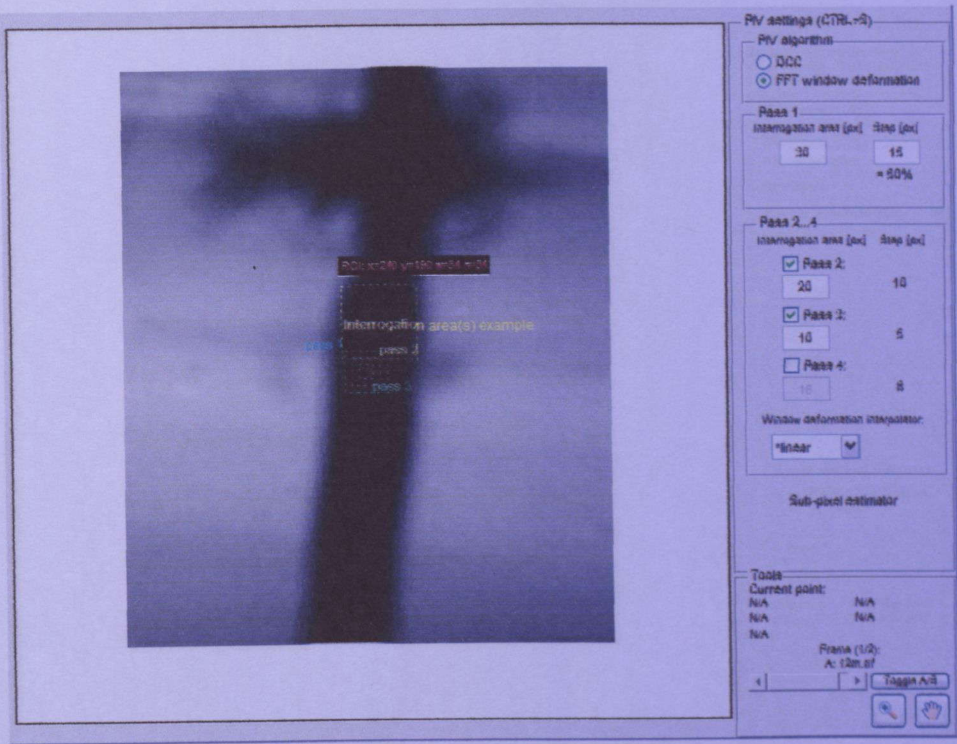
7d) Code for editing initial image to grayscale image



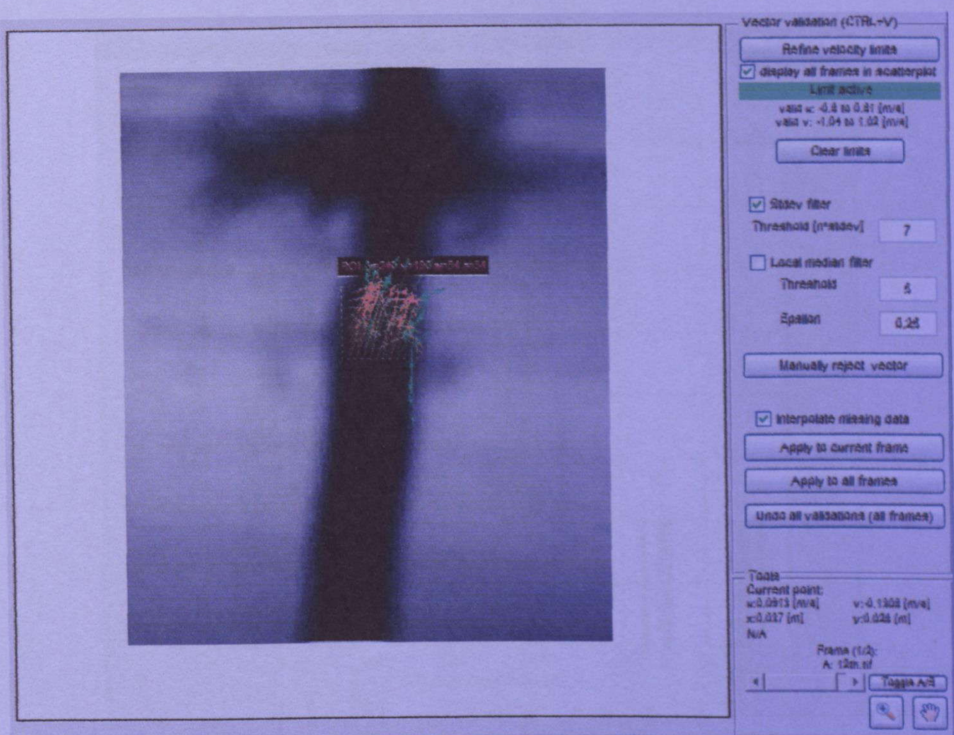
7e) Selecting ROI



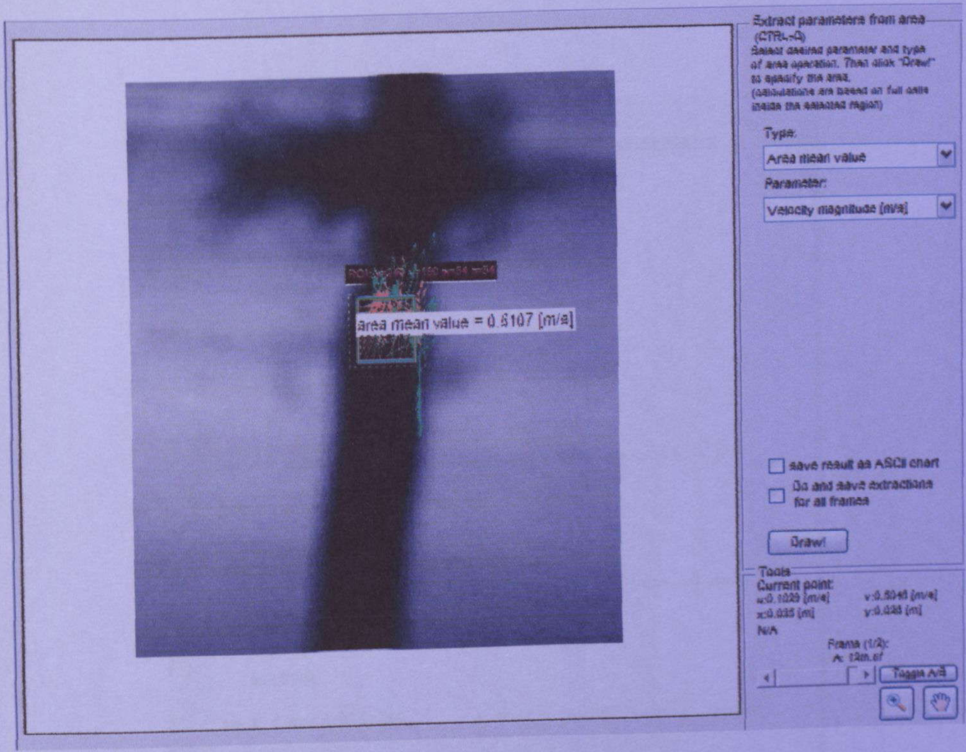
7f) Selecting PIV setting



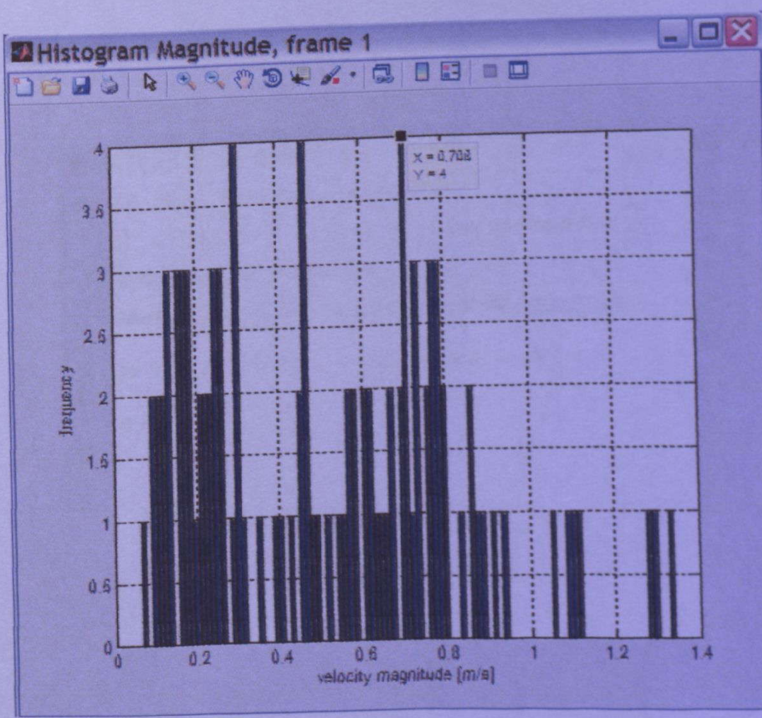
7g) PIV analysis and vector validation



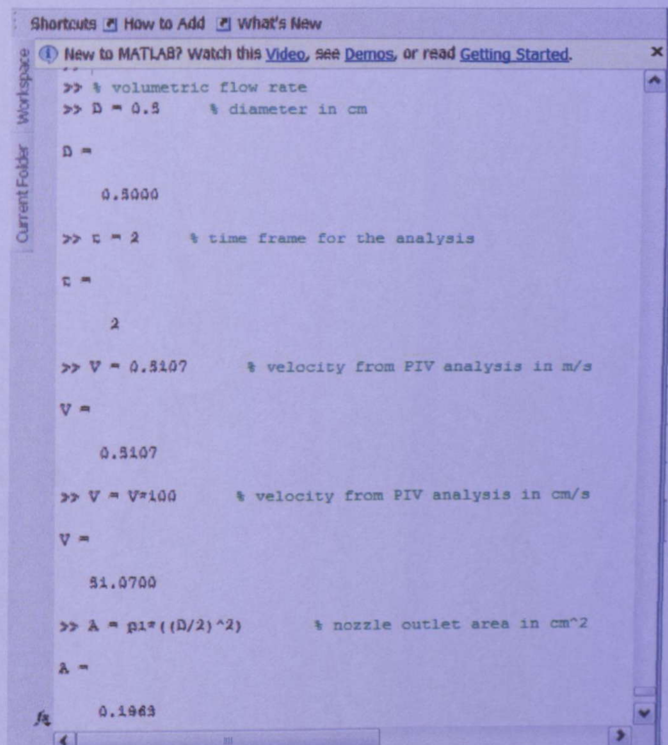
7h) Extract parameters from area



7j) Histogram of Frequency vs. Velocity



7k) MATlab code for volume rate calculation



cont.