TOWARDS A MORE ACCURATE FLOW RATE ESTIMATION TECHNIQUE FOR OIL SPILLS FROM PIPELINES

By

Muhammad Hazim Bin Suffian

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

SEPTEMBER 2013

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

TOWARDS A MORE ACCURATE FLOW RATE ESTIMATION TECHNIQUE FOR OIL SPILLS FROM PIPELINES

by

Muhammad Hazim Bin Suffian

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Dr Mark Ovinis)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPTEMBER 2013

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 contain herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HAZIM BIN SUFFIAN

ABSTRACT

In 2010, an oil rig on the Gulf of Mexico exploded and sunk into the ocean. A leak was discovered on the seabed one mile under the sea. Different techniques were employed to quantify the amount of oil leaked into the ocean, however their results varied quite significantly. The most accurate method to date is a standard deviation of 2.6% by Crone using Optical Plume Velocimetry (OPV). In this work, a novel method to estimate the flow rate with a higher accuracy is sought. There are two approaches in this work, one involves the use of a 3D vision system to estimate volume of the fluid flow and the other uses existing optical flow technique to estimate velocity of the fluid flow. Related works on 3D reconstruction, optical flow and the experimental setup are done to replicate the flow conditions under the sea. These approaches will assist in the final goal of estimating the flow rate of a fluid flow with higher accuracy and consistency. Experiment shows that, due to the limitations of the Kinect, the 3D reconstruction approach of the fluid flow could not be implemented causing a setback to the approach. The limitations of the Kinect must be overcome to continue with the approach. Oppositely, the optical flow approach shows an error of 2.08% in the experiment. The formation of bubbles in the video could reduce the accuracy of the method. As a conclusion, a method is developed with an error of 2.08%.

ACKNOWLEDGEMENT

I would like to express my greatest appreciation to my supervisor, Dr Mark Ovinis, for me to have the opportunity to work on the project. His supervision, ideas and advices has assisted me throughout the whole project. A word of appreciation also goes to the engineer, Mr. Shahrul Abu Bakar and technician, Mr Suhairi Idris over at the Design and Prototyping Centre (DPC) of Universiti Teknnologi PETRONAS. Last but not least, I would like to give my utmost gratitude and appreciation to my family and fellow friends who provide a lot of help and support in my work. Praise to Allah as He allow this work to be accomplished.

CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1. BACKGROUND OF STUDY

In 2010, the oil rig on the Gulf of Mexico exploded and fires engulfed the entire oil rig (see Figure 1) causing the oil rig to sink to the bottom of the ocean. As a result, a total of 11 workers died. The disaster caused an oil leak (see Figure 3) and had a major impact to the marine environment and the marine wildlife as shown in Figure 2. Compensation must be paid by the oil company (BP) as a penalty. However, as penalties imposed on the ==company are based on the amount oil leaked, the amount to be paid was uncertain as the amount of oil leaked was unknown. Thus, there was a need to estimate the total amount of oil leaked.

Figure 1: Oil rig explosion

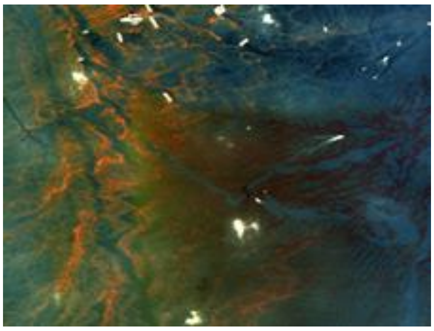


Figure 2: Effect on environment

Figure 3: Oil leak

2. PROBLEM STATEMENT

As oil spills are typically in millions of barrels, an inaccurate estimate will result in a quite substantial error. Because of this, the existing techniques are not acceptable. The most accurate method to date is a standard deviation of 2.6% by Crone. A more accurate flow estimation technique is sought.

3. PROJECT SIGNIFICANCE

The development of this new method will assist in estimating the flow rate of a fluid flow with higher accuracy and consistency. It may also have the potential to be applied to other cases of fluid rate estimation.

4. OBJECTIVE

The objective of this work is to:

1. Develop a new flow estimation technique with a standard deviation of 1%.
2. Replicate Crone's experimental setup to validate the accuracy of the new technique

5. SCOPE OF STUDY

The scope of this work is a vision system setup that includes:

- Experiment setup to obtain fluid flow as per Crone et al
- Integration of image acquisition device (Kinect)
- 3D reconstruction
- Optical flow

CHAPTER 2

LITERATURE REVIEW

1. HISTORY OF OIL SPILL – DEEPWATER OIL DISASTER

A number of oil spills have occurred in the past century since the beginning of the discovery of oil. The Deepwater Oil Disaster that occurred on the 22nd April 2010, however, was the largest accidental spill in world history [3]. The effect of this major event was tremendous as the marine ecosystem was polluted and marine wildlife was badly harmed as shown in Figure 4. Explosion on the oil rig was caused by the failure of eight different safety systems [4], thus leading to the sinking of the oil rig. A preventive measure called blowout preventer (BOP), as show in Figure 5 failed to cut out the oil supply during the disaster and this caused the oil from the mile deep well to flow out freely into the open ocean as shown in the Figure 3. It failed because of pieces of drill pipe kept its blind shear rams from sealing its well [5]. It took the company, BP and the government a total of 87 days to seal the oil well. Numerous efforts had been taken ranging from a specially built dome to junks and muds to control the leak. Through all the issues, one issue still remained uncertain, which is the estimated volume of oil spilled into the ocean. Two types of technique being used, one is the estimations based on satellite imagery and the other, estimations based on video of the flow [1].

Figure 5: Harmful to wildlife

Figure 4: BOP

1.1 Estimations based on Satellite Imagery

John Amos used publicly available satellite images as shown in Figure 2 to come out with an estimate on the oil spilled into the ocean [6]. He determined the area of the oil covered in the ocean and multiplied it with the thickness of the oil, assumed to be 1 micron, to estimate the oil volume. Dr. Ian Macdonald [7], a professor of Oceanography from Florida State University, took a step further by not assuming constant oil thickness, with the introduction of an established protocol – the Bonn Convention. Bonn Convention estimates the thickness of oil based on the color of the surface of the oil contaminated water.

1.2 Estimations based on Video of the Flow

A 30 second video of the oil leak one mile below the sea surface was released to the public as in Figure 6. Scientists and researchers took the video as a challenge to come out with an estimated flow rate from the video. Dr. Timothy Crone, a marine geophysicist from Columbia University's Lamont-Doherty Earth Observatory, used a technique called Optical Plume Velocimetry, which involves temporal cross-correlation of the visual intensity of two pixels in a video [2]. Besides that, Dr. Eugene Chiang, an astrophysicist from University of California estimated the velocity of oil coming out of the riser based on the angle of flow and the rate at which oil would naturally rise through sea water [1]. Lastly, Dr. Steven Wereley, a mechanical engineer from Purdue University, used a method called Particle Image Velocimetry [8]. This method analyses how fast the structures of the flow move across the screen in terms of pixels [9].

Figure 6: Oil leak video

1.3 Estimations from different Methods

The result of the estimated flow rate varied quite significantly for each method implemented. Table 1 below shows the estimated volume and its weakness for each method being implemented.

<table>
<tr><th>Method</th><th>Scientist</th><th>Estimated Flow Rate (bbls/day)</th><th>Weakness</th></tr>
<tr><td>Satellite imagery without the Bonn Convention Protocol</td><td>John Amos</td><td>5 000 – 20 000</td><td>Assumption of no oil was burned and evaporated</td></tr>
<tr><td>Satellite imagery with the Bonn Convention Protocol</td><td>Dr. Ian Mcdonald</td><td>26 500</td><td>Bonn Convention not recommended for analysing large spills [6]</td></tr>
<tr><td>Optical Plume Velocimetry</td><td>Dr. Timothy Crone</td><td>50 000 – 100 000</td><td>Poor imaging system
• Low speed (fps)
• Low resolution</td></tr>
<tr><td>Angle of flow and the rate of flow</td><td>Dr. Eugene Chiang</td><td>20 000 – 100 000</td><td rowspan="2">Assumption of the percentage of oil from the flow, poor video quality and no information inside the flow</td></tr>
<tr><td>Particle Image Velocimetry</td><td>Dr. Steven Wereley</td><td>72 129 (±20%)</td></tr>
</table>

Table 1: Flow estimation methods

Based on Table 1, estimations from video analysis are generally much higher than the estimations from the satellite images. However, all the estimations slowly changed and became closer and closer to Crone's method and Wereley's method [11].

2. FLOW RATE ESTIMATION

Flow rate is defined as the volume of fluid that flows past a given cross sectional area per second. There are two general governing equations.

2.1 Volume to estimate Flow Rate

One way to find the estimated flow rate is to implement 3D reconstruction, which can be used to estimate the volume of an object [14]. Kinect is equipped with a depth sensor, where its basic principle is the emission of IR pattern [15]. The depth sensor in Kinect has the ability to return (x,y,z)-coordinates of 3D objects in which the image processor uses the IR pattern to calculate the depth displaced at each pixel in the image. The estimated volume can then be computed for flow rate estimation using the governing equation:

$$Q = \frac{dV}{dt}$$

where:

V = volume (cm^3)

t = time (s)

2.2 Velocity to estimate Flow Rate

In fluid mechanics, for steady and incompressible fluid flow involving only one stream of a specific fluid flowing through a control volume [10], the governing equation is:

$$Q = V.A$$

where:

Q = Flow rate (m^3/s)

V = velocity of fluid (m/s)

A = cross sectional area of fluid flow (m^2)

3. RELATED WORKS

Previously, it is found that the methods based on video analysis are much more accurate compared to the other one. This can be seen in the results obtained from work of Crone, Chiang and Wereley and the fact that they eventual agreed upon estimate was close to that of flow estimation methods based on video analysis. Crone had setup an experiment that has the ability to replicate conditions under which seafloor vent video as shown in Figure 7 [2]. To facilitate further analysis and comparison of the new technique with his, the experimental setup was replicated.

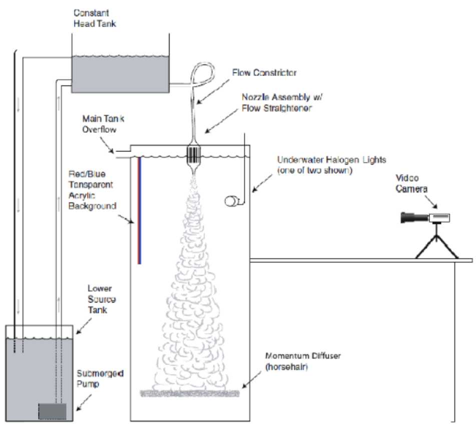


Figure 7: Experiment setup

Previous works on Kinect to estimate the flow rate of fluid flow include that by Emalisa [12] and Khairi [13], who did some preliminary work using Kinect for flow rate estimation. Table 2 shows a summary of their work.

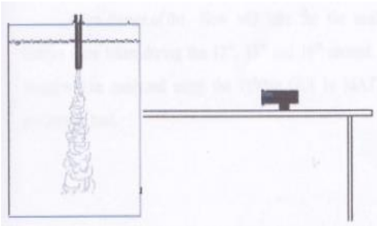
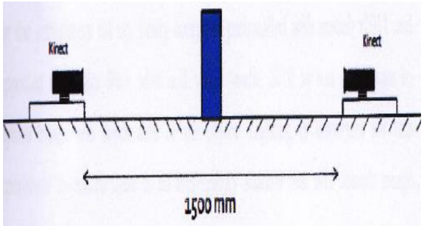
Work	Emalisa	Khairi
Experimental Setup		
Approach	PIV	Kinect depth and 3D
Percentage Error (%)	4.26	7-12
Limitations	Flow is assumed to have constant flow rates.	Use of solid objects instead of liquids

Table 2: Comparison of previous works

CHAPTER 3

METHODOLOGY

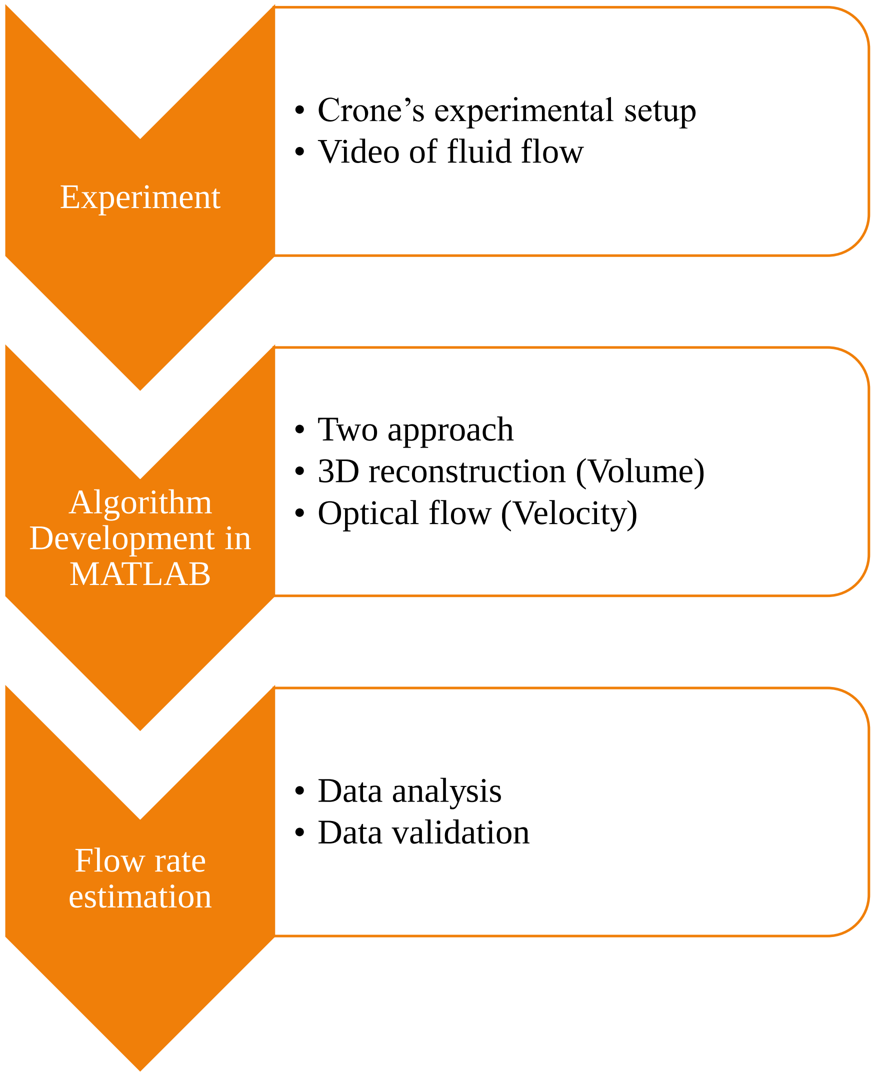


Figure 8: Methodology

1. EXPERIMENTAL SETUP

Crone’s experiment setup is implemented as shown in Figure 7. The video camera that is used is the Kinect camera by Microsoft. The fluid flow from the nozzle is captured by Kinect and the video sequence subsequently is processed. The setup of the experiment is shown in Figure 9 to Figure 13. A support structure is fabricated to support the main tank as well as a safety measure.

Figure 9: Main tank and support

Figure 10: Head tank

Figure 9: Nozzle

Figure 10: Computer setup

2. ALGORITHM DEVELOPMENT

This section is the one of the main focus of the entire work. The image processing that is implemented is done in MATLAB. In this section, two approaches are presented as shown in Figure 13.

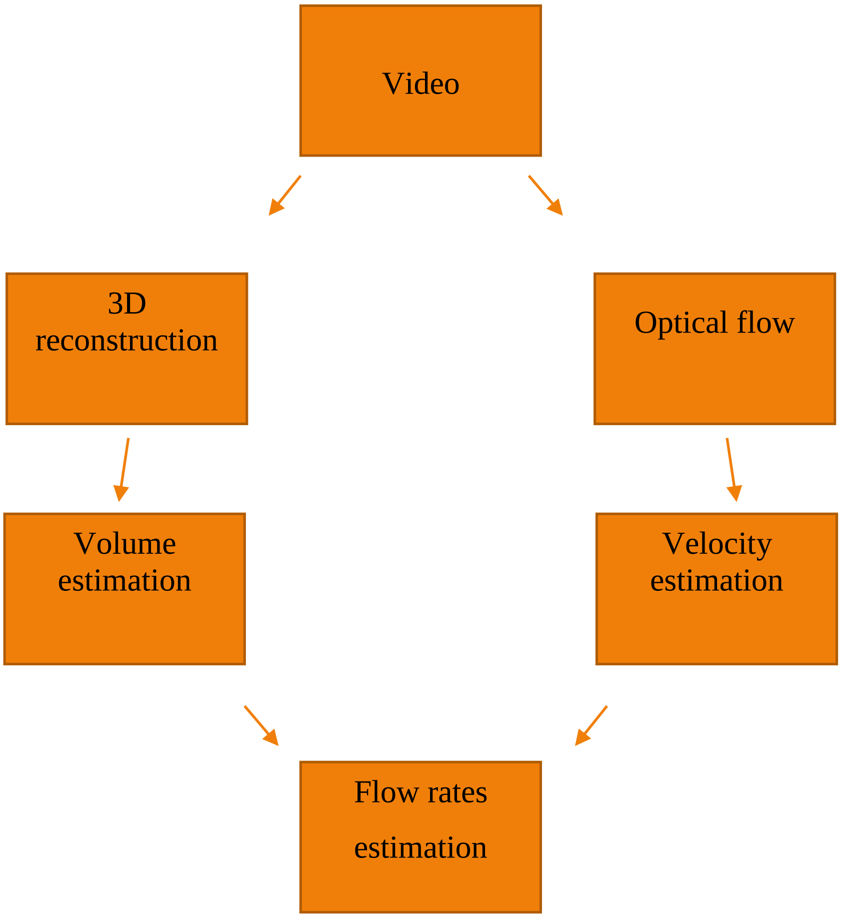


Figure 11: Two approaches

2.1 Flow Recording

The technique being developed is not real-time i.e. post-processing because of limitations in computational resources. A recording algorithm for the fluid flow was developed and the flow recorded and stored in an array in MATLAB, to facilitate post-processing. Field Programmable Gate Array (FPGA) may be considered for real-time processing.

2.2 Volume

Three Kinects were used for 3D reconstruction. A technique called Iterative Closest Point (ICP) [19] is implemented to merge depth values from the Kinect. A transformation matrix relates one scene to another thus combining all the available data. From 3D reconstruction, the volume can be estimated with a technique called alpha shapes [11]. Alpha shapes are a generalization of the convex hull of a point set where it is essentially the volume bounded by a set of points. This technique computes the volume of the basic alpha shape for 3D point set.

2.3 Velocity

Optical flow will be implemented to estimate the velocity of the fluid flow. A common method called Lucas and Kanade [17] will be implemented on a selected region of interest (ROI) of the fluid flow. The ROI is selected near the nozzle as near as possible as done by Crone [2]. However, few assumptions are made in estimating velocity:

1. the fluid flow is still considered as it still in a pipe (conservation of mass)
2. the fluid flow has a cross sectional area of a circle

2.4 Flow Rate Estimation

2.4.1 Velocity to estimate Flow Rate

$Q = V.A$

where:

V = velocity of fluid (cm/s)

A = cross sectional area of fluid flow (cm^2)

Optical flow is the apparent motion of brightness patterns in an image where it corresponds to the motion field [16]. One of the most common method for optical flow is by Lucas and Kanade [17]. The algorithm presented by Lucas and Kanade attempts to find an optimal value for a disparity vector, h, which represents an object's displacement (pixel/frame) between successive images [18]. The method developed presents a desirable level of flow accuracy which is capable of distinguishing regions varying in activity level [18]. With this, the velocity of a fluid flow can be estimated as:

$V = h \times FPS \times k$

where:

V = velocity of fluid (cm/s)

h = pixel displacement (pixel/frame)

FPS = frame per second (frame/s)

k = calibration constant of the image (cm/pixel)

Calibration constant is the ratio of a set of known correspondences between point features in the real world (cm) and their projections on the image (pixel) whereas FPS is the speed of the video changing from one frame to another. On the hand, area of the fluid flow:

$$A = \frac{\pi D^2}{4}$$

where D is the diameter of the fluid flow where velocity, V is measured

2.4.2 Velocity to estimate Flow rate

$$Q = \frac{dV}{dt}$$

where:

V = volume (cm^3)

t = time (s)

The volume of the fluid flow can be estimated by the method mentioned previously. With the time, t known, the flow rate can be determined.

3. GANTT CHART

No.	Detail/Work	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP I															
1	Preliminary research work		■	■	■	■	■	■	■	■	■				
2	Procurement of materials			■	■	■	■	■	■	■	■				
3	Preliminary experiment and testing										■	■	■	■	■
4	Preliminary algorithm development										■	■	■	■	■
5	Experimental setup										■	■	■	■	■
FYP II															
1	Procurement of materials	■	■	■	■	■	■	■	■	■	■	■	■		
2	Experimental setup	■	■	■	■	■	■	■	■	■	■	■	■		
3	Experiment and testing	■	■	■	■	■	■	■	■	■	■	■	■		
4	Algorithm development											■	■	■	■
5	Discussion , analysis and validation											■	■	■	■

Figure 12: Gantt chart

CHAPTER 4

RESULT AND DISCUSSIONS

This section shows the result and discussion of this work from the elements shown in figure 8.

1. VIDEO

A video had been successfully captured with the experimental setup similar to that by Crone. The figure below shows the sequence of frames of the video with an average speed, FPS = 19 frame/s and with a calibration constant, k = 0.1319 cm/pixel.

Figure 13: Image sequence of fluid flow

2. 3D RECONSTRUCTION APPROACH

In the experiment, the Kinect could not detect the presence of the fluid flow, thus no depth values is produced for 3D reconstruction. This is because of the limitation possessed by the Kinect:

1. Which emits infrared laser that is absorbed by water.
2. Refraction will cause inaccuracy of depth values.

Possible solution to overcome this problem is to use of a 3D underwater camera such as Mini-3D underwater stereoscopic video camera. A solid object (see Figure 14) was used in place of the fluid flow to further develop this method. The camera setup is positioned as shown in Figure 15. Figure 16 shows the result of combining all the depth values obtained from three Kinects. After calibration, the 3D reconstruction of the solid object can be obtained as shown in Figure 17.

Figure 14: Solid object

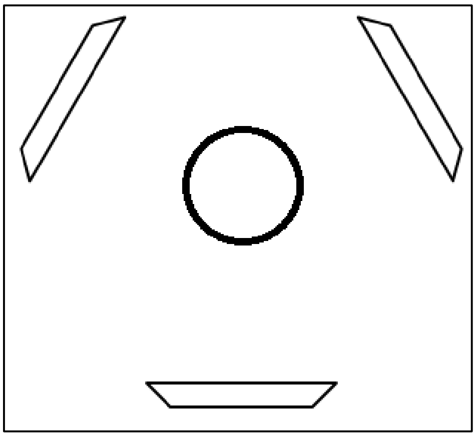


Figure 17: Camera setup

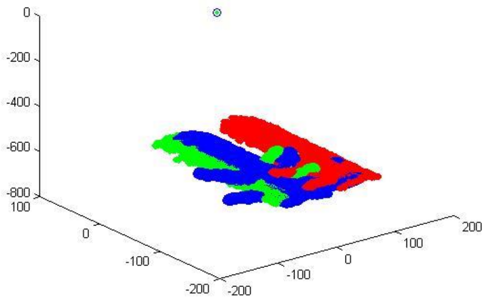


Figure 158: Three 3D points set

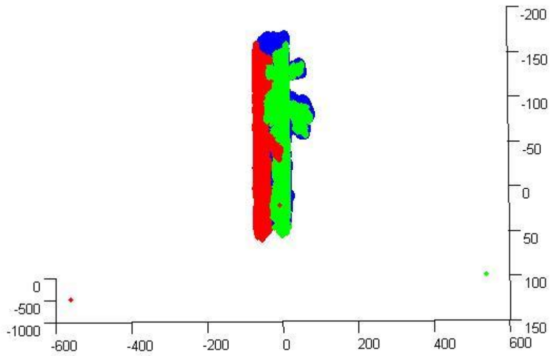


Figure 19: 3D reconstructed object

The volume of the reconstructed 3D object as shown in Figure 17 can then be estimated with alpha shapes. With the algorithm, the result of the estimation of volume is 1018.4 cm^3.The actual volume of the object is estimated 640.96 cm^3. The percentage error is 58.89%.

$$Percentage\ error\ (\%) = \frac{1018.4 - 640.96}{640.96} \times 100 = 58.89\ \%$$

The percentage error is high, one of the reason is because there is no accurate method of estimating a volume for a point cloud.

3. OPTICAL FLOW APPROACH

With this method, the velocity of the fluid within the image can be estimated. Lucas and Kanade, which is the most common method for optical flow, is being used in this work. Figure 20 shows the algorithm implemented on the video where the vertical velocity of the highlighted region is determined.

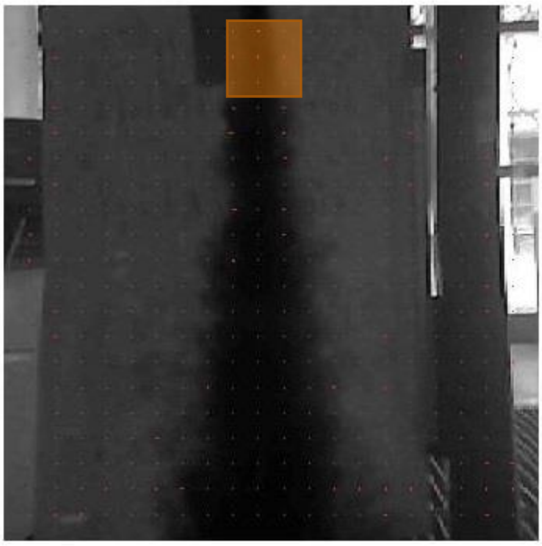


Figure 20: Fluid flow and region of interest

The table below shows the velocity obtained for two fluid flows:

Fluid simulation	Pixel displacement (pixel/frame)	Diameter, D (cm)
Fluid flow 1	2.0677	2.9
Fluid flow 2	2.1276	2.5

Table 3: Result of optical flow method

4. FLOW RATE ESTIMATION

As there is no fluid involved in the 3D reconstruction because of the absence of depth values, only optical flow is considered to estimate the flow rate. To estimate the flow rate, the equation derived previously is used. The derived constants of the system is listed in Table 4. The estimated flow rate is calculated and shown in Table 5.

Element	Value
Speed, FPS (frame/s)	19
Calibration constant, k (cm/pixel)	0.1319

Table 4: Constant values

Simulation	Fluid flow 1	Fluid flow 2
Pixel displacement, h (pixel/frame)	2.0677	2.1276
Velocity, V (cm/s)	5.1819	5.3320
Diameter, D (cm)	2.9	2.5
Area, A (cm^2)	6.6061	4.9094
Estimated flow rate, Q_{exp} (cm^3/s)	34.2321	26.1769
Actual flow rate, Q_{act} (cm^3/s)	33.5189	24.0132
Percentage Error (%)	2.08	9.01

Table 5: Flow rates

The percentage error for the simulation of fluid flow 1 and fluid flow 2 varies, where the percentage in fluid flow 2 is higher. The probable cause of the higher percentage error is because of the presence of bubbles in the flow, this could reduce the accuracy of the estimation. Other than that, the method produces a satisfying result with percentage error of 2.08%.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Two approaches presented to estimate flow rate better. The 3D construction approach needs further work as the Kinect is unable to detect depth underwater as planned. Future work for this approach can be focused on overcoming this limitation and developing the method further. More 3D reconstructions of other shapes of solid objects can be done to investigate any functional relationship between the actual and the estimated values.

The optical flow approach in this work produces a quite significant result with a percentage error 2.08%. Future work can be done towards this approach by improving the experimental setup to eliminate the formation of bubbles. Since there is only two simulation, it is insufficient to compute the standard deviation for the method. Therefore, the setup needs to be modified allowing more flow rates to be simulated so that more data can be obtained and analyzed.

As a conclusion, this work has developed a more accurate method in flow rate estimation. There are limitations and setbacks that need to be considered that can be improved and developed for future work.

REFERENCE

[1] The amount and fate of the oil. National Commision on the BP deepwater Horizon oil spill and offshore drilling.

[2] Crone, T. J., McDuff, R. E., & Wilcock, W. S. (2008). Optical plume velocimetry: a new flow measurement technique for use in seafloor hydrothermal systems. *Experiments in fluids*, *45*(5), 899-915.

[3] Moss, Laura. "The 13 Largest Oil Spills in History." *Mothernature Network*. N.p., 16 July 2010. Web. 19 June 2013. <http://www.mnn.com/earth-matters/wilderness-resources/stories/the-13-largest-oil-spills-in-history>.

[4] Mullins, Justin. "The Eight Failures That Caused the Gulf Oil Spill." *Newscientist.com*. N.p., 08 Sept. 2010. Web. 19 June 2013. <http://www.newscientist.com/article/dn19425-the-eight-failures-that-caused-the-gulf-oil-spill.html>.

[5] Weber, Harry R., and Michael Kunzelman. "BP Oil Spill Blowout Preventer Failure Caused By Piece Of Drill Pipe." *Green*. N.p., 23 Mar. 2011. Web. 19 June 2013. <http://www.huffingtonpost.com/2011/03/23/bp-oil-spill-blowout-prev_n_839649.html>.

[6] John. "Gulf Oil Spill Rate Must Be Much Higher Than Stated - 6 Million Gallons So Far?" Web log post. *Skytruth*. N.p., 27 Apr. 2010. Web. 19 June 2013. <http://blog.skytruth.org/2010/04/gulf-oil-spill-rate-must-be-much-higher.html>.

[7] Gillis, Justin. "Size of Oil Spill Underestimated, Scientists Say." *The New York Times*. N.p., 13 May 2010. Web. 19 June 2013. <http://www.nytimes.com/2010/05/14/us/14oil.html?_r=1&>.

[8] Subcommittee Briefing on "Sizing up the BP Oil Spill: Science and Engineering Measuring Methods"" *Comittee on Energy and Commerce*. N.p., 18 May 2010. Web. 19 June 2013. <http://democrats.energycommerce.house.gov/index.php?q=news/subcommittee-briefing-on-sizing-up-the-bp-oil-spill-science-and-engineering-measuring-methods>.

[9] 9M. Raffel, C. Willert, S. Wereley, J. Kompenhans, Particle Image Velocimetry: A Practical Guide, Springer, New York (2007). (ISBN: 978-3-540-72307-3)

[10] Munson, Bruce Roy. Fundamentals of Fluid Mechanics, Sixth Edition. 6th ed. Hoboken, NJ: Wiley, 2009. 195.

[11] Edelsbrunner, H., & Mücke, E. P. (1994). Three-dimensional alpha shapes. *ACM Transactions on Graphics (TOG)*, *13*(1), 43-72.

[12] Kamsani, E. (2012). *Development of an automated flow rate estimation method.* Published degree dissertation, Universiti Teknologi Petronas, Malaysia.

[13] Rahim, K. (2012). *Development of a 3D automated flow estimation technique.* Published degree dissertation, Universiti Teknologi Petronas, Malaysia.

[14] Stelldinger, P., & Latecki, L. J. (2006). 3D Object Digitization: Volume and Surface Area Estimation. In *Proc. IEEE Int'l Conf. Image Analysis*.

[15] Andersen, M., Jensen, T., Lisouski, P., Mortensen, A., Hansen, M., Gregersen, T., & Ahrendt, P. (2012). *Kinect depth sensor evaluation for computer vision applications*. Technical report ECETR-6, Department of Engineering, Aarhus University (Denmark).

[16] Robyn Owens *(1997).* Optical flow. *[ONLINE] Available at: http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/OWENS/LECT12/node4.html. [Last Accessed 15.12.2013]*.

[17] Lucas, B. D., & Kanade, T. (1981, August). An iterative image registration technique with an application to stereo vision. In *IJCAI* (Vol. 81, pp. 674-679).

[18] Bruhn, A., Weickert, J., & Schnörr, C. (2005). Lucas/Kanade meets Horn/Schunck: Combining local and global optic flow methods. *International Journal of Computer Vision*, *61*(3), 211-231.

[19] Ge, Y., Maurer, C. R., & Fitzpatrick, J. M. (1996). Surface-based 3-D image registration using the iterative closest point algorithm with a closest point transform. *Medical Imaging: Image processing*, *2710*, 358-367.

APPENDIX I

```
% Device Initialization
numDevices = mxNiEnumerateDevices();
disp(sprintf('%d devices are connected', numDevices));
context = mxNiCreateContext('Config/SamplesConfig.xml');

% Initialization
width = 640; height = 480;
figure, h1 = imagesc(zeros(height,width,'uint16'));
figure, h2 = imagesc(zeros(height,width,3,'uint8'));
nof = 2; % Number of frames
rgb_video = uint8(zeros(height,width,3,nof));
depth_video = uint16(zeros(height,width,nof));

% LOOP
for k=1:nof
    tic
    mxNiUpdateContext(context);
    [rgb, depth] = mxNiImage(context);
    % Actualiza Figuras+
    set(h1,'CData',depth);
    set(h2,'CData',rgb);
    drawnow;
    disp(['itr=' sprintf('%d',k) , ' : FPS=' sprintf('%f',1/toc)]);
    rgb_video (:,:,:,k) = rgb;
    depth_video (:,:,k) = depth;
end

% Device Termination
mxNiDeleteContext(context);
```