Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1988

Measurement of Two-Phase Flow with the Digital Image Processing Method

Jae-Young Lee*, Kyung-Soo Lee*, and Young-In Kim
HANDONG UNIVERSITY
School of Mechanical and Metallurgical Engineering
* School of Computer Science and Electronic Engineering
3 Namsong ri Heunghae-eub, Pukku, Pohang,
Kyungbuk, Korea, 791-940 Email: jylee7@han,ac.kr

Abstract

This paper discusses the photographic method and digitial image processing technique for the measurement of the void fraction in two-phase flow. A software is developed to measure the void fraction and the interfacial area concentration from the image captured by the camcoder connecting to image capture board in the personal computer. From the careful sensitivity study on the edge detection algorithm, the specific sequential combination of the first derivative convolution algorithm is recommended for two-phase flow under the natural light condition. The coexistance of bright part and dark part in a bubble image due to complex lay scatterring under natural light condition was treated reasonably. The present image processing technique could be used as one of useful tools for the two-phase flow measurement.

1. Introduction

Visual observation has been made in the study of the two-phase flow to understand phenomena and to generate flow regime map. To understand in a deeper level, many sensors have been developed and replaced the visual observation. Traditionally, probes using electrical impedance change between the water and vapor have been used: Serizawa[1,2,3] observed the turbulent effect in bubbly flow and Ishii[4,5,6] measured interfacial area concentration with three-needle probe. Local void fraction could be successfully measured with probe, but the interfacial area concentration has still a room to be improved.

Recent progress in digital image processing technology makes it possible that visual observation could be a useful sensor to measure the void fraction and the interfacial area concentration in the two-phase flow. It could provide reference data for the calibration of other probes. When we use a normal camera, the transparent and appropriate light condition is needed. However, if we use neutron lay or gamma lay with high penetrating power, we could apply this technique for the system without any transparent part. This technique could be fully computerized from capturing to processing the image. It could be used for monitoring the system as well as measure the precise physical data.

In this paper, an image processing system including both the hardware and software for the two-phase flow is developed. Using the image captured from the vertical air-water system, the sensitivity of various edge detection algorithms is performed. Also, the void fraction and the interfacial area concentration are measured from the image processed.

2. system and sensors

The hardware of the image processing system is composed of camcoder for monitoring, 60 frame per second, image capture board; KASAN provision, and a personal computer. In this study, there is no special treatment in light condition. because if the algorithm is working under the bad condition, it could work well under the better condition such as mounting water jacket to eliminate the curvature effect on the tube surface and good light orientation. A software is, also, developed to process image automatically under Windows 95 Operating System. The loop to get the image of the two-phase flow is constructed as shown in Fig. 1. The air and water in mixed in the mixing chamber and flow up through the vertical acryl pipe with 2cm in diameter and 2m in length. The air water separator at the top of the pipe separates them away. Various flow regime was found in the vertical flow channel such as the bubbly flow, the slug flow, and the churn turbulent flow. As shown in Fig. 2. the flow regime in the present loop are in a good agreement with others.

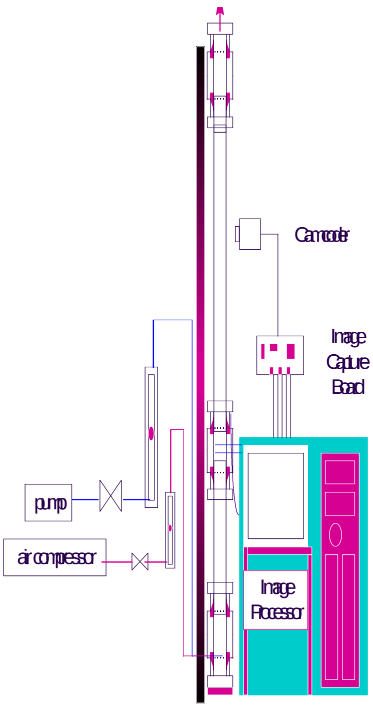


Fig.1 The flow loop and image sensor system

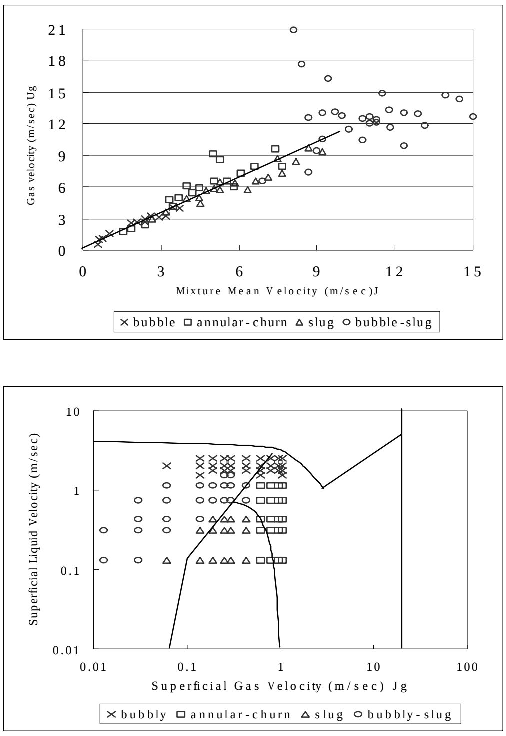


Fig.2 The flow regime map and drift flux velocity from the present flow loop

3. Image processing

3.1 Edge detection algorithm

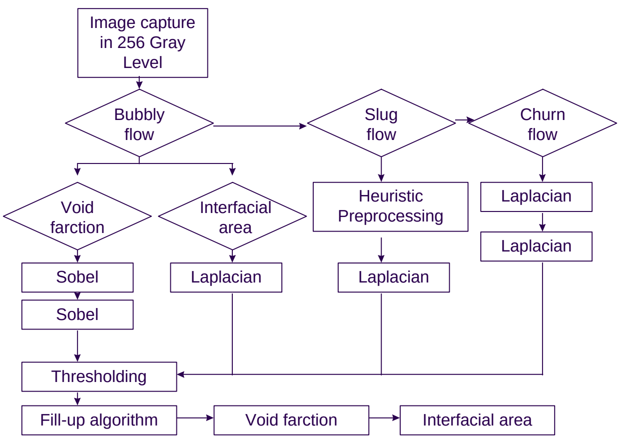


Fig.3 The proceddure of the image processing

Figure 3 shows the procedure of the image processing to get the valuable data At first, the original two-phase image captured is preprocessed by the edge detection algorithm. To find proper edge detection algorithm for the two-phase flow, several conventional edge detection algorithms are tested. It is found that the combinations of several edge detection algorithms in a special order show good performance. After detecting edge, counting the numbers of pixels in and on the boarder of bubble gives us void fraction and interfacial area concentration respectively. Discrete convolutions are heavily used in image processing for image smoothing, crispening, edge detection, and other effects. A convolution is merely a weighted sum of pixels in the neighborhood of the source pixel. The weight are determined by a small matrix called the convolution mask or convolution kernel. The location of the center corresponds to the location of the output pixel.

a) Homogeneous operator
The homogeneity operator subtracts each 8 surrounding pixels from the center pixel of 3X3 windows. This operator is the simplest and quickest edge detectors. Normally, thresholding improves the results.

b) First order derivative
Common gradient (or orthogonal gradient) operators find horizontal and vertical edges. These operators work by convolution. There are the row detector Hr and the column detectors, Hc. The amplitude can be determined by computing the vector sum of Hr and Hc

$$H(x,y) = \sqrt{H_r^2(x,y) + H_c^2(x,y)} \tag{1}$$

The edge orientation can be found by

$$\theta = \tan^{-1} \frac{H_{c(x,y)}}{H_{r(x,y)}} \tag{2}$$

The Robert's operator has a smaller effective ares than other masks, make more susceptible to noise. The other masks are better able to average out fluctuations. The Sobel operator is more sensitive to diagonal edges than vertical and horizontal edges. The Prewitt operator is more sensitive to vertical and horizontal edges than diagonal edges.
- Prewitt opeator

$$\begin{aligned} G_x &= Z_7 + Z_8 + Z_9 - Z_1 + Z_2 + Z_3 \\ G_y &= Z_3 + Z_6 + Z_9 - Z_1 + Z_4 + Z_7 \end{aligned} \tag{3}$$

- Sobel Operator

$$\begin{aligned} G_x &= Z_7 + 2Z_8 + Z_9 - (Z_1 + 2Z_2 + Z_3) \\ G_y &= Z_3 + 2Z_6 + Z_9 - (Z_1 + 2Z_4 + Z_7) \end{aligned} \tag{4}$$

c) Second order derivative operators.
Ideally, an edge detector should indicate only edge at the center of an edge. This referred to as localization. It becomes necessary to employ a process called thinning to reduce the edge width to one pixel. The second order derivative edge detectors provide better localization. Another advantage of second order derivative operators is that the edge contours detected are closed curves. The Laplacian operator which is distinguished from the other operators because it is omnidirectional. The Laplacian operator produces sharper edges than the most other technique. These highlight include both positive and negative intensity slopes. But one problem with Laplacian operator as an edge detector is its susception to noise.

$$\nabla^2 f = 4z_5 - (z_2 + z_4 + z_6 + z_8) \tag{5}$$

$$\nabla f = \begin{bmatrix} G_x \\ G_x \end{bmatrix} = \begin{bmatrix} \frac{\delta f}{\delta x} \\ \frac{\delta f}{\delta y} \end{bmatrix} \tag{6}$$

$$\theta = \tan^{-1} \frac{G_x}{G_y} \tag{7}$$

3.2 Histogram and pixel counting

Image threshholding is typically used with edge detectors to emphasize the edges. This emphasizes the strong edges and deemphasizes the weak edges. Thresholding can use one or two levels. Images can use one threshold value to set those above the threshold to the maximum pixel value and those below the threshold to 0. An upper and lower threshold can also be used to alter pixel values.

4. Results and discussions

It was found that the direct use of one edge detection algorithm to the two-phase flow generates two edges from one bubble because of the brightest part and the darkest part are appeared in a bubble due to the complex light scattering. In this section, after discussing the performance of the edge detection algorithm, the measurement of void fraction and the interfacial area concentration will be presented.

4.1 Performance of the edge detection algorithm

The direct application of the previous edge detection algorithm shows bad performance, so that we mixup several algorithm to get better edge detection. Through many trial and errors, the following combination of the algorithm shows relatively good performance:

SPD: Sobel operator – Lapacian Point operator- Dilation operator
DSP: Dilation operator – Sobel operator- Lapacian Point operator
SSD: Sobel operator – Sobel operator – Dilation Opeator
SS : Sobel operator- Sobel operator .

We select two-phase image in a random manner from the image data bank and applied above algorithms. Except large slug, SPD and SSD work well in the edge detection.

(a) Bubbly flow

The image to be analyzed was obtained with low water flow rate, 3 lpm, and air flow rate,1 lpm, The image of the vertical bubbly flow with the high liquid flow rate needs special device such as the high speed camcoder or the strobrogh. This image is, however, good enough to check the performance of the edge detection algorithms. As shown in FIg. 4, the original image have curvature effect , darker in the left part than the right part. so the bubble in the left part is dark to be detected. Five combinations were applied and the results are shown in FIg.4, SPD and SSD , Prewitt algorithm detects edge more sparsely than the Sobel Algorithm. Dialtion algorithm have the effect of thicker edge boarder. In this point of view, double operation of Sobel operators are recommended for the bubbly flow.

(b)The Slug flow

The slug flow image selected in Fig.5 shows the big cap-type slug and the small bubbles waiting for agglomerations. Since the half of the image is almost same as the bubbly flow, the same algorithms, SPD and SSD shows good performance. Also, the bright part in cap and dark part in the center of the slugs are well detected. But there are many spurious edges are generated. So to get information of the void fraction and interfacial area concentration, The bubble boundary detection needs special algorithm. Figure 6 shows normal slug flow which has a large transparent part in a slug. The body of the slug is not detected well from any combination of the algorithms. Heuristic edge detecting process could help to get the clear edge. Fortunately, the slug flow is simple to process because its shape is simple and only a few slugs are expected in a image.

(c) Churn flow

Fig.7 shows the typical churn flow. It is very difficult to identify bubble edge with the naked eye. In this case, Sobel algorithm generates many spurious edges, but dilatant algorithm could effectively merge the nearby edges. Apparently, SSD shows a good representation of edges. Since Laplacian operator could not generate edges well because of large background noise in the image, the new image representing edge never shows closed curve. Therefore special treatment of the processed image is required to generates closed bubble contours. In this study we open 5 pixels windows in horizontal direction and count the edge pixels. If double edges pixels are found in the windows, then we eliminate one edge pixels to make thin and closed edges. After this process, the void fraction and the interfacial area concentration could be evaluated from the image.

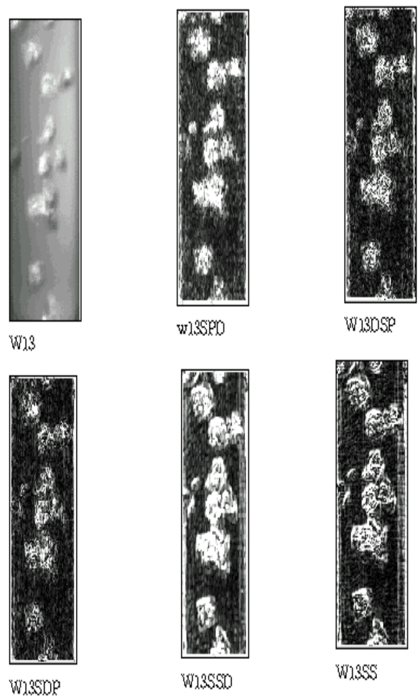


Fig.4 The preprocessing of the bubbly flow

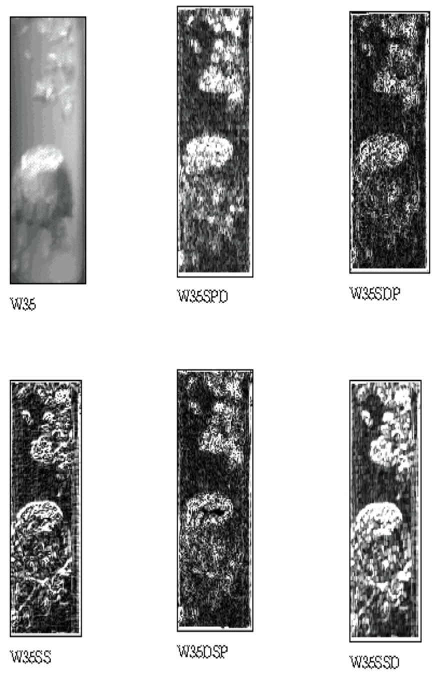


Fig. 5 The preprocessing of the slug flow

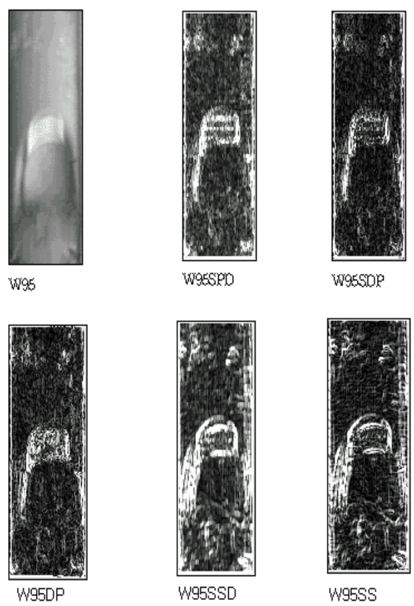


Fig. 6 The preprocessing of the slug flow

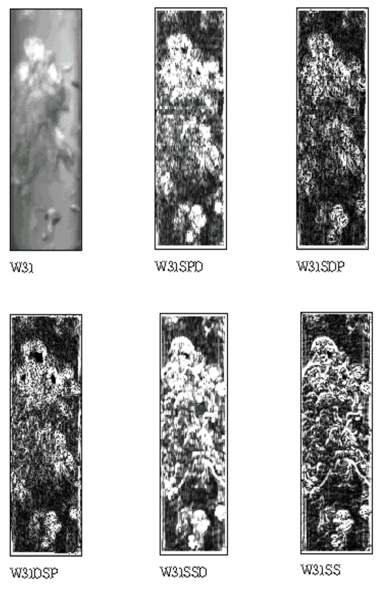


Fig.7 The preprocessing of the churn flow

4.2 Void fraction

After detecting edge with the proper algorithm, the background noise is removed using the thresholding process and the inside pixel of the edge boundary is counted for the void fraction. The local distribution of the void fraction was measured using the algorithm developed here. In Fig.8, The local distribution of the void fractions are represented. The original image in Fig.9(d) is processed by the SS and SD algorithms. The heuristic measurement is made in FIg. 9(a) and it is plotted in Fig.8 as a W13_0. The distribution shows nealy flat but has a peak at the center. The SS algorithm shows under prediction in the left part because the bubble near the left wall is not detected well, but normally over predict within 5% in this area. SD algorithm has the effect of dilatant effect so that the left side void fraction is better predicted than the SS, but normally over predicts it.

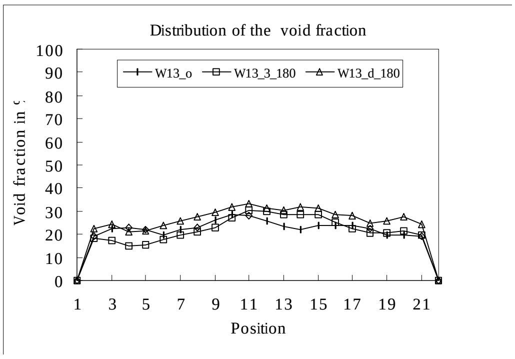
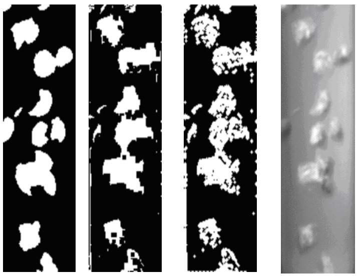


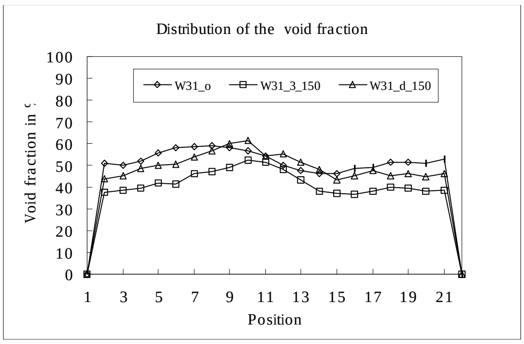
Fig 8. The local distribution of the void fraction in the bubbly flow regime



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

Fig 9. The results of image processing to get the information of the void fraction

Identification of bubbles in the churn turbulent regime is quite difficult, so the heuristic determination of the bubble boundary has large error basically. The void fraction measure from the processed data is in FIg. 10 and The original image and processed image are presented in FIg.11. The error at the center part is small but near the wall, the relative error could be 20%. But the void peak in the left side near the center is measured from any edge detecting algorithm. So the image processing using the computerized digital image processing could be useful to measure the void fraction.



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

Fig 10. The local distribution of the void fraction in the bubbly flow regime

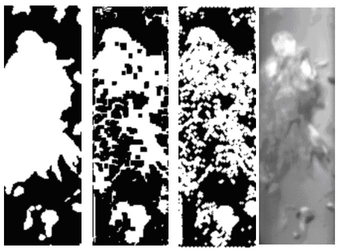


Fig 11. The results of image processing to get information of the void fraction

4.3 Interfacial area concentration

The interfacial area concentration could be easily measured by counting the numbers of pixels on the boarder of edge. To get the local value, the image is divided by several regions and the pixels corresponding to the edge is counted for local distribution. As expected, Interfacial area concentration strongly depends on the shape of bubbles, The twice use of Sobel algorithm is near the heuristic measure as shown in Fig.12. As shown In Fig.13(c), dilatant algorithm enlarge the noise pixel and make the system count it as bubble. Especially at the right side of wall, there are many spurious dots are generated and results in the over prediction. The dark bubble at the left wall is not correctly measured and causes the under prediction in the void fraction. The noise near the wall contributes the over prediction of the interfacial area.

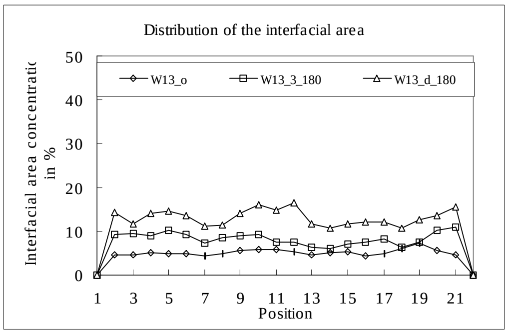
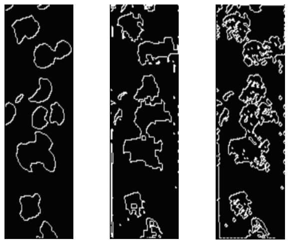


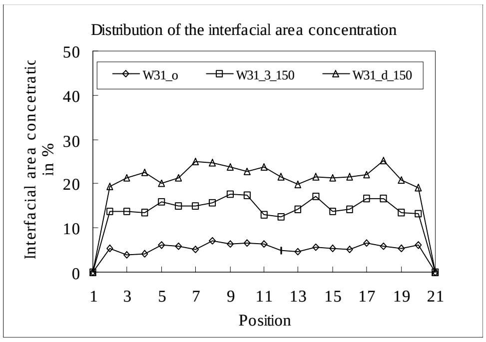
Fig 12. The local distribution of the void fraction in the bubbly flow regime

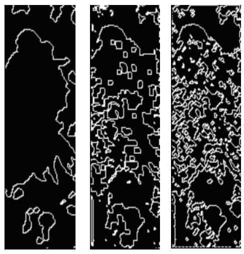


(a) (b) (c)

Fig 13. The results of image processing to get information of the void fraction

The discussion on the churn flow is difficult because the heuristic measure of the interfacial area is inaccurate. The complex structure of bubble agglomeration prevents us from generating the interfacial structure. As expected, the interfacial area concentration strongly depends on the edge detection algorithm. The evaluated data by counting the number of pixels are presented in Fig.14. In Fig. 15, the heuristic measure (a), SS (b), and SD (c) are presented. There are large deviation among measures. To evaluate the algorithm, another measure like the chemical method using the volatile material is required. In Fig.14, the SS algorithm shows middle data in between the heuristic measure and the SD measure. SS could be recommendable for the two-phase flow analysis.





(a) (b) (c)

Fig 14. The local distribution of the interfacial area concentration in the churn flow regime

Fig 15. The results of image processing to get the information of the interfacial area

5. Conclusions and Future Studies

In this study, the digital image processing technology is applied to the two-phase flow analysis. A PC-based image handling system is constructed with the Camcoder and image capture board with the PC. The software to capture and to process the image is developed. It was found that combination of the first derivative convolution edge detector works efficiently for two-phase flow. The void fraction and interfacial area concentration are successfully detected. From the above discussions, the image processing could be a useful tool to measure two-phase flow.

Acknowledgements

This work is supported by the Ministry of the Science and Technology in Korea.

References

[1] A. Serizawa, I. Kataoka, and I. Michiyoshi, Turbulence Structure of Air -water bubbly flow, I. Measuring Techniques, Int. J. Multiphase Flow 2,221 (1975)

[2] A. Serizawa, I. Kataoka, and I. Michiyoshi, Turbulence Structure of Air -water bubbly flow, II. Local Properties, Int. J. Multiphase Flow 2,221 (1975)

[3] A. Serizawa, I. Kataoka, and I. Michiyoshi, Turbulence Structure of Air -water bubbly flow, III. Transport Properties, Int. J. Multiphase Flow 2,221 (1975)

[4] M. Ishii and K. Mishima, Study of Two-Fluid Model and Interfacial area, Argonne National Laboratory Report ANL-80-111, NUREG/CR-1873 (1980)

[5] Kalkack-Nabaro, Lahey, RT, Jr. Drew, D.A, and Meyber,R, " Interfacial Area Density, Mean Radius and Number Density Measurement in Bubble Two-Phase Flow, " Nucl. Eng. & Des. Vol 142, (1993) pp.341-351

[6] I. kataoka and M. Ishii and A Serijawa, " Sensitivity Analysis of Bubble and Probe Geometry on the Measurement of Interfacial Area Concenntration Gas Liquid Two-Phase Flow

[7] Jae Young Lee and Hee Cheon NO, " Local Chemical and Thermal-Hydraulic Analysis of U-tube Steam Generator, Nucl. Eng. and Des.