Development of Two-Directional Image Processing Algorithm to Measure Bubble Size and Volume in Two-phase Flow

Seong-Jin Kim,[a] Goon-Cherl Park [b]

a Nuclear thermal hydraulics engineering laboratory, Department of Nuclear Engineering, Seoul National University, San 56-1, Sillim-dong, Kwanak-gu, Seoul, 151-742, Korea, nannaya2@snu.ac.kr

b Nuclear thermal hydraulics engineering laboratory, Department of Nuclear Engineering, Seoul National University, San 56-1, Sillim-dong, Kwanak-gu, Seoul, 151-742, Korea, parkgc@snu.ac.kr

1. Introduction

Recently, Digital Image Processing (DIP) has been focused as the method for the analysis of two-phase flow such as subcooled boiling phenomena. Specially, in many studies on the measurement of the bubble size, DIP with high speed camera technique [1,2] is used. In the previous studies, the images were taken in one-direction and were considered as an axisymmetric object such as a sphere to calculate the volume or equivalent diameter. However, since the object has the three-dimensional degrees of freedom, one-directional image processing is limited to axisymmetric objects. In this paper, to overcome this limitation of one-directional image processing, the simple algorithm was developed using two images for a same object in an orthogonal direction. The main structure of algorithm based on an active contour model is the reconstruction into three-dimensional objects from two images. The developed two-directional image processing is applied to the virtual bubble images.

2. Developed Algorithm and Results

2.1 Active Contour Model

To measure the bubble size and volume from the images, boundaries between backgrounds and bubbles should be discriminated. It means that the extraction of bubble edges should be preceded. The active contour model is used to decompose or segment visual information into the concerns and their background part of objects, which is called as snake model and first proposed by Kass [3]. The snake is an energy-minimizing spline guided by external constraint forces and influenced by image forces that pull it toward features such as lines and edges. Fig. 1 shows the concept of the snake where the arrows represents the moving directions of snake's points towards the borders of the analyzed object. The proposed energy function is given by the integral equation (1)

$$E_{snake} = \int_0^1 \left[E_{\text{int}}(v(s)) + E_{ext}(v(s)) + E_{image}(v(s)) \right] ds \quad (1)$$

The position of the snake is described parametrically by $v(s) = (x(s), y(s))$. E_{int} represents internal potential energy of the contour and E_{ext} is the energy which models external constraints imposed onto the contour shape. E_{image} represents the energy derived from image features, such as image brightness distribution. In this paper, the central contour model proposed by P. Szczypiński and P. Strumiłło [4], was used to extract the boundary edges.

2.2 Description of the Developed Algorithm

The developed algorithm to reconstruct object from two images has some assumptions. It is assumed that two images are positioned at an orthogonal plane. Therefore one image is on the xz-plane and the other is on the yz-plane. It is assumed that those images are silhouettes of objects to each planes, also. The concerned object is considered as what it has two contact points with planes, which are parallel to xy-plane. The contact points are positioned at the top and bottom of a cuboid including object as shown in Fig. 2-(a). Then, the silhouettes of xz-plane and yz-plane have two points of contact with line with lines, which are parallel to x-axis and y-axis, respectively. Those points are positioned at the top and bottom of a rectangle including projected images. The top point of contact with the cuboid is corresponding to that with the rectangle in xz and yz-plane. Similarly, The bottom point of contact with the cuboid is corresponding to the bottom point of contact with the rectangle in xz and yz-plane. These assumptions are used to constrain two images.

Under the mentioned assumptions, each boundary edge is extracted by the snake. Using each height of two rectangles, image scales are calibrated to have a same height. At this time, the snakes for image projected on xz-plane don't have y-coordinates information, and snakes of silhouette on yz-plane don't x-coordinate information. The y-coordinate information of snake in xz-plane could be obtained from the snake on yz-plane. That is, the y-coordinate of snakes in xz-plane becomes the y value of corresponding to z-coordinate in the line connecting two contacting points on the parallel lines with y-axis as shown in Fig. 2-(b). As the same way, the x-coordinate of snakes in yz-plane becomes the x value of corresponding to z-coordinate in the line connecting two contacting points on the parallel lines x-axis. It is shown in Fig. 2-(c). Then four points could be found on one plane which is parallel to xy-plane. It is assumed that four points are positioned at the ellipsoidal boundary. Then the volume of bubble is calculated by stacking ellipsoidal area and the equivalent diameter is calculated by calculated volume.

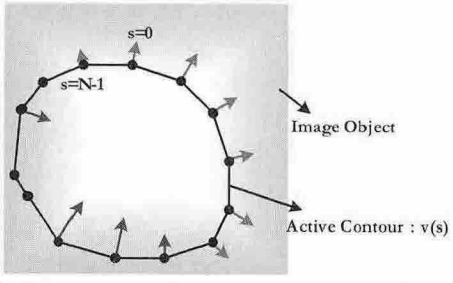

Figure 1. Construction of an active contour model.

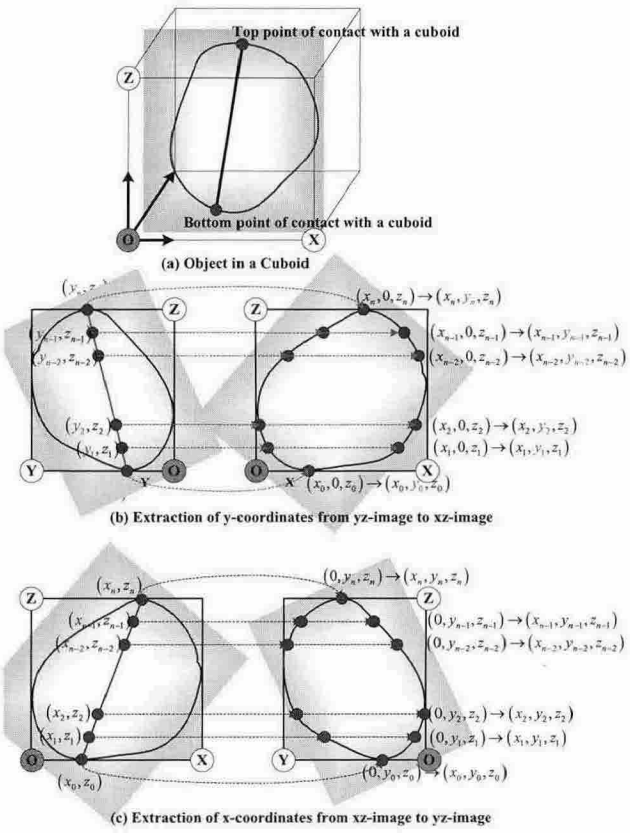

Figure 2. Descriptions of the developed algorithm to reconstruct two images.

2.3 Reconstruction Results

Two virtual bubble images on xz-plane and yz-plane, are selected as shown in Fig. 3-(a). Fig. 3-(b) shows the reconstructed three-dimensional image from two-images using developed algorithm. The reconstructed images can present more accurate information such as bubble volume and equivalent diameter than one image.

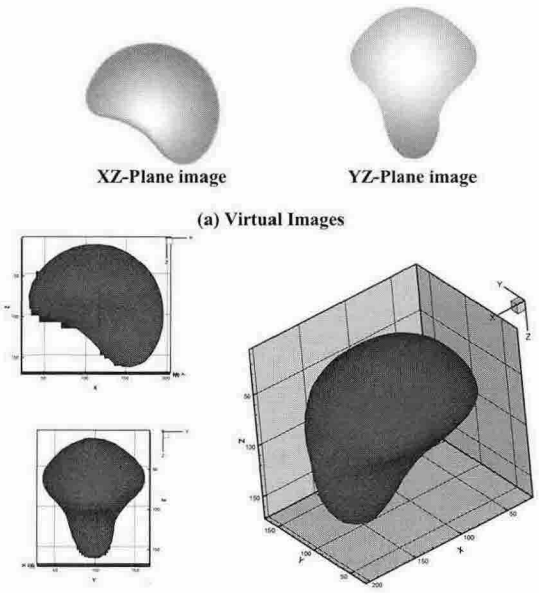

Figure 3. Virtual images and reconstructed three-dimensional image using developed algorithm.

3. Conclusion

The algorithm was developed to reconstruct two images into three-dimensional image. The limitation using one directional image processing was overcome by taking and reconstructing two orthogonal images. The analysis of the reconstructed image by the developed algorithm will be useful to obtain more accurate volume of the bubble and equivalent diameter.

REFERENCES

[1] Rong Situ, et. al., Photographic Study of Bubble Behaviors in Forced Convection Subcooled Boiling., International Journal of Heat and Mass Transfer, Vol.47, pp.3659-3667, 2004.

[2] Reinhold Maurus, et. al., Automated High-Speed Video Analysis of the Bubble Dynamics in Subcooled Flow Boiling, International Journal of Heat and Fluid Flow, Vol.25, pp.149-158, 2004.

[3] M. Kass, A. Witkin, D. Terauzopoulos, Snake : Active Contour Models, International Journal of Computer Vision, Vol.1, No.4, pp. 321-331, 1988.

[4] P. Szczypiński, P. Strumiłło, Application of an Active Contour Model for Extraction of Fuzzy and Broken Image Edges, Machine GRAPHICS & VISION, Vol.5, No.4, pp. 579-594 , 1996.