B214 液中気泡挙動のファジィ推論に基づく P I V 計測

A novel fuzzy logic PTV measurement of bubble behavior in gas-liquid two-phase flow.

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Abstract

The conventional PIV or PTV systems cannot work well in the measurement of bubbly flow. Neither the gray level cross-correlation method and binary image cross-correlation method nor four-frame PTV can track bubble properly because whole image of each bubble cannot be always recorded due to illumination problem. High velocity and random motion of bubble are also the causes for the problem. The behavior of bubble in image sometimes causes an uncertainty to a degree and therefore cannot be measured well by the previous PIV methods. Fuzzy logic has proven to be a simple and robust method for process control. In this paper, the fuzzy logic has been applied in the measurement of bubbles in a gas-liquid two-phase flow. Two frames of digitally recorded, single exposure particle images are used. The purpose of current research is to establish a novel PTV method based on fuzzy logic to measure the bubble behavior from bubble images with uncertainty.

Fuzzy logic and Fuzzy PTV

Fuzzy logic was emerged as a profitable tool for the controlling subway systems and complex industrial process and it is used very widely now, such as in household and entertainment electronics, diagnosis systems and other expert systems. The principles of fuzzy logic have been used in many fields of the image processing and pattern recognition, such as image enhancement, image segmentation and image classification. In the present research we try to apply the fuzzy logic in Particle Tracking Velocimetry (PTV), especially in the tracking the motions of the bubbles and particles.

The fuzzy PTV is based on the following assumption. If two particles in the first image are close enough, then the pair of vectors that looks the most similar must be the correct pair of displacement vectors for these two particles. It is a very reasonable assumption from the continuity of a flow field. There are four inputs to the fuzzy PTV processor for each vector pair: the difference of two vectors (δV); the different of sizes of two vectors (δS); the distance between the vector midpoints in pixel ($Dist$) and the difference of particles' areas (δA).

$$\delta V = |\vec{V}_1 - \vec{V}_2| \quad \delta L = \left| |\vec{V}_1| - |\vec{V}_2| \right| \quad \delta A = |A_1 - A_2| \quad (1)$$

Here the standard 50% overlapping triangular input membership functions are used as shown in Figure 1.

Figure 1. Input membership function with 50% overlapped

The output of the fuzzy processor is determined by the four inputs and the fuzzy rule base. The rule base of fuzzy PTV is shown in a matrix format in Table 1. Each input measure has three elements in its fuzzy set: {Small, Med, Large}. Every fuzzy set has a corresponding set of membership functions. The membership functions assign a numeric weight, or degree of membership μ , for all elements in each input measure's respective fuzzy set. The inputs are computed for each vector pair to be analyzed. The fuzzy process output from the rule base is the fuzzy set of confidence in the vector pair. The set of confidence singletons and their associated numerical weights are: {High=0.8; Med=0.5; Low=0.1; None=0.0}. The fuzzy processor output for one pair of vectors is given by:

$$Confidence = \frac{\sum_{i=1}^{N_R} Conf_Out_i \cdot \mu_out_i}{\sum_{i=1}^{N_R} \mu_out_i} \quad (2)$$

Where N_R is the number of fired rules.

Results and Discussion

This method is tested on a pair of computer-generated bubble and particle images. The pair of images represent a solid rotated bubbly flow which has no real physical meanings concerning bubble-liquid flow. The area of particles varies from 1 pixels to 15 pixels and the area of bubble is between 10 pixels to 50 pixel. The images also conclude 15% noise with area from 1 pixel to 50 pixels. The following figure is an example of these kinds of flow fields. The Figure 2 is the corresponding velocity vector map and the result of fuzzy PTV. The vectors with a small circle represent the velocity vectors of bubbles and the others are the velocity vectors of particles.

(a) Original velocity vector field.

(b) The result of Fuzzy PTV

Figure 2. The velocity vector fields

With the Fuzzy PTV, we find out 395 vectors from all 406 vectors, including 48 bubble pairs and 347 particle pairs. There are less than 5 spurious vectors among them. All these statistical numbers show that this Fuzzy PTV is effective and accurate. At the same time, this Fuzzy PTV is very robust because its correct pair ratio is higher than 95% although the images include very high noise (about 18%). Furthermore, the pair ratio will not decrease with the increase of particle image number density. The high pair ratio can also be achieved when the image density is high. The results of medium and high image density are shown in the Figure 3 and Figure 4, respectively. The summary of three tests is listed in Table 1.

Case	N_p	N_b	N_n	N_p'	N_b'	N_p''	N_b''
1	351	55	90	347	48	1	0
2	708	143	122	699	116	2	0
3	1267	188	180	1223	152	0	1

Table 1. The results of three test. N_p , N_b and N_n stand the total numbers of particles, bubbles and noises. N_p' and N_b' are the numbers of found vectors of particles and bubbles. N_p'' and N_b'' are the numbers of spurious of vectors of particles and bubbles.