Three-dimensional simultaneous measurements of a rising microbubble position and flow surrounding the microbubble by a digital hologram

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Abstract Three-dimensional simultaneous measurements of the position of a rising microbubble, and of the velocity field surrounding it, are performed by micro-digital holographic velocimetry. The rising position of the microbubble and the many particles surrounding the microbubble can be reconstructed by a digital hologram. This technique has successfully been applied to the 3-D dynamics of a hydrogen microbubble, in a vertical water channel, that emanates from a platinum electrode by electrolysis. The velocity of the microbubble and the flow of particles surrounding the microbubble are simultaneously obtained.

1. Introduction

Microbubbles are encountered when working in various fields of industrial applications. Their behaviour within the bulk of water has especially been of great interest. In order to study the effect of the flow of microbubbles, techniques such as PIV, PTV, etc. have been employed to investigate their flow and to make related measurements. Naito et al. [1] proposed combining holography with stereo shadow imaging with two laser beams. Their method was established for measuring the velocity of bubbles with micro- and milli-meter sizes. We have previously shown the construction of intensity profile from a holographic image of a microbubble where the profile exhibited two peaks separated by a distance related to the microbubble’s diameter [2]. A 3-D position of a bubble can be determined by the center of the two peaks, and by the center point of the bubble image focused by a digital hologram. This technique has been applied in the determination of rising microbubble position and the 3-D velocity field surrounding the microbubble.

2. Experimental setup

Figure 1 is a schematic of the experimental setup that shows the location of a laser beam from one single source. In this experiment, A Nd:YLF laser (λ = 527 nm) was used as a light source outputting a pair of laser pulses at a repetition rate of 1 kHz, and a pulse delay of 100 µsec. The laser beam was expanded to illuminate the center of a test section. The test section (height = 62 mm, width = 24 mm, and depth = 10 mm) shown in Fig. 1, was made of glass. For this test 40-micron nylon spherical particles were used. The working fluid was a 0.2% NaCl solution in water. In this work, the hologram fringe images were captured through a high-resolution digital CCD camera (IDT NR5S2) without a lens with a resolution of 2336 x 1728 (7 µm / pixel), that captured the images at 1 kHz, and used 1024 x 1024 pixels in the full imaging area. The camera and the laser were synchronized by a pulse generator, and the exposure time was set to 100 µs. The system was design to work with 800 frames using the camera memory with a sampling rate of 1 kHz. Microbubbles with spherical shapes were generated by a potentiostat built into a platinum electrode.
The voltage was set at 3.1V.

3. Results and discussion

The pictures of the fringe image near an electrode are shown in Figs. 2 (a) and (b). The black rod-like shadow in the picture is the electrode 100 µm in diameter. Moreover, it is believed that the stationary fringes were the ones that remained sticking to the glass side. One fringe image above the electrode is shown moving upward from the bottom toward the top. Many such fringes were captured in individual frames. The pictures of the reconstructed images are shown in Fig. 3, where according to the computer hologram algorithm, the positions of the reconstructed particles were determined to be 14.0 mm away from the CCD surface. For the final picture, the stationary fringes in Fig. 2 representing the electrode were removed. Figure 4 shows hologram images of the microbubble and of the seeding particles flowing into the observation region. For this picture, the images of two fringes were chosen and marked by circles as points A and B. Figure 5 shows distributions of digitally reconstructed profile representing the microbubble and seeding particles flowing into the observation region [1]. Figure 5 (b) shows a seeding particle presenting a peak resulting from its intensity profile. Figure 5 (a) shows that a microbubble presenting two peaks, and those also result from their intensity profiles. Two peaks in the reconstructed intensity were also identified in our previous result [1]. Figures 6 (a) and 2 (b) are the reconstructed images from the two frames. The microbubble that is shown above the platinum electrode is made by digital reconstruction [2]. The diameter of the micro bubble remained approximately within the neighbourhood of 140 µm. The velocity and the diameter obtained from the reconstruction image, and flow parameter gave the estimated values in terms of non-dimensional numbers, where the bubble’s Reynolds number was approximately 1.67, and the Eotvos number was 2.67x10³. From the estimation by Clift et al. (1978) [3], these values are distributed in a spherical shape. Therefore, the microbubble is drawn in form of a sphere for 3-D visualization. The figure also shows the reconstruction of particles. The number of seeding particles is approximately 500. The
reconstructed volume is $8 \times 8 \times 10 \text{ mm}^3$. Almost all particles are uniformly distributed surrounding the microbubble. It can be seen that starting from the bottom the flow is upstream; and that the velocity of the microbubble can be obtained from the two images and found to be approximately 10 mm/sec. The seeding particles on the images do not dramatically change because their flow speed is slower than that of the microbubble. The obtained instantaneous 3-D velocity vectors from the three visual perspectives are shown in Fig. 7, although we photographed the time evolution of these vectors for 0.8 second (not shown). It can be seen that the flow is moving upward, and the quick flow arises especially in the upper part of the microbubble. This is a flow which is made the rising microbubble and it arises. Moreover, the vector distribution around the rising bubble is higher than in any other domain. The reason is the flow induced by the rising bubble only exists. This is because only the existence of the rising bubble causes the flow. The instantaneous velocity vectors on the images do not drastically change because the flow speed is relatively slow. An average of 100 instantaneous velocity vectors was obtained from the 500 particles reconstructed.

![Figure 2](image)

Figure 2 Fringe images of a rising microbubble; (a) $t=279\text{ msec}$, (b) $t=379\text{ msec}$
Figure 3  Reconstruction of a rising microbubble and particles; (a) $t=279 \text{msec}$, (b) $t=379 \text{msec}$

Figure 4  Hologram images of a rising microbubble and particles; $t=279 \text{msec}$
Figure 5 Distributions of reconstruction profile (a) Micro-bubble A, (b) Seeding particle B

Figure 6 A rising microbubble and particles surrounding the microbubble; (a) t=279msec, (b) t=379msec
Figure 7 Vectors of a rising microbubble and particles between $t=279\text{msec}$ and $t=379\text{msec}$

4. Conclusions
In this paper, the reconstruction of a rising hydrogen microbubble was obtained by a digital hologram. Profiles of seeding particle were also obtained by the digital hologram. The simultaneous measurements of the bubble and the seeding particles were performed. The interaction between the microbubble and flow around its bubble can be observed by the reconstructed image. This technique will also apply to a similar rising bubble such as boiling bubble.

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5. References