Volumetric reconstruction of particulate dispersions from a light field image by means of a plenoptic camera

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For the whole field PIV (Particle image velocimetry) techniques, instantaneous and volumetric recording of the dispersed tracer particles is required. Holographic PIV is the optical method that captures the depth information of the particle locations, the method, however, has difficulty in recording the consecutive several images. Tomographic PIV is 3D3C and time-resolved velocimetry technique that employs the multiple cameras in order to recover the depth information of the particles that was lost by the planar sensors, therefore the method suffers from a painful calibration between physical domain and sensor coordinates due to the multiple cameras. Recently, the light field camera that employs only one sensor with a microlens array. In contrast to the multi-camera technique, optical system of the light field imaging system was drastically simplified. The camera employs the microlens array in the vicinity of the sensor. By the characteristic structure, the image from the multiple angle of view could be captured by the single light field camera instead of the multiple pair of the sensor and lens. From the multiple angular images, the camera could get the depth information and the focal plane could be adjusted as the post processing by the computer, which enables to refocus the particles after the image acquisition, i.e. the volumetric particulate field can be reconstructed for the PIV or spray diagnostics. This paper firstly reports the concepts of light fields and plenoptic photography which is followed by the demonstrations of the volumetric reconstruction of particulate fields from a light field image. Effective spatial resolution is discussed.

Light field imaging and volumetric reconstruction of particulate field

The conventional PIV technique measures the velocity field of fluid flow in two spatial dimension with two velocity components. Stereo-PIV is the 2D3C measurement with two cameras from different directions using laser sheet as a light source. Holographic PIV allow the reconstruction of the position of the particles in the three-dimensional space using a principle of the holography. The method, however, requires delicate optical setup and has difficulty in recording the successive images. Tomographic PIV (Elsinga 2006) is the recently developed 3D3C and time-resolved velocimetry technique that employs the four cameras in conjunction with the algebraic reconstruction technique (ART) (Gordon 1974) for the determination of the three dimensional particulate field. However, the measurement system tend to be complicated and in the actual measurement, the optical access is restricted in a limited viewpoint including the internal flows such as the I.C. engine, the complexity of calibration as well. By this technique, the notable limitations of the aforementioned techniques was overcome by using a light field camera. Figure 1 depicts the simplified optics of the camera. Although the conventional imaging system could not record the approaching angle of rays, light field camera enables to record the additional angular information of ray so that the focal plane of the image could be adjusted after the image acquisition and could generate images from multi-angle of view as well. The study develop the reconstruction method of the volumetric image from a captured light field image by ray-trace technique and demonstrates the three-dimensional reconstruction of the volumetric particulate field.

**Fig. 1** Optical arrangement of the plenoptic 2.0 system. Rays from the particle pass through the main lens and microlens arrays.

**Fig. 2** Three dimensional view of instantaneous particle images. Colors represent the depth location in mm.

Figure 2 is the example of the reconstructed particle field. Physical dimension of volume is 19.8 x 19.8 x 4.62 mm. The volume is discretized into a grid of 450 x 450 x 105 voxels. The 200 particles were present in the test section and each particle size is equal to a voxel size. The particle fields were reconstructed after 20 iterations of MART using a relaxation parameter of 0.6 and the calculation time is 300 sec approximately. In the present optical configuration, the resultant spatial resolution is 44 μm, that is equal to 1 voxel, in x-y plane, whereas 176 μm in z direction that is equal to 4 voxel. The deviation of the centroid position of the particle is 9 voxels. From the several comparison of the image reconstruction, it was found that the effective spatial resolution was significantly affected by the f number of the main lens. Under the larger N.A., i.e. the smaller f number, the depth resolution could be increased, total depth of field, in contrast, was decreased. By the present investigation, the trade-off relation between depth of measurement volume and spatial resolution was clarified and the relation should be optimized for the particle image velocimetry by noting the spatial scale or structure of the fluid flow.

**References**
