Society of Engineering Science 51st Annual Technical Meeting

1–3 October 2014

Purdue University, West Lafayette, Indiana, USA

Error sources in three-dimensional microscopic light field particle image velocimetry

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ABSTRACT

Three-dimensional (3D) microscopic velocimetry methods have been increasingly developed in recent years to meet the measurement demands of microfluidic systems. As all 3D microscopic velocimetry techniques involve reconstructing a volume from two-dimensional (2D) sensor(s), sources of uncertainty arise that are unique from 2D velocimetry methods. This study discusses the error sources associated with a recently developed microscopic light field particle image velocimetry (LFPIV) method. The LFPIV technique combines altered optical hardware with postcapture computation to reconstruct 3D volumes. A microlens array placed at the intermediate image plane of an infinity corrected objective captures the directionality of light rays, which may then be reparameterized to form a 3D focal stack. The error sources of LFPIV are typical of image-based 3D reconstruction. We group these errors into four categories: experimental setup, calibration, 3D reconstruction, and velocimetry. All 3D microscopic particle image velocimetry methods introduce additional complexity into the experimental setup and the particular challenges of LFPIV will be highlighted. Calibration errors arise from imperfect mapping between the 3D world and LFPIV instrument (optics and computation inclusive). The most unique error source in 3D velocimetry methods stems from 3D reconstruction. Objects are typically estimated with large error on the depth dimension. We discuss the magnitude of this error for LFPIV and its dependency on instrument design. Methods for improving reconstruction quality, such as 3D deconvolution and focus-based thresholding, are assessed. Most importantly, the impact of these error sources on uncertainty, accuracy, and resolution of velocity measurements is quantified using data from a microchannel flow field, a numerical model and simulated data. Comparisons to existing techniques are made whenever possible.