On the development of a novel low cost high accuracy experimental setup for Tomographic Particle Image Velocimetry

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This work deals with the critical aspects related to reducing the cost of a Tomo-PIV (Elsinga et al. 2006) setup and with the bias errors introduced in velocity measurements by the coherent motion of ghost particles (Elsinga et al. 2010).

The basic idea for reducing the cost of the Tomo-PIV system is the use of two imaging systems composed by three (or more) low speed single frame cameras. In the authors’ knowledge, in all the Tomo-PIV experiments performed until now, double-shutter or hi-speed cameras are employed as in planar PIV; however, the requirement of double shutter cameras in planar PIV, due to the need to acquire two separate images from the same point of view for the image correlation, ceases to exist in a Tomo-PIV setup. In fact, as previously said, the particle displacement (hence velocity) within a chosen interrogation volume is obtained by the 3D cross-correlation of the reconstructed particle distributions corresponding to two subsequent exposures. The particle distributions can be reconstructed from images acquired from several viewing directions by a different set of cameras at each exposure. Thus, while three double-shutter cameras are required (at least) for the reconstruction of a certain velocity field, the approach proposed in this work requires the use of two (or more) imaging systems composed by three normal (single shutter) low-cost cameras.

It has to be remarked that another easy implementation could be the use of two double shutter cameras (available in all the labs that perform Stereo-PIV experiments) together with two single shutter cameras obtaining two imaging systems composed by the two double shutter cameras and by the first and the second single shutter camera for the first and the second exposure, respectively.

The accuracy of the proposed experimental setup is not expected to be compromised. In fact, considering the experimental setup with 3+3 single shutter cameras (each of the volumes is reconstructed by only three cameras, while using six cameras in total), this approach is expected to result in much more accurate estimate of the velocity fields with respect to the simple adoption of three double shutter cameras because it is less affected by the effects of ghost particles since their distribution is strongly camera-orientation dependent. In the proposed approach the ghost particles are not formed in the two subsequent exposures by the same set of actual particles, so they are expected to randomly contribute in the cross-correlation maps; accordingly, the bias effect is completely removed, at the expense of a reduction of the signal-to-noise ratio.

According to the numerical simulations on 2D synthetic image fields (Fig. 1), with a source density $Ns = 0.25$ the Modulation Transfer Function MTF of the proposed low-cost (LC) system strongly benefits of the high number of true particles, and it is comparable with that of the 6 double shutter cameras (6cam) system, while the MTF of the traditional 3 double shutter cameras (3cam) system is consistently lower (the higher is the source density, the higher is the number of ghost particles; accordingly the bias effects are more intense).

For the same reason, the MTE (Novara et al. 2010) is effective independently of the flow features (i.e. the velocity gradients in the depth direction: see Novara and Scarano 2011), and the achievable reconstruction accuracy can be comparable to the case of the configuration with six double shutter cameras.

References