Fat-sheet PIV with computation of full 3D-strain tensor using tomographic reconstruction

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A new technique (fat-sheet 'Tomo-PIV') is presented to measure instantaneously the full 3D-velocity gradient tensor in a light sheet plane, which is an important quantity e.g. for turbulent research. So far this tensor has been measured by dual-plane Stereo-PIV, fast scanning PIV (only for slow flows), and with less spatial resolution by 3D-PTV and digital holographic PIV. The experimental setup of Tomo-PIV is similar to Stereo-PIV but using three cameras and a somewhat thicker sheet.

First the intensities of all voxels within the light sheet are reconstructed using a MART tomographic reconstruction algorithm (Elsinga et.al. 2005). Then the volume is split into two parts, z < 0 and z > 0, and for each part a three-dimensional cross-correlation is done to compute two planes of 3C-vectors and subsequently all 9 components of the velocity gradient tensor. First the accuracy of the proposed method computing only a single vector plane is compared to standard Stereo-PIV using synthetic and real data. It is quantified how the spatial resolution and accuracy of Stereo-PIV is limited by the laser sheet thickness and in-plane and out-of-plane flow gradients due to non-identical interrogation volumes for both cameras.

Tomo-PIV does not suffer from this limitation, but has other error sources mainly from imperfect reconstruction due to optical defects. For synthetic data Tomo-PIV has less errors and better spatial resolution than Stereo-PIV especially for thicker light sheet needed e.g. for cross-flow measurements. For real images Stereo-PIV was about a factor of 2 better in low gradient regions.

Then it is shown for synthetic and real data how Tomo-PIV can compute two closely-spaced vectors fields and the 3D-strain tensor using a thicker light sheet. Using synthetically generated images the out-of-plane gradients are measured within 5-10%, for real images within 10-20%. This is similar to what has been reported for dual-plane Stereo-PIV requiring 4 cameras and two double-pulse lasers, where the errors depend strongly on accurate laser sheet profile and position determination.

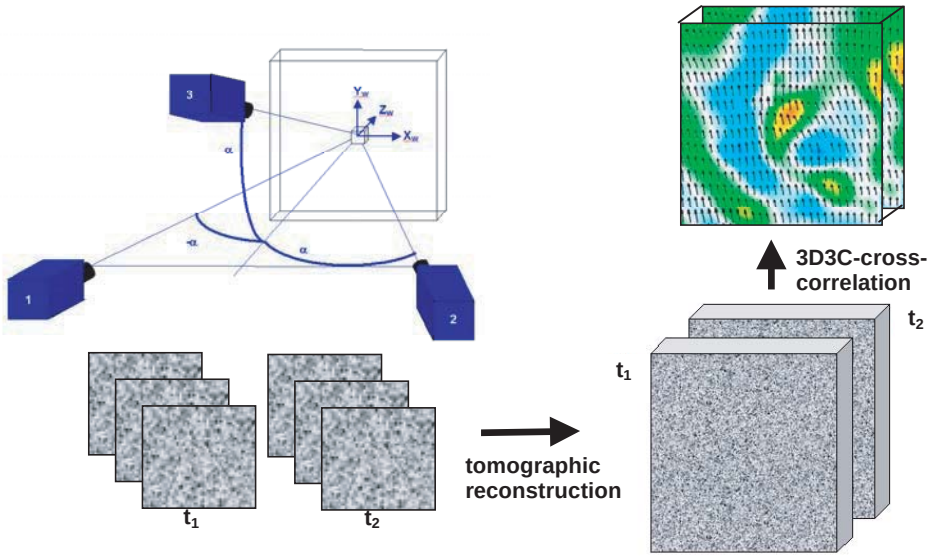

Fig. 1. Computation of dual-plane vector fields by fat-sheet Tomo-PIV.

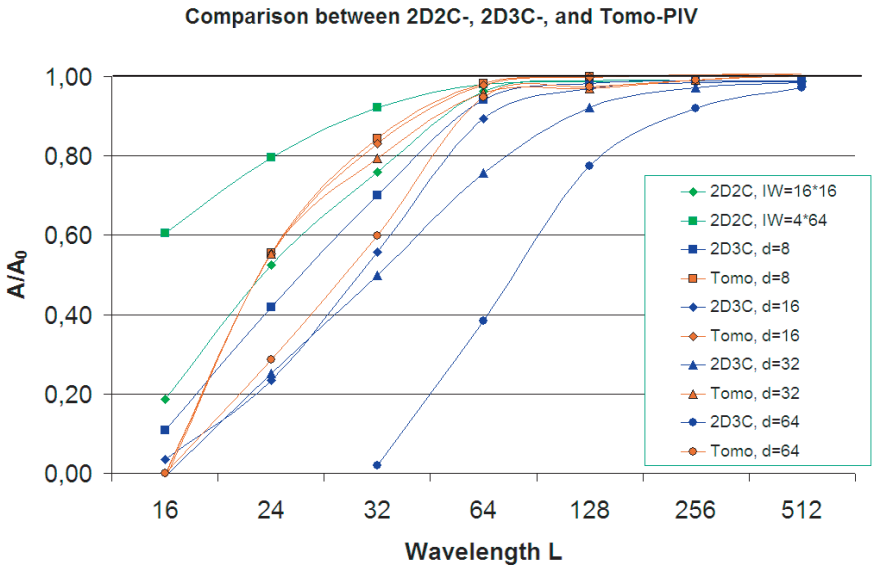

Fig. 2. Reduction in measured amplitude as a function of wavelength L and light sheet thickness d for 2D-PIV (green lines), Stereo-PIV (blue), and Tomo-PIV (red).