Rapid 3D velocity reconstruction from volumetric particle fields via re-slicing and recombination

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3D processing of volumetrically reconstructed particle fields is still a very time-consuming part in 3D-3C velocity field reconstruction. The iterative procedures of multi-pass processing with interrogation volume adaptation and deformation in 3D cross-correlation (3D CC) or 3D Least-Squares Matching (3D LSM) again increase the computational cost extensively. The number of iterations can be largely reduced when an initial guess of the translational particle displacement field is determined with 1st order accuracy. Volumetric particle fields are usually reconstructed from limited number of angular displaced camera orientations with a typical camera number of 4. The reconstruction of a relatively dense particle distribution in a volume from few projections can be modeled as finding the sparsest solution of an underdetermined linear system of equations. Maximizing the sparsity via regularization is an optimization approach and typical values of reconstructed voxels occupied by particles should be or order of 1% of the total voxel volume when the reconstruction with 4 cameras is aimed to reconstruct the original with minimum ghost particle and smearing (Petra et al. 2007). This gives a particle image density of roughly N=0.01ppp. In addition, a constant VGT is assumed in the IV and the following condition must be fulfilled for constructive add-up of individual particle correlation (Soria 2008)

\[ \rho_i - \mathcal{Q}_i + \mathcal{Q}_s \leq (0.5 \text{ particle radius}) \]

where the position \( r \) means the radial distance of the particle from the center of the IV, \( \mathcal{Q} \) the second invariant of the rate of strain tensor and \( \mathcal{Q}_s \) the second invariant of the rate of rotation tensor. Therefore, for particles with a diameter of 3 voxels the maximum slip relative to the average displacement is of order of 1 voxel within the period of \( \Delta t \) to achieve a constructive add-up of the individual cross-correlations. From this condition and the sparsity it becomes obvious, that 2D CC processing of the 2D planar projection images of the particle field in the IV may be useful to circumvent the processing costs of full 3D CC while it may achieve the same quality of the velocity estimation in the different components of the velocity vector. With the above given conditions, the initial guess can be determined in a robust way from the 2D processing of the planar projections of the interrogation volume after re-slicing the voxel volumes in parallel sheets. Total processing time can be speed up about a factor of 20 in comparison to standard processing. An example of the re-slicing and successive 2D processing and recombination as a 3D velocity field is shown in figure 1 and figure 2 for the flow field of a vortex ring obtained in 1 minute processing time on a 4-core CPU for 75,000 vectors.

Fig. 1 Reconstruction of particle image patterns in orthogonal sheets through the center of the voxel space (Brücker et al. 2012). The planar particle images are gained from re-slicing the voxel space with a sheet thickness equivalent to the thickness of the light-sheet in the original recordings (thickness 21\textmu m) and planar projection of the sheet into a planar image.

Fig. 2 Recombination of the velocity data into a 3D velocity grid with equidistant spacing after re-slicing and 2D CC processing in the orthogonal planes (3D streamlines, isosurface of vorticity (green)) and isosurface of streamwise velocity (red)). The vortex core shows the Tsai-Widnall instability as azimuthal waviness.

References
