Low computation cost reconstruction technique for Tomo-PIV

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One of the main challenges of applying Tomo-PIV is high compute resources demands of the data processing stage. Calculation of a single 3-dimensional velocity field can take 30–60 minutes. The main task of this study is optimization of the tomographic reconstruction part of Tomo-PIV in terms of data processing time. A new fast algebraic reconstruction technique – MENT (Maximum Entropy) – is presented in current work.

MENT Reconstruction technique

In contrast to widely spread MART technique, which updates each voxel of the volume at each iteration, MENT technique operates on two-dimensional discrete functions. The number of those functions is equal to the number of cameras. The reconstruction algorithm iterates through pixel arrays and reconstructs those discrete functions. After the iterations are finished the volume is restored in a single pass using the reconstructed functions. The exact formula of both steps are shown below:

\[ h_j^{(i)}(u,v) = \sum_{i=0}^{p} h_j^{(i)}(u,v) \]  

\[ f(x,y,z) = \frac{1}{V} \prod_j h_j^{(i)}(u,v) \]

Here \((x, y, z)\) are voxel coordinates, \((u, v)\) – are pixel coordinates, \(f\) – is the reconstructed volume, \(h_j\) – are special functions which are subject to iterative process, \(p\) – are recorded projections, \(L_a\) – is the line of sight of the corresponding pixel.

Accuracy Comparison using synthetic images

The reconstruction quality and velocity field estimation accuracy acquired using both SMART and MENT were studied and compared. Tomographic reconstruction accuracy was estimated using reconstruction quality criterion \(Q\). Velocity field accuracy was estimated as the value of root-mean-square deviation between the exact and calculated velocity values (total error over the velocity field):

\[ \delta = \sqrt{\frac{1}{n} \sum_{i=0}^{n} (u_{0i} - u_i)^2}, \] where \(u_{0i}\) is real velocity and \(u_i\) is calculated velocity for the \(i\)th velocity vector in the calculated velocity field. All the tests show that MENT scheme performs a bit worse than the MLOS-SMART scheme in average, but the difference in accuracy is rather small and is acceptable considering the expected benefits in computation time. The MENT scheme seems to be about 20% less accurate in tomographic reconstruction, but still preserves the reconstruction quality \(Q\) about 0.7 out of 1.

Fig. 1 Comparison of the reconstruction quality \((Q)\) (a) and the velocity error (b) of different reconstruction techniques. 15 SMART iterations, 1 MENT iteration.

The difference in velocity field accuracy between the two schemes is even smaller – approximately 5-7 % for the low and medium particle concentration rates. The reconstruction time of a single volume with \(N_s=0.4\) was 262 seconds for SMART and 18 seconds for MENT (1 core of Intel Core 2 4300 CPU was used).

MENT-enabled TomoPIV Measurements in a Slot Jet

The proposed reconstruction technique was used in the Tomo-PIV experiment on a turbulent submerged slot jet. Mean velocity profiles in a crosswise horizontal section of the jet at \(X/d = 3\) are shown in Fig. 2. Profiles on the left correspond to the behavior of the measured velocity along the slot in the central plane \(Z/h = 0\). The rest profiles illustrate velocity distribution across the channel on the centerline of the jet \(X/d = 0\). The maximum difference between two techniques is shown by the normal to the wall velocity component \(W\).

Fig. 2 Profiles of all mean velocity components across a channel, \(Z/h = 0\) (a) and along channel depth, \(Y/d = 0\) (b) obtained by SMART (diamonds) and MENT (triangles) algorithms for \(X/d = 3\)

The reconstruction time of SMART (10 iterations) and MENT (1 iteration) in this processing was 149 and 22 seconds, respectively.

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