Accuracy assessment of a Lucas-Kanade based correlation method for 3D PIV

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Tomographic PIV offers a tremendous potential for the characterization of three-dimensional velocity fields. This gain in capacity comes however with new questions and challenges. Research has been carried out towards reducing the problem complexity. Indeed, handling 3D volumes represents a huge amount of data and potentially prohibitive processing times and may constraint algorithm choices. In this article we propose a new approach for 3D cross-correlation, based on a Lucas-Kanade method with gradient-based iterative volume deformation, which is the extension to 3D of the approach of Champagnat et al. 2011. It has a highly parallel structure, is thus very well suited for GPU and has consequently a large potential for important gains in computational times.

Firstly, we recall the general principles of the method, with an emphasis on the useful parameters and their influence. We then use synthetic tests to propose a characterization of the algorithm in terms of spatial resolution, and to assess the impact of interpolation schemes used during volume deformation on bias and rms errors. Finally we assess the algorithm’s robustness to noise, especially tomographic PIV noise, ie ghost particles, by using synthetic simulations of 3D tomographic PIV experiments and comparing it to the state-of-the-art (LaVision Davis 8.2 with direct-correlation).

Finally, the influence of the shape of the reconstructed particles, linked to the geometrical arrangement of the tomographic setup is considered, together with the different responses of the interpolation schemes.

General principle

The present implementation is the extension to 3D of the algorithm FOLKI-PIV, described in Champagnat et al. (2011). Considering a discretized physical volume, let k denote the index of a voxel in the grid. As in traditional correlation-based PIV, our objective is to determine the displacement u(k) of a particle pattern contained in the interrogation volume (IV), V(k) centered around voxel k. The mathematical objective however differs and belongs to the Lucas-Kanade paradigm (see Baker and Mathews, 2004, for a review), as it amounts to minimize the sum of squared differences (SSD):

$$u(k) = \arg \min_v \sum_m v(m-k) \left( m - \frac{u(k)}{2} \right)^2 - E \left( m - \frac{u(k)}{2} \right)^2 \right)$$

(1)

To achieve this objective, an iterative approach is used, with similarities to traditional volume deformation methods (Scarano 2013). Two different interpolation schemes are available to perform the deformation: the standard, linear one, and a cubic B-Spline scheme. Use of the latter is made possible in the 3D context while maintaining reasonable computational times, thanks to the recent optimization performed by Champagnat and Le Sant (2013). In this study, we will thus also assess the gain achieved with this higher-order interpolation, in particular in situations with important tomographic noise.

Synthetic tests and results

We perform synthetic tests to assess the performances of FOLKI3D. In a first part, 3D blob-like Gaussian ideal particle distributions are generated to determine the spatial resolution of the algorithm (as introduce in Scarano and Riethmuller 2000), as well as the impact of the interpolation scheme in the volume deformation step on the subvoxel accuracy. In a second part, the algorithm’s robustness towards tomographic noise, ie ghost particles, is assessed, by considering reconstructions obtained from synthetic images. The impact of coherent ghost particles in the reconstructed field is studied, by considering shearing motions, as in the of Elsinga et al. (2011). We then compare the algorithm performances to that of Davis 8.2. Fig 1 shows an example of velocity error as a function of the interrogation volume radius R (half of the IV side), for both algorithms, together with error obtained by FOLKI3D on ideal volumic distributions. It is observed that the Lucas-Kanade approach using a B-Spline interpolation indeed guarantees very accurate results.

In the paper, this gain is also confirmed by considering various values of camera apertures, corresponding to different quantities of ghosts and to more or less elongated particles in the reconstructions.

References