3D RECONSTRUCTION OF THE DENSITY FIELD OF A JET USING SYNTHETIC BOS IMAGES

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ABSTRACT: Background Oriented Schlieren (BOS) is an experimental technique whose goal is the reconstruction of the density field of any transparent flow through the resolution of an inverse problem. The basic BOS observable is the deviation of a light ray across a flow of varying optical index. More precisely, the deviation is measured as the difference, in pixel unit, between the two pixels of the CCD camera hit by the same ray without or with the presence of the flow of interest. These differences can be estimated for all pixels of an image thanks to optical flow techniques [1]: the set of all such measurements is called a projection. In fluid research, the density is a fluid property that can not be observed directly, yet it is related to the optical index via the Gladstone-Dale equation. The measured angle of deviation is then the integral of the density gradient along the optical path. Here we rely on the paralaxial approximation in which the optical rays are considered as straight lines even in the presence of the flow. After discretization, one has to solve an inverse problem $Ax = y$, with y the measured angles of deviation for all available projections and x, the unknown 3D density field, both being casted as (high dimensional) 1D vectors. The observation matrix, A, is essentially the composition of a tomographic projection matrix with a 3D gradient operator. While 2D and 3D-axisymetric cases had been successfully solved using only one projection, the general 3D case requires several projections in order to define correctly the solution. Yet, in practical experimental setups the use of hundreds of projections, as used in conventional computed tomography (CT), is prohibited. In his PhD thesis, [2] I. Ihrke is the first to design a 3D BOS experiment and to reconstruct the flow, however in a way that is more qualitative than quantitative.

Our objective is to reconstruct an instantaneous 3D density field with a good accuracy using only a limited number of views. The resulting inverse problem is not only ill-posed but severely under-determinate, hence its resolution requires regularization. We propose to use a variable splitting (VS) formulation, with regularized criterion

$$J(x,v) = \|Ax - y\|^2 + \alpha R(v) + \beta \|x - v\|^2 \quad ,$$

where $R(v)$ is a regularization term. J depends on two set of variables related one to the other through a quadratic coupling penalty. This formulation allows to derive alternate descent schemes on x and v, and can be considered as a justification of iterative fit/smoothing empirical strategies such as the one presented in [3]. While the proposed formulation can be used for various regularization functional R, a basic problem is to efficiently solve the separable quadratic regularization case. Conventional solvers do not seem adequate to such a huge problem. So, following the work of Pan et al. [3], we propose a SART-type algorithm implemented on Graphic Processing Units (GPU). The resulting software is validated on synthetic BOS images of a 3D density field issued from numerical calculation. The effect of using a limited number of projections for various Signal to Noise Ratio (SNR) is studied in order to evaluate the expected performance of the software on a real 3D BOS experiment.

References

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