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Lagrangian Analysis applied to High-Speed Tomographic PIV

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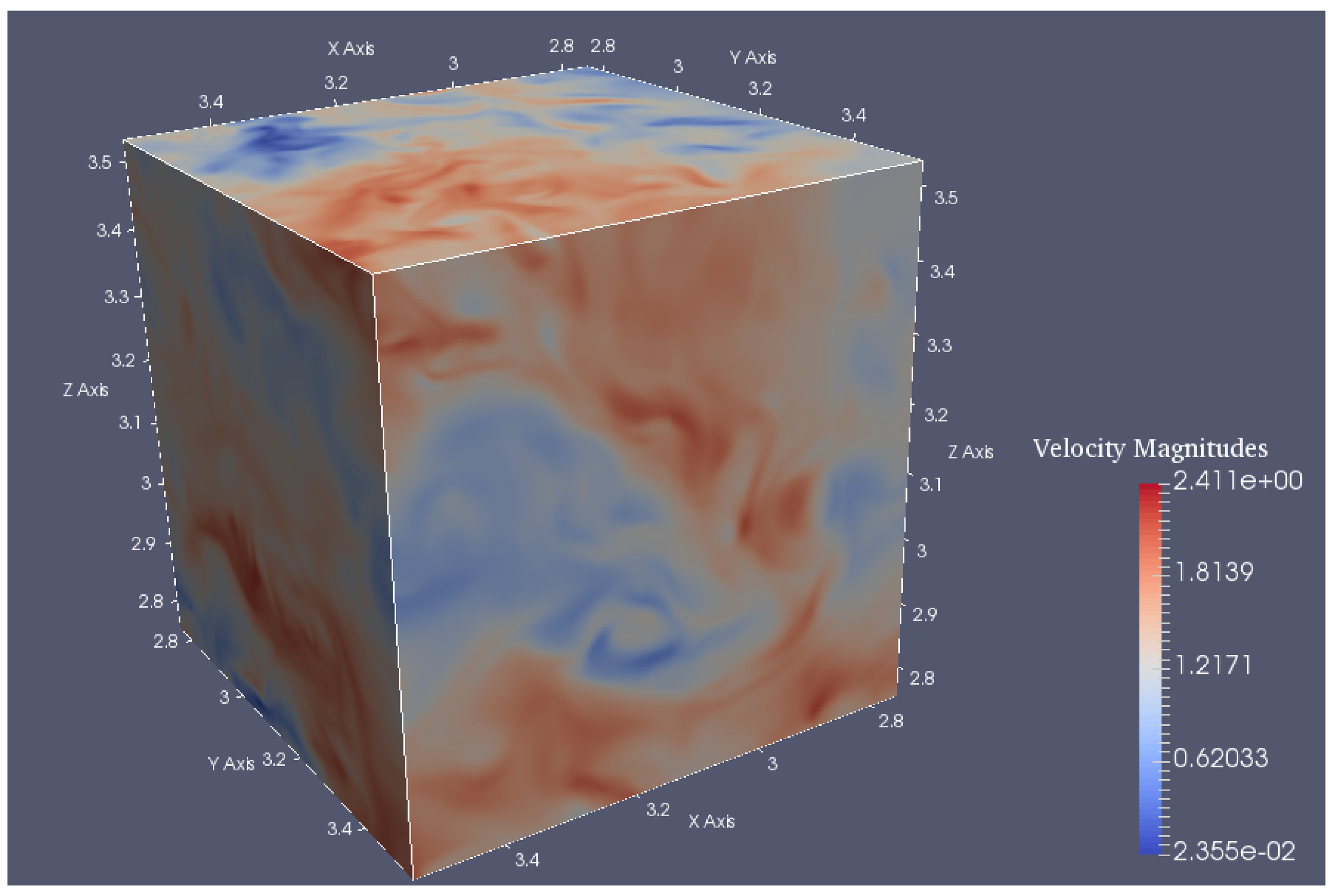
Abstract

We are investigating the feasibility of Lagrangian analysis of time-resolved 3D velocity fields in turbulent flames obtained using high-speed tomographic particle image velocimetry (PIV). Errors associated to the spatial and temporal resolutions of the experiment were evaluated using a direct numerical simulation (DNS) of an isotropic turbulent flow. An algorithm for Lagrangian analysis was implemented in MATLAB and consisted in tracking virtual particles introduced at random locations in the flow. The coarse resolutions of an experiment results in modest velocity and larger vorticity errors.

Introduction

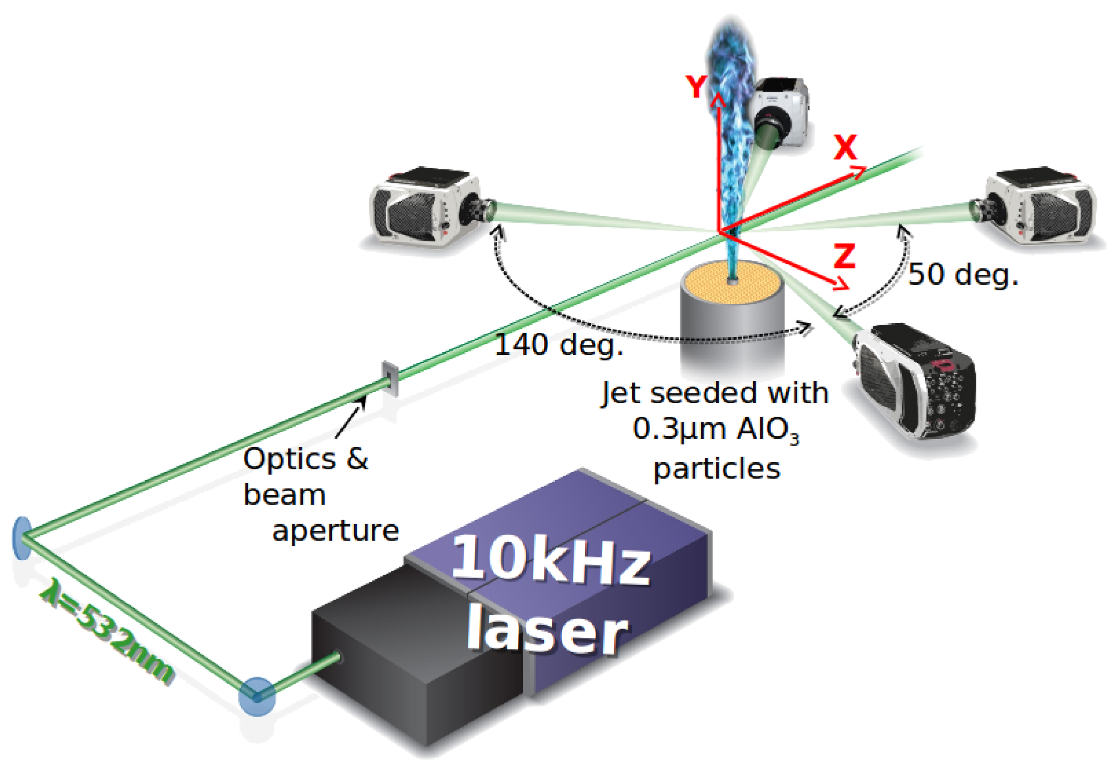
Understanding turbulence in flames is extremely important in order to design and build advanced combustion systems for power generation and propulsion. There are two ways of computationally studying turbulent dynamics – an Eulerian and a Lagrangian approach. In the Eulerian frame of reference, turbulence is analyzed at given points in a domain as time progresses. In the Lagrangian frame of reference, fluid properties are studied along the trajectories of virtual particles that are transported by the flow. This project aims to implement a Lagrangian particle tracking algorithm onto an experimental tomographic particle imaging velocimetry (TPIV) system.

DNS of Isotropic Turbulence



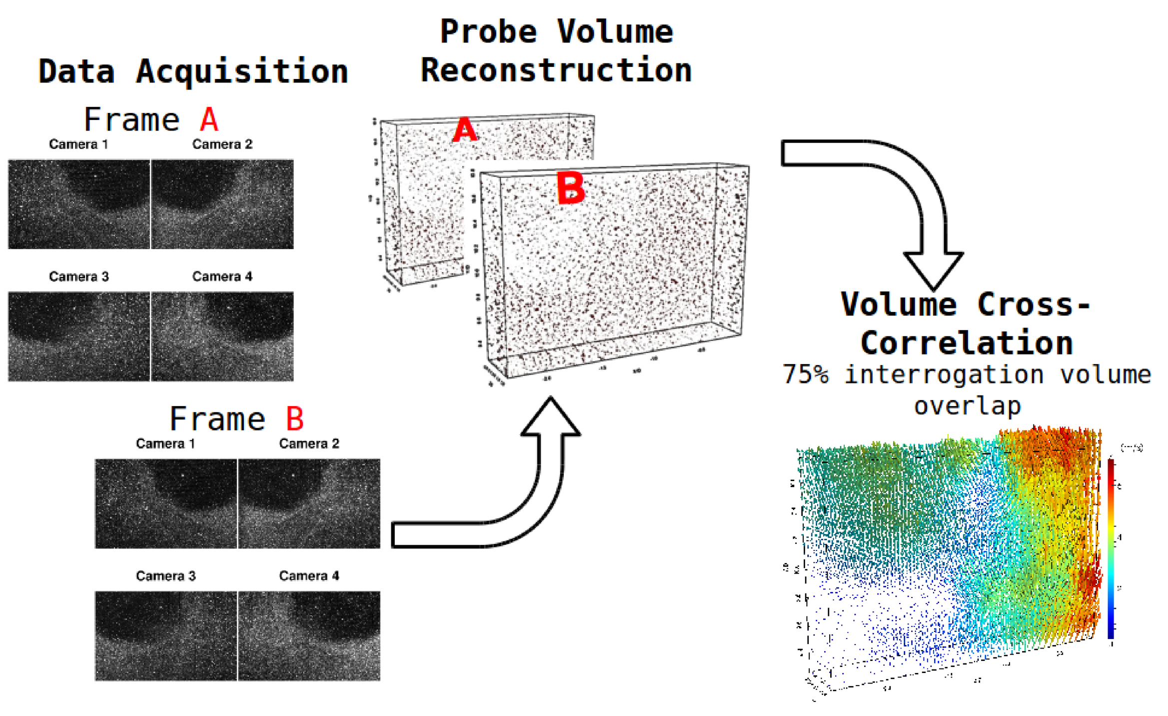
- Kolmogorov time scale – $\tau_k = 0.0446$
- Kolmogorov length scale – $\eta_k = 0.00287$
- Temporal resolution $\Delta t = 0.002$, spatial resolution $\Delta x = 0.0061$
- DNS size - 128 voxel 128 time step
- 1000 particles are injected at given positions selected randomly, every 32 time steps
- Particle trajectories are calculated by integrating the velocity field at the particle locations using the Runge-Kutta 4th order algorithm

TPIV Experiment

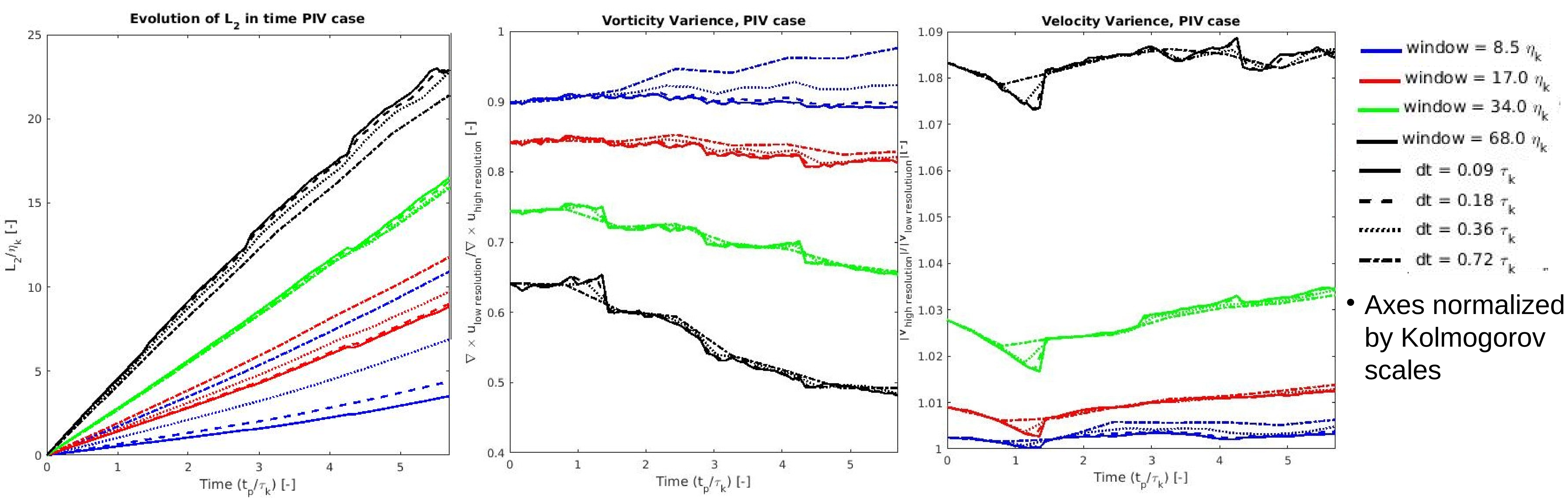


Processing

- Due to volume cross correlation, PIV introduces spatial averaging



Lagrangian Tracking errors in simulated PIV



- Axes normalized by Kolmogorov scales

- The mean particle position error (L_2) grows linearly in time.
- Errors in velocity and vorticity are more sensitive to spatial averaging than to the temporal resolution.

Summary and Future Work

- Lagrangian Particle Tracking was implemented first on 2D and 3D laminar velocity fields with exact solutions (Taylor-Green vortex), then on a 3D simulated turbulent velocity field downloaded from the Johns Hopkins turbulence database
- Errors in particle positions, velocity magnitudes, and vorticities were studied
- We hope to eventually implement Lagrangian Particle Tracking onto an experimental turbulent flame system measured using TPIV

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