Flow Visualization and Measurement Using an Affordable Particle Image Velocimetry System

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Background

- Particle image velocimetry (PIV) is a non-intrusive optical measurement technique used to obtain instantaneous fluid velocity. It provides detailed, quantitative, and spatially resolved measurements of complex flow fields, such as airflow over airfoils or hemodynamics within arteries.
- PIV has applications across interdisciplinary fields such as aerodynamics, biomedical engineering, and environmental sciences.
- However, the high cost of traditional PIV setups limits its accessibility.

We present a PIV system under $600 and demonstrate, by employing various data processing methods, that our setup can capture a range of interesting flow characteristics.

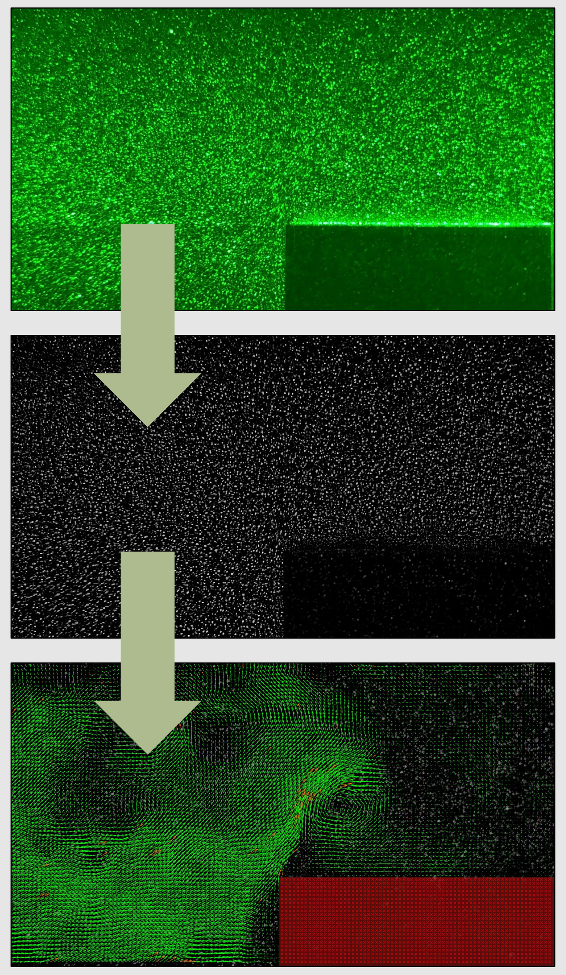
Experimental Setup

- The tank was filled with approximately 8.9 gallons of water (dimensions: L 35 in × W 7.3 in × H 8 in).
- The pump operated at its lowest speed setting to accommodate the frame rate limitations of the iPhone camera.
- Tracer particles were added at a concentration of 1 g/gal, equivalent to approximately 1.5 teaspoons total.
- In our experiment, we captured flow around a cube-shaped obstacle. Videos were recorded at 240 frames per second with a resolution of 1080p.

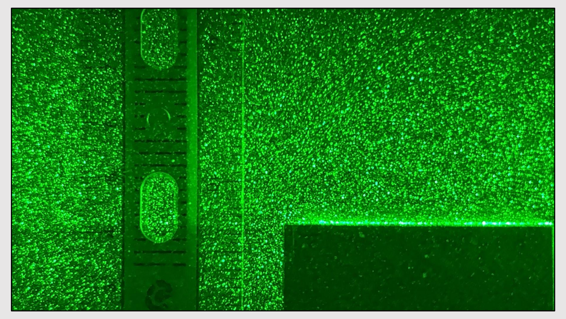
- In addition to the components listed to the right, we fabricated a custom lens-to-laser attachment using 3D printing.

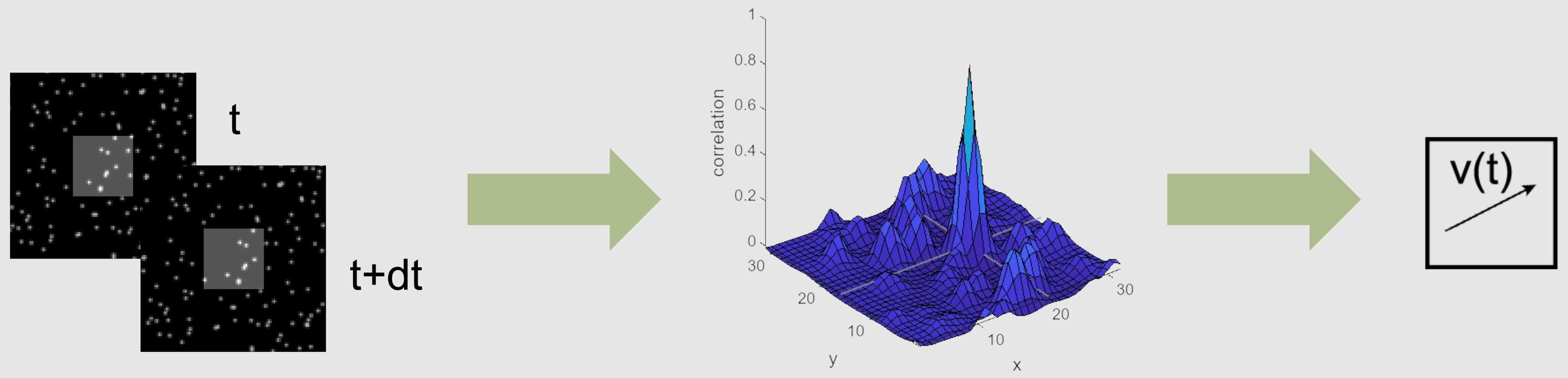
Item	Purpose	Price
LANDEN 90L 10.8 Gallon Rimless Low Iron Aquarium Long Fish Tank	Holds the fluid (water) being studied	$164.99
PULACO 10W 160GPH Submersible Pump	Generates a flow to be visualized	$13.99
OXLasers 532nm 12V High Power TTL Green Module	Illuminates the seeding particles in a particular plane	$68.00
LaVision Polyamide Particles 55 µm, 0.5kg	Small, neutrally buoyant particles that follow the fluid's motion	$186.73
Thorlabs Plano-Concave Cylindrical Lens, Uncoated	Expands the laser into a plane and compresses the plane into a thin sheet	$62.95
iPhone Camera	Visually captures the motion of seeding particles in fluid (water)	No purchase necessary
MATLAB and Simulink Student Suite Individual License	Access to PIVlab (toolbox inside MATLAB), an open-source particle image velocimetry software used to preprocess, analyze, and postprocess image data	$99.00
		Total: $595.66

Data Collection and Processing



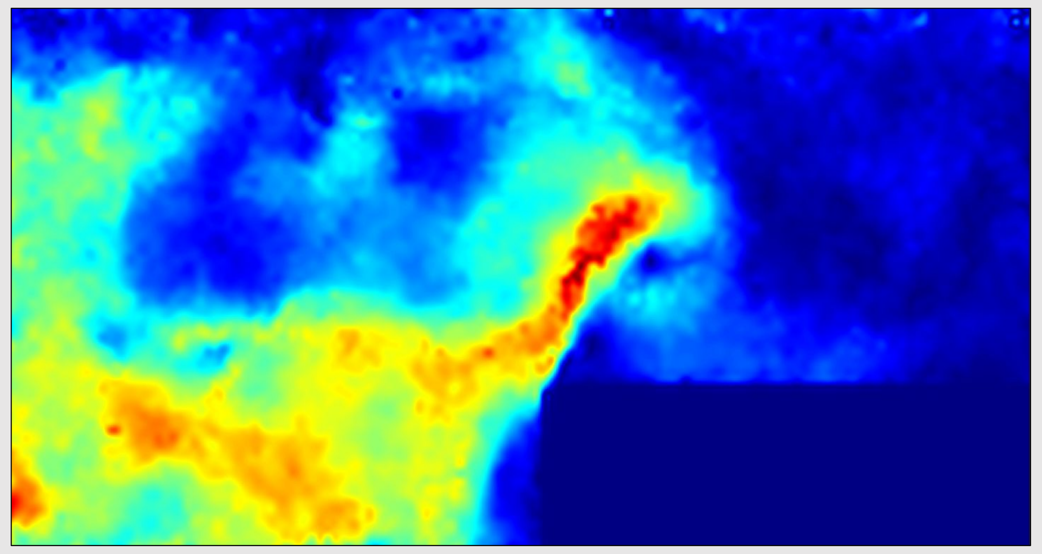
- Frames are imported into PIVlab and preprocessed with contrast enhancement techniques such as contrast limited adaptive histogram equalization (CLAHE).
- Calibration was performed using a reference image (right) to convert pixel and frame measurements into physical units of meters and seconds.

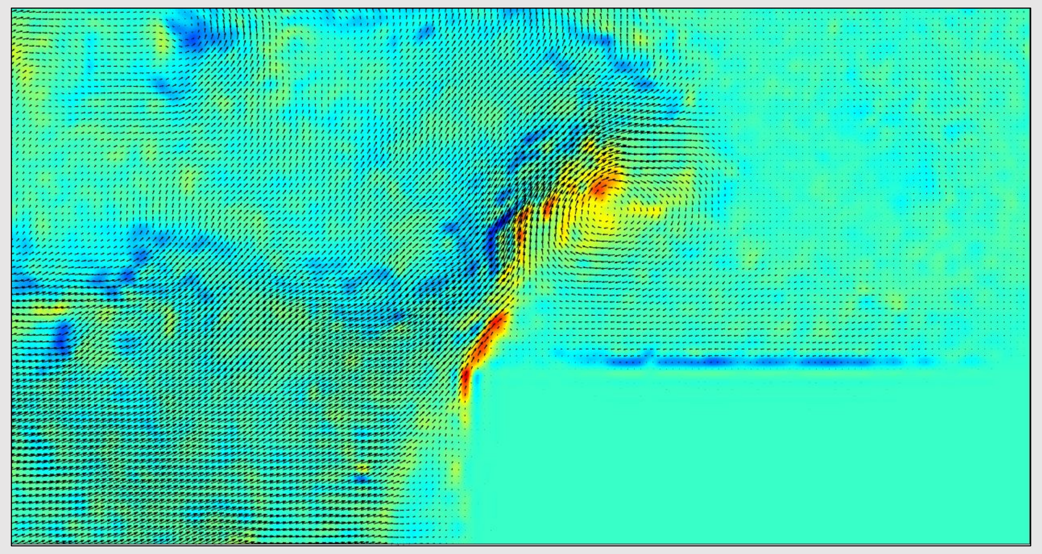




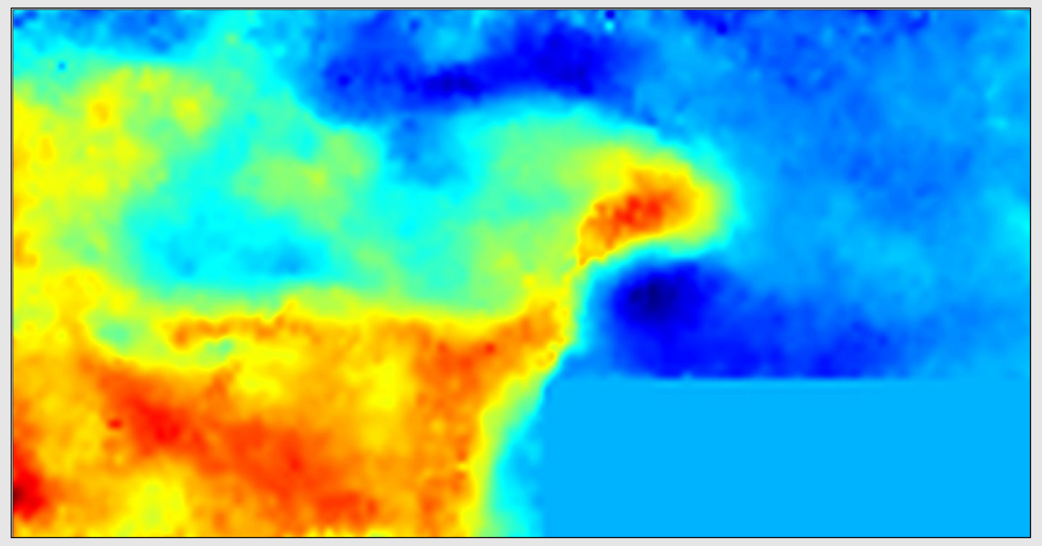
A multipass FFT (Fast Fourier Transform) cross-correlation algorithm is applied to small interrogation windows within the image pairs to estimate the displacement of the particles. From the known time interval and particle displacement, the instantaneous velocity vectors of the fluid are computed across a plane.

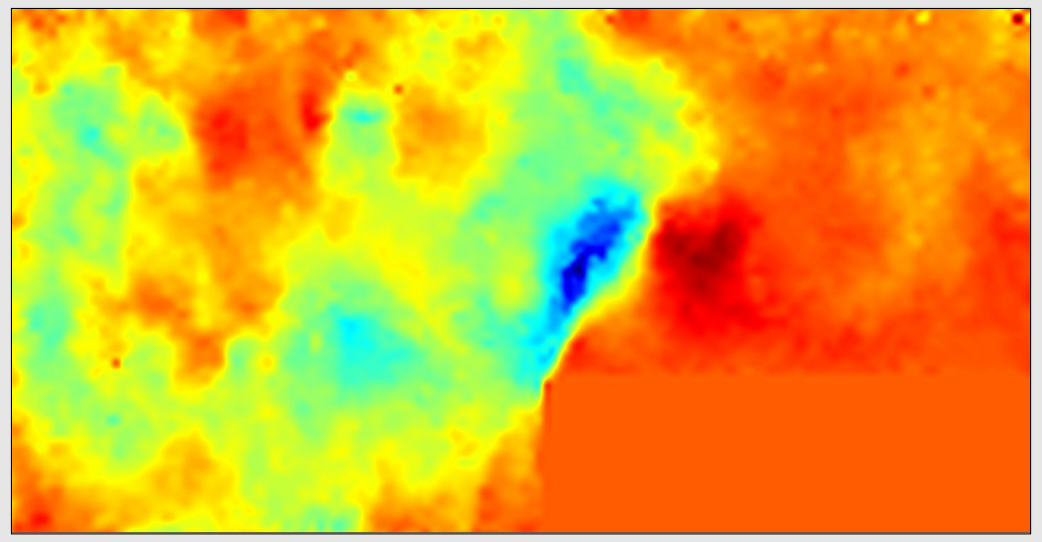
Data Visualization



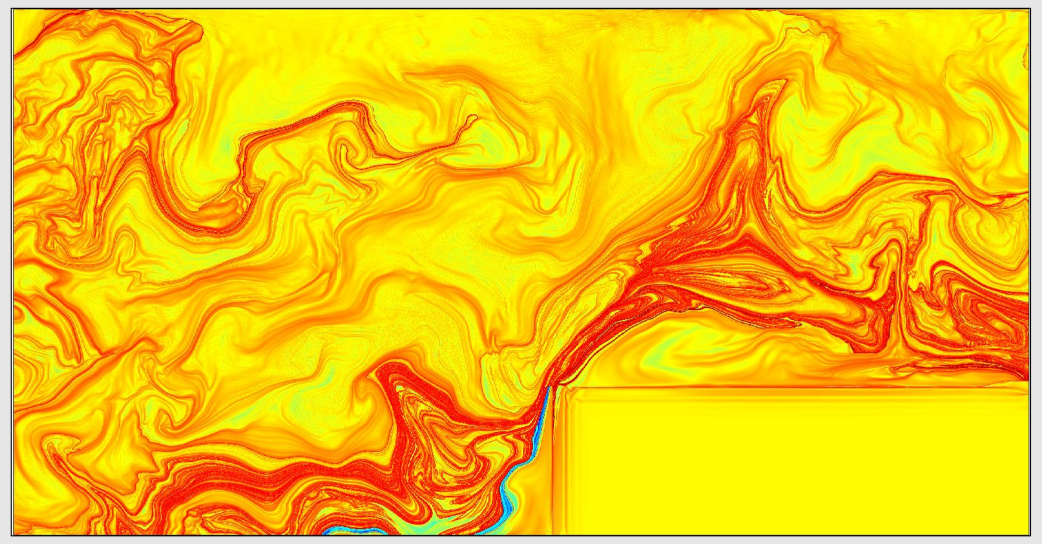


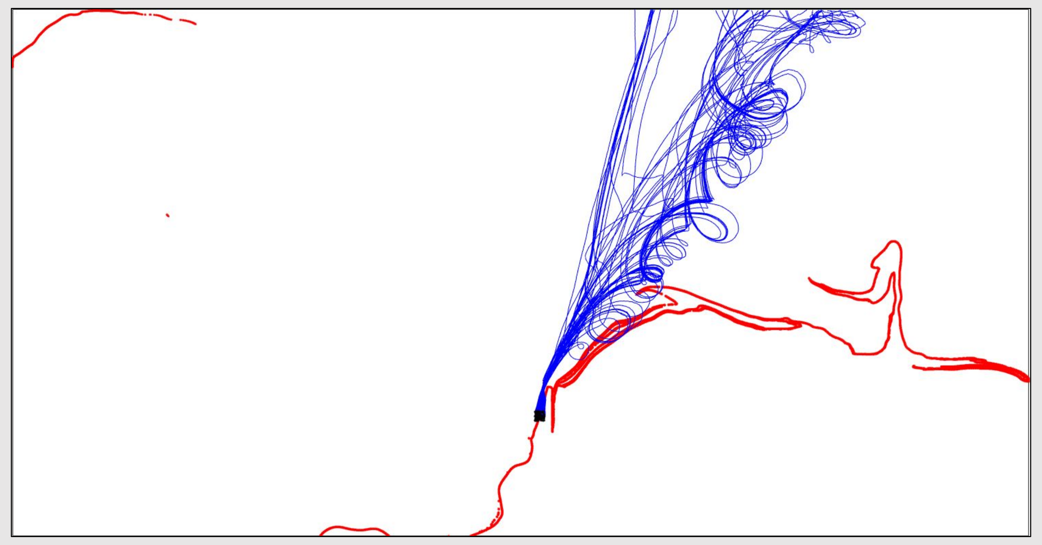
Both of the images above capture the flow near the corner of the block at a single time point. The left image shows the speed field, where warmer colors indicate higher velocities. We can observe that the obstacle blocks the acceleration of the flow. The right image shows the vorticity field overlaid with velocity vectors. The regions of high positive and negative vorticity appear as red and blue patches respectively. We observe that the corner redirects the incoming flow, creating regions of strong vorticity near the corner.





The left image shows the horizontal velocity component extracted from PIV measurements near the corner obstacle. Red and yellow regions indicate positive horizontal flow, while blue regions indicate zero or negative horizontal flow. The right image shows the vertical velocity component extracted from PIV measurements near the corner obstacle. Warmer areas represent upward flow, while colder regions represent downward flow. At the corner, we see the horizontal and vertical components change sharply.





The left image shows the finite-time Lyapunov exponent (FTLE) field computed from the PIV data. The FTLE measures how much neighboring fluid particles separate over a finite time interval. Locations marked in red correspond to high FTLE values, meaning that particles starting very close together at these points will rapidly separate and trace out very different paths over time. The right image shows the locations of highest FTLE values (red ridges) together with 100 particle trajectories (blue lines), seeded near a red point (black marker). As the particles evolve in time, they quickly diverge from one another.

Acknowledgements

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- We gratefully acknowledge the work of Shadden, Lekien, and Marsden (2005), who developed the theory connecting FTLE ridges to Lagrangian Coherent Structures (LCS) in unsteady flows.
- We also thank Thielicke and Stamhuis (2014) for the development of PIVlab, which enabled efficient and accessible Particle Image Velocimetry analysis in this project.
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