Introduction to the IVy Software for Processing Videos to Derive Streamflow

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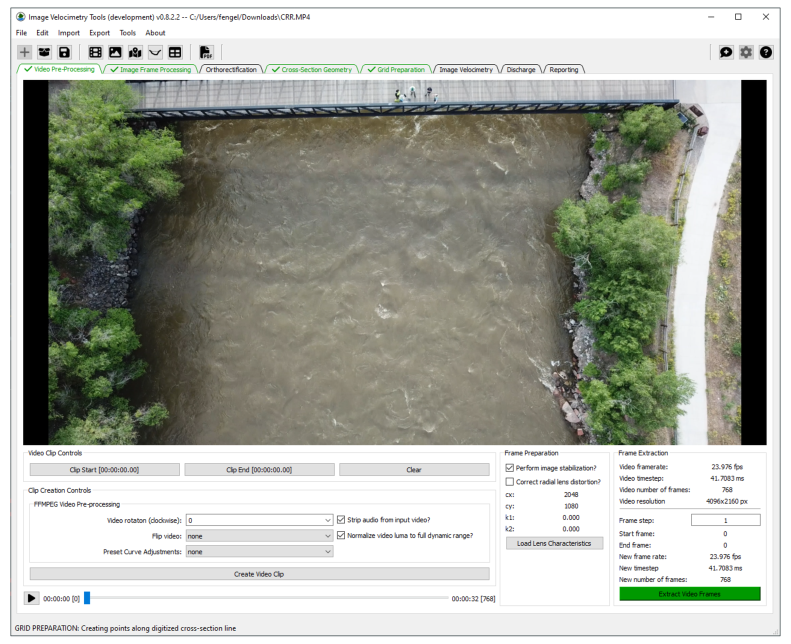
Introduction

Non-contact streamflow measurement techniques, including image velocimetry, have revolutionized hydrological monitoring by enabling safe, efficient data collection during hazardous conditions. The Image Velocimetry Tools (IVy) application, developed by the USGS, translates research into operational tools that hydrographers can use to process videos into accurate streamflow measurements. IVy bridges the gap by offering a standardized, reproducible workflow to ensure data consistency and reliability.

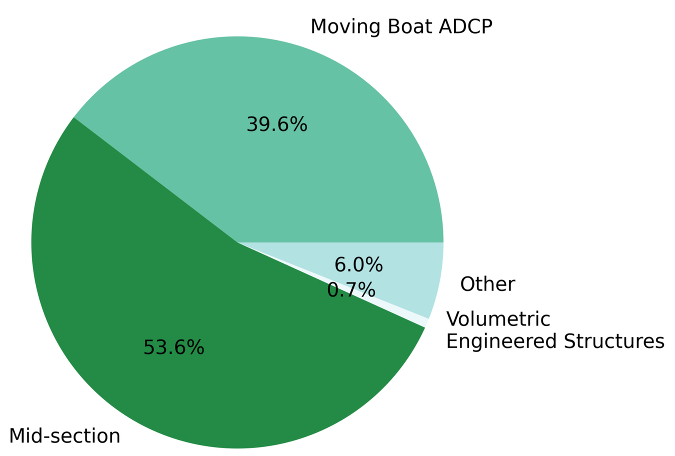


The IVy Tools application's overview image shows a loaded video in the Video Processing tab.

Motivation

The USGS manages over 12,000 streamflow gages, requiring approximately 200,000 annual in-person site visits. Conventional measurement methods face challenges, including accessibility during floods, safety risks, and high operational costs. Image velocimetry provides a non-contact alternative that addresses these issues, offering high spatial resolution measurements for difficult or unsafe locations to access. These capabilities expand monitoring networks, reduce costs, and improve decision-making for water resource management.

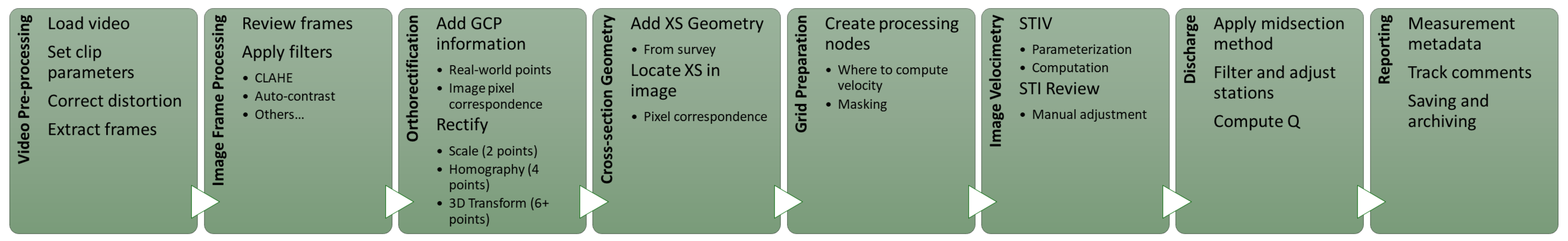
Several image velocimetry algorithms have been developed for estimating flow velocity in rivers[1,3]. Although software applications exist for processing image velocimetry, for example RIVeR[6] and FUDAA-LSPIV[4] for particle image velocimetry, a highly functional, open-source, and free application for Space-Time Image Velocimetry (STIV) does not exist. Moreover, none of the existing software directly meet USGS Fundamental Science Practices (FSP) and reporting/archival needs.



USGS discrete discharge measurement statistics for the 2023 water year.

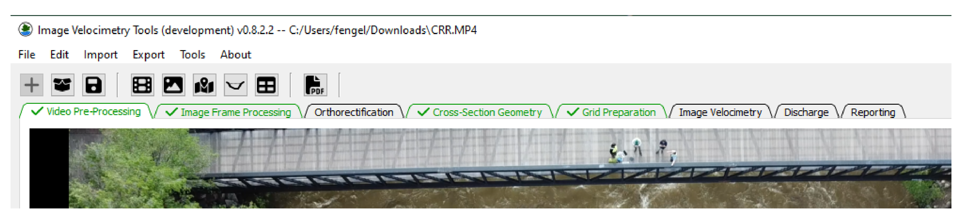
How IVy is Organized

The IVy interface is designed to promote a standard workflow. This workflow is established by tabs separating typical IVy project tasks. As users work through each task, IVy provides feedback using color and icons.



IVy simplifies the many steps needed to compute streamflow from video using image velocimetry, to make it easy for the user to produce repeatable results.

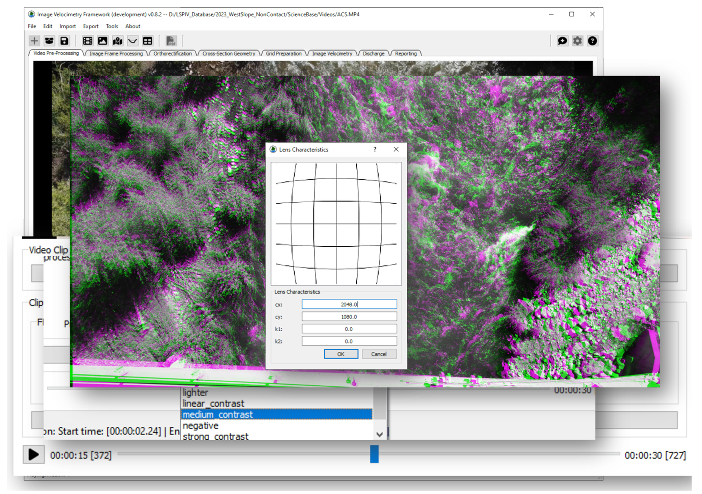
IVy guides users through each stage of processing a streamflow measurement. Tools for loading and processing videos, transforming images into maps, adding bathymetry surveys, and computing velocity are provided. Discharge in IVy is calculated using the midsection method.



IVy tab layout enables a logical workflow. Tab icons and coloring aid the user through the processing steps.

Video Processing

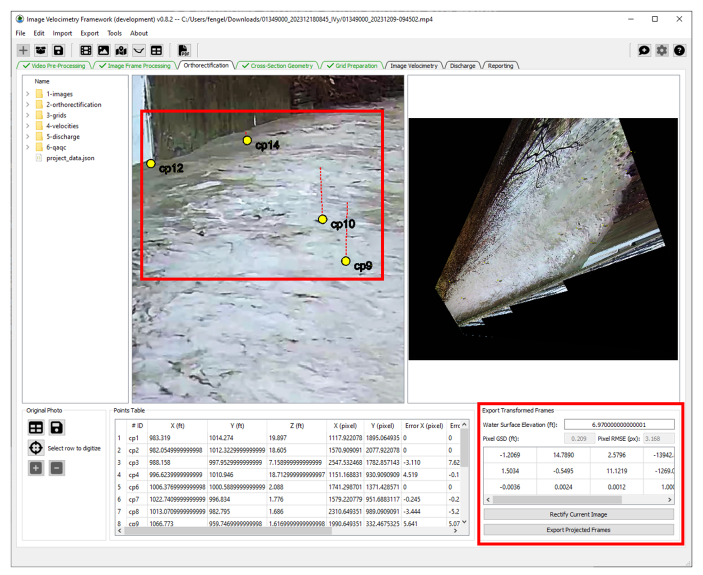
Users can load a video showing the water surface and appropriate ground control features taken from the nadir (e.g., from a drone), or a perspective view (e.g., handheld, tripod- or fixed-mounted camera). All common video formats are accepted. User can correct lens distortion using a simplified Brown's Distortion model. Video with motion can be stabilized within IVy automatically.



Example lens distortion correction and image stabilization user interface.

Orthorectification

IVy is capable of converting nadir and perspective imagery into transformed imagery using three methods: simple scaling, homography, and 3D transformation. Videos captured from a nadir view can be scaled directly with just 2 ground control points. For *opportunistic* videos, 4 points on the water surface can be leveraged. Cameras that are fix-mounted to gaging equipment can leverage full 3D transformation using ≥ 6 points and a known water surface elevation.



Orthorectification interface in IVy for a 3D Transformation. Red squares highlight the reprojection of ground control points onto the perspective image (top) and the resulting projective matrix (bottom) respectively.

Space-Time Image Velocimetry

STIV computes water surface velocity along search lines in videos[2]. Recently, we developed a 2D implementation of STIV, used in IVy, that extends traditional STIV to find the primary flow direction based on maximizing a function describing multiple search lines radiating from a point[5]. Multiple search lines are radiated from each velocity node, creating Space Time Images (STI) for each line. The most prominent tilt angle (θ_{max}) in the image is identified using an autocorrelation function ($\hat{R}$, ACF) approach.

$$F(\theta) = \int_0^{\rho_{max}} \hat{R}(\theta, \rho) d\rho$$

To select the STI corresponding to the primary flow direction, $F(\theta)$ is maximized for all angles θ for a given search line orientation ϕ.

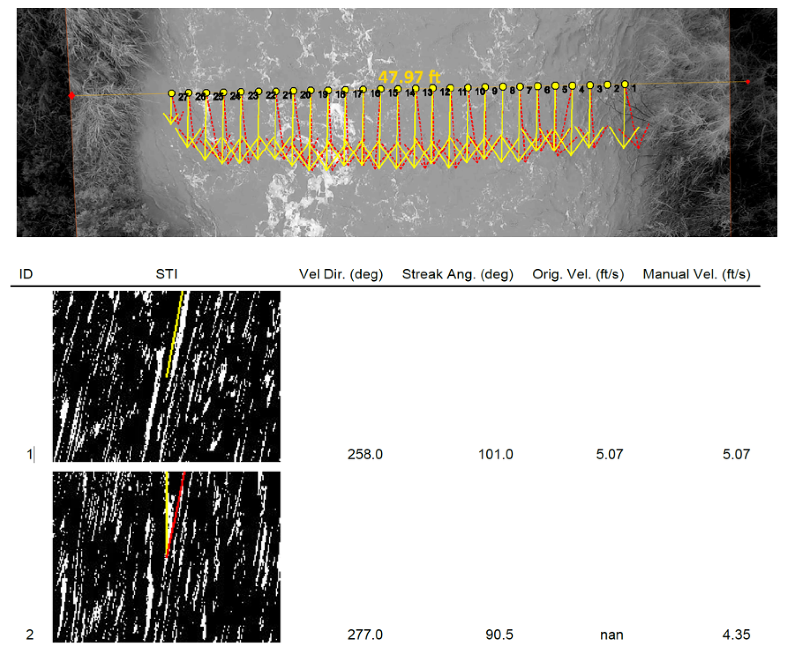
$$p(\phi) = max[F(\theta)]_{\theta=0^{\circ}}^{\theta=180^{\circ}}$$

which enables calculation of velocity magnitude (U) and direction (ϕ) based on the inclination angle of the streaks:

$$U = \frac{S_x}{S_t}\tan(\theta_{\mathrm{max}})$$

where S_x is pixel size, S_t is the frame interval, and θ_{max} is the angle of peak correlation. S_x and S_t are determined from the metadata of the video and extracted frames.

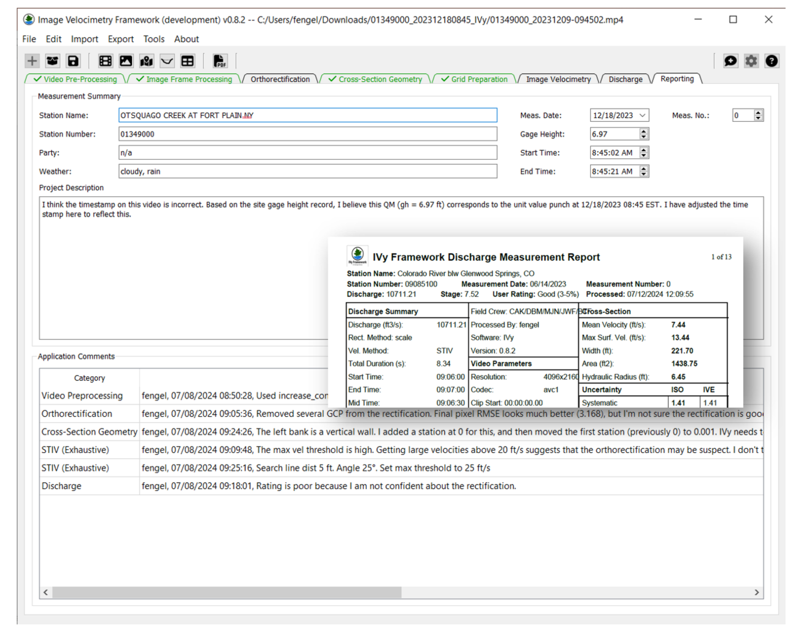
This new, 2D STIV enables a more accurate determination of the true component of flow contributing to river discharge at a cross-section.



STIV result vectors are visualized to indicate 2D flow magnitude and direction (red), & component velocities normal to a supplied XS (yellow). STI are shown with the ACF angles (yellow). Users can manually override the angle if needed (red).

Reporting

Providing reporting capabilities for methods is important, as is fulfilling FSPs dictated by the USGS. IVy provides this capability through the Reporting tab. Users can create comments throughout the application that are added to the current project. Metadata about the measurements, location, field party, time, and more are also included. When the user has completed all processing and has reached a final streamflow, IVy will create an immutable comment with the saved result. A PDF can be exported that contains all of the information, comments, and other metadata from the measurement that is suitable for review and archival. Finally, IVy enables the saving of a shareable project file containing everything needed to reproduce the results.



Reporting capabilities in IVy, including a PDF file export (a snippet of the first page is shown here), and fields for storing common project information and metadata.

Future Directions

USGS has been providing internal training in the correct application of image velocimetry, using IVy and other software applications. We are working on publishing interim guidance, standard operating procedures, and policies. The IVy software will be reviewed and made fully public in early 2025. Other expanded capabilities for IVy on the horizon include:

- Enhance IVy with machine learning for automated feature detection.
- Automate processing workflow, enabling deployment from edge computing hardware.
- Develop a database for paired image and field measurements to refine methodologies.
- Enable batch processing, and generate time series of image-derived streamflow.
- Encourage open-source community involvement.

Learn More

Scan the QR code here to explore and learn more information, including instructions for downloading and installing IVy Tools, where to get example data, and more.

References

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