FlowVelo: An image-based tool to automatically measure flow velocities

This program tracks flow velocities using image or frame sequences. It includes measuring the camera position and orientation (camera pose), automatic extraction of the water area for feature searching, particle detection and filtering, particle tracking and filtering and scaling the tracks to get flow velocities. Furthermore, a function is included to automatically co-register frames in case of camera movements.

Source code:
https://github.com/AnetteEltner/FlowVeloTool/python3_version

Requirements:
Python 3.6
Additional libraries:
- scipy 1.4.1
- scikit-learn 0.22.2
- scikit-image 0.16.2
- shapely 1.7.0
- imageio 2.8.0
- opencv-python 4.1.1.26
- seaborn 0.10.0
- matplotlib 3.2.0
- pyttk 0.3.2
- pandas 1.0.1
- numpy 1.18.1

Running FlowVelo on Windows

- Install PyCharm
- In PyCharm:
    - Go to *File* → Create *New Project…*
        - Choose location to folder you like
        - Set Base interpreter to Python 3.6
    - Go to *File* → *Settings*
        - Go to *Project: "your chosen folder"*
            - Go to *Project Interpreter*
                - Go to *+*
                - Install libraries mentioned in requirements
- Download source code of FlowVeloTool from GitHub
- Unpack FlowVeloTool.zip and put all scripts including the tutorial folder into chosen location folder
- Open *GUI_FeatureDetectionTracking.py*

- There might be an issue with the screen resolution, hindering the visibility of the entire window. If this is the case, please lower the screen resolution.

Input data:

- **Interior geometry** of the **camera**. Minimum information needed is focal length in mm, sensor size in mm and sensor resolution in pixels. There is an example file *interiorGeometry.txt* in the tutorial data and corresponding explanation of parameters in *interiorGeometry_explained.txt*.
- Optional data to scale the velocities:
    - **Object space coordinates** (ID,X,Y,Z) of **GCPs** (Ground Control Points) used to estimate camera pose. There is an example file *markersGCPobj.txt* in the tutorial data. If no GCPs are given it is possible to set the **exterior camera geometry** (i.e. camera position and orientation) directly, if it is known. **Image coordinates** (id,x,y) of **GCPs** used to estimate camera pose in pixels (origin of image coordinate system is the top left corner of the image). There is an example file *markersGCPimg.txt* in the tutorial data. Locations of GCPs in the image are illustrated in *locationGCPs_frame3.jpg*. Image coordinates might also be measured interactively with the FlowVeloTool (although it might be buggy) instead of providing the file.
    - In case the exterior camera geometry is not used, the perpendicular **distance** of the **camera** to the **water surface** can be utilised to estimate the image scale and thus scale the velocities. This should be provided in [m]. For instance, in case of UAV imagery the flying height above the water surface can be used scale the velocity values assuming a Nadir view of the camera. In case the image scale is used, information about the water level is not needed.
- Optional data to mask the water area:
    - **3D point cloud** (X,Y,Z) of area of interest to define search area. There is an example file *3DmodelPointCloud.txt* in the tutorial data. If no point cloud is given, it is also possible to import a binary image file where the water area is masked (i.e. white water area in front of black background).
    - Instead of the 3D point cloud, also a **binary mask** file can be used to mask the water area. This might be useful in the case of using only the image scale for velocity estimation or if no 3D point cloud is given.
- **Water level** (not in case of using the image scale)
- Folder with the image/frame sequence

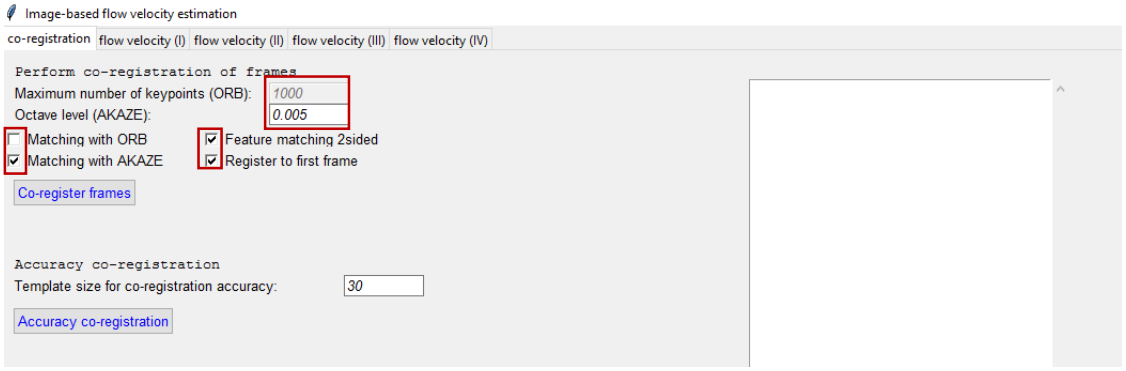
Tutorial data:

FlowVeloTool.zip available at
https://cloudstore.zih.tu-dresden.de/index.php/s/2XWTnzqCkoOJvkF

For questions please contact: Anette.Eltner@tu-dresden.de

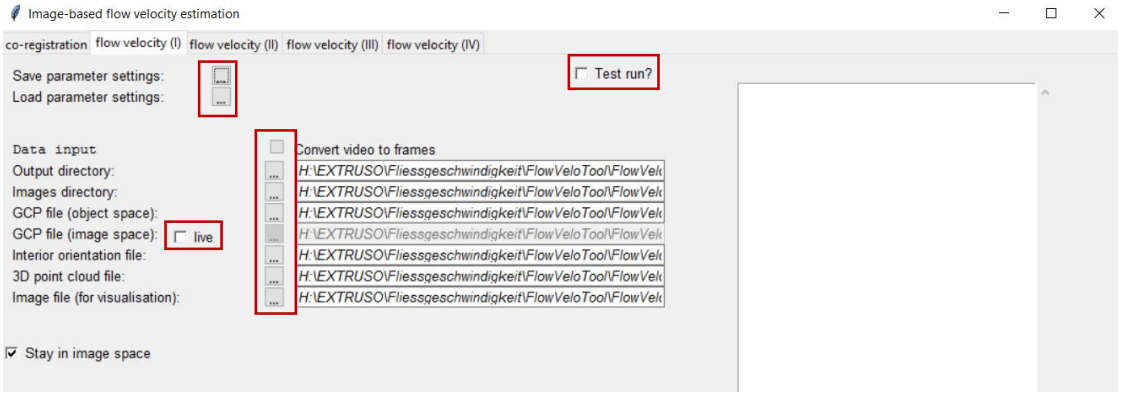
Short Guideline to estimate flow velocities:

1. Perform co-registration (stabilization) of frames, if camera has been moved during data acquisition



- "Maximum number of keypoints"; parameter to choose, when ORB option set as matching variant
- "Detector response threshold"; parameter to choose, when AKAZE option is set as matching variant (mostly values between 0.02 to 0.005, the lower the value the more features are detected and the longer computation time will be)
- "Matching with ORB" if checked, uses ORB feature descriptor
- "Matching with AKAZE" if checked, uses AKAZE feature descriptor
- "Feature matching 2sided" check to increase robustness of matching, but also increases computation time
- "Register to first frame" if checked registers all frames of sequence to first frame of that sequence, if unchecked registers every new frame to previous frame of that sequence

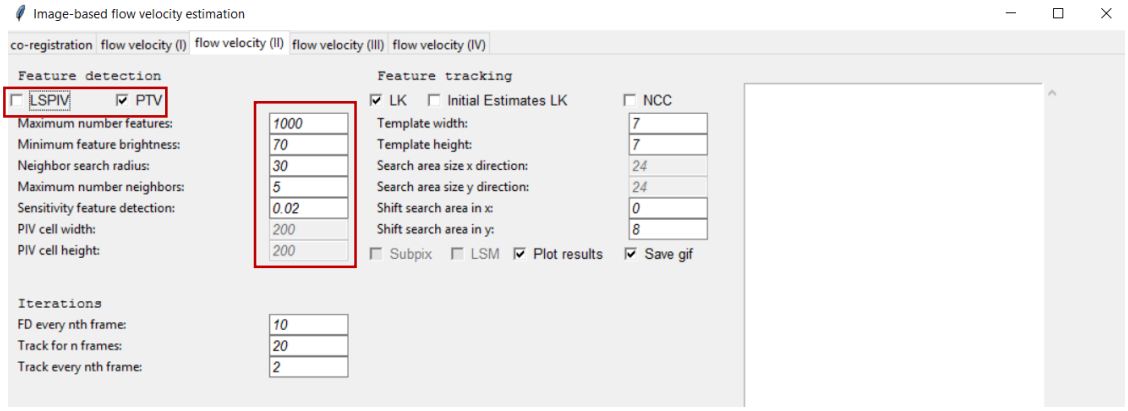
2. Set parameters for flow velocity measurement:



- "Save parameter settings"/"Load parameter settings": All parameters settings of the flow velocity tool can be saved and loaded (this can be for instance helpful if different parameter choices are tested to find the optimal one for tracking)

- “Convert video to frames”: If video file is available instead of single frames, video has to be converted first into frames, which can be done with the built-in option
- “GCP file (object space)”: ascii (txt-) file containing point id, X coordinate, Y coordinate, Z coordinate
- “GCP file (image space)”: ascii (txt-) file containing point id, x image coordinate (in pixels), y image coordinate (in pixels)
- “live” if checked, image coordinates of GCPs have to be measured manually. The corresponding image to measure in will be loaded after it has been selected in a corresponding interrogation pop-up window.
- “Interior orientation file”: ascii (txt-) file containing focal length, principle point, radial distortion parameters, tangential distortion parameters, affinity and shear parameters, sensor size and image resolution
- “3D point cloud file”: ascii (txt-) file containing coordinate X, coordinate Y, coordinate Z
- “Image file (for visualisation)”: Select image file (.img) in which results of feature detection and tracking will be displayed.
- “Test run?” to perform test measurements to check if settings are suitable. Only the first twenty frames will be processed.
- “Stay in image space”: if unscaled tracking results are sufficient, this option can be checked and therefore no information regarding the exterior orientation, water level and 3D point cloud file is needed

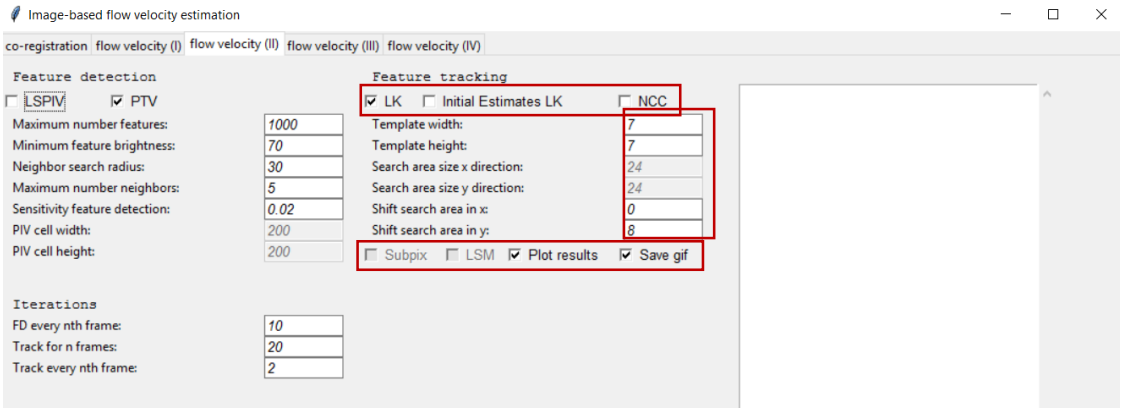
3. Set parameters for feature detection:



- “LSPIV”: defines interrogation areas in a raster pattern, whose content is then tracked
- “PIV cell width”: define distance between center points of interrogation areas along x-axis, option for LSPIV
- “PIV cell height”: define distance between center points of interrogation areas along y-axis, option for LSPIV
- “PTV”: individual particles are detected, who are then tracked
- “Maximum number features”: Define maximum total number of detected good features to track, which will be kept for subsequent filtering steps

- “Minimum feature brightness”: Define the threshold for minimum brightness of a feature to be considered as particle for tracking. The higher the value is chosen, the brighter the feature has to be. Thus increasing this value leads to a decrease of detected features. Option for PTV.
- “Neighbor search radius”: Define the threshold for the radius (in pixels), in which nearest neighbours are searched for to perform the subsequent cluster filtering. The higher the value, the more features will be filtered as more features will be included in the next filtering step. Option for PTV.
- “Maximum number neighbors”: Define the threshold for how many neighbors are allowed within the previously defined neighbor search radius. The higher the value, the more features are kept. Option for PTV.
- “Sensitivity feature detection”: Define the quality level for features to be kept. It considers the quality measure defined by the minimal eigenvalue (corner score). The defined value will be multiplied with the corner score of the best feature and all features with scores below this product will be excluded. The higher the value is chosen, the less features will be detected. Option for PTV.

4. Set parameters for feature tracking:

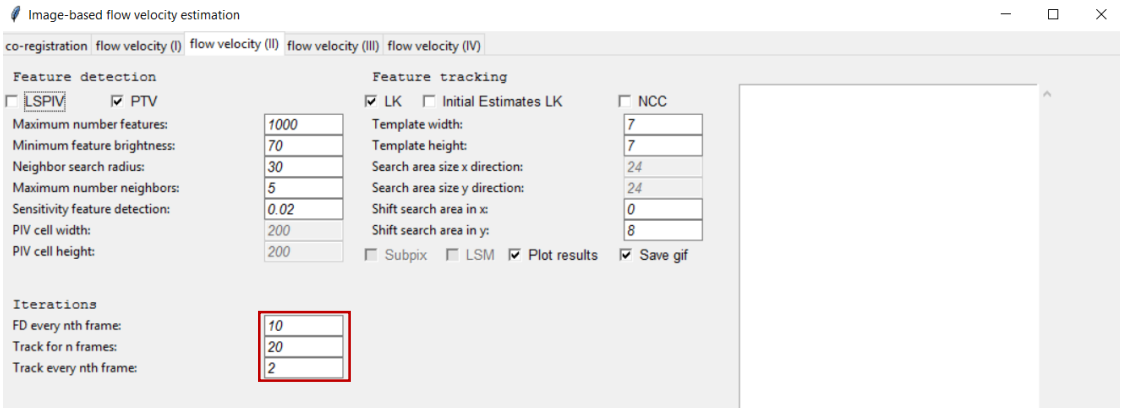


- “NCC”: Feature matching is performed with Normalized Cross Correlation.
- “LK”: Feature matching is performed with Lucas-Kanade approach.
- “Initial Estimate LK”: Check this option if LK should use the tracked position as approximate values for the matching in the next frame.
- “Template width”: Define the template width (length in x direction of the image). The size has to be odd and is defined in pixels. The wider the template, the longer the processing time but the smaller the chances for ambiguities.
- “Template height”: Define the template height (length in y direction of the image). The size has to be odd and is defined in pixels. The higher the template, the longer the processing time but the smaller the chances for ambiguities.
- “Search area size x direction”: Define the width of the search area (size in x direction) within which the template is moved to find the corresponding

region (e.g. particle). The size is defined in pixels. The higher the value the longer the processing time and the higher the chances for ambiguities.

- "Search area size y direction": Define the height of the search area (size in y direction) within which the template is moved to find the corresponding region (e.g. particle). The size is defined in pixels. The higher the value the longer the processing time and the higher the chances for ambiguities
- "Shift search area in x": Define the approximate flow speed (in pixels) in the x direction to improve matching chances. The higher the flow velocities are, the larger the shifts will be.
- "Shift search area in y": Define the approximate flow speed (in pixels) in the y direction to improve matching chances. The higher the flow velocities are, the larger the shifts will be.
- "Subpixel": Check this option if matching results refined to subpixel accurate positions are aimed for. This step comprises a weighted centroid fit to find the peak location.
- "LSM": This option is still under development. Instead of NCC or LK, matching is performed via least square adjustment. Results are subpixel accurate positions.
- "Plot results": Decide whether results will be plotted.
- "Save gif": Decide whether tracking results will be saved in an animation.

5. Set parameters for repetition of feature detections and duration of feature tracking

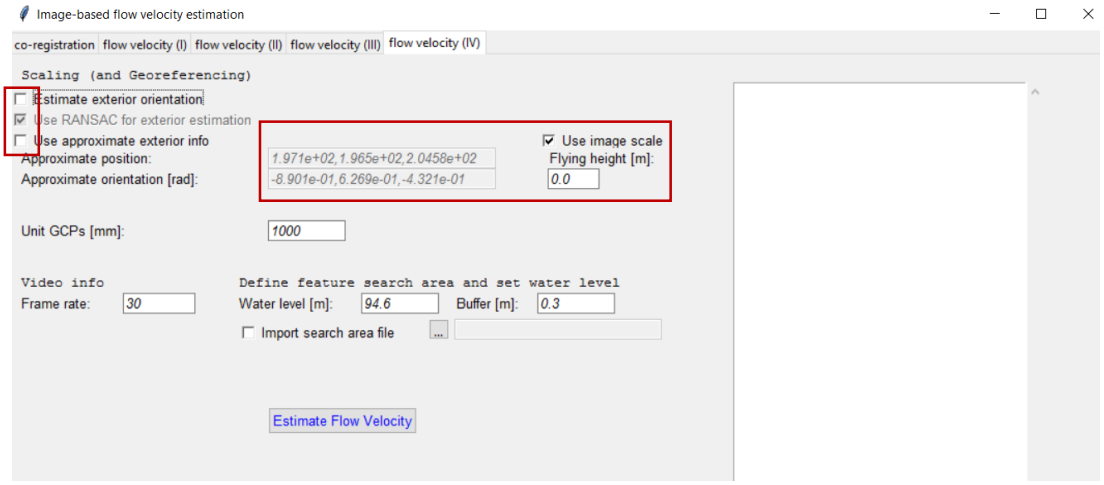


- "FD every nth frame": Define after how many frames new features are detected.
- "Track for n frames": Define across how many frames features are tracked.
- "Track every nth frame": Define how many frames are to be skipped before next matching. For instance, to track features in every frame the value has to be 1, in every second frame 2, every third frame 3), and so on.

6. Set parameters for track filtering:

- "Only filter and scale tracks": Choose this option if tracking has already been performed successfully and you want to re-adjust filtering options. If option is checked, press "Estimate flow velocity" button (frame "flow velocity (IV)") and load "Tracking_FT_nbrFrames_*_FD_nbrFrames_*.txt" file.
- "Minimum count features": Define across how many images a feature has to be tracked minimally to be considered as reliable track. The value is defined in percentage of the total traceable number (i.e. the "Track for n frames" value).
- "Minimum track distance": Define the minimum distance (in pixels), which features have to move between consecutive frames (corresponding to the needed minimum length of a sub-track), thus the track will be considered as reliable track if all sub-tracks are above this threshold.
- "Maximum track distance": Define the maximum distance (in pixels), which features have to move between consecutive frames (corresponding to the allowed maximum length of a sub-track), thus the track will be considered as reliable track if all sub-tracks are below this threshold.
- "Steadiness": Define how strong features can change their direction (in degrees) from one frame to the next (value corresponds to maximum allowed standard deviation of directional changes of all sub-tracks of one track).
- "Range track directions": Define the maximum range (in degrees) within sub-tracks of a track can change their direction.
- "Bin nbr main flow direction": To be tested. Should be 0.
- "Buffer main flow": Define how strong an entire track can deviate from the main flow direction (in degrees), which is calculated as average direction of all track directions.
- "setValue velocity threshold": A statistical outlier filter; *threshold = mean + setValue * standard deviation*. Define the setValue to calculate a threshold above and below which features are removed. The higher the value, the more tracks are kept.
- "setValue filter radius [pix]": for local outlier filter choose maximum radius within which features are considered for statistical filtering.

7. Set parameters for camera pose estimation:

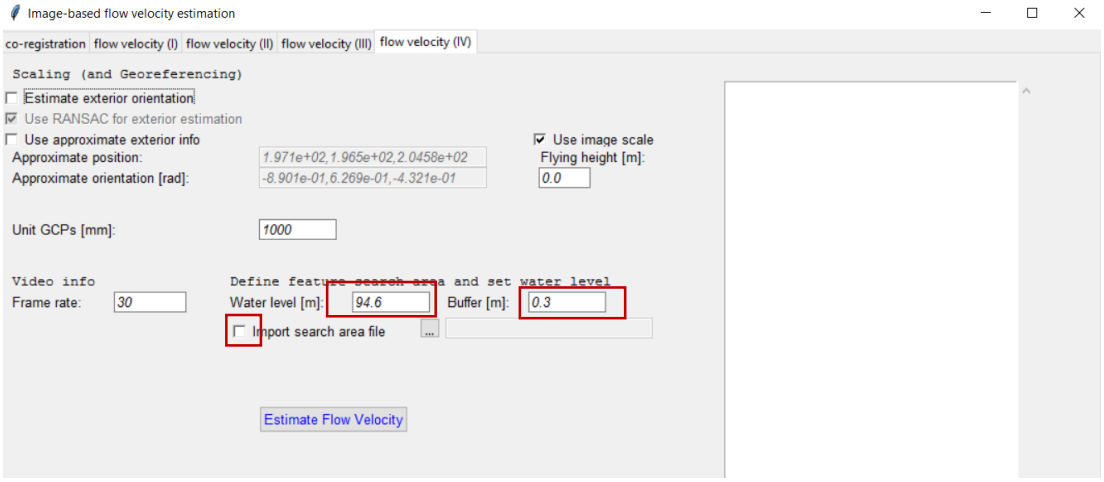


- "Unit GCPs": Define the unit of the GCPs because all measurements in the FlowVelo-Tool are performed in mm (e.g. therefore also the interior camera geometry has to be provided in mm)
- "Estimate exterior orientation": This parameter has to be checked if the camera pose estimation has to be performed using GCP coordinates measured in object space (e.g. with a total station) and measured in the images
- "Use RANSAC for exterior estimation": To estimate the camera pose via spatial resection some approximate values of the camera orientation and position are needed. If this information is not provided, check "Use RANSAC for exterior estimation". This option will also test if there might be outliers in the GCPs and if so, they will not be used for the pose estimation. If "Use RANSAC for exterior estimation" is not checked, you need to type in approximate values of the camera pose ("Approximate position" in X,Y,Z and "Approximate orientation" in omega,phi,kappa).
- "Use approximate exterior info": It is possible to use a-priori known information of the camera pose only. If this is the case, uncheck both "Estimate exterior orientation" and "Use RANSAC for exterior estimation" and type the exterior orientation parameters in the approximate position/orientation fields.
- "Use image scale": It is possible to use a-priori known information of the camera distance to the water surface only to scale the velocity measurements. If this is the case, uncheck both "Estimate exterior orientation" and "Use RANSAC for exterior estimation" and type in the distance in [m]. If image scale is considered, no water level and buffer has to be provided.

8. Set parameter to scale velocities:

- "Frame rate": Define the frame rate (in seconds) with which videos or images were captured.

9. Set parameters to define water area (feature search area) and set water level to correctly retrieve 3D coordinates of tracked features:



- "Water level": Define the water level (in m).
- "Buffer": Define the buffer for the water level, which is needed in very complex terrain or when camera pose estimation is not very accurate to buffer the water-shore borders.
- "Import search area file": If the feature search area is defined manually (e.g. in GIMP), provide a binary mask image (e.g. png) of masked water area. The tool automatically derives the corresponding contour containing the image coordinates of the border of the mask (which is also saved as result).