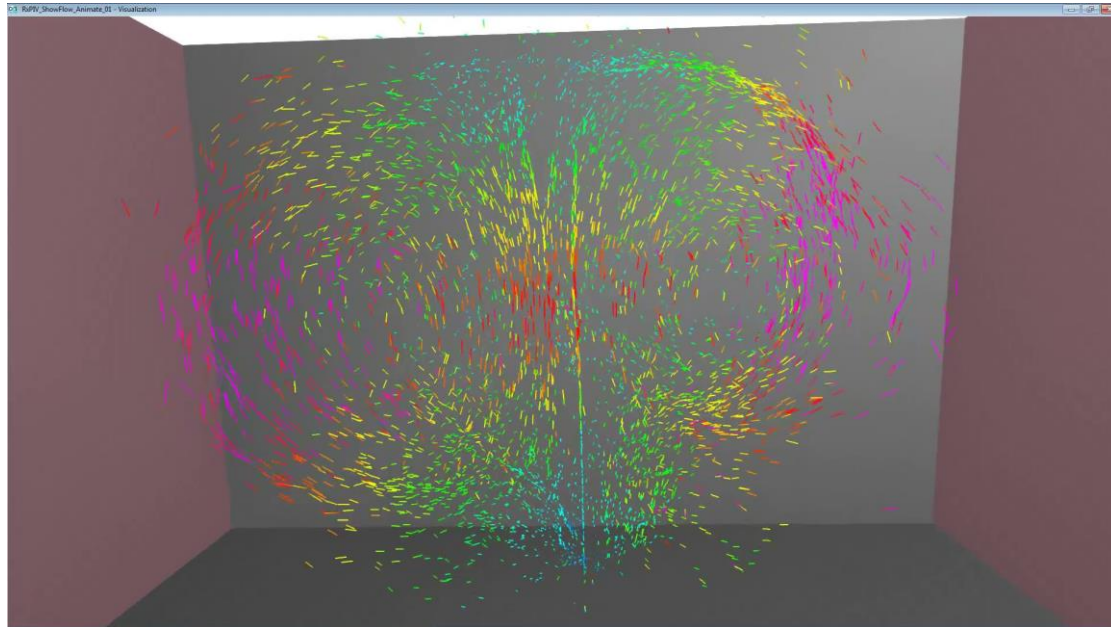


HowTo for RxFlow

Raytrix Particle Tracking and Velocimetry



Content

1. [Important Changes](#)
2. [Graphical User Interface](#)
3. [Workflow](#)
4. [Algorithm Parameters](#)
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Important Changes to Previous Release

Overall-Quality:

... describes a heuristic measure of reliability and quality of a data sample (3D particles and velocities). It relates the detected match count to the optimal number of matches. Value range is [0...1] for un-constraint to strictly constraint. The particles displayed in 'Positions' view are colored by their overall-quality [red...green]. Use visualization slider 'Min. overall-quality' in 'Positions' parameter tab, to filter visualization by overall-quality.

The other filters still apply to post-processing. Nevertheless, using overall-quality filter their default values are adequate in most cases.

Cancel Active Estimation:

Canceling the active estimation won't invalidate the estimation framework. The active estimation is stopped and the associated data is deleted. The estimation can be continued, with altered parameters if applicable, from the same time index.

Data Export:

- VTK output for velocity grids now contains the grids 'density' (number of measurements used for respective cell) in addition to velocities.
- Overall-Quality for each measurement is logged to **.vels** and **.tracks** files. **FORMAT CHANGED** see [Result Data Export](#)



Important Changes to Previous Release

Background Image:

- Computation of background image is now independent on usage of processed image. The same background can be used for processed and non-processed image input.
- The image **index range** for background computation is now independent of the estimations start index. I.e. in PIV mode both bg images estimated in range 2...31 are applied correctly to first/second double shoot image in estimation starting at index 1.

Grid Parameters:

- '**Smoothing Factor**' is given relative to cell size. If ==0 no smoothing is applied (plain average in cell). For ==1 measurements with 'cell size' distance to respective cell are comprised weighted depending on distance.
- '**Min. Overall-Quality**' applies threshold filter to input data. Measurements with overall-quality below threshold are discarded in grid computation. Recommended 0.3 to 0.4 in most cases.
- '**Auto Set**' button now copies all filter settings (max re-projection error etc.) from GUI to parameter dialog

Visualization:

- Re-centering by right-click. Right-click a particle in 3D particle view centers 'Positions' and 'Velocities' view to clicked particle.



Graphical User Interface



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Tool strip controls

Basic controls for system setup and estimation/visualization process

Image visualization

Visualization of images, lens calibration and detected particles

3D visualization

Visualization of reconstructed particles and flow/track estimations.
Divided into a pure particle “Position” and a “Movement” visualization.

Image Progress

Progress information for image number and estimation stages (2D / 3D).

Configuration tabs

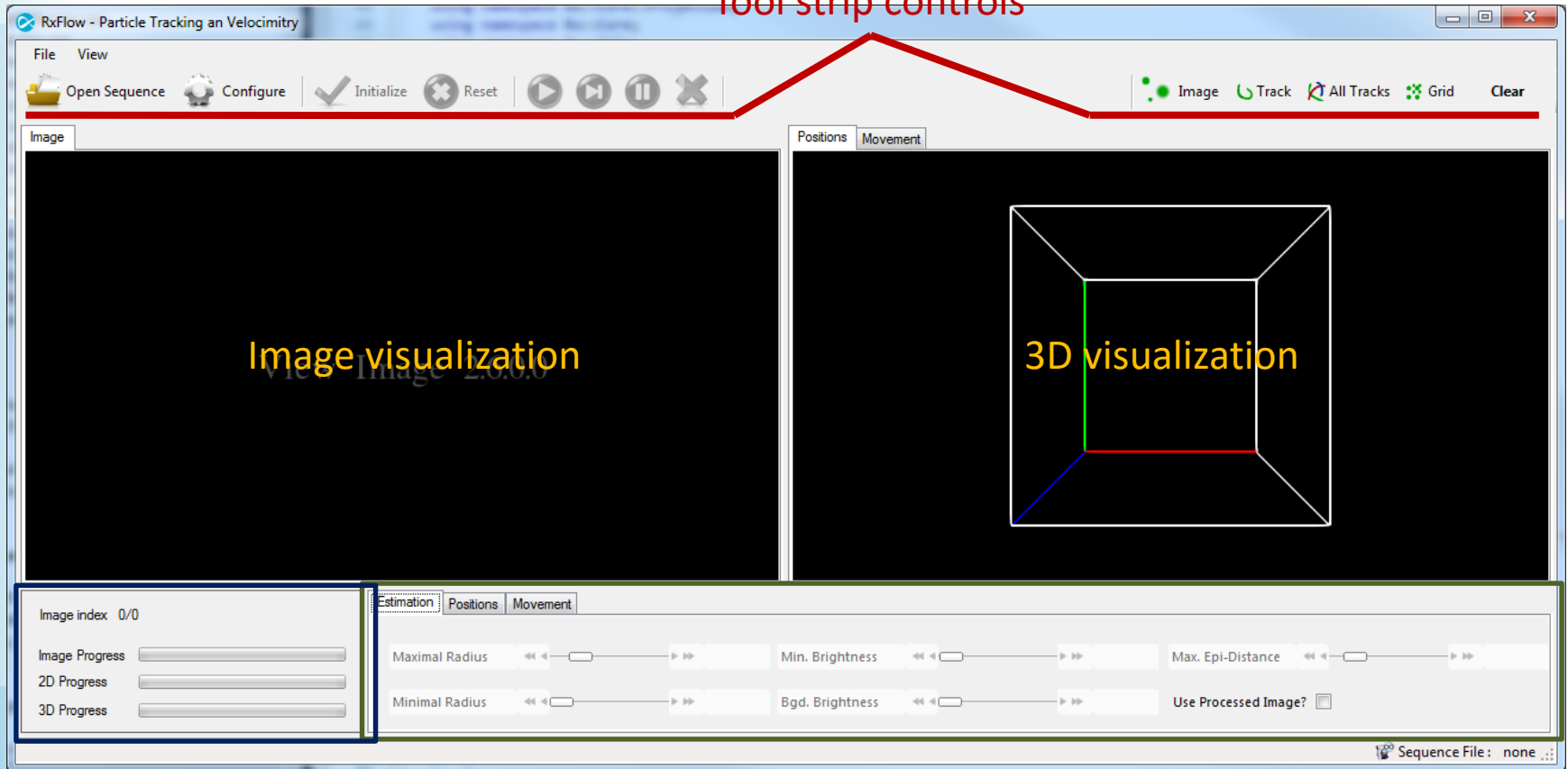
Controls for configuration of estimation and visualization.



Graphical User Interface

Layout

Tool strip controls



Progress information

Configuration tabs



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Open Sequence

Load a ray-sequence file from disk. Same as drag-and-drop file to GUI.

Configure

Opens Configuration Dialog. Allows for setting basic system properties. A configuration file can be loaded via “File” menu bar or drag-and-drop.

Initialize

Initializes framework after successful configuration and sequence load. Enables estimation and visualization. Fixes specific parameters such as camera type etc.

Reset

Resets system after initialization and discards ALL gathered data. The configurations (system, visualization, grid) remain and can be re-used.



Play

Starts continuous estimation for the whole image sequence. Selected visualization types (except for grid) are updated with each processed image.

Next

Starts estimation for the next image. Enters “Pause” state afterwards.

Pause

Stops a continuous estimation at next image. Continue estimation using **Play/Next**.

Cancel

Cancels active estimation. Triggers first-chance stop of estimation threads. Data of active time index is cleared and state of previously estimated time index is restored. Continue estimation at canceled time index using **Play/Next**.



Graphical User Interface

Tool strip controls

Single Image

Activates the visualization of a single image/time-step. 2D visualization displays detected particles in actual image, 3D visualization displays particle positions and position increments.

Single Track

Displays a single track (position history for a single particle) in “Movement”

All Tracks

As above for all tracked particles at once.

Grid

Visualize an adjusted velocity field as regular grid or flow lines. See GRID

Clear

Clears the visualization and cancels updates until an other mode is selected



Workflow



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Workflow

1. [Create/load system configuration](#)
2. [Open image sequence](#)
3. [Initialize system](#)
4. [Estimation](#)
 - Continuously, all images successively
 - Stepwise, trigger each estimation separately and visualize results
5. [Result visualization](#)
 - [Choose visualization mode](#)
 - [Compute/view grid if applicable](#)
6. [Store results to file](#)

Use “[Reset](#)” tool strip button to clean up old estimation and restart at 1 or 3.



Workflow Step 1 : Algorithm Configuration

Load existing configuration:

- From menu “File->Load Configuration”
- Using drag-and-drop
- Open configuration dialog (ToolStrip “Configure”) and click “Load Config”

Creating a new configuration :

1. Open configuration dialog via ToolStrip “Configure”
2. Setup camera type and either
 - Set “Manual Calibration” to false if metric calibration is available in ray-sequence
 - Set “Focal length” and “Focal distance” of actual camera setup
3. Set estimation parameters (see following pages)
4. Select working directory. Click text box right of “Working directory”
5. Select image sequence file. Click text box right of “Sequence File”
 - Alternatively use “File->Open Sequence” or drag-and-drop in main window

For re-use store configuration from configuration dialog “Save Config”.



Workflow Step 1 : Algorithm Configuration

Important Parameters

For most setups only a few parameters have to be adopted to the image properties. For a more detailed description see next section.

- **Calibration:** without metric calibration at least **Camera Type** has to be set
 - Metric calibration available in ray-sequence? => set “Manual Calibration” to “false”
 - Else set “Focal distance” and “Focal length” and set “Manual Calibration” to “true”
 - Focal distance = distance to most far focus plane, i.e. backside of scene
- **Density of particles:** Start with medium and set to high if 3D processing is slow.
- **Particle brightness minimum:** Set to avoid high runtime of 2D processing.
 - Use “View->Context Info” and click image in “Image” visualization to get information on image brightness at pixel of “darkest” particle
- **Bounding box :** Exclude areas not to be reconstructed, to reduce processing time.
 - Use “View->Context Info” to determine pixel coordinates of bounding box
- **Start/Stop image :** Select sub sequence to process.

IMPORTANT: For PIV mode the start image index **MUST** be the first image of a double shoot! Please validate this for each sequence in RxLive



Workflow Step 2 : Estimation

After the systems configuration and initialization are applied, the system is in 'Paused' state at first image of selected subsequence. The estimation can be...

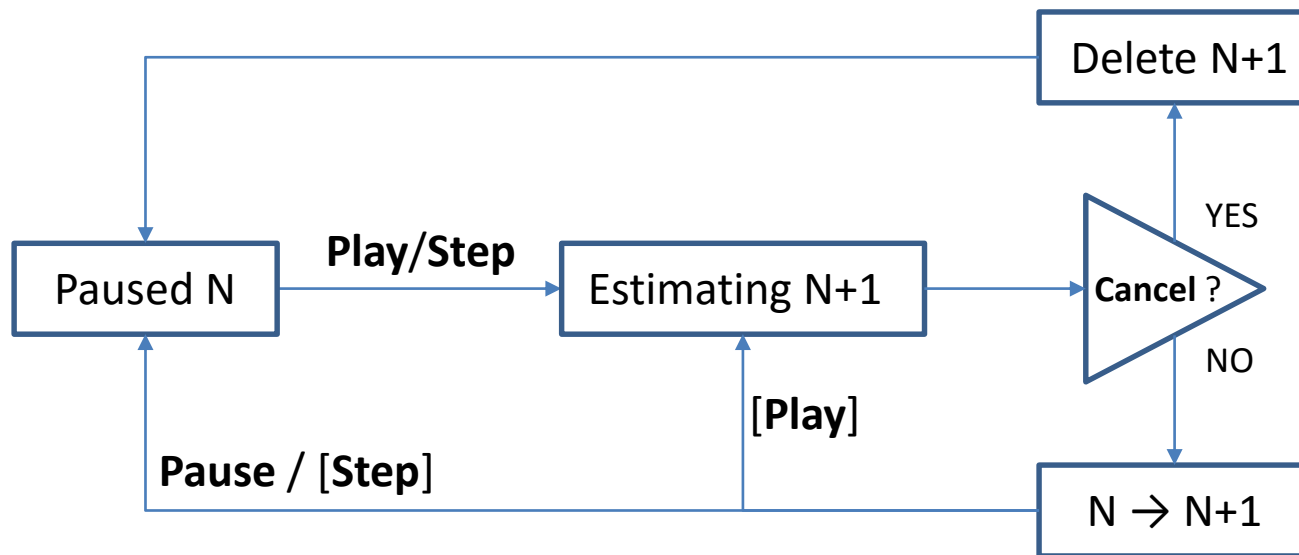
- Started by
 - **Play**: starts continuously estimation of succeeding images.
 - **Step**: starts single estimation for NEXT image.
- Stopped by
 - **Pause**: waits for active estimation to be completed. Pauses the system to visualize the respective results.
 - **Cancel**: discards the active estimation. Pauses the system this time index. No data is displayed since estimation was canceled. Next call to **Step** or **Play** continues with canceled time index.
- Full **Reset**
 - For deleting ALL estimations and temporary data. Only configuration and parameter settings will be kept.



Workflow Step 2 : Estimation

The state-flow for estimating sequences for indices $N=\text{start} \dots \text{stop}$ is controlled as displayed below. Except for canceled estimations the visualized time index is as of 'Paused N'.

After canceling an estimation no data is displayed until the next successful estimation using **Step** or **Play**.



Workflow Step 3 : Visualization

Whenever the system has entered 'Paused' state, the visualization type and parameters can be adopted. If an estimation is in progress, data is displayed and updated for each completed time index but filter parameters can't be altered.

Two view contexts are available for visualization of data (see [GUI Layout](#)). A 2D context displaying the active image and gathered 2D particle data. A 3D context for visualizing 3D particles, velocity vectors and grid structures.

For post-processing of data various filters can be applied. In especially certain thresholds can be used to discard particles, that are assumed to be unreliable or imprecise. See section [Visualization](#) for more details.



Workflow Step 4 : Grid Computation

Assuming a constant flow, a series of estimations can be used, to estimate a time-averaged velocity field. For this, a regular grid is created and its cells are 'filled' with the observed particle velocity. Using a weighted average filter, the noise in velocity estimation (especially z-axis) can be reduced significantly.

The **Grid** is computed using all measurements, that are not invalidated by the constraint filters (min. overall-quality, max. velocity etc.). Using the cell count in each dimension the spatial resolution can be altered. Additionally the 'Smoothing Factor' controls the size of smoothing factor. For $=0$ no smoothing is applied. **Smoothing is applied in z-direction exclusively!**

Flowlines represent simulated particle movements. For a given number of particles samples are distributed equally in the grid volume. Each sample is propagated through the velocity field according to direction and magnitude of local velocities. For an intuitive representation of the velocity field an animation simulates moving particles traveling the flowline trajectories.

Call the grid configuration dialog "Configure Grid" in the movement parameter tab to parametrize and compute grids/flowlines. See grid parameters for a detailed description.



Algorithm Parameters



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Algorithm Parameters

System parameters – stage 2D/3D : applies to resp. stage in progress bar

- **Calibration:**
 - **Manual Calibration:** if false, calibration parameters are read from image sequence. CAUTION: if sequence is not calibrated, estimation will be invalid.
 - **Camera Type:** determines additional calibration information internally
 - **Focal Length/Distance:** for metrical reconstruction without calibrated image sequence. Not all combinations are valid in used thin lens equations. Focal distance has to be at least 4x focal length.
- **Estimation** (green: can be altered in “Estimation” tab after system initialization)
 - **Background brightness avg.:** 2D stage. Approximate brightness of background scene [0...255]. Allows for more stable particle detection for scenes with bright backgrounds.
 - **Density of particles:** 3D stage. use LOW if only <1 particle per lens is observable (at minimum particle brightness). Use HIGH if multiple particles are visible in each lens. – tradeoff between computational effort and amount of uniquely estimated 3D particles



Algorithm Parameters

- **Estimation** (green : can be altered after system initialization)
 - **Max. epipolar distance:** 3D stage. 2D particles combined to a single 3D particle have to fulfill epipolar constraints. Higher values allow for more but also more unreliable matches. Recommended setting is 0.5 to 1.0 pixels
 - **Particle brightness minimum:** 2D stage. Provides a threshold to brightness of detected particles [0...255]. Particles with lower brightness won't be considered (not rejected but not detected!). Low values can cause image noise to be detected as particles. High values can result in combining particle groups to a single particle!
 - **Radius Min/Max:** 2D stage. Smaller/larger particles are rejected before time tracking and depth matching are applied. Given in pixel.
 - **Time Matcher Type:** 2D stage. VISUAL uses the particle size and brightness as similarity measure. DISTANCE uses only the minimal movement constraint. The latter is especially dedicated to double-shot images or very slow movements.



Algorithm Parameters

- **Estimation**
 - **Lens Types:** 2D stage. The different lens types are treated differently during estimation. Mostly type 2 and 3 will be most useful for reconstruction.
 - **Number of Threads:** ... to be used for processing in 2D and 3D. Speedup for multi-core systems in case of high particle count.
 - **PIV mode:** activates double-shot mode. Time tracking is applied only between succeeding image pairs (1<->2; 3<->4 etc.).
 - **Particles per lens limit:** skip lenses where more particles are detected to avoid high runtime 3D estimation
- **Image Properties**
 - The **Bounding Box** describes an area within the image that is to be analyzed. Use “View -> Context Info” window to determine correct range.
 - **Invert image brightness:** transforms image pixel-wise to 255-brightness. Use to detect dark particles on bright background (e.g. backlight illumination).



Algorithm Parameters

- **Misc**

- **Enable Visualization:** When set to false, NO visualizations will be available. Allows for processing long sequences by fixing memory usage. '**Auto Set**' feature in grid dialog will **NOT** be available.
- **Start/Stop** image: give index range of images in ray sequence to process. Progress information displays image index, progress bar relative progress in [start...stop].
IMPORTANT: For PIV mode the start image index **MUST** be the first image of a double shoot! Please validate this for each sequence in RxLive
- **Time Delta:** Time in seconds between successive images. In PIV mode the delay in a double shoot, inverse of recording FPS else.
- **Working Directory:** Click text slot to give the directory for temporary data and default directory. Avoid network devices since filesystem re-connections can cause swap data to be lost.
- **Ray-Sequence File:** If no file is given, please set afterwards using "File->Open Sequence" or drag-and-drop to GUI.



Algorithm Parameters

- **Background Image**
 - For scenes with a static background a “BG Image” can be determined, to reduce the backgrounds impact on particle detection.
 - Assumes static a background and it’s visibility in each pixel in at least one image. (not necessarily all in the same image)
 - For PIV mode two images are computed. (for first and second shot)
 - Create by
 1. Click tool strip “Compute BG Image”
 2. Select image index range and brightness tolerance (= noise in background)
 3. Start computation

The background image[s] can be exported as ray-sequence via “File->Export BG Image”. It can be imported for later sessions (via “File->Import BG Image”).

The exported sequence can also be used with RxLive for additional processing.



Algorithm Parameters

- **Processed Image**

- To improve particle detection quality, the raw image can be normalized with the ray-sequence's gray image.
 - Toggled by the "Use Processed Image?" checkbox in "Estimation" tab
- Normalization reduces brightness decrease at lens borders and, by this, improves particle detection.
- Since the normalization amplifies image noise close to lens borders, the grey image's quality is crucial.
 - Switch between non-/normalized images to check image quality and estimation stability

NOTE:

The particle brightness and the scene's background will change. Be sure to adopt the respective algorithm parameters accordingly.



Algorithm Parameters: Grid Adjustment

Grid computation and visualization

- Computes interpolated/averaged displacements for a regular grid using a series of estimations (assuming a constant flow)
- Visualization as
 - Regular grid : displacements at equidistant 3D positions
 - Flowlines : similar to “All Tracks” using synthetically generated tracks. 3D particles are generated and propagated using interpolated grid velocities.
- In combination with “Enable Animation” flowlines provide an intuitive visualization of the overall movement simulating a high particle density.

In addition to the position and displacement constraints certain grid properties can be configured. See next page.



Algorithm Parameters: Grid Adjustment

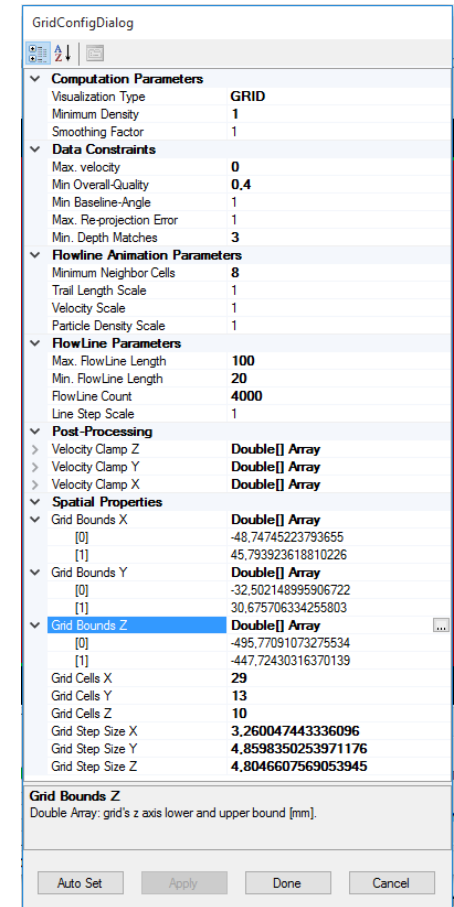
De-/activate the grid configuration dialog from
“View->Grid Configuration” or “Configure Grid” button
in “Movement” tab.

“Auto Set” : generates a guess for grid configuration
using the visualization parameters.

“Apply” : triggers computation/update of grid/flowlines

“Done” : as above and closes configuration dialog

“Cancel” : discards all changes and closes dialog



The screenshot shows the 'GridConfigDialog' window with the following parameters:

Category	Parameter	Value
Computation Parameters	Visualization Type	GRID
	Minimum Density	1
	Smoothing Factor	1
Data Constraints	Max. velocity	0
	Min Overall-Quality	0.4
	Min Baseline-Angle	1
	Max. Re-projection Error	1
	Min. Depth Matches	3
Flowline Animation Parameters	Minimum Neighbor Cells	8
	Trail Length Scale	1
	Velocity Scale	1
	Particle Density Scale	1
FlowLine Parameters	Max. FlowLine Length	100
	Min. FlowLine Length	20
	FlowLine Count	4000
	Line Step Scale	1
Post-Processing	Velocity Clamp Z	Double[] Array
	Velocity Clamp Y	Double[] Array
	Velocity Clamp X	Double[] Array
Spatial Properties	Grid Bounds X	Double[] Array
	Grid Bounds Y	Double[] Array
Grid Bounds Z	Grid Bounds Z	Double[] Array
	Grid Cells X	29
Grid Properties	Grid Cells Y	13
	Grid Cells Z	10
	Grid Step Size X	3.260047443336096
	Grid Step Size Y	4.8598350253971176
	Grid Step Size Z	4.8046607569053945

Grid Bounds Z
Double Array: grid's z axis lower and upper bound [mm].

Buttons: Auto Set, Apply, Done, Cancel



Algorithm Parameters: Grid Adjustment

Computation parameters

- “Visualization Type” : Either **Grid** or **Flowlines**. The former computes the regular velocity field. The latter updates the grid (if needed) and visualizes simulated particle tracks.
determine plain average in cell.
- “Minimum density” : Threshold for quality of information per cell. If fewer input samples (estimated velocities) are available for a certain cell, the respective velocity is set to 0 (invalidated).
- “Smoothing factor” : Size of smoothing area in “Grid Step Sizes”. Corresponds to the standard deviation of a Gaussian smoothing kernel. For $sf=0$ no smoothing. For $sf=1$ the filter radius is $\frac{1}{2} + 1$ cell and measurements outside the cell (distance $> \frac{1}{2}$ cell) are weighted by distance.
Smoothing is applied in z-direction exclusively!



Algorithm Parameters: Grid Adjustment

Data Constraints (same as visualization constraints see [Particle analysis](#))

Velocity measurements violating any of the thresholds are assumed invalid and are not used for grid computation.

“Max. velocity” : Upper limit for magnitude of velocity measurements.

“Min Overall-Quality” : Lower limit for overall quality for involved 3D particles.

“Min Baseline-Angle” : Lower limit for relative positions of involved lenses. In [rad]
MIN = 0 : Lenses are allowed to lie on a line (instable depth matching)
MAX = $\pi/2$: At least 3 lenses form a right triangle (more stable but less often)

“Max. Re-projection Error” : Upper limit for re-projection quality of involved 3D particles.

“Min Depth Matches” : Lower limit for number of 2D particles used to estimate each 3D particle involved in velocity estimation.



Algorithm Parameters: Grid Adjustment

Flowline Animation Parameters

Grid parameters applicable for “Visualization type : FLOWLINES”. Control visual appearance of simulated particle movement on flowline trajectories. **No grid re-computation needed when parameters are changed.**

“Min. Neighbor Cells” : For flowline generation velocities are interpolated from grid. Each position in flowline trajectory needs at least the given number of interpolation source cells.

“Trail Length Scale” : Scale factor for ‘length’ of animated particles.

“Velocity Scale” : Scale for speed of animated particles on flowline trajectory.

“Particle Density Scale” : Scale for number of particles animated on a single flowline.



Algorithm Parameters: Grid Adjustment

Flowline Parameters

Grid parameters applicable for “Visualization type : FLOWLINES”. Control visual appearance of simulated particle movement on flowline trajectories.

“Max. FlowLine Length” : Maximal length (time steps) of flowlines. Long tracks are able to resolve areas with low velocities.

“Min. FlowLine Length” : minimal length (time steps) of flowlines. Short tracks are able to resolve areas with sparse grid occupancy.

“Flowline Count” : Total number of flowlines. High track count is more suitable for animated visualization (“Enable Animation” in movement configuration tab) but increases computational visualization effort.

“Line Step Scale” : Scales estimated velocity for generation of tracks. In combination with min/max length the spatial resolution of flowlines can be controlled.



Algorithm Parameters: Grid Adjustment

Post Processing

“Velocity Clamp” minimum [0] and maximum [1] cutoff for velocities in each axis direction.

- E.g. allows for visualization of slices of the velocity field.
- In combination with flowlines sliced animations can be generated.

Spatial Properties

“Grid Bounds” minimum [0] and maximum [1] of grids bounding box. The minima define the bottom-leftmost-back cell position. The maxima the top-rightmost-front cell position.

“Grid Cells” define the number of cells in each axis direction. A grid with cell count $x=20$, $y=15$, $z=10$ cells has a total of $20*15*10 = 3000$ cells.

“Grid Step Size” [read only] size of a cell in x/y/z axis. That is $(\text{max}-\text{min})/\text{cellCount}$



Visualization



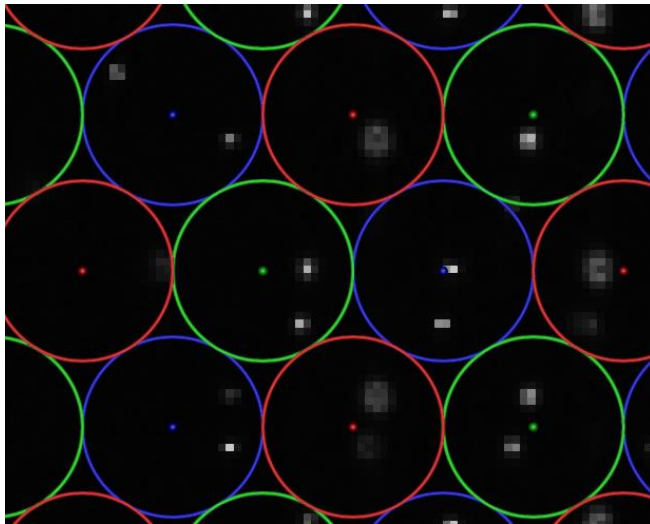
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Visualization

Image – all modes

1. Calibration of lens grid : Lens area (large colored circles). Lenses are colored by lens type.
2. Detected particles in each lens. Circles mark the estimated particle radius.
Green particles are considered valid, red invalid (too large, out of lens area...)
3. Re-projection (see next page). Visualizes estimation for selected 3D particle.



Visualization

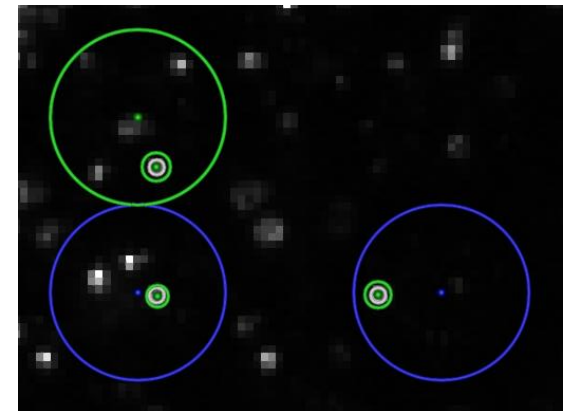
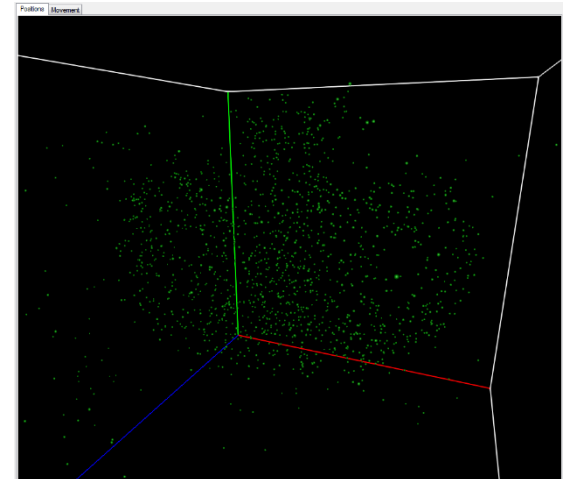
Position – all modes

- Visualizes estimated positions for all active particles
- Particles are colored by overall-quality $[0..1] = [\text{red}..\text{green}]$
- Left-click a particle for visualization of re-projection
- Right-click on a particles re-centers 3D view

Particle analysis

- Select particle in position view (left-click)
- “Context Info” frame displays particle information
 - Position in 3-space in [mm]
 - Re-projection error in [px]
 - Match-count
 - Minimal baseline angle [rad]
 - Overall-Quality

Re-projection describes the “what if” 2D position assuming the particle estimation is perfect.

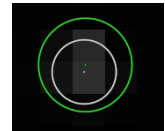


Visualization

Position – parameters

- Thresholds for validity of particles. Set via [Configuration tabs](#) “Positions”.
- 3D particles with properties violating any threshold are excluded from ALL visualization modes.

“Re-projection error” : maximum allowed deviation between detected (green) and re-projected (white) 2D particle.



“Match-count” : min. number of 2D particles used for estimation. More matches result in more stable 3D positions.

“Min baseline angle” : Quality of relative positions of involved lenses. In [rad]
MIN = 0 : Lenses are allowed to lie on a line (instable depth matching)
MAX = $\pi/2$: At least 3 lenses form a right triangle (more stable but less often)

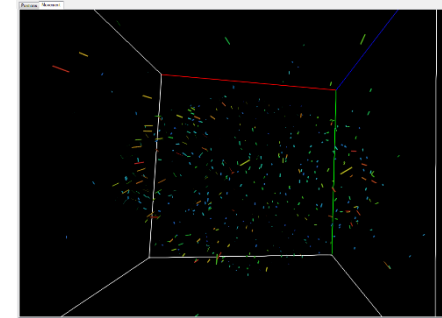
“Min. overall-quality” : minimum quality allowed for valid particles. Relates observed match count and optimal match count of 2D particles.



Visualization

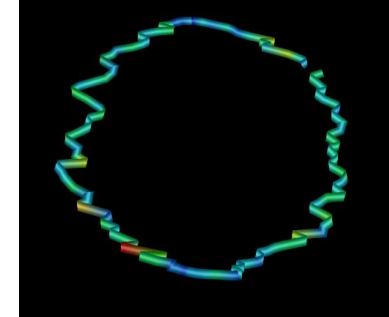
Movement – single image

- Visualizes estimated position displacement for all time tracked particles from previous to active image
- Colored line segments **red** = fast -> **blue** = slow



Movement – single track / all tracks

- Shows the position history for a single and all particles respectively as a curve (= track).
- Segments (= single image displacements) are colored by speed as above.



In addition to the particle thresholds, constraints (see next page) to the displacements can be applied using the movement **Configuration tabs**.



Visualization

Movement – parameters

Thresholds for validity of velocities. Set via [Configuration tabs](#) “Movement”.

- In-/Valid => ex-/include from visualization and grid computation

“Max. Velocity” : threshold for particle velocity in [mm/s]
(requires correct “Time Delta” setting in main configuration)

“Velocity Scale” : scale for displayed velocities to improve visibility
(applies to single image and grid visualization)

“Track Index” : select the track to visualize in “Single Track” visualization.

“Min. Track Length” : threshold for minimal number of time matches in tracks to visualize. Applies to “Single Track” and “All Tracks” modes.

“Enable Animation” : Replaces continuous track curves by animated virtual particles.



Result Data Export



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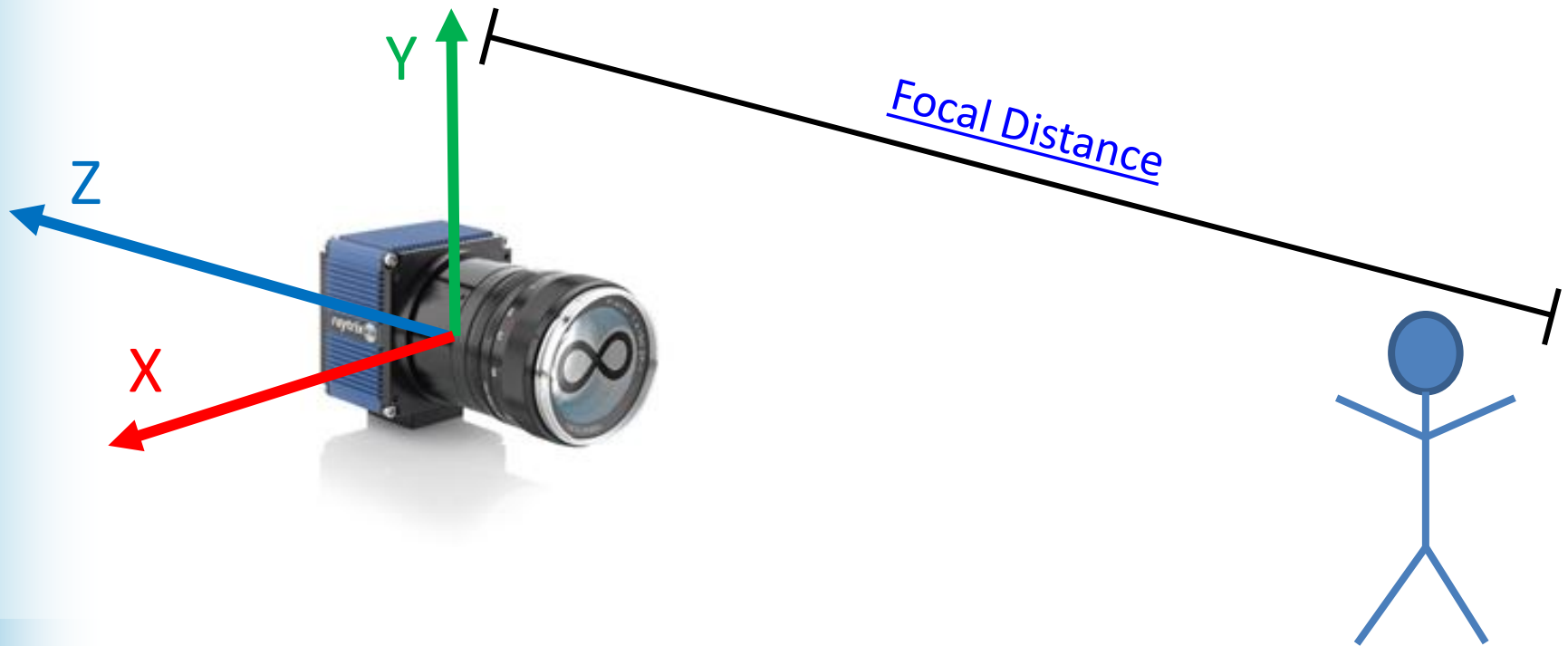
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Result Data Export

- Export data to text files (whitespace separated, row major) using the “File->Save...” menu buttons
- “Save Tracks” exports all estimated 3D positions in [mm]. In addition the image number, the quality information and the according track ID.
- “Save Velocities” exports all local velocities for successive image pairs. Velocities are given in [mm/s], providing the algorithm’s “Time Delta” parameter is set correctly.
- “Save Grid” exports the regular grid positions and velocities as plain text or to vtk file format.
- The used coordinate system is given relative to the camera system in [mm]. See next page.



Conventions on coordinate parameterization



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Result Data Export

Save All Tracks provides particle per line information on:

- Image number of particle
- Actual position in [mm]
- Match count
- Re-projection error in pixels
- Maximal baseline angle in radians
- **NEW: Overall Quality**
- Track ID (same ID for all time indices of “same” particle)

Format:

#image posX posY posZ #matches error angle **overall-quality** TrackID



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Result Data Export

Save Velocities provides velocity per line information on:

- Image number of reference time N-1
- Image number of match time N
- Velocity in [mm/s] at given position
- Position in [mm] (half way between matched particles)
- Number of 2D time matches used for 3D particle time match
- Minimal number of 2D matches of involved 3D particles
- Maximal re-projection error of involved 3D particles
- Minimal baseline angle of involved 3D particles
- **NEW: Overall Quality**
- **Track ID (same ID for all time indices of “same” particle)**

Format:

(N-1) N | velX velY velZ | posX posY posZ | #time-matches #particle-matches | error angle overall-quality | TrackID



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Result Data Export

Save Grid copies computed grid to plain text (.grid extension) or vtk format

- Use file-extension selector in file dialog to choose format

Text format :

- First line: 3x cell count | 3x cell size in [mm] | 1x dummy 0
- Second line:
 - Position [mm] in x/y/z component of top-left-front grid node
 - Position [mm] in x/y/z component of bottom-right-back grid node
 - 1x dummy 0
- Following lines : Grid node position in [mm], velocity in [mm/s] and cell density
 - posX posY posZ velX velY velZ **density**

VTK files :

Are stored in rectilinear grid format, e.g. for import to ParaView. The cells velocity are stored in import data “velocity_vectors” array. The number of measurements per cell are stored as “density” array.

