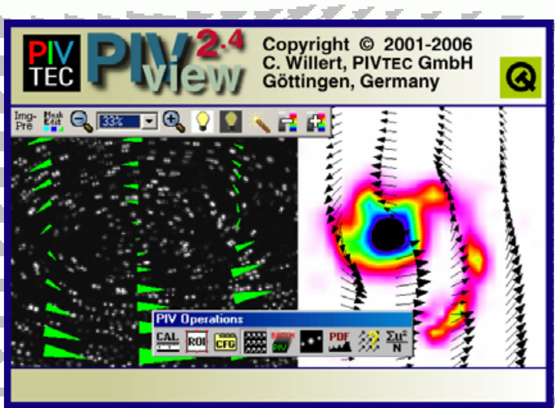
PIVTEC

PIVVIEW2C/3C
Version 2.4

User Manual



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Acknowledgements

The PIVTEC Software was and continues to be developed in close cooperation with the Institute of Aerodynamics and Flow Technology of the German Aerospace Center (DLR) in Goettingen, Germany.

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Contents

Overview of PIVview

Background

PIVview is a compact program package for the evaluation of particle image velocimetry (PIV) or speckle displacement recordings. Its original and primary intention was to provide a quick-look data retrieval from PIV recordings. Experience has shown that this quick-look capability is essential in the optimization of the acquisition process.

Features

During its development *PIVview* has matured from a simple PIV image probing program to a (nearly) complete PIV evaluation package including:

- advanced processing algorithms:
  - multiple-pass method
  - mulitple-grid (pyramid) method
  - double-correlation method
  - second order, image deformation methods
  - various peak detectors and fitting algorithms)
  - ensemble correlation
- classical and nonlinear peak detection
- image pre-processing (various filters, masking)
- region of interest selection
- interactive calibration
- outlier detection and replacement
- data postprocessing (vorticity, strain)
- vector and contour display / print capability
- data export (TecPlot, ASCII and netCDF)
- PIV data import for further post-processing
- WYSIWYG export using BMP, PNG, and others
- batch processing of image and data sequences
- data set statistics calculation
- stereo PIV processing capabilities
- drag-and-drop capabilities
- mask editing
- command-line programs

Since version 2.0 *PIVview*'s user interface has been making use of the platform-independent QT-library (Trolltech, www.trolltech.com) and can be made available on most Unix systems (e.g.. Linux, Solaris).

Upcoming features

Since *PIVview* is a continuously evolving program suite; new features and improvements are constantly added. *PIVTEC* is always open to new suggestions and encourages users to forward these as well as any bug reports.

What *PIVview* is not

PIVview does not include any form of data acquisition such as PIV camera and laser control, experiment synchronization, etc. This guarantees that the program can be operated on any PC-system running a 32-bit Windows operating system.
Also *PIVview* has no intention of replacing the capabilities of full-featured plotting packages such as *TecPlot* or *Origin*. The plotting capabilities of *PIVview* merely provide the user with visual feedback of the processing results while also providing the capability of quickly obtaining a hardcopy of the calculated data.

PIVview Versions

Two versions of *PIVview* are available: a demo version as well as a licensed version.
The demo version - downloadable from *PIVTEC*'s internet server - provides nearly all features of the licensed version except for data-export and batch-processing. The demo version can be distributed freely and is especially useful for optimizing a PIV experiment or for demonstrating the principles of PIV evaluation.
Full use of all of *PIVview*'s features is only possible by obtaining a license through *PIVTEC* GmbH.

Credits

PIVview was conceived and is maintained by C. Willert, *PIVTEC* GmbH, Göttingen (Germany), and developed in close cooperation with the PIV-Group of the German Aerospace Center (DLR) in Göttingen.

System Requirements

PIVview should run on essentially any of today's *Windows* operating systems.

- 32-bit Microsoft Windows (tested on *Windows* versions 95, 98, NT4, 2000, XP)
- Pentium class processor
- >32 MB of RAM (depending on *Windows* version)
- 256-color SVGA or better graphics display
- hard disk space:
  program executables: ~5 MB
  example files: ~30 MB
  utility programs: ~4 MB

If you merely want to try out *PIVview* you need not install it on your system. The program can be run from the CD-ROM by double clicking the `PivView2CDemo.exe` file.

Alternatively *PIVview* can be installed from the setup CD-ROM in several ways:

Installation Method A

1. Put the *PIVview* CD-ROM into your CD-ROM drive.
2. In your file browser double click the file `autorun.exe`. This starts an installation option dialog.
3. From there the setup procedure can be initiated. Alternatively, the documentation or latest release notes can be viewed.
4. Follow the instructions in the installation program.

Installation Method B

1. Put the *PIVview* CD-ROM into your CD-ROM drive.
2. From the Windows Start button click Run.
3. Type the following Run command line:
   `D:\PIVVIEW2\SETUP\SETUP.EXE`
   (If necessary substitute the appropriate drive letter for your CD-ROM drive in the above command.)
4. Follow the instructions in the installation program.

What is installed where ?

By default the *PIVview* program and its associated files are installed in the system's `Programs` or `Program Files` directory. Other destinations can be chosen during setup. All(!) files associated with *PIVview* are copied into this directory tree, that is, no files are copied to the `Windows` system directories. This also means that the program can be removed efficiently by deleting this directory although the system's uninstall method should be preferred.

Aside from the files, the installation programs installs a few short cuts to the system's start menu.

PIVview makes extensive use of the *Windows* registry to store its current configuration settings. These are located under:

`\HKEY_LOCAL_MACHINE\Software\PivTec\PIVview2`

Removing *PIVview*

The best way to remove *PIVview* is to use the Uninstaller which is part of the Windows operating system (found under `Configuration\Software`).

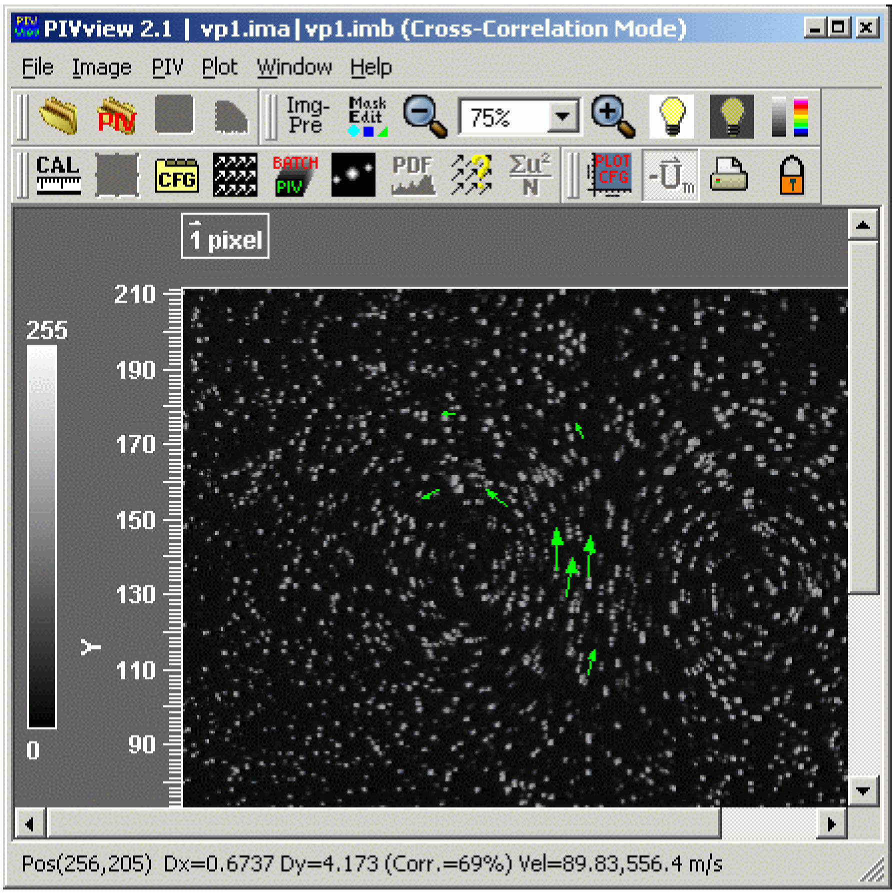
Alternatively the software is completely removed by deleting the *PIVview* installation directory. This however does not remove the registry entries associated with *PIVview*.

Getting acquainted with *PIVview*

The user interface of *PIVview* is similar to many common *Microsoft Windows* based applications and features:

- a title bar
- a menu bar
- several toolbars
- a main window to view data (workspace)
- a status bar

PIVview is based on a single document software architecure, that is, only one image (pair) can be opened by each *PIVview* instance. If you need to open several PIV images simultaneously you need to start several instances of *PIVview* which can be started through the menu option: **File**/**New Window**. (Please note that the settings of last *PIVview* instance closed are stored in the registry.)



Main window of PivView with image pair loaded and interactively sampled interrogation vectors. The intensity LUT is displayed on the left. The top-left shows a reference scale vector.

Title bar

The title bar displays the file name(s) of currently loaded image or data file(s) and *PIVview*'s current mode of operation (e.g. cross-correlation, autocorrelation or speckle shift mode).

Menu bar

The menu bar is used to perform any required operation within *PIVview* and contains seven sub-menus:

- *File* for loading images, saving data, setting preferences or exiting the program;
- *Image* for basic image display related functions (brightness, look-up tables, zoom, etc.) as well as image enhancement;

- *PIV* for performing PIV analysis, defining PIV interrogation parameters or regions of interest;
- *Plot* for configuration of plotting parameters or exporting a plot of the currently displayed data;
- *Windows* to activate additional data display windows such as correlation plane, 2-D and 1-D histograms, or data probing menu;
- *Help* to display *PIVview* version information or available program options.

Main window

Once loaded, PIV images are displayed in the main window. Image pairs are displayed by by selecting the brightest pixels from both images.

The image (pair) can be interactively interrogated at any position using the left mouse button. The interrogation parameters for cross-correlation analysis are defined in various setup menus. The results of the correlation analysis are displayed in the status bar at the bottom as well as in the form of a color-coded vector (defined in the Plot/Vector setup menu).

Main window - Lookup table

A lookup table (LUT) is used to convert image intensities to screen intensities or colors. The image above shows the currently selected LUT as a vertical bar on the left — in this case a linear intensity ramp with 0 (black) at the bottom and 255 (white) at the top.

The number at the top of the LUT represents the intensity of brightest display pixel. The image brightness can be changed by using the menu entries **Image/Brigher** or **Image/Darker** or the short-cut keys, b and d, respectively. Pixel intensities exceeding the maximum display intensity are either clipped at the maximum or wrap back to the bottom of the LUT (**Image/Clipping**).

The display of the LUT can be turned off with the menu option **Image/Hide LUT**.

Main Window - Reference Vector

The reference vector‘s main purpose is to have a visual reference when a complete data set is plotted or exported. It‘s magnitude and display is defined via **Plot/PlotConfig./Ref.Vector**.

Main Window - Scroll Bars

The scroll bars on the right side and bottom edge of the main window can be used to pan the image to a different viewport if the entire image does not fit into the display window.

Status Bar

The status bar generally reports the cursor position in both image units [pixels] as well as physical coordinates. Also the image intensity is given. In case of interactive interrogation, the correlation result is shown (e.g. position, displacement, velocity, correlation coefficient).

If the image has been evaluated these fields provide information about the data point closest to the cursor.

Note: Many of the toolbar buttons and menu entries only become active if image or data is available.

The *PIVview* Menu Entries

The *File* Menu

Evaluation Mode – specifies one of the three *PIVview* operation modes:

- *Cross-Correlation Mode* - the standard mode for PIV analysis based on double-frame, single-exposure images (image pairs).
- *Autocorrelation Mode* - PIV analysis based on single-frame, double-exposure images which are common in photographic PIV.
- *Speckle Displacement Mode* - for the analysis of speckle displacement image pairs. This mode is similar to the cross-correlation mode but instead of converting the data to velocity it is presented as displacements. Also the two required images are loaded separately.

Preferences – opens a dialog which allows to set a variety of *PIVview*-global settings such as file extensions, default data output, etc.

Open image – opens a file dialog for loading a PIV image (pair) or speckle shift image.

Open data – opens a file dialog for loading a PIV or speckle shift data set.

Save data set – opens a menu with output options to save computed PIV data in a file. The **Save** menu option uses the file title (without extension) to create a name for the output file and places it in the same directory with the original image. With the **Save as** option the user can define the name and destination directory of the output file.

Create Tecplot Data – to save the processed data set in a format compatible with *Tecplot*. Style files for *Tecplot* are also generated.

Parameters... (Load, Save, Save as) – stores or retrieves the current *PIVview* parameter configuration in/from a file. This file is formatted in *netCDF* and therefore is platform independent but cannot be read be a standard text editor.

Recent images, Recent files – are listed by their names and are opened by clicking on them. Note that the PIV mode of operation does not automatically change for different image types.

New Window – starts are another instance of *PIVview* by opening additional main window. New windows operate completely independent of one another.

Exit terminates *PIVview* program. The current PIV, image and plotting parameters are stored in the *Windows* registry and are restored when the program is started again.

Tip: Use parameter files if you plan to work with different types of images.

The *Image* Menu

Image PreProcess – opens a dialog in which a variety of image pre-processing options can be set, such as splitting of the PCO-camera’s double image files, image filtering, histogram adjustment, background subtraction, etc.

Edit Mask – starts the mask editor ***PIVmask*** with the currently loaded image. Completed mask images can be loaded directly from in the image pre-proceesing menu.

Calc. Minimum Image – allows the selection of an image sequence from which a minimum intensity image is computed.

Horizontal Profile, Vertical Profile – shows plots of image intensity profiles for the current mouse cursor position.

Zoom out, **Zoom in** – change the image magnification. The scroll bars on the edges can be used to pan through the enlarged image / data set (Shortcut keys are **+** and **–**).

Brighter, **Darker** – changes the visual brightness of the currently loaded image. The image data itself is not affected (The shortcut keys are **b** and **d**).

Auto-scale – sets default intensity on image

Change LUT – changes the current image lookup table (LUT) or switches to previous LUT. Clicking on the function/button repeatedly cycles through all possible LUTs. Currently there is no provision for user defined LUTs. (Shortcut key is **L**).

Clipping – enables or disables image clipping for image intensties exceeding the LUT maximum intensity. With clipping on intensities greater than the maximum are set to the maximum. With clipped off the intensity wraps back to the bottom of the LUT (Shortcut key is **c**).

Show LUT – controls the display of the LUT bar on the left side of the image. (Shortcut key is CTRL+**L**).

Show Image – is useful to hide the image to better view the computed PIV data. (Shortcut key is **I**).

The *PIV* menu

Calibration – puts PIVview into calibration mode, hiding the current PIV data set and displaying a moveable ruler and origin. Within a separate dialog the magnification factor and reference point coordinates can be defined interactivley. After closing this menu PivView reverts back to the interrogation mode. (Shortcut key is **F3**).

PIV ROI – puts PIVview into the ROI-mode in which a rectangular portion within the image can be defined for processing. To use this function the *Use ROI* option in the **PIV Setup** dialog has to be enabled (Shortcut key is **F2**).

Process Log – shows a window with processing messages.

PIV Configuration – opens a tabbed dialog in which a wide variety of PIV processing parameters can be defined (Shortcut key is **F4** or via context menu by right-clicking the mouse).

Evaluate image – performs an evaluation of the loaded image (pair). For large data sets a progress bar is displayed during processing allowing the user to abort the interrogation. (Shortcut key is **F5**).

Batch Processing – opens a dialog through which ensemble PIV processing can be initiated.

Correlation Plane – displays the correlation plane and associated PIV image samples (if chosen) in a separate window. The data in this window is updated each time a new interactive interrogation is performed on the image (by clicking the left button within the image, Shortcut key is **F6**).

2-D Histogram (PDF) – also is only available for evaluated PIV images. It plots the calculated displacement data in a two-dimensional plane and can be used in the vector validation procedure. Additionally one-dimensional histograms (PDFs) show the projection of the 2-D data onto each major axis. (Shortcut key is **F7**).

PIV Data Probe – is a window that is available after a PIV image has been evaluated. It gives detailed information about any calculated vector within the data set. The vector closest to the mouse cursor is selected.

Statistics – provides information about the currently displayed PIV data set, such as mean and RMS values of displacement, velocity, vorticity, etc.

Live Evaluation – if enabled PIVview will display newly computed vectors during processing of the image.

Clear PIV Data – deletes the currently displayed PIV data set. Usually any modification in the **PIV Configuration** menu has the same effect.

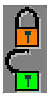
The *Plot* menu

Plot Settings – opens a dialog in which the layout and properties of the plotted PIV data can be controlled. Among these are vector coding and length, scalar image display, axis and axis labeling, reference vectors, and color definitions (Shortcut key is P).

Subtract Mean – displays the vector field with or without the mean displacement of the data set subtracted. This is especially useful for displaying flow structures that might be hidden in a large, nearly uniform, convective flow.

Print Preview, Printer Setup, Print – handles printing within PIVview and includes previewing, layout and printer selection. (Shortcut key for printing is P).

Export as image> – stores the currently displayed data set or image in an image file (=screen capture). Export formats include BMP, JPEG, PNG and others. Current zoom factors are used in the exported image. The larger the zoom factor, the larger the resulting image.



Position objects – puts PIVview into and edit mode where workspace objects (image, luts, reference vector,...) can be freely placed to suit the user's preferences.

Save current LUT / Load LUT – save or load user specified pseudo-color lookup table

Default positions – restores the original positions of the workspace objects.

Save / Load plot configuration – stores/restores plot parameters

The *Window* menu

Hide Toolbars – hides all toolbars

Individual toolbars can be activated or deactivated one by one.

The *Help* menu

PIVview options – displays the command line options available for PIVview.

About PivView gives information about the program itself (e.g. release version number) as well as shows the currently registered end user.

The *PIVview* Toolbars

File>Open Image – is used to load a new image for PIV processing.

File>Open Data – is used to load a new data set for post-processing.

File>Save Data Set – opens a dialog with output options before saving the processed data set.

File>Create Tecplot Data – to save the processed data set in a format compatible with TecPlot. Style files for TecPlot are also generated.

Image>PreProcess – opens a menu with image pre-processing options (Short-cut key: CTRL+I).

Image>Edit Mask – starts the mask editor program PIVmask.

Image>Zoom out, **Image>Zoom in** – increases or reduces the magnification of the image on the screen. If the image no longer fits the screen scroll bars on the edges allow image panning (Short-cut keys: +,–).

Image>Brighter – increases the image brightness on the screen (Short-cut key: B).

Image>Darker – decreases the image brightness on the screen (Short-cut key: D).

Image>Auto-scale – sets default intensity on image

Image>Change LUT – changes the display look-up table (LUT). Each click of the icon picks the next or previous LUT in a circular list. When scalar data (e.g. vorticity) is displayed in place of the PIV image, the accompanying LUT is changed. (Short-cut key: L).

PIV>Calibration – opens a menu for online length calibration . Only the image with an overlaid ruler and origin are displayed (Short-cut key: F3).

PIV>PIV ROI – changes into selection mode region of interest (ROI), (Short-cut key: F2).

PIV>PIV Configuration – opens a tabbed menu with PIV processing parameters (Short-cut key: F4).

PIV>Evaluate Image – performs evaluation of PIV image using current configuration defined by the PIV processing parameters (Short-cut key: F5).

PIV>Batch Processing – opens the batch processing menu.

PIV>Correlation Plane – displays the correlation plane during interactive interrogation using the mouse.

PIV>2-D Histogram – displays a global histogram of the currently computed data set.

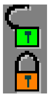
PIV>Data Probe – shows a window with detailed information about any calculated vector within the data set. The vector closest to the mouse cursor is selected.

PIV>Statistics – presents a summary of statistics of the computed data set including the number of data points, number of outliers, various mean values and standard deviations as well as the maxima and minima.

Plot>Plot Config. – opens a tabbed menu with vector and contour plotting parameters (Short-cut key: p).

Plot>Subtract Mean – subtracts the mean displacement from the data set before plotting it.

Plot>Print – sends the currently displayed data set to the printer.

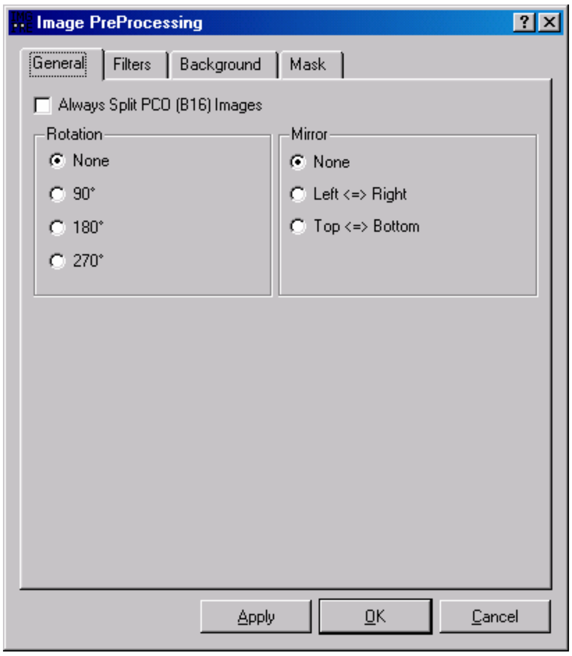


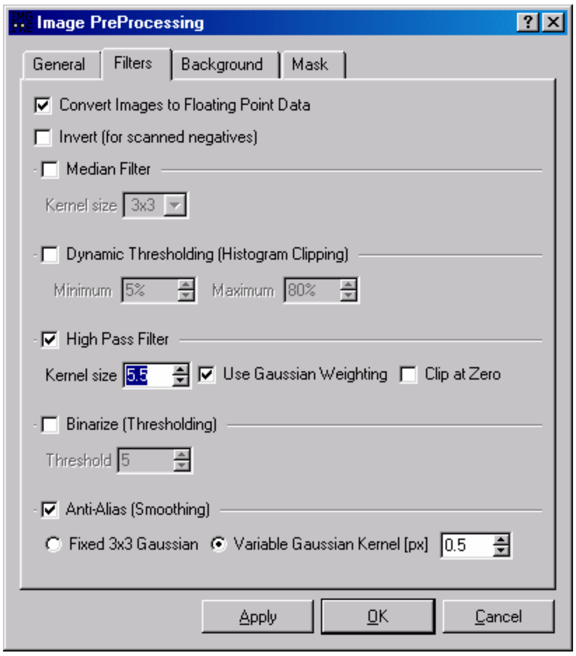
Plot>Position Objects – allows free position of workspace objects such as lookup-tables, image or reference vector.

The *PIVview* Dialogs

The Image Pre-Processing Menu

The purpose of this menu is to perform a variety of operations on the PIV image(s) prior to the PIV analysis. This includes basic image re-orientation, image enhancement using filters, background subtraction or mask overlays. Each of these are described in more detail below.





Tab General

Always Split PCO Images – PIV image pairs recorded with the PCO acquisition software are generally stored in a common file. The upper half of the image is associated with the first exposure while the lower half corresponds to the second exposure. This operation splits the input file into the two images. Otherwise the software will try to find the matching second image.

Rotation – rotates the image(s) in 90° increments. This operation as well as all others is performed on both images of a pair.

Mirror – can flip the image either left-to-right or top-to-bottom. Both flip operations together are equivalent to a 180° rotation.

Tab Filters

Filters are applied in the order they appear in the menu.

Convert Images to Floating Point Data – prevents truncation of data during filtering procedures (may increase overall precision).

Invert – computes the negative of the image by turning bright pixels into dark ones and vice-versa.

Median Filter – performs median filtering on the data using a 3x3 or 5x5 kernel.

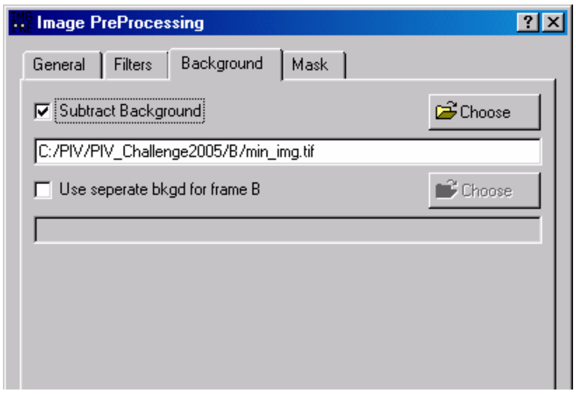
Dynamic Thresholding – performs percentage-based thresholding of the image. This operation determines the minimum or maximum cut-off thresholds by summing up the individual bin-counts of the image histogram. The threshold is value is determined when the percentage of pixels in the sum exceeds the percentage specified by the user. (Obviously this only works for images which a not binary.)

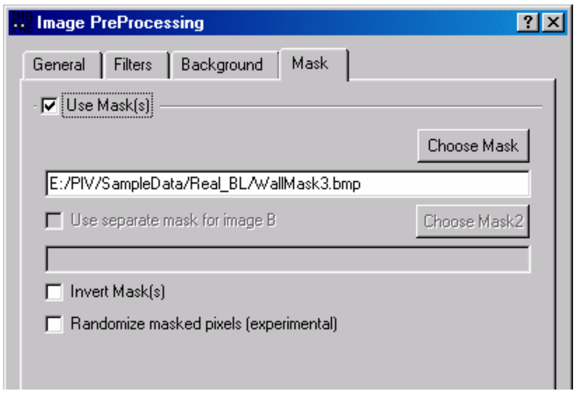
High Pass Filter – performs a high-pass filtering of the image by subtracting a lowpass-filtered version of the input image. Both the kernel size and filter-shape (Rectangle or Gaussian) of the low-pass filter can be specified. Gaussian filtering somewhat slower but positively influences the final result. Negative values are clipped only if this option is activated.

Binarization – binarizes the the image data by setting pixel values above the specified threshold to white (255) and lower values to black (0).

AntiAlias (Smoothing) – applies a low-pass filter which can be used to damp out spurious noise in the image.

Tip: The combination of the last three filters can significantly help in processing images with low signal to noise ratio.





Tab Background

Subtract Background When activated the specified image or image pair is subtracted from all data images upon loading. Background subtraction can improve the data yield in images suffering from strong background artifacts. The image size of this background has to match that of the PIV image. Separate background images for each image of a pair may be specified.

Tab Mask

Use Mask When specified mask images are used to blot out data in regions covered by the mask. Separate mask images for each image of a pair may be specified.

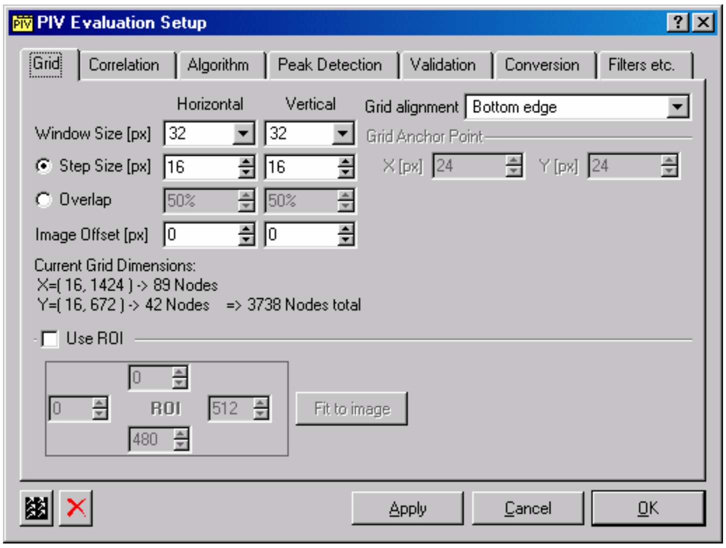
Invert Mask Inverts the pixels of the mask images prior to application.

Randomize masked pixels This is an empirical method to reduce the influence of the masked areas on the correlation signal. Normally masked pixels are set to zero prior to correlation. This may result in edge artifacts in the correlation plane. In this case the masked area is filled with random data that should have roughly the spectral characteristics of the unmasked data and generally reduces the edge artifacts in the correlation plane.

PIV Evaluation Setup

PIV Evaluation Setup – Grid

This dialog can only be opened when an image (pair) is loaded. The image is then overlaid with a grid of crosses indicating the centers of the correlation samples (i.e. interrogation windows).



Window Size

The menu entry defines the interrogation window size, that is, the rectangular size with which the PIV images are sampled to perform the local cross-correlation analysis. Frequently the interrogation window is also referred to as interrogation spot. The window dimensions can be freely set (e.g. 24x27 is also possible).

Step Size

defines the increment with which the images are sampled. These values define the mesh size of the final data size. Typical values are around 50% of the window size which satisifies the sampling criterion. Greater sample overlap (e.g. smaller step sizes) produces over-sampled data but does not necessarily yield additional information.

Image Offset

Applies a constant integer offset to the interrogation windows by offsetting the images with respect to each other. This offset is applied to the displayed image (with the exception of double-exposure *autocorrelation* images). Interrogation window offset is especially useful in the analysis of images with large convective displacement (e.g. pipe flow, wind tunnel flow, etc.).

Grid alignment

Allow the grid to be aligned either with the bottom or top edge of the image. Alternatively the grid may be locked to any specified point (pixel) the image.

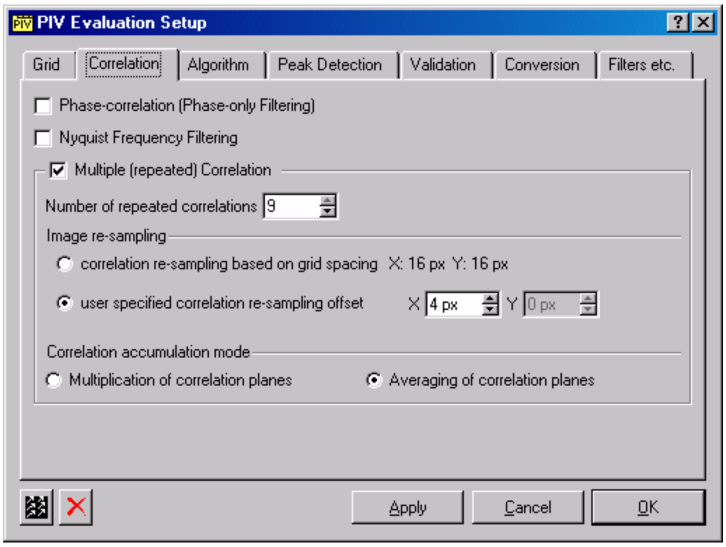
Use ROI

Restricts the evaluation to a defined rectangular region within the image. This region of interest (ROI) can either be set by entering boundary positions or interactively by using the ROI button on the toolbar or menu entry **PIV>Select ROI**.

***Process* Button** – closes this menu and starts evaluating the image.

***Default* Button** – resets all values in this menu to their default values.

PIV Evaluation Setup – Correlation



Phase-correlation (Phase only correlation)

This approach spectrally filters the data such that only the phase information is used in the calculation. The technique, proposed by Wernet (2005), has the potential of obtaining a higher correlation signal.

Nyquist Frequency Filtering

This option removes the highest frequency components in the cross-power spectrum (Fourier transform of the correlation function). This can be of use in the removal of camera noise artifacts (interlacing, multi-channel readout, etc.). The correlation plane window should be used in diagnosing the function's performance.

Multiple Correlation

This algorithm essentially calculates the correlation from at least two slightly spatially separated correlation planes. An approach based on multiplication of correlation planes was first proposed by Hart (2000). By calculating the product or sum of these correlation planes a new correlation plane results which ideally contains only the single displacement peak. Due to the random position of the noise peaks, which are present in all standard correlation planes, the final correlation plane will show no or strongly reduced noise peaks. Hence, this procedure effectively increases the detectability of the correlation peak associated with the particle shift.

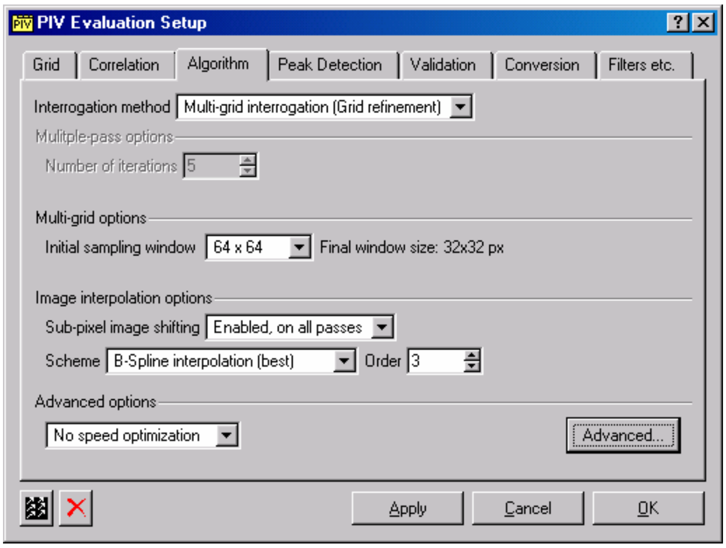
The algorithm requires additional processing time depending on the number of additional correlations calculated and does not perform equally well on all images. A careful adjustment of the offset between the sample positions is sometimes necessary. If correlation planes are too far displaced from each other the correlation signal may be lost entirely in high gradient flows. The correlation plane window should be used in diagnosing the function's performance.

When the number of repeated correlations is higher (more than 3) then the averaging mode should be preferred to the multiplication, because this approach is less susceptible to loss of correlation in one of the repeated correlations.

PIV Evaluation Setup – Algorithm

Advanced Correlation Techniques

If none of the advanced algorithms are activated *PVview* uses the classical cross-correlation method as described in various PIV references (e.g. Willert & Gharib, 1991). More advanced algorithms are briefly described in the following.



Interrogation method

Allows the selection of different PIV interrogation schemes:

Standard, single pass interrogation does classical PV interrogation without additional passes to improve the result

Multiple-pass interrogation The interrogation of the image is repeated at least once more. In the following passes the image sample positions are offset by the integer shift determined in the preceding pass. Once the residual shifts are less than one pixel a re-evaluation of the respective point is no longer necessary (e.g. convergence). The maximum number of interrogation passes can be specified. Two to three passes are generally sufficient for convergence.

Multiple pass interrogation not only increases the data yield due to the higher amount of matched particle images, but also reduces the so called *bias*-error (Westerweel et al. 1997). Outlier detection is used to validate intermediate data sets.

Multigrid interrogation uses a pyramid approach by starting off with larger interrogation windows on a coarse grid and refining the windows and grid with each pass. Outlier detection is used to filter the intermediate results.

Multiple-pass options

Number of iterations – specifies the number of passes during multiple-pass PIV interrogation.

Multi-grid options

Initial sampling window – specifies the starting interrogation window for multi-grid PIV interrogation. The final window size is set in the *Grid* menu tab.

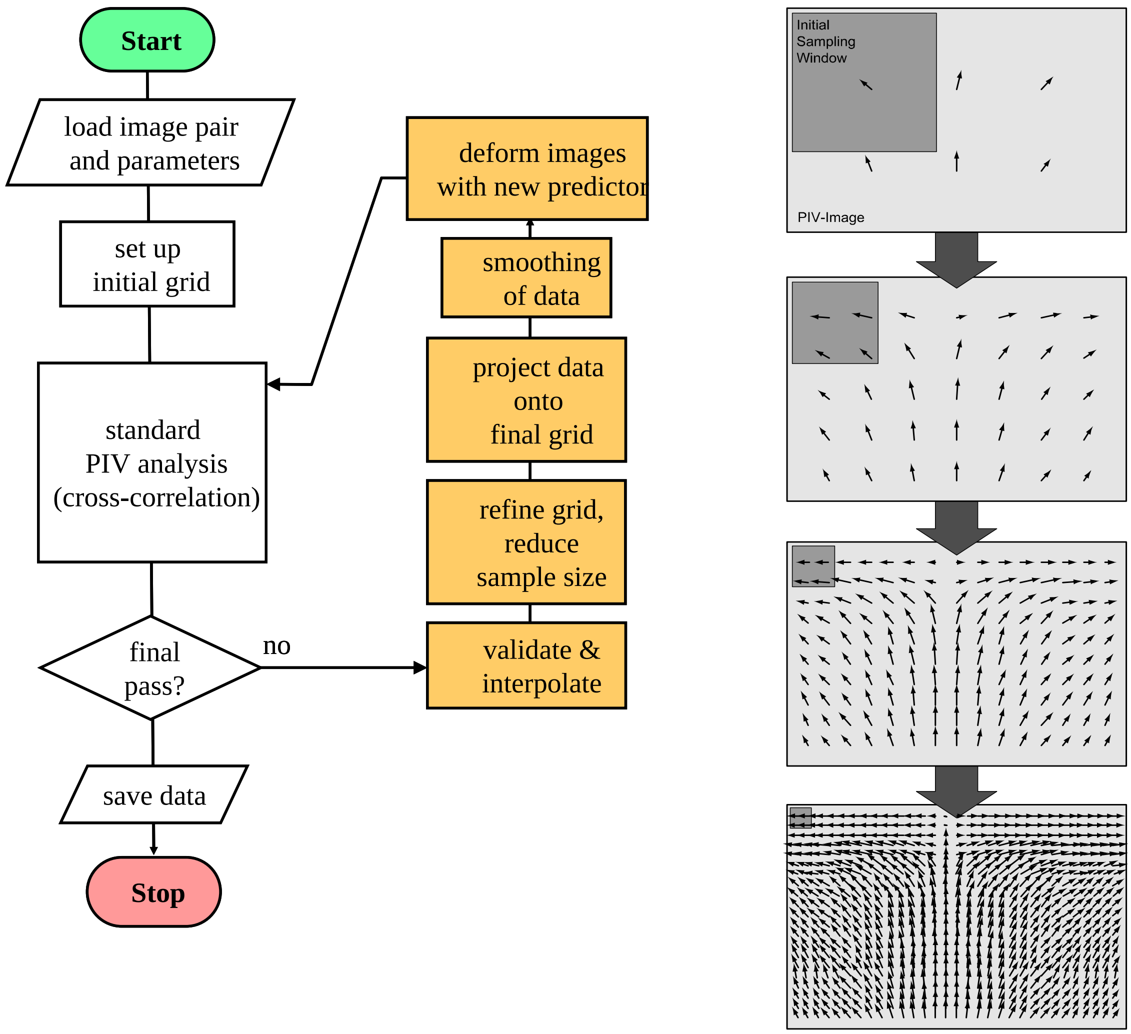
Image interpolation options

Sub-pixel image shifting – enables sub-pixel based image shifting (image deformation) on multiple-pass- or multi-grid interrogation. This technique is a second order method and involves a complete deformation of the image data using the displacement data of the previous interrogation passes.

Interploation scheme – provides a choice of different pixel interpolation schemes as well as the order. In general cubic B-splines were found to produce the best results.

Speed optimization options

To increase processing speed intermediate processing step may use faster peak fitting algorithms or simpler image interpolation schemes. This may have a minor influence on the final result (e.g. reduced precision and/or reduced vector detection rate).



Flowchart for coarse-to-fine multi-grid processing with image deformation for second order accurate PIV interrogation.

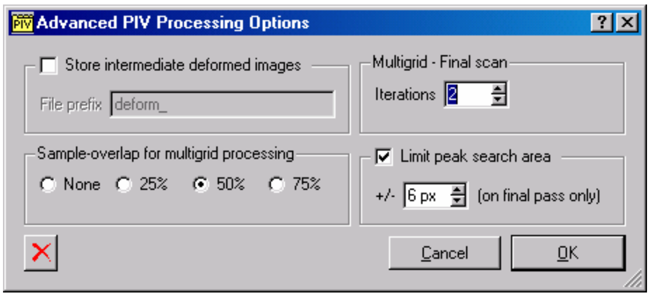
Advanced PIV Processing options

Store intermediate deformed images – is active during image deformation schemes. If checked the program stores the iteratively deformed images for each intermediate processing step (after image deformation).

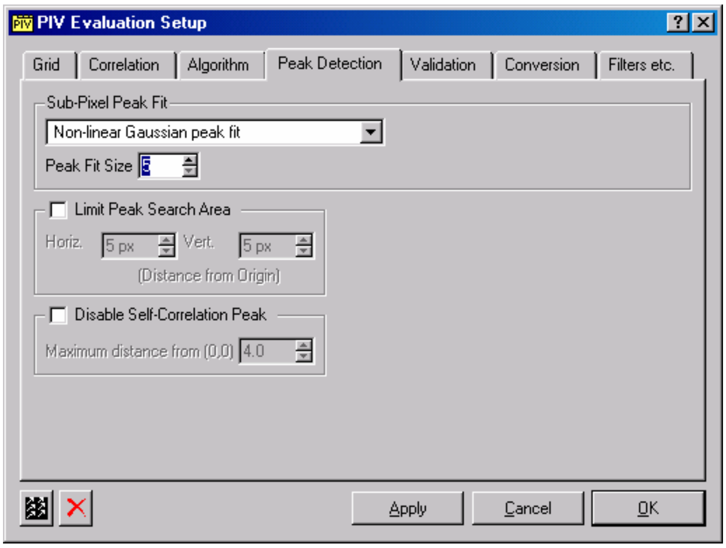
Sample-overlap for multi-grid processing – determines the sampling grid for the intermediate steps of mutli-grid schemes.

Multi-grid – Final scan – determines the number of repeated interrogations at the final grid resolution. Generally one final scan is sufficient whereas additional scans may increase the precision.

Limit peak search area – is active only for the final passes of multi-grid algorithm at the final grid resolution. In general the iterative schemes should converge on the underlying data within a few pixels (or less) such that the correlation peak search area can be restricted.



PIV Evaluation Setup – Peak Detection



Sub-Pixel Peak Fit

Various peak fit algorithms are available which recover the sub-pixel displacement of the correlation peak:

3-Point Gauss Fit This is the most frequently used scheme as proposed by Willert & Gharib (1991). It selects the four closest neighbors of a correlation maximum and fits a 3-point Gaussian curve along each of the two major axis.

Least Squares Gauss Fit Similar to the 3-point Gauss fit but uses all 8 points surrounding the maximum. Since it uses more data for the location of the peak the noise in the result is generally less than with more simple fits. This peak fit method is recommended for most applications.

3-Point Parabolic Fit Similar to the 3-point Gauss fit except that it is *only* fits a parabola through the three points.

Center-of-Mass Fit This sub-pixel locator uses a specified number of correlation values surrounding the maximum (3x3, 5x5, etc.) and calculates the associated first moment or center of mass. It is generally not well suited for the narrow correlation peaks recovered from typical PIV images. In cases where larger particle images or larger features have to be correlated, the correlation peak will be wider and this fitting algorithm may yield more accurate data.

Whittaker Reconstruction Recnstructs the correlation function from all correlation values along the horizontal and vertical line crossing the brightest correlation value (peak) and estimates the maximum from this function.

Nonlinear Gaussian Peak Fit Uses up to N^2 points for a parametric fit to a Gaussian-shaped function allowing for peak ellipticity. The peak shape is estimated from the autocorrelation function of the image samples which may reduce overall processing speed.

Limited Peak Search Area

When activated the correlation peak detection is restricted to an area whose size can be selected. For data with a small dynamic range a limited search area can significantly increase the data yield. That is, only the area enclosed by the given rectangle is scanned for the correlation peaks.

Disable Self-Correlation Peak

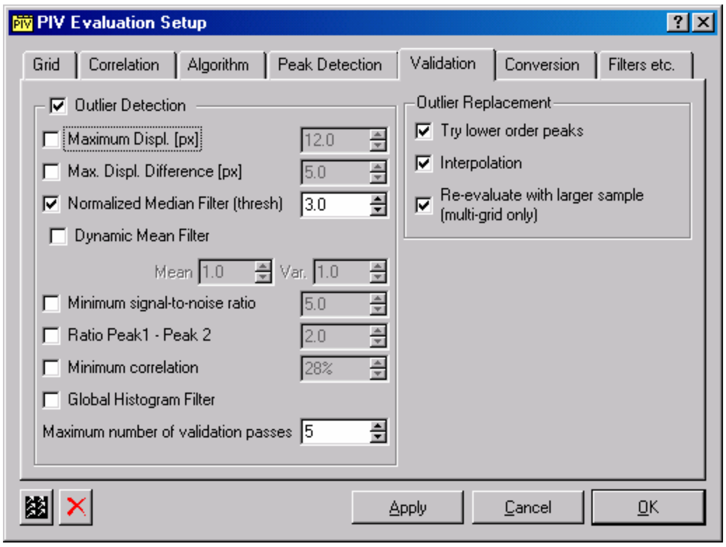
disables the use of the correlation peak near the origin which may be useful in images with strong (stationary) background artifacts which may hide the actual signal. Correlation peaks falling within the specified radius from the origin are disabled.

PIV Evaluation Setup - Outliers

Outlier Detection Methods

The definition of outliers in experimental data can be very subjective. In general an outlier in PIV data can be considered to be a spurious vector within an otherwise homogenous displacement field (see Sec.6.1, Data Validation, in Raffel et al., 1998 for more information).

When activated several methods for outlier detection are available. By combining the various methods most outliers are detected with very little valid data disabled (known also as optimization of cost).



Maximum Displacement – Any displacement vector exceeding the specified magnitude is considered to be an outlier.

Maximum Displacement Difference – This method computes the magnitude of the vector difference between the vector in question and its eight surrounding neighbors. When this difference exceeds the specified value for more than 4 neighbors, then the analysed vector is labelled to be an outlier.

Normalized Median Filter – applies a median filter to each vector along with its eight neighbors. A vector is an outlier if the difference to the median displacement value is greater than the given threshold.

Dynamic Mean Filter – This filter works very effectively even in flows with discontinuities (e.g. shocks). However it requires a careful adjust of the coefficients to work reliably (see Raffel et al., 1998, p.153 for more information).

Minimum signal-to-noise ratio – disables all displacement vectors which have a SNR less than the specified value.

Ratio Peak 1 to Peak 2 – disables all displacement vectors for which the ratio between the strongest and second strongest correlation peak is less than the specified value.

Minimum correlation – disables all displacement vectors for which the correlation peak value is less than the specified value.

Global Histogram – restricts valid vectors to be within a certain range of displacements. This rectangular or elliptical domain has to be set interactively within the PDF-window using the mouse.

Outlier Replacement Schemes

Once outliers have been detected they can be optionally replaced with new data. Two replacement schemes are available:

Other Correlation Peaks – The program stores the three highest correlation peaks found in each correlation calculation. If the highest correlation peak turns out to be an outlier this options picks the next highest correlation peak and repeats the outlier detection procedure.

Interpolation – Applies a bi-linear interpolation to estimate the replacement vector. When several of the immediate neighbors are also outliers then a Gaussian-weighted interpolation scheme is used.

Re-evaluate with larger sample – If none of the alternative correlation peaks fulfill the validation criteria, the image can be locally re-evaluated with the next largest interrogation sample in the multi-grid processing scheme.

Note: All correlation peaks are first tried out before any data is interpolated.

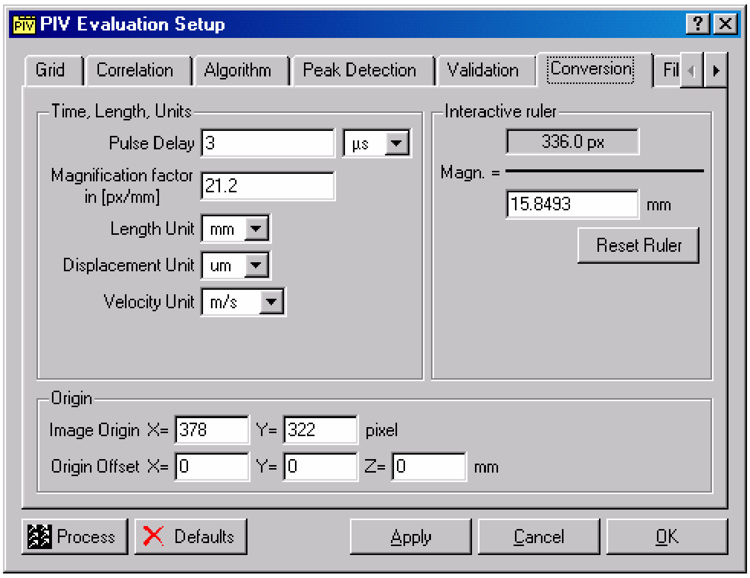
The **Apply Button** can be used to immediately see the effect of the outlier detection and replacement provided that the image is already evaluated.

PIV Evaluation Setup - Conversion

This dialog is used for setting the magnitude and time conversion factors which are necessary to obtain velocity data in a physical grid. Within *PIVview* the horizontal display axis is always associated with the X-axis, the vertical with the Y-axis. No Z-coordinate is used. If the measured PIV plane is not aligned with the desired physical space coordinates, the user has to perform the required transformation on the *PIVview* output using other software.

When this menu is activated, a ruler and current origin are displayed within the image. The ruler may be used to mark off know lengths in the image. The magnification factor can be interactively set by supplying the associated physical length in the menu.

Movement of the origin changes the entries in the menu accordingly.



Pulse Delay – specifies the time delay between the two exposures in the image pair. Generally does not apply to speckle displacment data.

Magnification Factor – The scale factor used to conversion the image displacement to a physical displacement. It can also be set interactively using the calibration menu.

Length Unit – The units used for the physical coordinate system. It is also associated with the magnification factor.

Displacement Unit – The unit associated with speckle displacement data. Also the physical particle image displacement prior to its conversion into velocity.

Velocity Unit – The unit associated with the velocity as estimated by PIV.

Origin

The origin is used as the reference point for the physical coordinate system of the data set. It can be translated within the image by holding down the left mouse button.

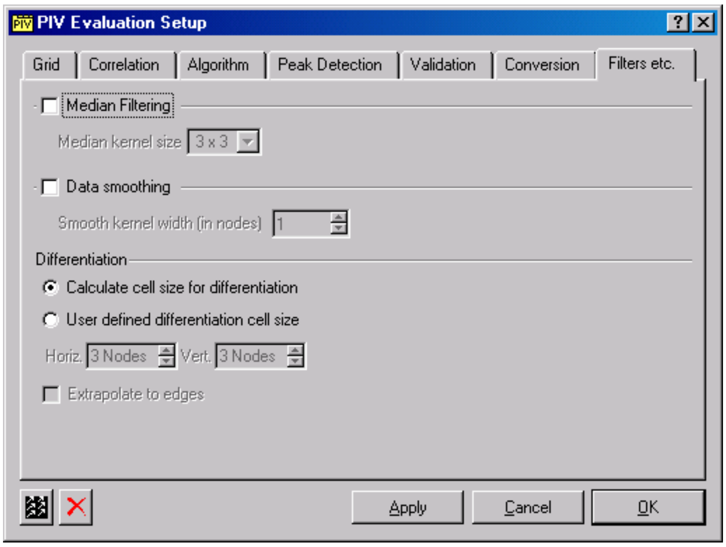
Origin Offset – Additional offset in physical space units if reference point is not at (0,0,0) in physical space.

Magnification Factor – This field is used for the calculation of the magnification factor by using the pixel length of the ruler within the image (numerator) and the actual distance in physical units (denominator). Only the physical distance can be modified here. The ruler length can only be changed by altering the ruler end points in the image.

The **Apply Button** can be used to immediately see the effect of the conversion factors on the data and grid.

PIV Evaluation Setup – Filters etc.

The menu tab allows the selection of various post-processing options.



Median Filtering

The final data set is once median filtered using either a 3x3 or 5x5 kernel.

Data Smoothing

The final data set is once smoothed using a Gaussian weighted kernel of specified width.

Differentiation

Calculate cell size for differentiation The estimation of differential quantities (e.g vorticity, shear strain, etc.) relies on calculating differences between neighboring vectors and can therefore be very noisy especially if the seeding density is low and the data points are closely spaced. Generally it was found that differentials calculated from PIV data sampled at less than 50% overlap are increasingly noisy due to artifacts introduced as a consequence of nearly identical particle image pairs in neighboring sampling positions.

In other words, for correlation planes calculated from two nearly overlapping sampling areas most of the particle image pairs can be found in both samples. Especially in areas of high gradients the data will be biased according to the mean displacement of all pairs. Closely sampled data will then show a similar bias in neighboring points and thereby provide an underestimated differential.

When activated, this option checks the sampling (interrogation) window overlap and from it determines an optimal distance from which to calculate the differentials.

Alternatively, the user can specify the spacing for the calculation of the differentials.

Extrapolate to edges – Generally differentials cannot be estimated at the borders of the data set. However, by extrapolating the vectors beyond the edge using the interior vectors the differential at the edges can be estimated.

Region of Interest

 This display mode can only be activated if the ROI-option is checked in the Grid Tab of the PIV-parameter menu.

The region of interest (ROI) is used limit the evaluation grid to a defined rectangular region. This region is shown as a red/white border whose corners and mid points can be translated by holding down the left mouse button.

Yellow +'s inside the ROI indicate the centers of sampling positions for the correlation analysis. Their spacing is defined in the Grid tab of the PIV configuration menu.

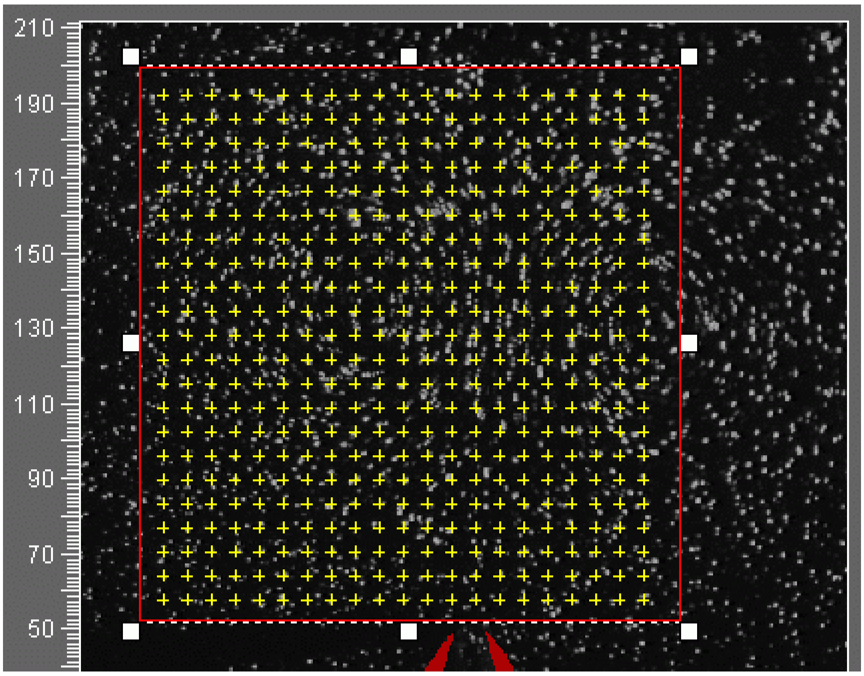
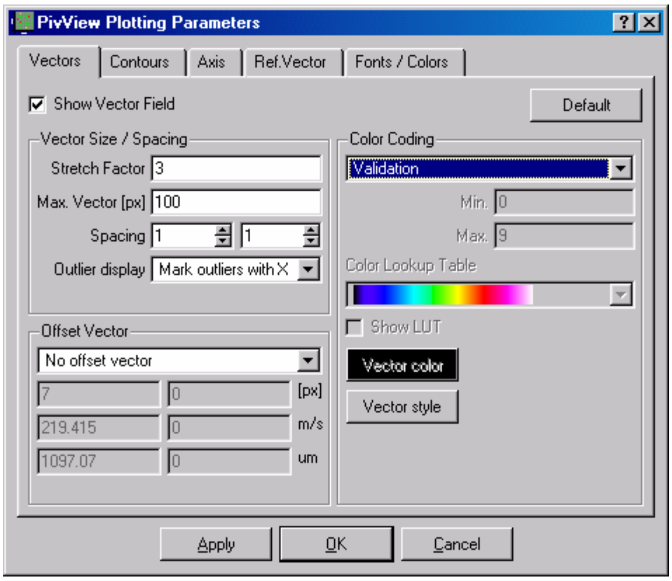


Image overlaid with ROI-selection rectangle. Yellow crosses mark the centers of the interrogation windows.

Plot Configuration Menu



Vector Plotting Parameters

Show Vector Field – has to be enabled to show the vectors. If a data set is available, that is, the image is evaluated, then enabling this option will immediately display the vector field.

Vector Size / Spacing

Both the vector head length and width can be specified here. Also there is the choice to fill in the arrow heads.

Vector Stretch Factor – Specifies the amount the displacement is scaled with respect to the image. For example, a vector with length 10 pixels with a scale factor of 2.0 is 20 pixels long when plotted on the image. The stretch factor is always based on the pixel displacement of the data.

Maximum Vector – Can be used to avoid plotting vector whose length exceeds the value specified (e.g. outliers). The magnitude is specified in pixels.

Spacing – This option allows vectors to be skipped and is useful when the data is too dense to be properly displayed.

Outlier display

Determines how outliers should be treated on the screen:

Mark outliers with X – when activated any vector labeled as an outlier will only be indicated by an x.

Hide Outliers – when activated any vector labeled as an outlier will not be shown.

Show Outlier Vectors – when activated any vector labeled as an outlier will be shown.

Offset Vector

Subtract Image Offset – When activated the image offset specified in the evaluation setup menu will be subtracted from each displacement vector.

Subtract Mean Displacement – When activated the mean displacement of all vectors in the field will be subtracted. If disabled a user specified offset can be subtracted (see below).

Specified Offset Vector – The user can specify a given displacement to be subtracted from the vectors. This value is given in pixel displacement but is also displayed in physical units for reference. This field only become active if the Subtract Mean option (above) is disabled.

Color Coding

Magnitude – color-codes the vectors according to their magnitude. Generally a rainbow-type of LUT is used (several are available). The minimum and maximum magnitudes for the color bar can be specified in the fields below.

Signal-to-noise Ratio – color-codes the vectors according to their signal-to-noise ratio in the displacement estimation.

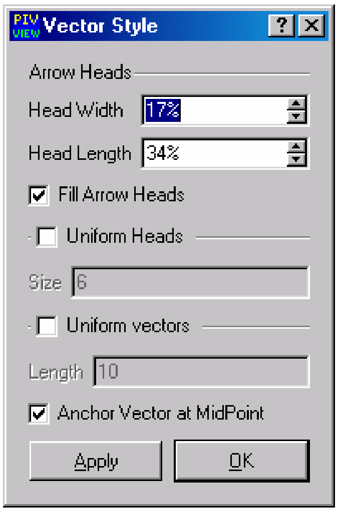
Validation – color-codes the vectors according their status of validation. The color coding can be set in the **Fonts/Colors** tab of the menu.

Uniform Color – alternatively the vector can be plotted in a desired uniform color; that is without color-coding. The color may be chosen through a color selection menu.

Apply Button – any change to the setup can be immediately displayed by pressing this button.

Vector Style

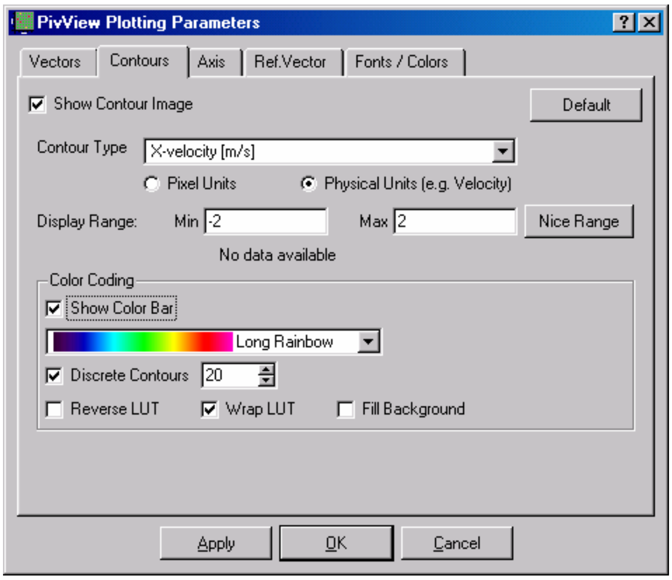
This sub-menu provides further choices on the vector shape, size and positioning.



Contour Plotting Parameters

Within *PIVview* a contour image describes a color-coded representation of a scalar quantity derived from the PIV data. These include velocity magnitude, vorticitiy, strain or single components of velocity.

Show Contour Image – has to be enabled to show the contour image. If a data set is available (i.e. image is evaluated) then enabling this option will immediate display the contour plot. Bi-linear interpolation is used to fill in the area between the individual data points.



Contour Type

Specifies which kind of data is plotted as a contour plot. The contour display range can be adjusted below.

Vorticity

plots the out-of-plane vorticity ω_z as estimated by finite differences:

$$\omega_z = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right)$$

Shear Strain

plots the in-plane shear strain ε_{xy} as estimated by finite differences:

$$\varepsilon_{xy} = \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)$$

Normal Strain

plots the sum of the in-plane extensional strains η as estimated by finite differences:

$$\eta = \varepsilon_{xx} + \varepsilon_{yy} = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)$$

Displacement Magnitude

plots the pixel displacement vector magnitude.

Velocity Magnitude

plots the velocity vector magnitude.

Physical Displacement Magnitude

plots the actual physical displacement of the particle images or speckle patterns.

Correlation Coefficient
color-codes the image according to the correlation coefficient from the displacement estimation.

Enstrophy
color-codes the squared magnitude of the out-of-plane vorticity ω_z.

Lambda operator
color-coding according to:

$$\lambda = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)^2 - 4 \left(\frac{\partial u}{\partial x} \frac{\partial v}{\partial y} - \frac{\partial u}{\partial y} \frac{\partial v}{\partial x} \right)$$

Vector Count
color-codes the number of validated data in averaged PIV data sets (only for averaged data).

3-C vector residuals
color-codes the residuals from a 3-C vector reconstruction for stereo PIV (only available for stereo PIV data).

(other options may also be available)

Contour Display Range

Specifies the range of contour values to be shown. These values are also displayed on the lookup-table above the contour plot.

Nice Range
calculates nice (or round) limits for the color bar using the maxima available from the current data set.

Show Color Bar
This option determines whether the reference lookup table is shown. This color bar is placed above the data field.

Discrete Contours
when enabled discrete contour levels are shown. Otherwise a smooth transition from minimum to maximum is used.

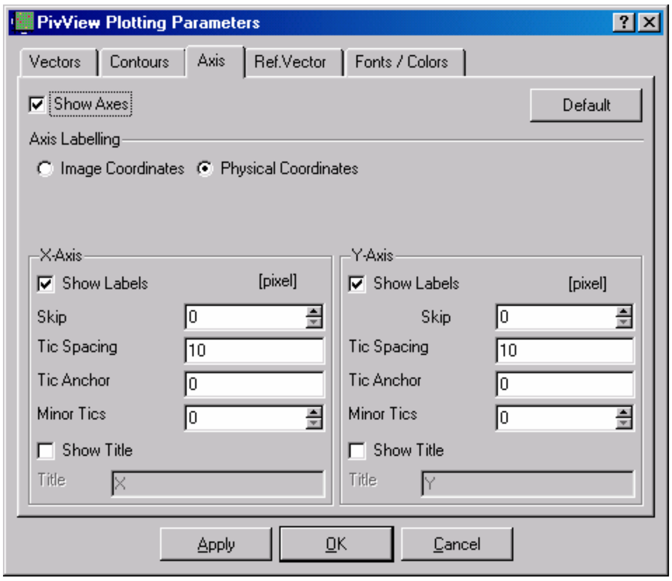
Reverse LUT
when enabled reverses LUT

Wrap LUT
starts from the lower end of the look-up table for values exceeding the specified range.

Fill Background
fills the image background with the zero-contour color.

Axis Plotting Parameters

This dialog controls the type of axis and axis labeling on the displayed data. Either image or physical coordinates may be used. The appearance of each axis may be controlled independently.



Show Axes – has to be enabled to place axes on the edge of the image or plot.

Image coordinates – plots the data in image space [pixels].

Physical coordinates – plots the data in physical (object) space using the currently active scaling factors.

Show Labels – has to be enabled to place labels on either of the axes.

Tic Spacing – defines the increment of the tics to be labeled (major ticks).

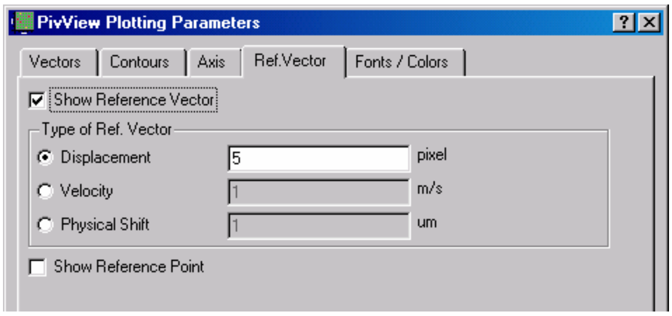
Tic Anchor – sets a (virtual) starting point for the major ticks to ensure a nice layout with even label numbers.

Skip – defines which of the major ticks should not be labeled (0 for to label all major ticks, 1 to label every other, etc.).

Minor Ticks – sets the number of minor ticks between two major ticks.

Show Title – has to be enabled to place a title on either of the axes. The title is defined in the entry field below.

Reference Vector



Show Reference Vector – has to show a reference vector in the upper left corner. It is only displayed in the presence of a vector map or during interactive interrogation.

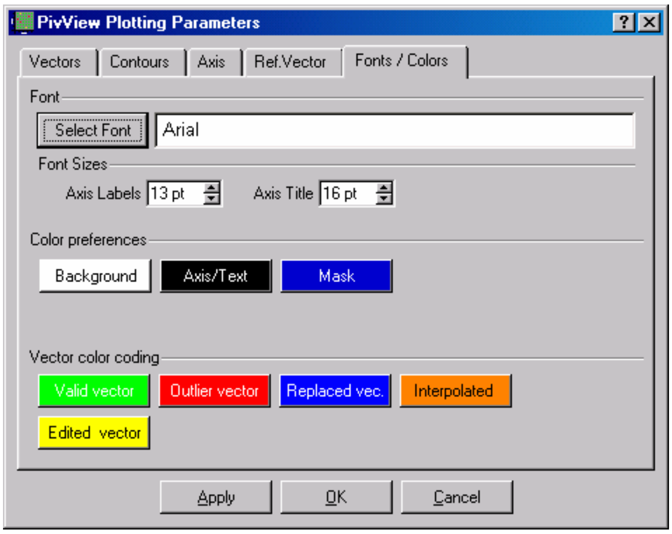
Type of Ref. Vector – three different forms of labeling the reference vector are possible:

Displacement – chooses a image based reference scale in pixels;

Velocity – labels the vector with the currently active velocity unit;

Phys. Shift – uses the physical shift of particle images.

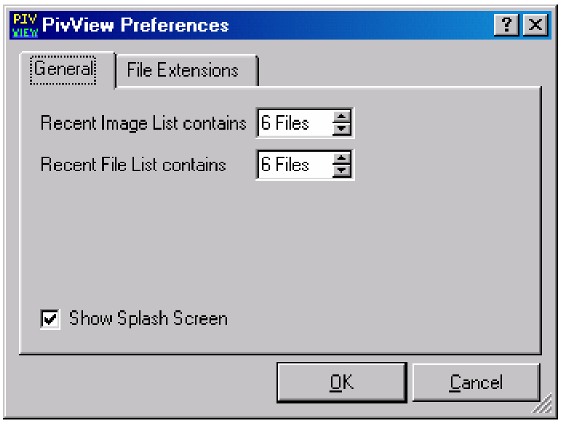
Fonts / Colors

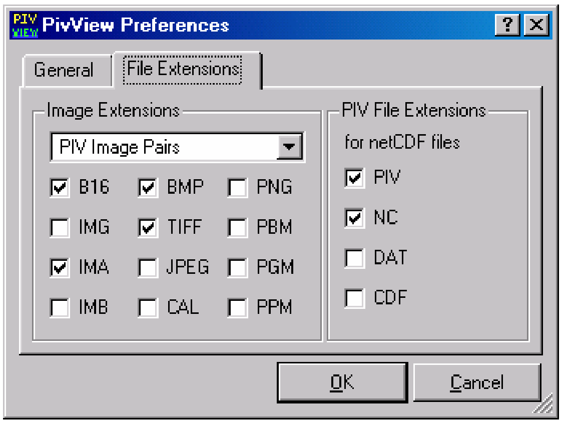


Font – allows the selection of the font type and size used for axis and LUT labels.

Color Preferences / **Vector color coding** – defines the color for various plot items and data types (e.g. outliers vectors).

The Preferences Menu





Recent Image List – determines how many image files should be listed in the File>Recent Images menu option.

Recent File List – determines how many PIV data files should be listed in the File>Recent Files menu option.

Show Splash Screen – if enabled, shows the startup splash screen.

File Extensions

This menu associates a variety of image types with certain file extensions. These extensions are then used as file filters in various image selection dialogs. The drop-down selection offer the following image types:

PIV Images Pairs – are used for cross-correlation PIV and defines the first image of a pair of single exposed PIV images.

Double Exposed PIV Images – are used for the selection of images for autocorrelation PIV.

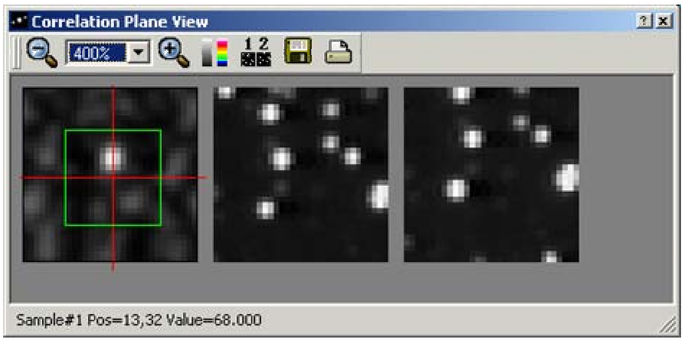
Speckle Reference Images – defines the zero-state (e.g. un-deformed) image used in speckle shift measurements.

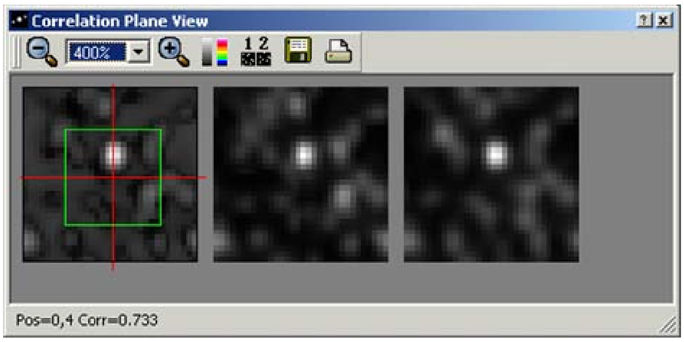
Speckle Signal Images – associates images where the speckles have been displaced with respect to the zero-state image.

Mask Images – are images that are overlaid and disable any data covered by them.

Correlation Plane Window

The correlation plane data is color-coded using the currently active lookup table - in the example above, a gray-scale LUT. Bright pixels indicate a high correlation value, dark ones a low correlation. The local correlation values are displayed in the status line by moving the mouse across the image.





Red lines – at the center of the correlation plane marks the origin, that is, the position of zero displacement.

Green Rectangle – near the center of the correlation plane indicates the region of interest for the peak detection algorithm. It is only visible if the ROI peak search is enabled in the processing setup.

Image Samples – to the right of the correlation plane the two image samples from which the correlation was calculated are displayed if the toolbar button is enabled.

Note: In case of double-correlation, the two images represent the two correlation planes from which the plane shown on the left was calculated.

Change Image Magnification – these buttons increase or decrease the magnification of the displayed image data.

Change LUT – alters the lookup table (LUT) used to display the correlation / image data. Each time the button is pressed a new LUT is applied.

Display of Image Samples – this button must be enabled to display the image samples in addition to the correlation plane.

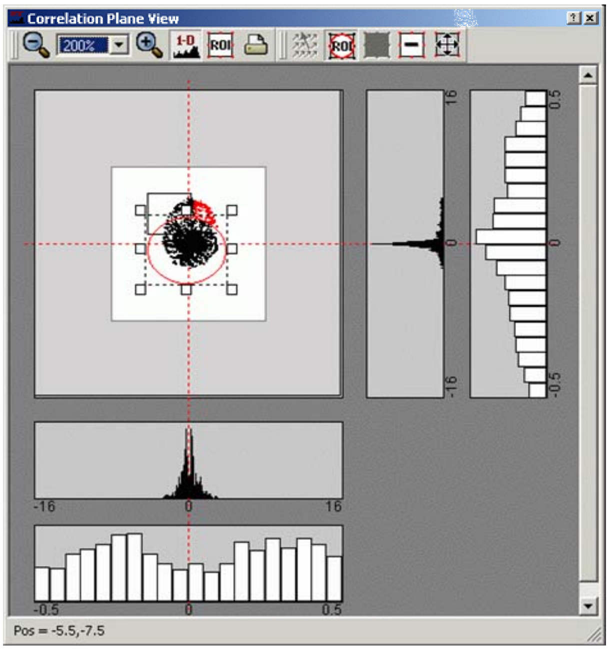
Saving the Correlation Data – the currently displayed correlation data and image samples can be stored in ASCII files by pressing this button. Once the data is saved the button is deactivated until new correlation data becomes available.

Printing – of the correlation plane using printer selected in Plot/Print Setup menu option.

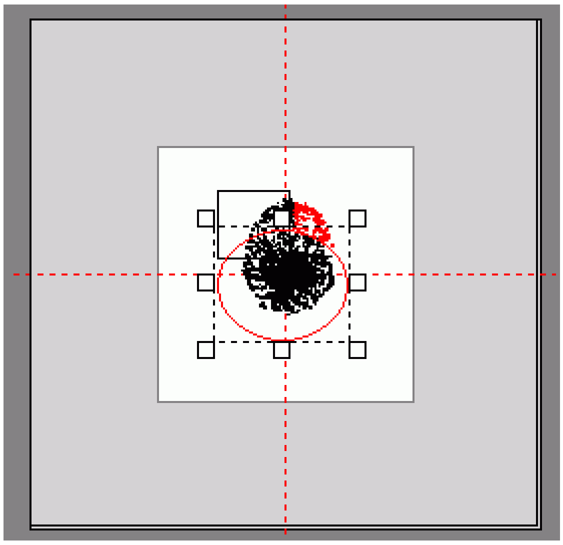
Global Histogram Window

This plot gives a visual representation of all displacement values available for the evaluated image. Each colored point in the two-dimensional plane represents a displacement vector whose coordinates correspond to the actual shift in pixels. The boundary of this plot is defined by the size of the correlation plane with zero shift at the center.

The rectangular and elliptical regions near the center are user-sizeable regions of interest. These ROIs can be used as a form of data validation: any points on their exterior are considered to be outliers. To use this function, the Global Histogram option must be enabled in the validation menu.



Global histogram of PIV data with two ROIs enabled, one rectangular (currently selected) and one elliptical. The one dimensional PDFs are shown for the X-axis below and for the Y-axis on the right.



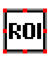
Detail of the figure to the left. Points outside of the ROIs are labeled as outliers as indicated by their red color.

One-Dimensional Histograms – immediately bordering the 2-D histogram are vertical (right) and horizontal (below) one-dimensional histogram of the two respective displacement components. They are projections of the two-dimensional histogram onto either of the major axes. Their range therefore corresponds to the respective dimension of the correlation plane.

Sub-Pixel Histograms – these histograms, located the furthest from the 2-D histogram, are generated by plotting only the non-integral part of the displacement values. Their range is from -0.5 to 0.5 with a default bin-width of 1/20th a pixel.

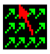
Sub-pixel histograms are especially useful to check whether peak-locking effects are present in the data.

Zoom in / Zoom out – these buttons increase or decrease the magnification of the displayed histogram data.

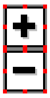


This button enables the global histogram validation. Alternatively the Outlier Configuration menu can be used.

toggles the currently selected ROI between elliptical and rectangular shape.


Validation with new ROI – if global histogram validation is enabled, then a change to the ROI can be tested directly on the data with this button.


Default ROI – this function resets the currently selected ROI such that it nearly covers the entire histogram plane. This is especially useful if the ROI is lost off the histogram plane.

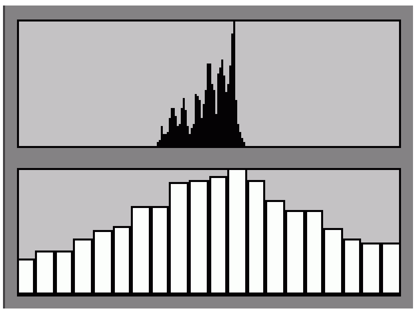

Adds or removes ROIs from the histogram plane. Up to hree ROIs can be activated.

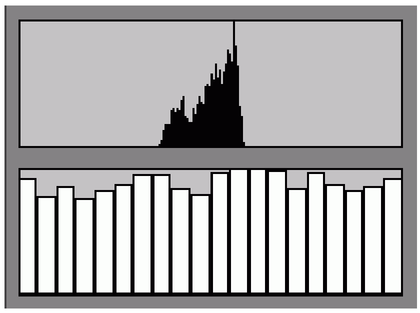
1-D PDFs and Peak Locking

The histograms (PDFs) below illustrate the effect of peak-locking which is a tendency of the peak-fitting algorithm to lock into integer values. The histogram on the top shows the presence of peak-locking in the form of integer-spaced peaks. The corresponding sub-pixel histogram below shows a triangular shape with increased counts near integer values (middle of histogram).

The histograms on the below were obtained from the same image but processed with a different peak fitting algorithm (least-squares fit). No peak-locking can be observed - the sub-pixel histogram has a near uniform distribution.

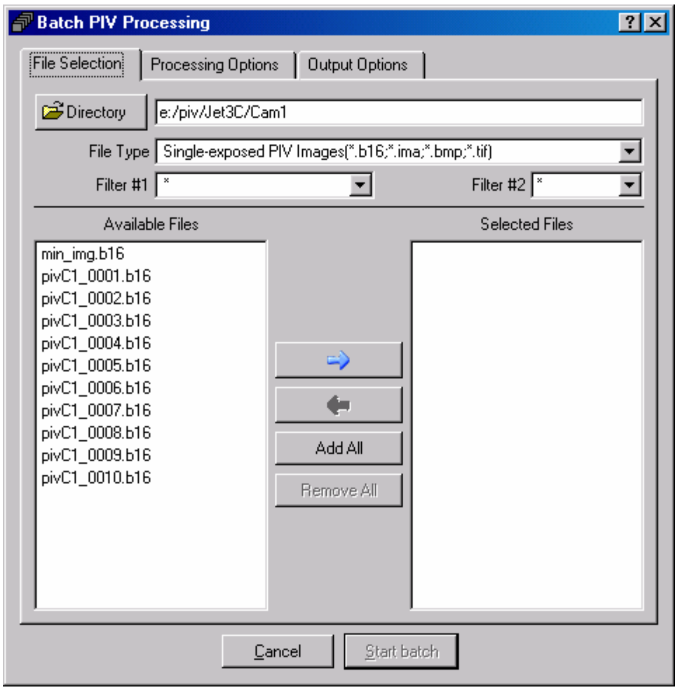
Peak-locking generally arises through a combination of certain particle image sizes (typically too small) whose narrow peaks in the correlation plane are analysed with the wrong type of peak fitting algorithm. Another cause may be the non-uniform spatial pixel response of the recording device (CCD) in combination with particle images with diameters less than 3 pixels.


One-dimensional PDFs of PIV data containing peak-locking effects.


Same PIV-data as on the left but processed with a different peak-fitting algorithm – no peak locking is noticable.

Batch PIV Processing

Batch processing is a means by which large number of PIV recordings can be evaluated in an efficient manner. A common set of analysis parameters is used for all images. During the processing the program accumulates the mean and RMS displacement and velocity data which are stored in a separate file after completion of the processing sequence.



Available Files – the left column shows the files currently available in the specified directory. Multiple files can be selected by holding down the CTRL or SHIFT keys (just as in the *Windows Explorer*) Using the **Add** button the file selection is transferred to the list of files to be processed.

Selected Files – The right column shows the files currently chosen for batch processing. In analogy to the left column multiple files can be selected by holding down the CTRL or SHIFT keys. Using the Remove button the file selection is removed from the list.

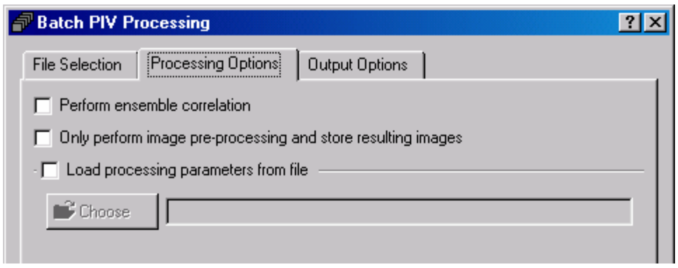
Directory – this field displays the currently selected data (image) directory. It can be changed using the Directory button on the left.

File Type – this field acts as a file filter showing only file which match the chosen extensions (File type association is defined through File>Preferences>File Type.)

Filter #1 - Selects files in data directory with this (prefixed) filter. Allows selection of all odd or all even numbered files.

Filter #2 - A file filter that may be freely modified. Caution: Without the asterisc (*) no files may be displayed.

Batch Processing Options

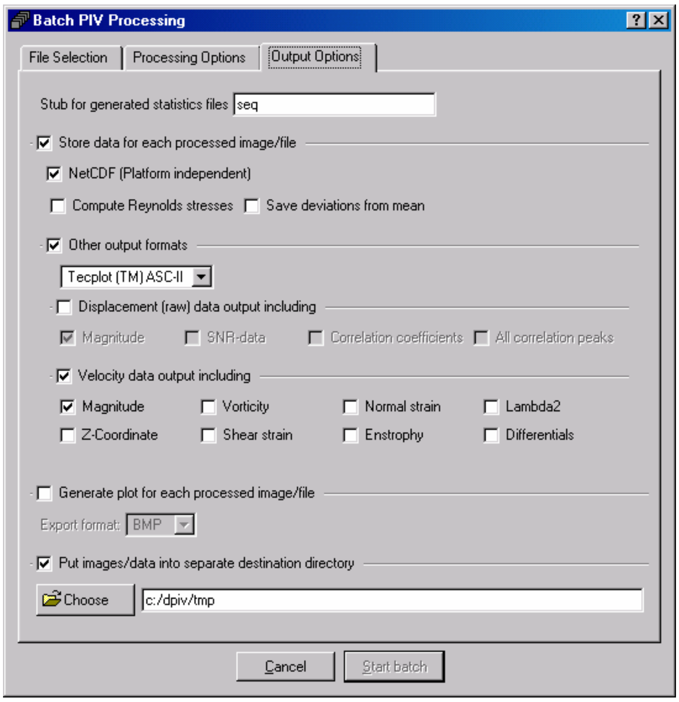


Perform ensemble correlation – Rather than calculating the displacement field for each image pair, this method computes the averaged correlation planes from all images before detecting any correlation peaks. This procedure is common in the analysis of µPIV applications and reduce the effects of underlying Brownian motion.

Load processing parameters from file – When enabled, the images will be processed using the parameters in the specified file. Otherwise the evaluation uses the currently defined parameters.

Batch Processing Output Options

A variety of output options may be defined in this menu. Preferably the data from each processing image should be stored in the platform independent netCDF format. This data can then be exported in any desired form using the same batch-processing menu.



Stub for Statistics Files – specifies the beginning letters of the statistics files generated during batch processing. These data sets are computed over all available files and are stored after the batch processing is completed.

For the stub `seq` the output files will be:

```
seqAvgPiv.dat    mean pixel displacement
seqAvgVel.dat    mean velocity
seqRmsPiv.dat    RMS pixel displacement
seqRmsVel.dat    RMS velocity
```

Store data for each processed image/file – When enabled, this option will store the displacement and velocity data for each processed image or file. Otherwise only the mean and RMS data sets computed from all images will be stored.

Generate plot for each processed image/file – when enabled, this option will generate an image file (plot) for each processed image using the currently defined plot configuration. This is useful if animated sequences of the data are to be compiled later on. (Note: These files are quite large and may result in the use of much disk space.)

Put image / data into separate directory – this option can be enabled to store the computed data in a directory different from the image directory. This can be useful when batch-processing images retrieved from a read-only medium (e.g. CD-ROM).

Definition of statistics terms

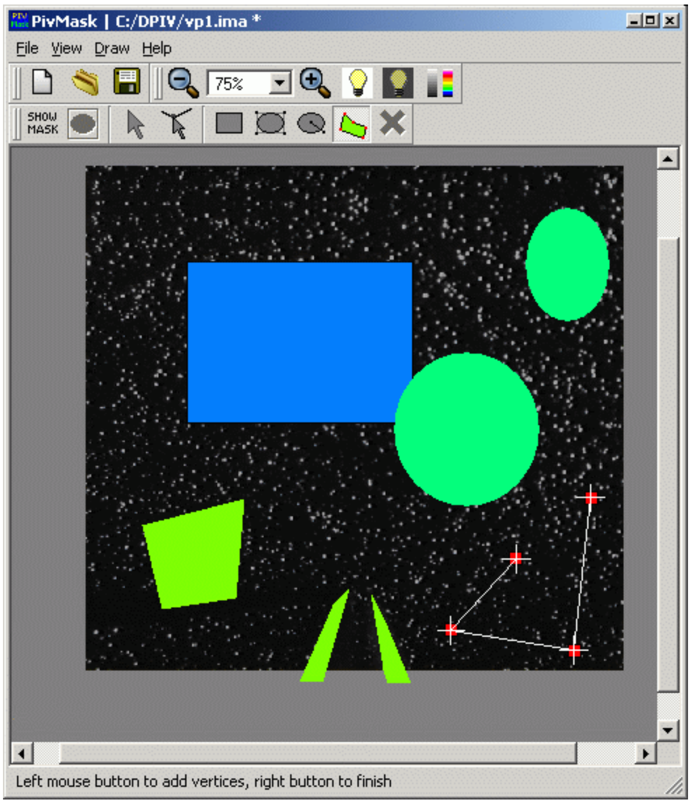
Statistical quantities such as the mean and standard deviation of velocity are calculated by the following equations:

Quantity	Formula	Notes
Mean value	$\bar{x} = \frac{1}{N}\sum_{i=0}^{N} x_i$	here N is the number of valid measurements x_i (including interpolated values)
Variance	$\sigma_x^2 = \frac{N\sum_{i=0}^{N} x_i^2 - \left(\sum_{i=0}^{N} x_i\right)^2}{N(N-1)}$	
Standard deviation	σ_x	defined as square root of the variance
Mean velocity components	$(\bar{u}, \bar{v}, \bar{w})$	calculated from sequence of PIV data sets using formula for mean value given above
RMS-velocity	$(\sigma_u, \sigma_v, \sigma_w)$	using formula for standard deviation
Fluctuation terms	$u'u' = \frac{1}{N}\sum_{i=0}^{N}(u_i - \bar{u})^2$ $u'v' = \frac{1}{N}\sum_{i=0}^{N}(u_i - \bar{u})(v_i - \bar{v})$ $u'w' = \frac{1}{N}\sum_{i=0}^{N}(u_i - \bar{u})(w_i - \bar{w})$ $\vdots$	Values for $v'v'$, $w'w'$ and $v'w'$ are calculated correspondingly. Only validated and interpolated vectors are used in the calculations. A multiplication with density ρ results in the respective Reynolds stresses.

PIVmask - Image Mask Editor

The program PIVmask allows the creation of image masks that can be overlaid on PIV images to prevent processing in these areas. Any PIV image can be opened using the File/Open function. Several simple shapes then are available for the creation of the mask.

Once finished the mask can be stored as a bitmap file. To enable its use by PIVview the appropriate option in the image preprocessing menu must be activated.



PIVmask in edit mode displaying several shapes during the creation of a polygon.

File Menu

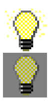
 **File / Load image** - loads one of the supported PIV image types.

 **File / New** - resets the image mask by removing all objects.

 **File / Save mask image** - saves the currently displayed mask as a bitmap file (BMP).

View Menu

 **View / Zoom in, Zoom out** - changes the magnification factor of the image on the screen.

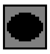
 **View / Darken image, Brighten image** - changes the brightness of the displayed image.

 **View / Change LUT** - changes the image display lookup table

View / Toggle pixmap size - displays larger tool buttons.

Draw Menu

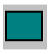
Draw / Toggle current mask - either calculates and displays the current mask by overlaying on the image or switches back to edit mode.



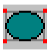
Draw / Invert mask - calculates the negative of the current mask.

Draw / Move/resize objects - allows selection of objects and as well as their size modification.

Draw / Move object vertices - allows the shape of polygon objects to be changed

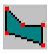


Draw / Draw rectangles - creates a rectangle on the screen by dragging the mouse. Its shape can be later modified using the resize objects entry. Pressing the shift key allows the creation of squares.



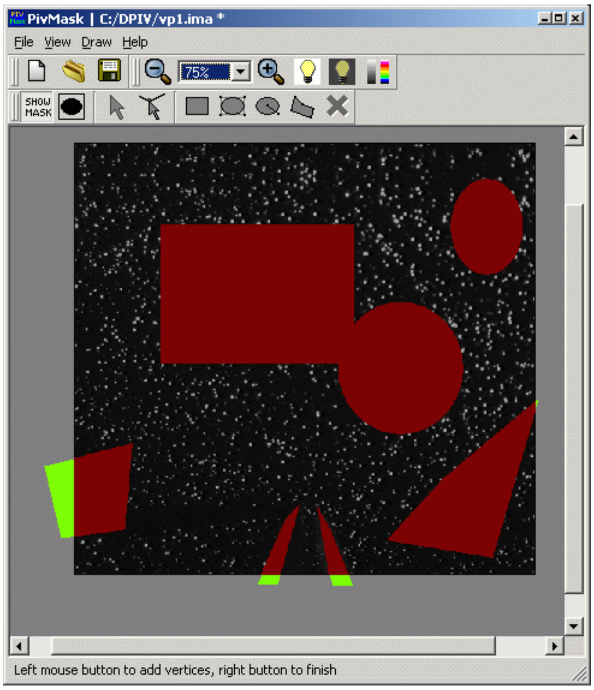
Draw / Draw ellipses - creates ellipses. Circles are generated by pressing the shift key.

Draw / Draw centered ellipses - creates ellipse starting from their center point. Circles are generated using the shift key.

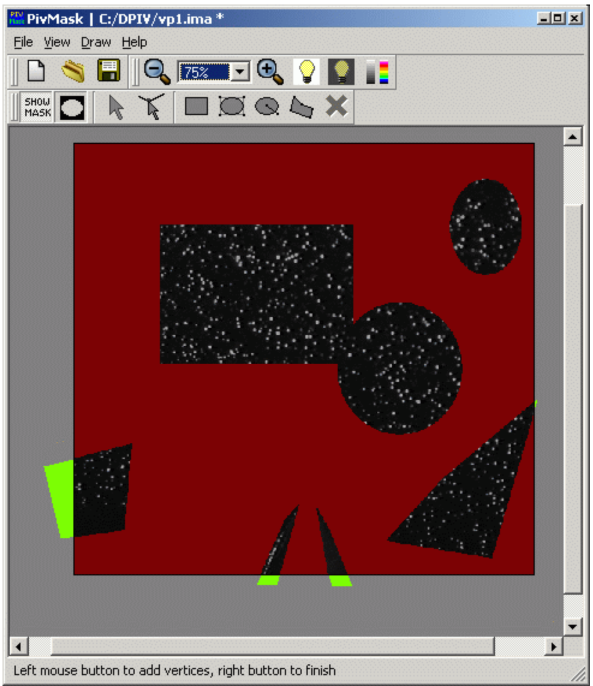


Draw / Draw Polygons - allows the creation of irregular polygon shapes. Points are added to the polygon with the left mouse button. The right button closes the current polygon.

Draw / Delete object - deletes the currently selected object.



PIVmask in mask display mode. Objects extending beyond the image dimensions have no influence on the mask.



PIVmask in mask display mode showing an inverted mask.

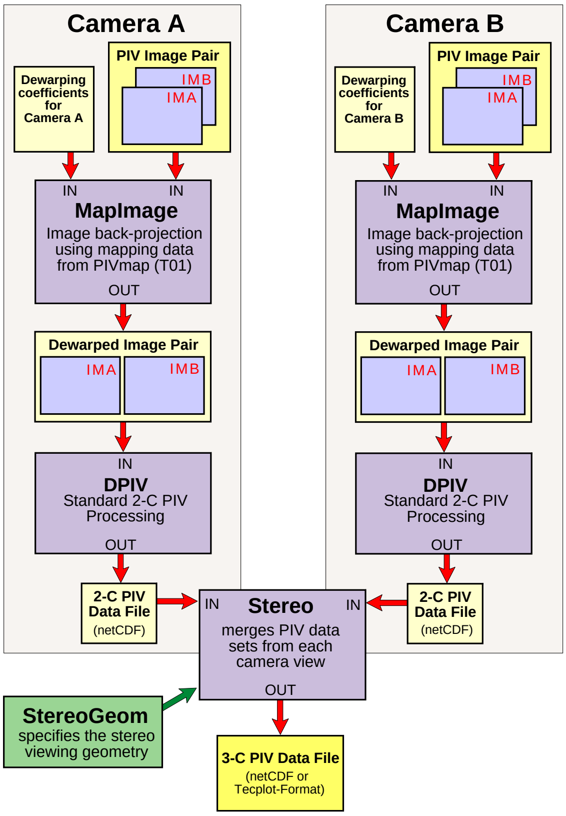
Stereo PIV Modules

Stereo PIV processing is possible through a separate set of modules for *PIVview*. These modules are tied into *PIVview3C* but can be also be used in stand-alone fashion.
Stereoscopic PIV is considerably more complex than standard 2-C PIV implementations. The use of the stereo modules is not quite as straight forward and requires that the user has a basic understanding of stereo PIV implementations - namely the concept of image registration through back-projection. Aside from reading this brief introduction new users are encouraged to study the stereo PIV example(s) supplied on the program CD.

Stereo PIV Procedure in *PIVview3C*

The figure at left illustrates the general procedure followed by PIVview for stereo PIV processing. The following files/information are required:

- a set of simultaneous acquired PIV images for both camera views (e.g. 1 PIV image pair per camera)
- images of a calibration grid placed parallel to the light sheet - one image per camera. The grid should also have some clearly identifiable reference marks on it to identify its orientation.
- the position of the cameras in physical space with respect to reference grid (more on this later).



The first step involves determining two sets of coefficients which allow the PIV recordings to be matched to each other. This projection of the images into a common image plane shall be referred to as image back-projection. The grid images are essential for determining the projection coefficients as the spacing between the grid lines is well defined. The modules ***PIVmap3*** and ***PIVmapT01*** (formerly named T01) use semi-automated line or dot grid detection algorithm for exactly this purpose.

Once the projection coefficients are known, PIV images for each view can be back-projected. The command-line program ***mapimage*** can also be used for this purpose. Note that *PIVview* does not allow you to load images as long as the mapping coefficients are unity (e.g. not calculated).

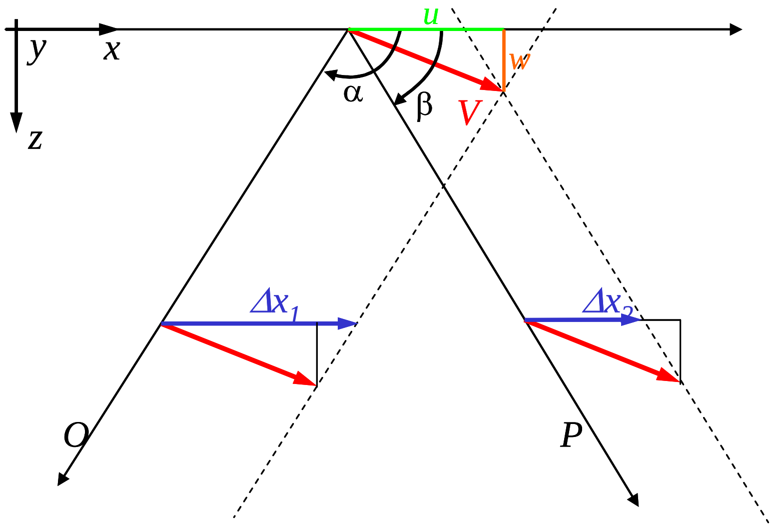
The back-projected PIV images can now be processed by standard (2-C) PIV interrogation. In *PIVview3C* the same interrogation parameters are used for both views to ensure that the resulting data sets exactly match in size and position. Command-line based PIV processing is possible by the programs ***dpiv*** and ***dpiv3C***.

The resulting pair of 2-C PIV data sets (or files) is now merged into a single stereo (3-C) data set by taking into account the stereo viewing geometry. The geometry information can be supplied relatively easily using the ***StereoGeom*** module. Views of the geometrical arrangement are available for three different orthogonal directions as a form of visual verification. Data set merging is either performed by *PIVview* internally or by the command-line program stereo.

In order to make file handling more user-friendly all information relevant for stereo PIV processing is contained in a common project file. This file is shared between the modules. Individual modules only update their specific sections. Platform-independence is guaranteed through the use of the *netCDF* data format that is also used for the data sets as well as other parameter files.

Vector reconstruction in stereo PIV

As mentioned above image pairs are first de-warped and processed for the respective view using standard 2-C PIV correlation processing algorithms. The resulting 2-C PIV data points from both views lie on a common grid but have to be combined using the local viewing angles. The figure below illustrates the viewing geometry in the xz-plane.



$$\begin{bmatrix} \Delta x_1 \\ \Delta y_1 \\ \Delta x_2 \\ \Delta y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\frac{O_x}{O_z} \\ 0 & 1 & -\frac{O_y}{O_z} \\ 1 & 0 & -\frac{P_x}{P_z} \\ 0 & 1 & -\frac{P_y}{P_z} \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$$\Delta\vec{X} = \mathbf{A} \cdot \vec{V}$$

$$\vec{V} = (\mathbf{A}^T \mathbf{A})^{-1} \mathbf{A}^T \Delta\vec{X}$$

The system of equations given on the left comprise a once over-determined (3 unknown velocity components vs. 4 known displacements) and are solved in a least-squares fashion. The residuals of this solution are a measure of quality of the vector reconstruction. In practice the residuals should be below 0.5 pixel. The validation tab of the PIV configuration menu allows a vector validation based on these residuals.

Enabling the Stereo Mode

The stereo modules of *PIView* are enabled by selecting the menu entry *File/Stereo*. A check mark next to the option signals that *PIVview* is in stereo PIV mode. The Stereo menu is then enabled.

Once the stereo mode is enabled certain features of standard (2-C) *PIVview* are disabled:

- ➢ The calibration mode is no longer available. All calibration is now supplied through the *PIVmap* image registration module, that is, the physical grid spacing together with the mapping coefficients define the image magnification factor. The origin is also defined through *PIVmap*.
- ➢ PIV images can only be loaded if the mapping coefficients are available. This prevents processing of images that have not been registered with respect to each other.

Stereo Menu Options & Toolbar

New project - allows a step-by-step creation of a new stereo project using the StereoWizard program including the image reconstruction (back-projection) procedure.


Open project - opens an existing stereo project. It loads previously calculated projection coefficients, the viewing geometry, the calibration images used by PIVmap as well as previously loaded PIV images (if available).


Save project - saves the current stereo configuration (coefficents, geometry & parameters) in the current file name.

Save as - allows the stereo configuration to be stored under a different name.

Recent projects - allows the selection of one of the (4) most recently accessed stereo projects.


Geometry - opens the stereo geometry definition window (module ***StereoGeom***). It is here where the camera position with respect to the viewing area (light sheet) is specified.


Image registration - opens the ***PIVmap*** module which is used for determining the back-projection coefficients.


Show Image A - displays the image as viewed from camera A (if loaded). If the data has been processed, the image will be overlaid with the corresponding (2-C) vector or contour map(s).


Show Image B - displays the image as viewed from camera B (if loaded).


Show combined data - displays the reconstructed 3-C data if available.

Creating a new stereo project with PIVmap3

The menu entry *Stereo/Image Registration* calls up the program *PIVmap3* which allows a step-by-step calibration of a stereo PIV configuration including the grid registration procedure.

Background on Stereo PIV

Most planar imaging techniques require some sort of calibration to associate image coordinates with physical coordinates. A viewing arrangement in which the object plane (e.g. laser light-sheet) is parallel to the image plane (co-planar arrangement) involves a simple linear transformation consisting of translation, scaling and possibly rotation. This is no longer the case for oblique viewing arrangements or if lens distortion is present. In effect the co-planar (on-axis) viewing arrangement should be considered as a special case of the oblique viewing arrangement. The calibration procedure for the more generalized oblique viewing arrangement typically requires high order mapping functions to transform image pixels to physical space coordinates.

Another calibration step is necessary for multi-component measurements such as DGV or stereoscopic PIV. In this case the positions of the cameras with respect to the image plane are required. The most pragmatic approach is a direct measurement of the camera positions with respect to the object plane (Willert, 1997) which is not necessarily trivial in complex geometries involving windows or change of media (i.e. air-water interface).

Soloff et al. (1997) introduced a mathematical formalism that combines back-projection and reconstruction in a single step. The procedure requires multiple images of the calibration target as it is translated at known displacements along the Z-axis (typical 5-7 recordings). The drawback of this approach is that the camera position is not retrieved directly and therefore unsuited for DGV. In effect the resulting projection equations connect object volume coordinates with planar image coordinates thus simplifying the vector reconstruction in stereo-PIV.

A third approach to camera calibration originates from the field of photogrammetry and image vision. Common here is the use of a pin-hole camera model with added parameters to account for radial distortions as suggested by Tsai (1986). The calibration procedure involves a so-called bundle adjustment of object-space calibrated feature points using a least squares method. In practice this can be achieved by translation of the target as in the previous case. More general approaches can even calibrate on sequences of randomly oriented target recordings. The major drawback of this method is that the camera parameters – so called internal parameters – such as pixel pitch need to be specified. Specification of these intrinsic parameters is especially difficult when imaging fiber bundles are used. Also this model does not seem to account for distortions introduced by tilting of the back-plane (Scheimpflug angle adjustment in stereoscopic PIV). In addition to the estimated camera position the Tsai camera model also yields distortion coefficients and estimated lens focal length which are not necessarily of direct interest in image coordinate calibration.

A slightly different approach to camera calibration is described in the following and has been implemented in the *PIVmap3* program. The basic aim is to provide an accurate image mapping to de-warp images on the hand as well as to retrieve the position for each individual camera without knowledge of the camera characteristics as in the pinhole camera model (i.e. pixel pitch, lens focal length). The image mapping function is calculated from a single recording of a calibration target that is placed in the object plane. The target should contain a known pattern such as a rectangular grid of lines, dots or crosses as shown in figure 4.

Calibration of the camera position is also based on an image series of the Z-translated targets as proposed by Soloff et al. (1997). The approach followed here is to use a functional relationship between the out-of-plane displacement and associated in-plane displacements to estimate the camera position. In practice, this involves solving the projection equations for the point at which the image coordinates (x_i,y_i) vanish. With the object coordinates (x_o, y_o, z_o) and image coordinates (x_i,y_i) the first order projection equations are:

$$x_i = \frac{a_{00}x_o + a_{01}y_o + a_{02}z_o + a_{03}}{a_{30}x_o + a_{31}y_o + a_{32}z_o + a_{33}}$$

$$y_i = \frac{a_{10}x_o + a_{11}y_o + a_{12}z_o + a_{13}}{a_{30}x_o + a_{31}y_o + a_{32}z_o + a_{33}}$$

$$\text{with } a_{33} \equiv 1$$

Although these equations do not include higher order distortions, they nonetheless are sufficient for most PIV applications and show deviations on the order of 1/10th of degree with respect to the more precise pinhole camera model by Tsai (1986). These higher order methods are also included in *PIVmap3*.

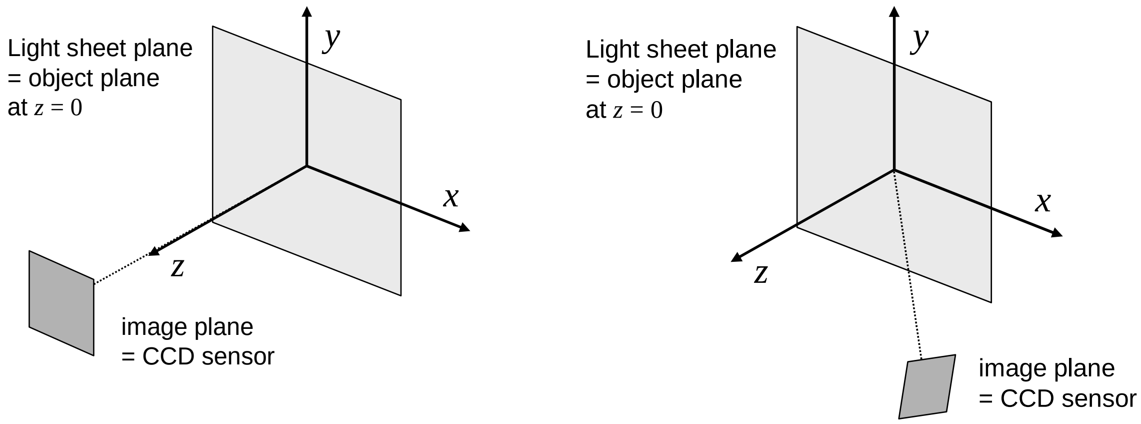


Figure 1: Coordinate system and viewing arrangements. Left: co-planar viewing arrangement with object plane parallel to image plane. Right: non co-planar (off-axis) arrangement with image plane tilted with respect to object plane.

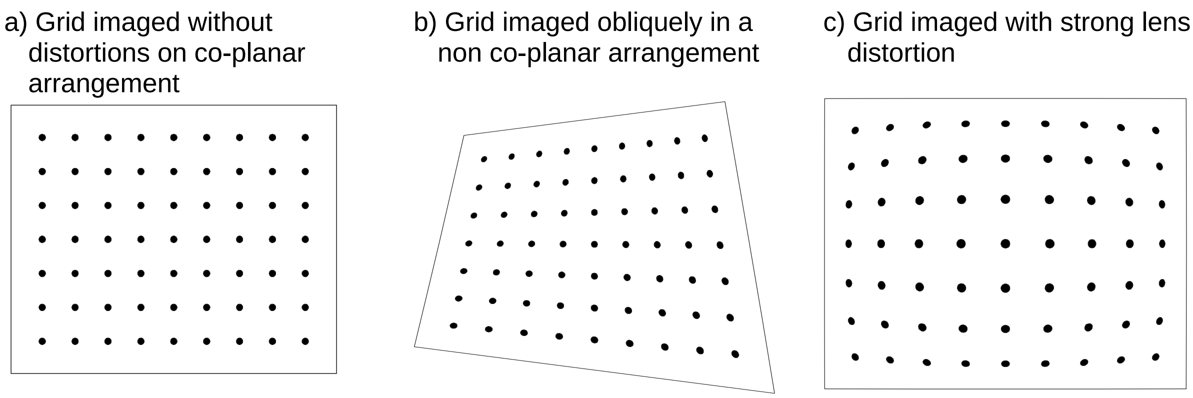


Figure 2: Examples of imaged grid under different viewing arrangements.

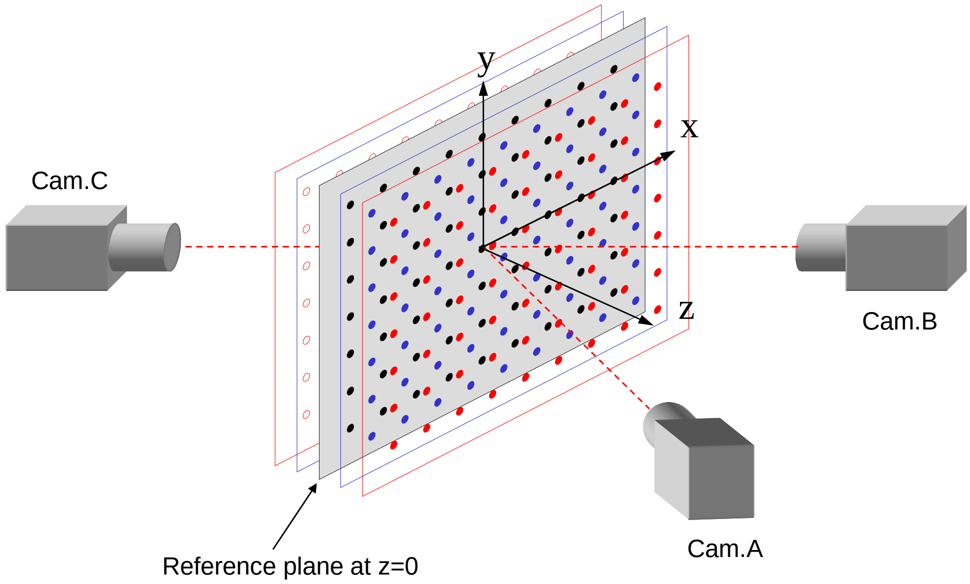


Figure 3: Multiple plane calibration procedure based on translation of calibration target. Camera A and B comprise a single-sided stereo configuration. Camera A and C view the light sheet from two sides. Here the light sheet thickness should be accounted for.

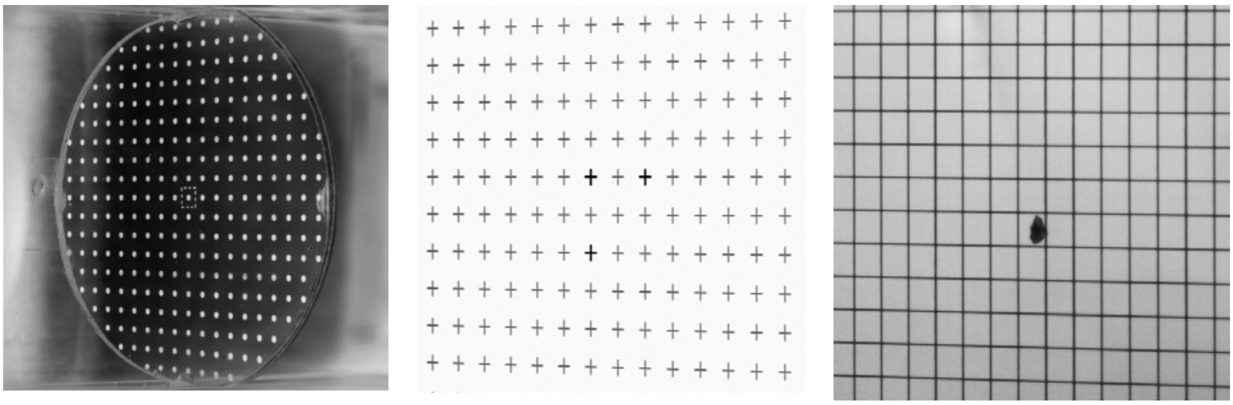


Figure 4: Images of various calibration targets. In all cases the camera is located to the right of the reference marks.

The program *PIVmap3*

This program is intended to provide accurate image-object calibration of oblique (distorted) camera views as well as estimate the position of the camera if a series of Z-translated images is available. The core of the program is an algorithm to reconstruct a regular grid from images of a calibration target. The following gives a brief overview of the reconstruction algorithm before the programs features are described in detail.

Grid reconstruction in *PIVmap*

The reconstruction of the grid itself is a three step process:

Step 1 – Image enhancement

A variety of filters can be used to increase contrast of the image if the following two steps fail to produce reliable results.

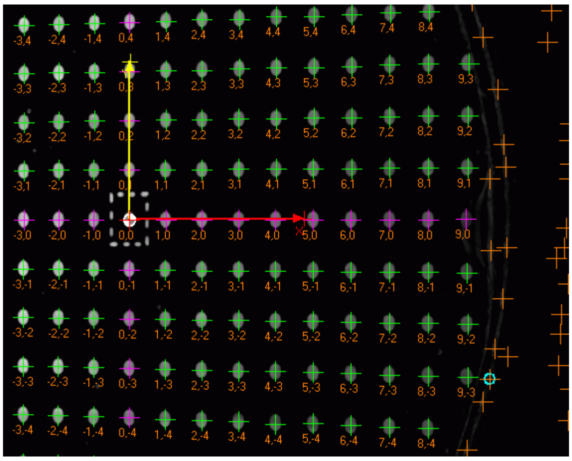
Step 2 – Feature extraction

This is based on correlation-based pattern matching, that is, a grid of dots is correlated with a template containing a single dot. Similarly a template containing a cross is used to detect a grid of crosses or line grid. As the correlation locks into features brighter than the background, images may need to be inverted a priori. This is done automatically by specifying the *type of target* in the input menu (e.g. black dots on white background). In any case, the image shown in the calibration menu should contain bright features (dots, crosses or lines) on a dark background. (See sections below for further details.)

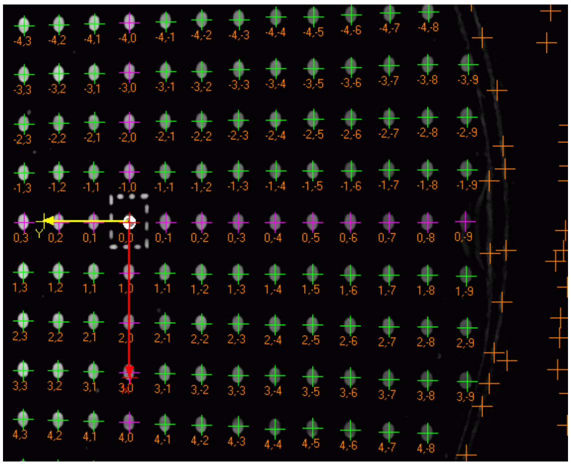
Step 3 – Grid reconstruction

This step attempts to assign physical coordinates to the detected feature points. The grid origin is assigned to the point closest to the origin of the manually placed helper coordinate axis (red and yellow arrows). The helper axes are then used to find the 4 neighboring points on the major axes as well as 4 neighboring diagonal grid points. The resulting group of 3x3 points forms the basis for the reconstruction of the remainder of the grid using a predictor-corrector approach. To allow for deviations of the grid nodes from their predicted positions a *reconstruction tolerance* is defined (given in percent).

The reconstructed grid will have grid index coordinates assigned to the valid correspondence points. Points on the major axes are shown in purple while unmatched points are shown in orange.



Reconstructed grid showing labeled grid points. Unmatched points are shown in orange.



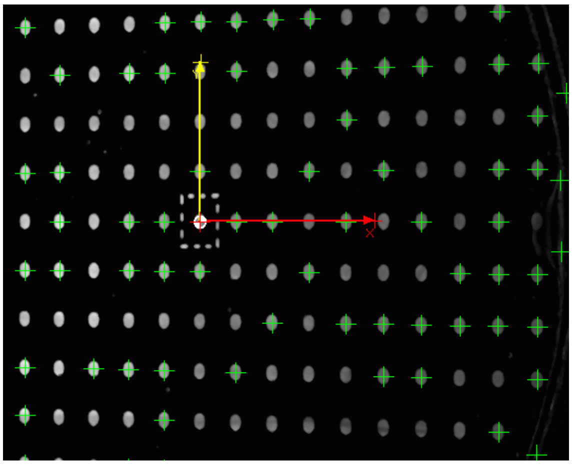
Reconstructed grid with X-axis pointing down, while Y-axis is pointing to left.

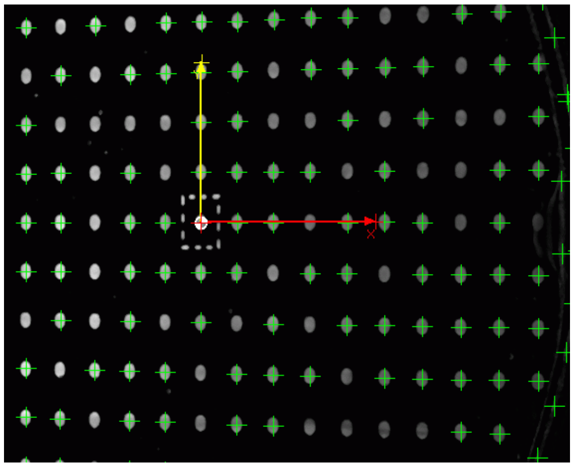
General strategy on feature extraction

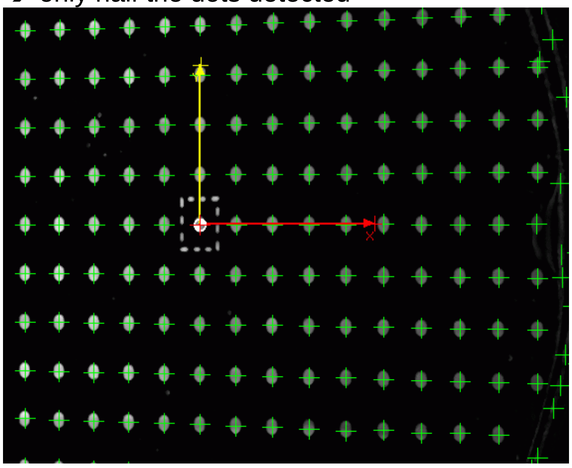
The image sample size and the sampling overlap determine the detection efficiency of the grid. As a rule of thumb, the sample size should be near the node distance in the image. In general one should start with a larger sampling window. If not all grid points were found change to next smaller sample or increase sample overlap. If grid points were detected more than once increase the merging radius to combine neighboring points. Depending on the tolerance the grid reconstruction procedure may ignore these misaligned calibration points.

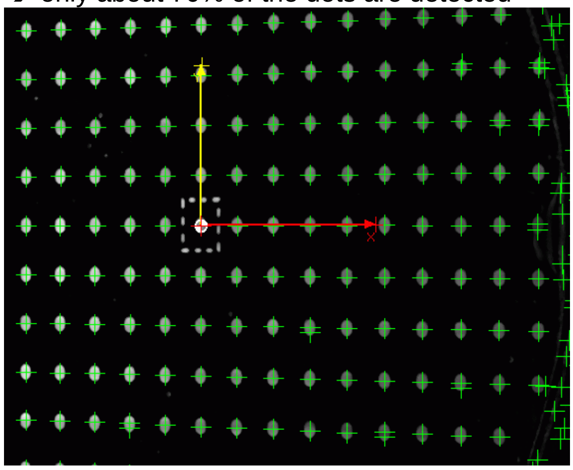
Effect of sample size on dot detection

The following images illustrate the effect on sample size on the feature extraction. Detected dots are labeled with a cross.


Sample size 128x128, 80% Overlap
➔ only half the dots detected

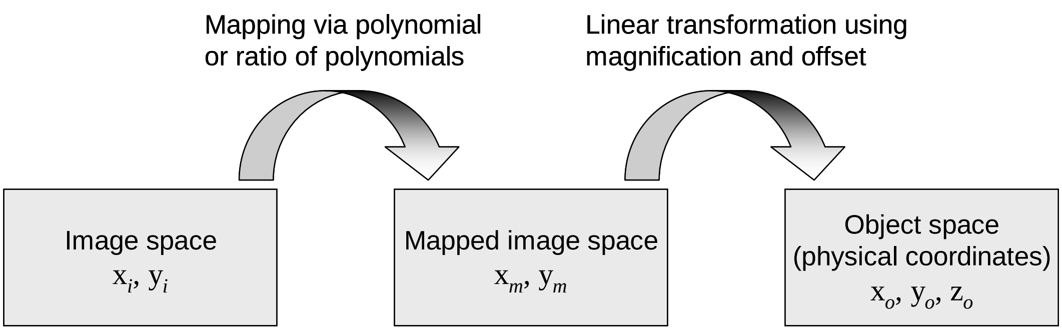

Sample size 96x96, 80% Overlap
➔ only about 70% of the dots are detected


Sample size 64x64, 80% Overlap
➔ all dots found, ideal parameter setting


Sample size 48x48, 80% Overlap
➔ some dots detected twice (resolved by increase of merging radius)

Calculation of the mapping function

Once the grid is reconstructed the image mapping function may be calculated. The mapping is a combination of two separate steps as shown in the figure below



The first mapping serves to *de-warp* the image to reconstruct the image space onto a Cartesian grid. At this point the image axes are parallel to the axes in physical space. The second step merely applies a linear transformation to convert from image space to physical space.

Mapping from image recording to reconstructed image

A variety of mapping functions are available for the first mapping step:

- polynomials up to degree 4

$$
\begin{aligned}
x_m &= c_{x0} + c_{x1}x_i + c_{x2}y_i \\
&+ c_{x3}x_i^2 + c_{x4}x_i\,y_i + c_{x5}y_i^2 \\
&+ c_{x6}x_i^3 + c_{x7}x_i^2 y_i + c_{x8}x_i y_i^2 + c_{x9}y_i^2 \\
&+ c_{x10}x_i^4 + c_{x11}x_i^3 y_i + c_{x12}x_i^2 y_i^2 + c_{x13}x_i y_i^3 + c_{x14}y_i^4
\end{aligned}
$$

$$
\begin{aligned}
y_m &= c_{y0} + c_{y1}x_i + c_{y2}y_i \\
&+ c_{y3}x_i^2 + c_{y4}x_i\,y_i + c_{y5}y_i^2 \\
&+ c_{y6}x_i^3 + c_{y7}x_i^2 y_i + c_{y8}x_i y_i^2 + c_{y9}y_i^2 \\
&+ c_{y10}x_i^4 + c_{y11}x_i^3 y_i + c_{y12}x_i^2 y_i^2 + c_{y13}x_i y_i^3 + c_{y14}y_i^4
\end{aligned}
$$

- projection equations, a ratio of polynomials ($1^{st} \div 1^{st}$, $1^{st} \div 2^{nd}$, $2^{nd} \div 1^{st}$, $2^{nd} \div 2^{nd}$)

$$x_m = \frac{a_{00}x_i + a_{01}y_i + a_{03} + a_{04}x_i^2 + a_{05}x_i y_i + a_{06}y_i^2}{a_{30}x_i + a_{31}y_i + a_{33} + a_{34}x_i^2 + a_{35}x_i y_i + a_{36}y_i^2}$$

$$y_m = \frac{a_{10}x_i + a_{11}y_i + a_{13} + a_{14}x_i^2 + a_{15}x_i y_i + a_{16}y_i^2}{a_{30}x_i + a_{31}y_i + a_{33} + a_{34}x_i^2 + a_{35}x_i y_i + a_{36}y_i^2}$$

with $a_{33} \equiv 1$

The choice of function depends on the degree of distortion in the image. In general, if the grid consists of straight lines a ratio of first order polynomials should be favored. However convergence of the polynomial ratios is not always guaranteed. Table 1 gives an overview of the associated number of coefficients and the required number of calibration points. If the number of calibration points exceeds the minimum count a standard least squares fit is used to calculate the coefficients for the polynomial mapping functions; a Levenberg-Marquardt nonlinear least squares fit is used in the calculation of the polynomial ratios.

Table 1.: Mapping functions and their coefficients.

Mapping function	Number of coefficients	Minimum number of calibration points
Polynomial, 1^{st} Order	6	3
Polynomial, 2^{nd} Order	12	6
Polynomial, 3^{rd} Order	20	10
Polynomial, 4^{th} Order	30	15
Ratio, $1^{st} \div 1^{st}$	8	4
Ratio, $1^{st} \div 2^{nd}$	11	6
Ratio, $2^{nd} \div 1^{st}$	14	7
Ratio, $2^{nd} \div 2^{nd}$	17	9

Mapping from reconstructed image to object space

Mapping between the reconstructed image and physical space is described by the following linear transformation:

$$x_{Obj} = \frac{x_m}{M} + x_{Offset}$$
where the magnification *M* is given in [pixel/mm]
$$y_{Obj} = \frac{y_m}{M} + y_{Offset}$$

PIVmap3 Input Menu

The main menu – shown Figure 5 – consists of two input areas: The left area is used to specify parameters that are common to all camera views and/or all image planes. The right area is specific to each supplied calibration image which is referred to here as *plane*.
In the *Global Settings* area the following parameters are specified:

Configuration data file

stores a summary of all parameter settings within the current instance of the program. The load function can retrieve previous parameter settings. The parameter files are ASCII formatted and may be edited with any text editor.

Type of target

specifies whether the images of the calibration target contain dots, crosses and lines. Further the image characteristics with respect to features (black-on-white or white-on-black) are specified here. This may be specific for each individual view.

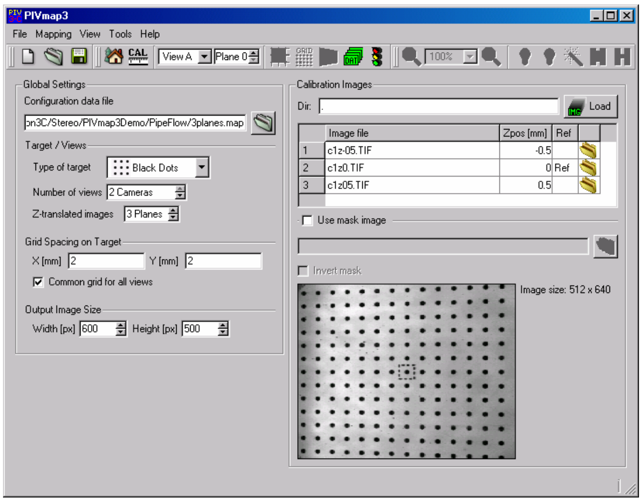


Figure 5: Main input menu of program *PIVmap*

Number of views

allows up to 4 camera views. Stereoscopic PIV would require only 2 views. A triple camera DGV-setup would require 3 views. A single camera view could be used to calibrate a standard 2-C PIV experiment.

Z-translated images

determines the number of calibration images for each view. At least two are required if the camera position is to be determined.

Grid Spacing on target

determines the physical distance of the calibration points on the target.

Output Image Size

specifies the image size of the reconstructed (de-warped) image. This parameter is common to all camera views.

Calibration input area

Load (Images)

permits the simultaneous selection of all calibration images associated with this camera view. The common directory of these files is specified above the table.

Table Area

The table itself lists the image files, their position in Z and the specified reference plane. Clicking on the image file shows a preview of the corresponding image in the area below the table. The out-of-plane translation (Z-position) of each image can be entered directly in the corresponding cell. The reference plane indicates that the camera position and image mapping is calculated with respect to the given image and is set by clicking on the corresponding cell. Single images can be loaded by clicking the icon on the far right of the table.

Mask image

can be used to mask out areas in the calibration images to improve grid reconstruction performance and also increase overall calculation speed (less correlations required). Mask inversion disables the complementary area. A common mask is used for all images of a single view.

PIVmap3 Calibration Area

Once a sequence of images has been loaded they may be displayed one-by-one in the calibration menu. The display should display the image with bright features (dots, crosses) on a dark background. If not, then the image type was not properly set in the main menu (i.e. black-on-white vs. white-on-black). Also any optional filtering that has been applied to the image will be made visible here. The image will be overlaid with a pair of coordinate axis, herein referred to as *Helper Axis*. These may be adjusted with the mouse and serve to define the principle directions in the grid. Details on this are given in the following section.

The calibration area is accompanied by a tab-menu containing the tabs *Filters*, *Scan*, *Scale* and *Map*. Their purpose is described in the following.

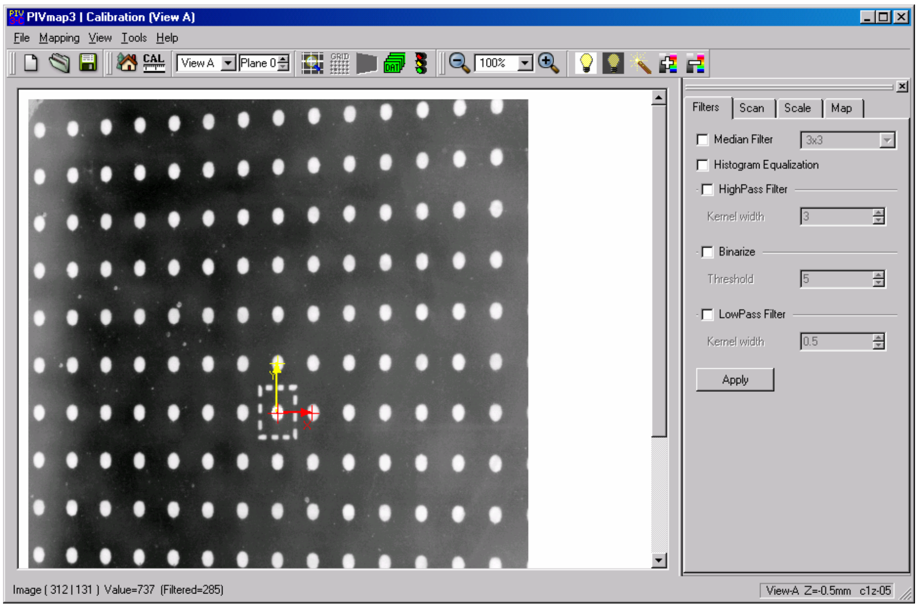


Figure 6: Calibration view of program PIVmap3 with Filters Menu shown.

Filters Tab

To improve the feature detection several filters may applied to the image. They are shown top-down in the order of their application.

Median Filter
: applies median filtering on the image. Either a 3x3 or 5x5 kernel may be used.

Histogram Equalization
: performs histogram equalization on the image.

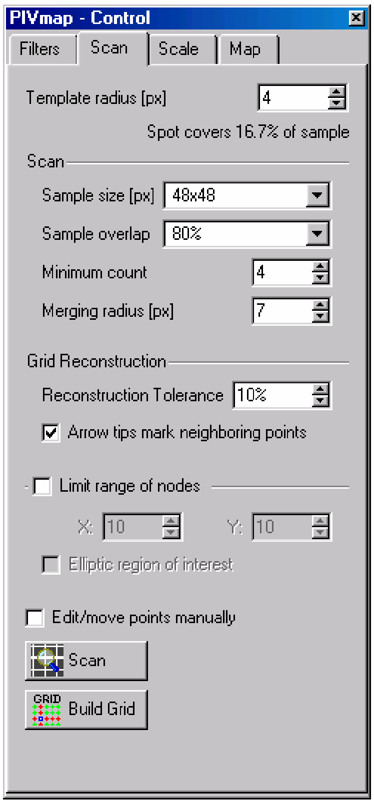
High-Pass Filter
: applies a Gaussian-weighted high-pass filter to the image. The width of the Gaussian filter function can be specified. Values between 3 and 10 are recommended. The processing speed decreases with increased width of the weight function.

Binarize
: converts the image to contain only black (0) or white (255) pixels by setting values above the specified threshold to 255. Lower values are set to 0.

Low-Pass Filter
: applies a Gaussian weighted smoothing filter to the image. In combination with the high-pass filter the resulting image will be band-pass filtered. Recommended kernel widths are the range of 0.5 – 1.5 pixels.

Scan Tab

Feature extraction in *PIVmap3* is based on a correlation approach in which a template of either a dot or cross is matched locally to the image. The position of best match indicates the center of the dot or cross in the locally sampled area. The performance of this matching process depends on the choice of sample size, sampling overlap and a few more parameters that are set in this tab.



Spot/Template radius
: specifies the radial dimension of the dot or cross in the template.

Sample size
: provides a choice of image sampling areas. Typically this size should roughly correspond to the mean spacing of the features to be extracted.

Sample overlap
: specifies the image sampling distance. A higher sampling rate increases the overall performance but decreases processing speed.

Minimum count
: As each sample produces an estimate of a feature point location, adjoining samples will detect the same feature point more than once. This value specifies the minimum number of times a feature point needs to be detected to qualify as such. The merging radius given below has a direct influence.

Merging radius
: specifies the scan area to combine near-by feature point estimates. Values between 3 and 10 are recommended.

Reconstruction tolerance
: is required to reconstruct the grid from the detected feature points. The reconstruction is based on a predictor-corrector approach where valid grid points are used to estimate the position of neighboring grid points. The search area is determined by this tolerance value. Values between 5 and 10 percent are recommended.

Arrow tips mark neighboring points
: is used to aid the reconstruction algorithm in finding the first points near the origin.

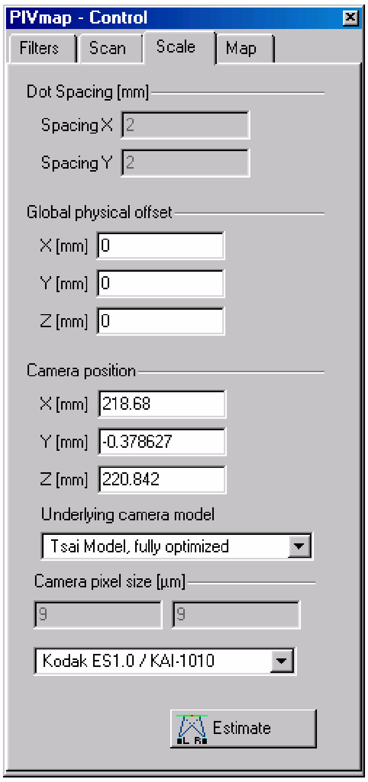
Limit range of nodes
: restricts the range of nodes in the reconstructed grid. This is useful if the image has many invalid feature points on the edges. The use of a mask (specified in the main menu) should however be favored. Circular or elliptic calibration geometries can be treated as well.

Edit/move points manually
: In some cases the grid reconstruction may fail, if falsely detected or missing feature points near the grid origin mislead the reconstruction. By manually moving these points the grid may be properly reconstructed nonetheless. However, these movements are lost if the scan operation is repeated.

Scan
: performs the feature extraction scan by the localized template matching scheme using the current parameter settings. Any manual change to previously detected feature points are lost.

Build grid
: tries to reconstruct the grid using the currently detected feature points.

Scale Tab



Dot Spacing

specifies the actual spacing of the grid points. This value is set in the main input menu of the program and cannot be changed here.

Global physical offset

assigns the coordinates of the calibration origin in physical space. Initially this value is zero and should be set according to the experiment's reference frame.

Camera position

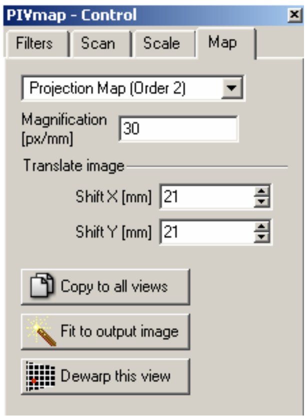
reflects the camera's position with respect to the origin of the grid in the specified reference plane (set in main menu). These values are irrespective of the global physical offset.

Estimate

tries to calculate the camera position using at least two calibrated planes. A valid image mapping (see Map) is required. The result, even for non-convergence is placed in the edit boxes above.
Various estimation schemes are available, some of which require additional input regarding the type of camera (sensor) with which the images were acquired.

Map Tab

Parameters specified in this menu determine image mapping coefficients that perform the back-projection from camera view to an un-distorted image. The choice of mapping function is specified on the top of this menu.



Magnification

determines the final magnification factor for the reconstructed image. This value is constant throughout the image.

Translate image

By default the origin of the grid will be shifted to the lower-left corner. These parameters allow the origin to be shifted.

Copy to all views

copies the current parameters to the remaining camera views. This is especially of interest when all reconstructed views should coincide after mapping them.

Fit to output image

is useful to approximately match the reconstructed grid to the specified output image size and should be used on a new set of calibration images. An even better match is achieved by manually fine tuning the magnification and shift parameters.

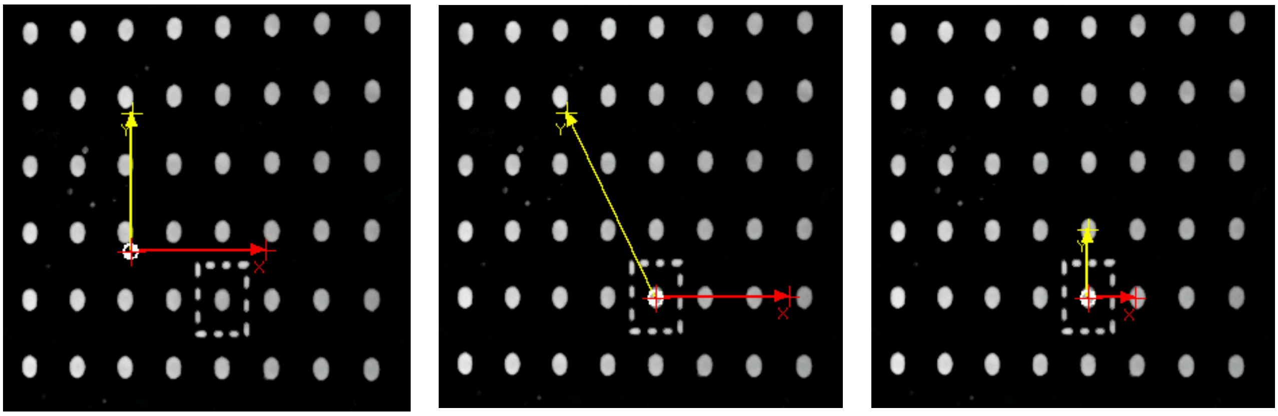
Dewarp this view

calculates the mapping coefficients for each reconstructed grid of this camera view. These mappings are used to back-project the original images which are then displayed. The overall speed of the mapping process depends on the output image size and the number of reconstructed planes.

Helper axis

Reconstruction of the grid is based on the a priori knowledge of the direction of the major axes as well as an approximate location of the origin. This is achieved by manually specifying a pair of *helper axes* for each calibration image. The figures below show how these axes may be placed in the image using the mouse. The tips of each axis should be placed on the points neighboring the origin to allow a more efficient grid reconstruction.

The function ‘Copy helper axis’ can be used to copy the coordinates from the previous plane to the currently displayed plane. This speeds up positioning over many calibration images.



Position of axes at beginning | Dragging the X-axis to the origin. | Alignment of Y-axis and arrow tips.

Figure 6: Manual positioning of the *helper axis* in the image.

Description of the *PIVmap3* menu entries


File/New

creates a new PIVmap3 project. All previously loaded images are removed and file names are reset.


File/Open…

loads a previously created PIVmap3 project. All current settings are lost.
File/Save
stores the current selection of image and parameters in a user-specified project file. This ASCII file is editable with any text editor (i.e. Notepad). The default extension is ‘map’.


File/Save

stores the current selection of image and parameters in a user-specified project file. This ASCII file is editable with any text editor (i.e. Notepad). The default extension is ‘`map`’.

File/Exit

leaves the program after asking the user for confirmation.

Menu *View*


View/Zoom out/in – changes the image display scale factor


View/Brighter – increases the image brightness on the screen (Short-cut key: B).


View/Darker – decreases the image brightness on the screen (Short-cut key: D).


View/Auto-scale – sets default intensity on image


View/Change color LUT – skips to the next available lookup table (LUT) to convert the grayscale images to pseudo-color.

Menu *Mapping*

Mapping/Input menu

changes to the main input area of the program

Mapping/Calibration mode

changes to the calibration area and displays the filtered image of the currently selected view and plane.

Mapping/Scan image

performs the feature extraction scan by the localized template matching scheme using the current parameter settings. Any manual change to previously detected feature points are lost.

Mapping/Create grid

tries to reconstruct the grid using the currently detected feature points.

Mapping/Show mapped image

calculates the mapping coefficients for each reconstructed grid of this camera view. These mappings are used to back-project the original images which are then displayed. The overall speed of the mapping process depends on the output image size and the number reconstructed planes.

Mapping/Process current view

performs grid reconstruction and image back-projection for all images in the currently selected camera view.

Mapping/Overlay mapped images

computes a combined image of all available back-projected views for the currently selected image plane. At least two valid (back-projected) camera views are required. This is especially useful to check the coincidence of the back-projections.

Mapping/Process all images

processes all images for all views including camera position estimation

Mapping/Center helper axis

This utility re-centers the helper axis to the middle of the image.

Mapping/Copy helper axis

This utility copies the helper axis from the previous plane to the current plane.

Mapping/Estimate camera position

tries to calculate the camera position using at least two calibrated planes of the current view. A valid image mapping is required. The result, even for non-convergence is placed in the calibration tab menu.

Mapping/Save calibration points

exports the detected and validated feature points for all available plane of the current view to a user-specified ASCII file.

Mapping/Export for *PIVview*

stores the current image projection coefficients along with all relevant data (i.e. image size, camera positions, etc.) in a user-specified *PIVview3C* project file. If an existing file is selected the new data is merged into it.

Menu *Tools*

Tools/Batch image dewarping

opens a menu allowing a series of images to be back-projected using the current image maps. The image interpolation function and destination directory may be specified.

Tools/Show log

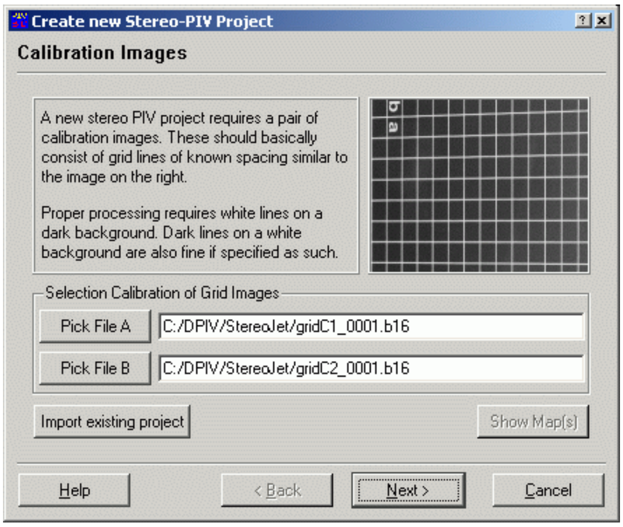
opens a window with past error messages, warnings and comments.

Creating a new stereo project with StereoWizard

The menu entry *Stereo/New project* calls up the program *StereoWizard* which allows a step-by-step definition of a stereo projection including the grid registration procedure.

Step 1 - Calibration image

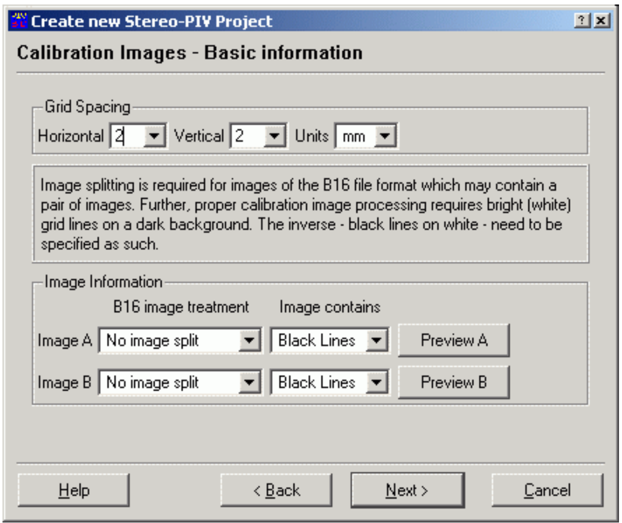
Here the user is asked to either load a pair of calibration grid images or an existing project he wishes to modify.



Step 2 - Calib.Image - Basic Information

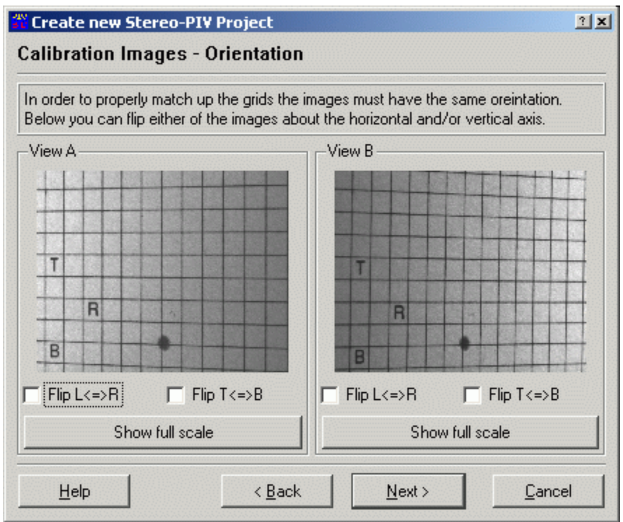
Using the dropdown entries give the actual (physical) spacing of the line in the grid (here 2 mm). Later the actual magnification factor is calculated from this.

Also, some information regarding the image type needs to be given. For proper grid detection it is important for the program to know whether the image contains dark lines on a bright background or bright lines on a dark background.



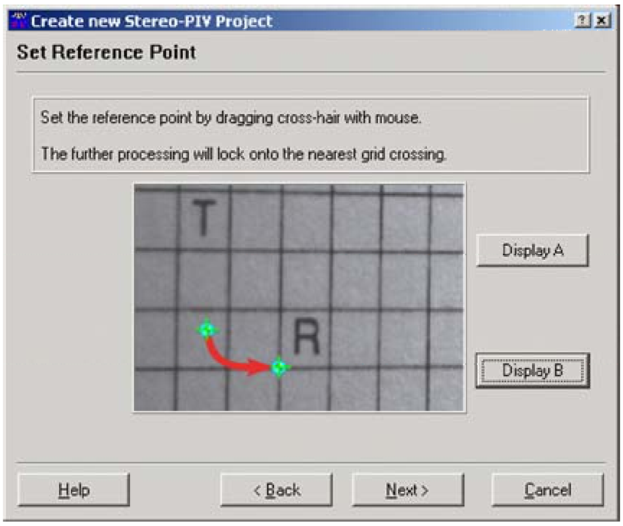
Step 3 - Calibration Images – Orientation

In case the image needs to be flipped in some way (mirror view), this can be achieved here.



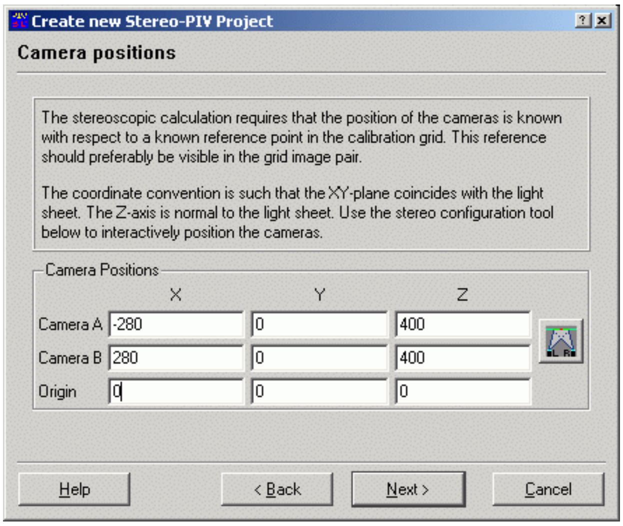
Step 4 - Set Reference Point

The buttons *Display A* and *Display B* show the currently loaded grid image. Using the mouse the position of the origin can be selected. The grid detection algorithm later snaps to the nearest grid crossing.



Step 5 - Camera Positions

This dialog allows the user to enter the positions of the camera with respect to the origin. In addition the physical (offset) coordinates of the reference point may be specified. Alternatively the *StereoGeom* program can be used to enter the coordinates.



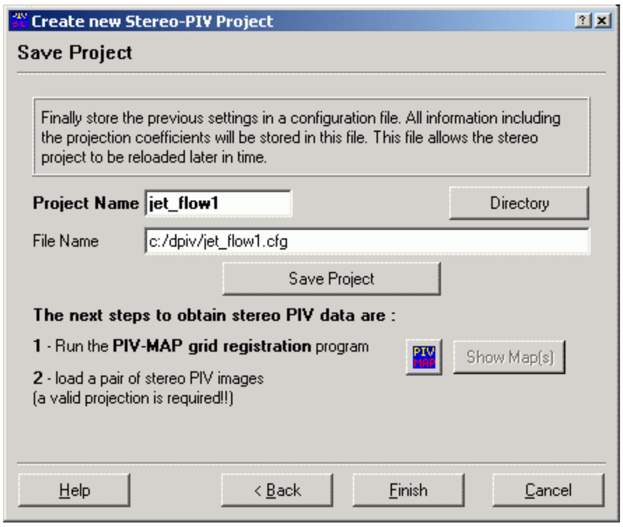
Step 6 - Save Project

Finally the project must be given a name and is saved at the chosen location.

To begin with the actual grid detection, start the *PIVmap* module by pressing the button. The next steps show how the grid is recovered and the projection coefficients are determined.

Once the wizard is closed *PIVview* asks the user whether to load the new project file into PIVview3C.

Parameters such as the camera positions may be modified at a later stage from within *PIVview3C*.



StereoGeom - Geometry Definition

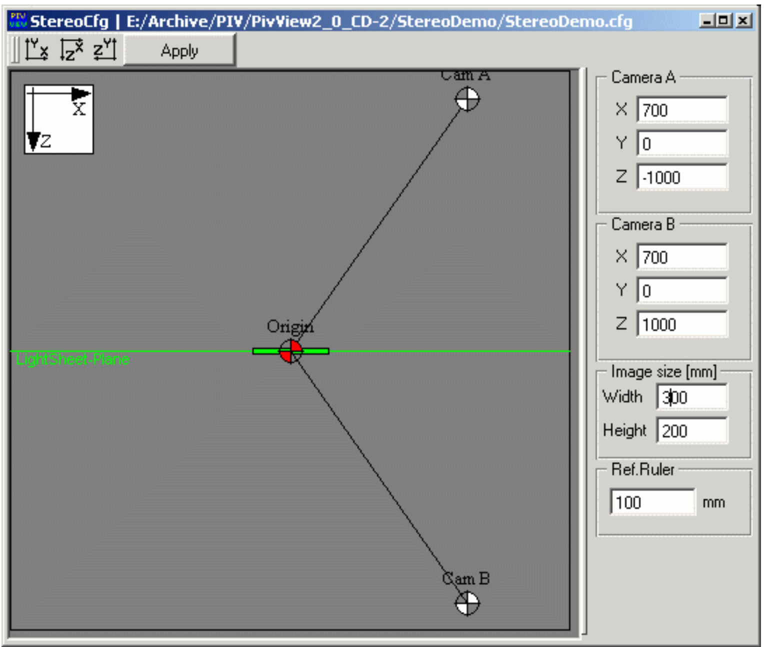
This stereo module is used to define the stereo viewing arrangement, namely the camera positions with respect to the light sheet. The entered coordinates are specified with respect to the same same reference point used by the *PIVmap* module. Please note that in current implementation of *PIVview* the z=0 plane always defines the light sheet plane, that is, the X and Y-axis lie in the light sheet, while the Z-axis points normal to this plane.

The camera positions can be entered directly in the fields on the right hand side. The positions within the geometry plot are updated immediately and give the user a visual feedback.

 These tool buttons allow the user to view the stereo geometry from three major (orthogonal) directions.

The Apply button is used to transfer the settings to *PIVview* such that the reconstruction of the 3-C velocity map is repeated using the new settings.

StereoGeom may also be used in stand-alone fashion. In this case a file menu allows the user to load or save existing stereo project files.



StereoCfg module showing XZ-projection of the camera / light-sheet geometry. In this example the cameras are placed on either side of the light sheet.

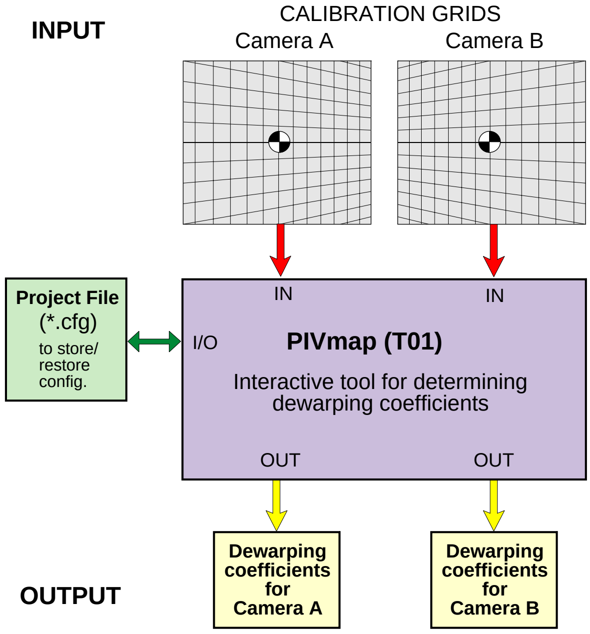
PIVmapT01 - Projection Module

This module is a semi-automated procedure for determining the image back-projection coefficients that are necessary for stereo PIV processing. For input it requires images of a calibration grid (see notes below) for each camera view. The grid reconstruction process can be split up into three major steps - the coefficient calculation tab dialog follows these steps.

Step1: Line detection is performed by interrogating image locally using the Hough transform which transforms the image intensity distribution into a polar coordinate space. Since straight lines show up as distinct bright spots in this transformation line segments are detected for each interrogation area.

Step 2: The line segments are subsequently assembled into sets of continuous lines spanning the entire image. Separation into two major directions as well as sorting of the lines are then performed to reconstruct a grid (meshing). In order to properly overlay the images, the origin can be shifted in grid intervals using a desired point of reference in the calibration grid.

Step 3: At this point the projection coefficients can be calculated using a desired magnification factor for the back-projected image.



For more information about this module please consult the paper by Ehrenfried (2001).

Some notes on obtaining calibration grid images

The grid must be made up of two sets of continuous, evenly spaced, parallel lines that are orthogonal to each other. The grid should either have bright lines on a dark background or dark (black) lines on a bright (white) background. The latter lends it self especially well to be printed by a laser printer. The grid should be aligned parallel with the light sheet of cover the entire field of view (if possible). The grid image should contain 10-30 lines in each dimension (roughly 30-60 pixel spacing) - this results in 100 to 1000 grid crossings.

Misalignment of the grid with respect to the light sheet may increase the measurement error. Reference marks placed on the grid allow doubtless identification of image orientation and also help in obtaining an image-object space referencing.

Important: Make sure to check the invert option in case your image has dark lines on a bright background. Otherwise *PIVmapT01* will not be able to properly detect the grid lines.

PIVmapT01 Toolbars & Menu Options

File/Load image - opens a file dialog for loading new calibration images.

File/Load project - opens and loads an existing project.

File/Save project - save current project.

Tools/Place origin - allows rough placement of the origin using the cursor. The grid detection set the origin to the line crossing closest to this point.

Tools/Complete evaluation - performs full reconstruction on loaded image(s) using current parameter settings.

Tools/Line detection - performs line detection on current image using the current Hough transform processing parameters.

Tools/Form mesh - tries to reconstruct the mesh from the detected set of lines.

Tools/Reconstruct grid - detects the line crossing in the mesh and determines the major axis.

Tools/Find optimal map - provides an initial guess for the back-projected image by trying to keep the magnification factors near unity. Fine tuning is possible with by changing the parameters in the Projection tab of the parameters.

Tools/Eval. parameters - opens a tab dialog that allows step-by-step processing of the grid images.

Tools/Show Info - gives information about the status of *PIVmap*.

Tools/Measure - places a ruler into the image allows the user to measure distances between two points.

Tools/Set ROI - allows interactive definition of a region of interest in which grid detection is to be performed.

Tools/Elliptic ROI - toggles the ROI shape between rectangular and elliptic.

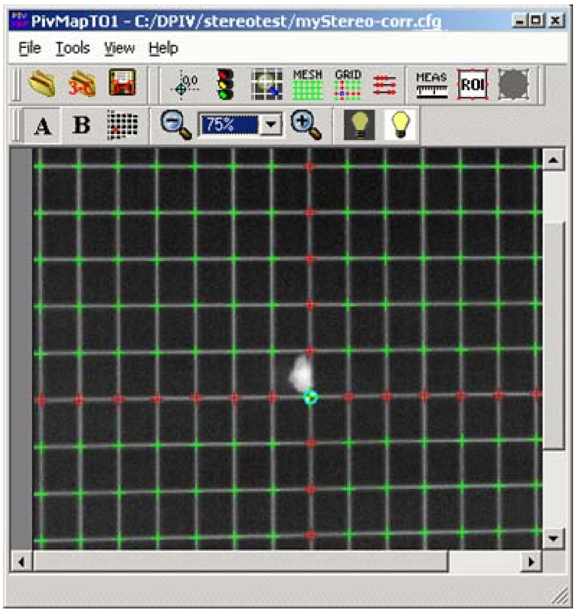
Tools/Best fit ROI - maximizes the ROI to fit the image size.

View/Show Grid A - displays the calibration image for camera view A.

View/Show Grid B - displays the calibration image for camera view B.

View/Back-projected image(s) - dewarps the loaded calibration images using the current sets of projection coefficients (if avaiable).

The View menu has a number of entries that are identical to those found in PIVview: zoom functionality, image brightness, etc.



Main window of PIVmapT01 showing calibration image overlaid with reconstructed grid. Red crossings indicate the major axis. The origin itself is marked by the yellow circle. Note that the image is a negative of the original which consists of dark lines on a bright background.

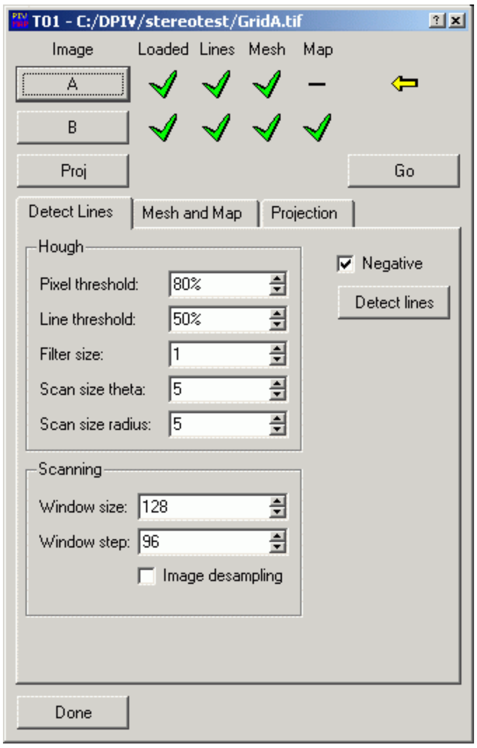
PIVmapT01 Tab Dialog

The tab dialog is accessed with the button  and is split into an upper portion giving feedback on the current status of *PIVmapT01* such as which image is available and displayed or whether grid reconstruction has been successful. The lower tab dialog (described below) follows the main processing steps of *PIVmapT01*.

The buttons **A** and **B** toggle the display between images A and B. The parameters in the first two tabs are unique to each image a change accordingly. The Projection-tab parameters are identical for both images.

The ***Go*-Button** starts a complete processing of the loaded images using the current parameter settings. If successful the mapped image pair is displayed in the main window.

PIVmapT01 Dialog - Detect Lines



This tab is devoted to the line detection portion of T01 based on the Hough transform. The following parameters can be set:

Pixel threshold - threshold for pixels to be used in the Hough transform.
High value = less lines, but faster.
Low value = more lines, slower.

Line threshold - threshold for detection of the maximum in the Hough plane.
High value = less lines,
low value = more lines.

Filter size - kernel size of filter for smoothing the Hough transform
(Can normally be set to 1, e.g. no filtering)

Scan size theta - angular increment used during maximum search. Default of 5 usually does not need to be altered.

Scan size radius - radius increment used during maximum search. Default of 5 usually does not need to be altered.

Window size - size of the sampling window used in the Hough transform. Its size should be larger than the typically distance between two grid lines. This window size also defines the length of the individual line segments. In case of strongly curved grid lines the window size should not be chosen to be too large which might impede the accuracy.

Window step - sampling distance between Hough interrogation windows. This distance should be smaller than the window size to ensure overlapping line segments.
Small value = slower, but high accuracy
High value = faster, less precise.

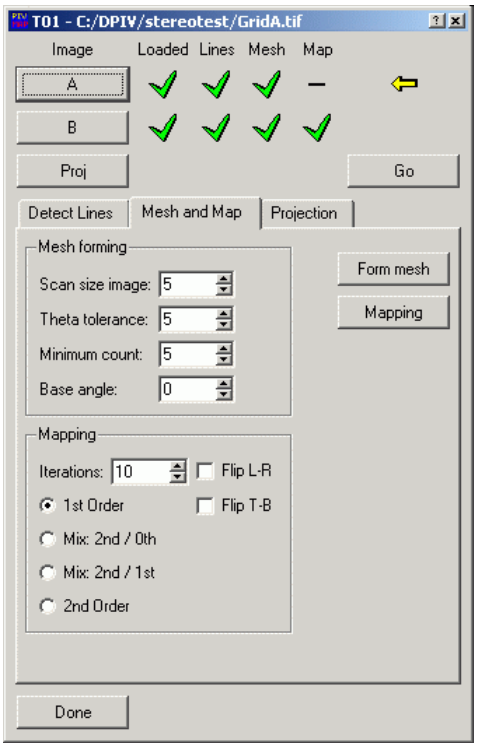
Image desampling – down-samples the image to speed up processing at the price of slightly reduced precision - especially useful during optimization of line detection parameters.

Invert - turns loaded image into its negative. The Hough line detection algorithm requires bright line data on a dark background.

Detect lines button – starts the detection algorithm. This process is the most lengthy step in the grid reconstruction process but can be aborted at any point, available line segments are displayed.

PIVmapT01 Dialog – Mesh & Map

This dialog contains all parameters necessary for reconstruction of the grid from the previously detected line segments.



Form mesh button - connects line segments to form continuous grid lines, The result is displayed by overlaying the image with green lines.

Mapping button - calculates the back-projection (mapping) coefficents.

Scan size image - search distance between neighboring line segments. Default of 5 usually does not need to be altered.

Theta tolerance - maximum possible angle (degrees) allowed between two neighboring line segments. For strongly curved grid lines this value may need to be increased (default = 5°).

Minimum count - minimum number of line segments necessary to form a grid line;
high value = less short lines, less chance of outlier lines,
low value = permits more short lines.
In case of outlier lines just increase this value.

Base angle - defines the principle direction of the X-axis. An angle of 0° corresponds to having the X-axis run horizontal from left to right. In case of diagonal lines choose a value of either +45° or -45°.

Horiz. Shift - shifts the vertical (Y) axis horizontally across the image. Defines the horizontal coordinate of the image origin.

Vert. Shift - shift the horizontal (X) axis vertically across the image starting from the bottom. Defines the vertical coordinate of the origin.

Flip L-R - flips the image left-to-right. Useful in case of using mirrors or viewing the light sheet from two different sides.

Flip T-B - flip the image top-to-bottom.

Iterations - maximum number of iterations used for the calculation of the coefficients;
low value = faster, higher chance of result not being converged,
high value = slower, better chance of convergence.

1st Order - sets mapping function to be a ratio of polynomials of first order.

Mix: 2nd/0th - mapping function only a second order polynomial (divisor is unity).

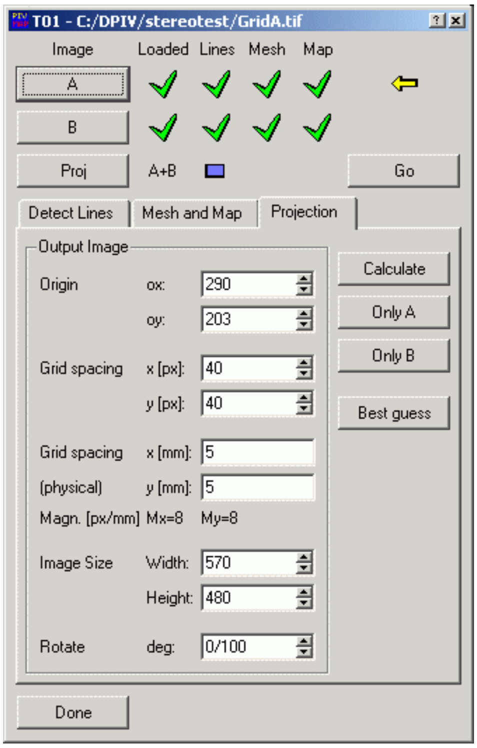
Mix: 2nd/1th - mapping function = ratio of 2nd order polynomial and first order polynomial (divisor).

2nd Order - mapping function = ratio of two second order polynomials.

Note: higher order mapping functions may result in more precision but may require more iteration steps.

PIVmapT01 Dialog – Projection

This dialog is used to set the image size of the back-projected images.



Calculate button - calculates back-projected images which are displayed in the main window of PIVmap. The images a overlaid with each other.

Only A - calculates back-projected image only for view A.

Only B - calculates back-projected image only for view B.

Origin ox/oy - x-, y-coordinates (pixel) of the image origin within the back-projected image.

Grid spacing x, y [pixel] - distance between grid lines in the back-projected image. This value should chosen to be close to the line spacing in the original images.

Grid spacing x, y [mm] - distance between grid lines in physical space. The ratio of this value and the pixel grid spacing gives the image magnification factor (also shown in dialog).

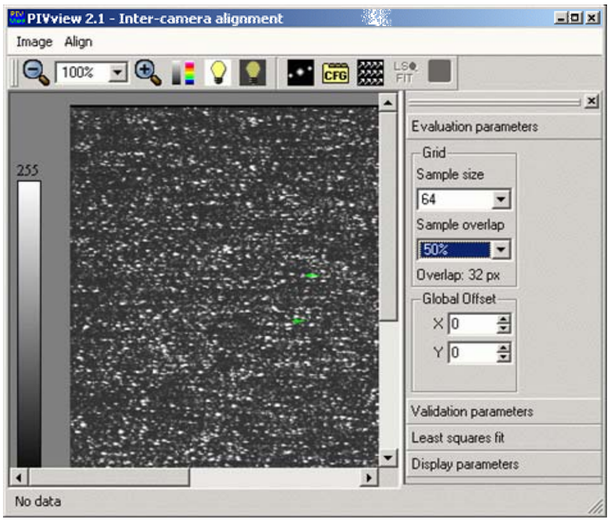
Image Size x,y - pixel dimensions of the resulting image which is shown as a red box in the main window.

Stereo View Disparity Correction

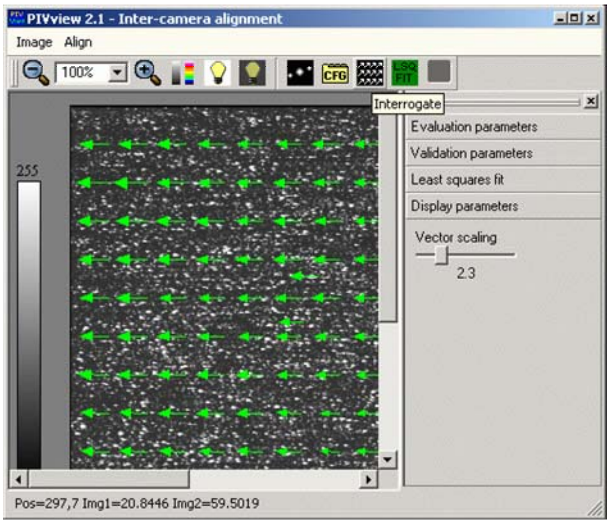
In practice it generally is not possible to perfectly align the calibration target with the light sheet. As a result the sampling windows of the PIV interrogation do not coincide between the two views. One way to account for this is to perform a PIV correlation analysis on the particle images acquired at the same instant from the two views, that is, correlating an image from view A with an image from view B. This correlation results in a vector map showing the misalignment between the two camera views. This disparity (misalignment) map can then be used to adjust the projection coefficients.

PIVview3C offers this alignment procedure in the Stereo Menu entry *Disparity Correction*[1], which opens the window shown on the right (provided a stereo project and image set has been loaded).

The alignment window shows an overlayed image of the two camera views. The mouse can be used to interactively correlation-probe the image, similar to the main *PIVview* window.



Main window of the *PIVview3C* stereo camera disparity correction.



Displacement vector map showing the misalignment between the camera views.

Disparity Correction Tool Buttons:

The functions of the view tool buttons are equivalent to those of other views so only those unique to this window are described here.

 shows the correlation plane window for interactive image probing.

opens the configuration menu shown to the right of image view.

 performs a full interrogation of the image pair followed by data validation. The result is displayed as a green vector map.

applies a least squares fit to the validated data and displays a red vector map of the fit.

 saves the coefficients of the current least squares fit and prompts the user whether to enable the fit in which case *PIVview* reloads the image set with modified projection coefficients.

Once the alignment map has been activated this window can be used to verify the actual alignment. Further alignment iterations are not possible.

---

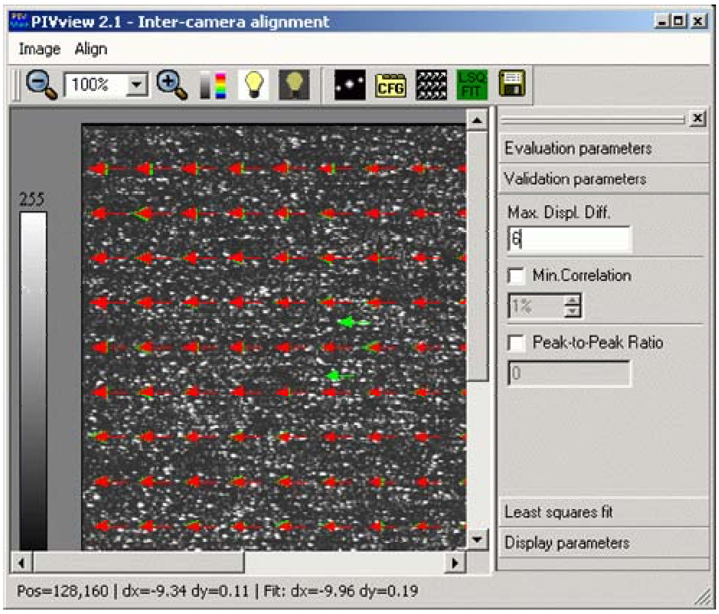
[1] In earlier versions of *PIVview* the misalignment correction between the camera views was referred to as *residual alignment*.

Some notes on performance:

In some instances the particle images viewed by one camera are only weakly distinguishable on the other. This is frequently the case for air flows seeded with small particles utilizing a forward-backward scattering arrangement. For this reason rather larger interrogation windows are necessary. When in doubt, we suggest increasing the interrogation window until consistent displacement fields are produced. The correlation plane window is also useful for this optimization.

The correlation module of alignment procedure actually makes use of all four images of a stereo PIV recording and uses a multiplication of correlation planes to enhance the correlation peak.

The alignment procedure allows a choice on which of the two projection maps are modified; the default is a symmetric adjustment of both views.



Disparity correction window after least-squares fit to offset data.

Command-Line Utility Programs

The *PIVview* program suite includes several command-line based utility programs that can be used for batch processing purposes, debugging, data retrieval, etc. These programs should be run from the command shell (e.g. DOS-box), and their path (`.\PIVview\Bin\` or `.\PIVview\Utils\`) should be added to the system's `PATH` variable.

These program are useful for batch processing large amounts of PIV-images without using *PIVview* itself (frequently done on Linux/Unix systems).

AVERAGE

This program first builds a list of files from the first and last file provided and then calculates statistics from these. The result is placed in a new file whose name is determined from the common file stub of the input files. It is useful in the calculation of quantities such as mean velocity field or Reynolds stresses.

Calling procedure:

```
average <dataIN_1> <dataIN_N>
```

Parameter description

`<dataIN_1>` (input) first file in sequences to be processed.

`<dataIN_N>` (input) last file in sequences to be processed.

Command line options

`-prefix<stub>` overrides the output file stub to the name provided

`-rms` also stores the RMS data in a separate file

`-reyn` computes Reynolds stresses from velocity data

`-fluct` computes fluctuations by removing mean from each data set

`-info` provides feedback during processing of data

`-tec` store result in *Tecplot* ASCII file

`-plt` store result in *Tecplot* binary file.

DPIV

The program ***dpiv*** reads the specified image(s) and parameter file and then performs complete PIV processing including:

- image pre-processing (filtering, background subtraction, etc.)
- correlation analysis (particle image shift extraction)
- data validation
- conversion to velocity or physical shift

The result is stored in a *netCDF* file such that it can be read by other *PIVview* programs. Use ncdf2tec to convert the data to a *Tecplot*-readable format. Unless specified with the -o option the output file name is determined from the image name.

Calling procedure:

```
dpiv <par_file> <imageA> <imageB>
```

Parameter description

`<par_file>` (input) *PIVview* generated parameter or data file (netCDF-format) with processing information.

`<imageA>` (input) PIV or speckle image

`<imageB>` (input) Second image of pair (if required)

Command line options

`-def`	performs second-order accurate image deformation PIV
`-mg`	performs multigrid (pyramid) PIV
`-auto`	perform autocorrelation processing; only one image is required.
`-noflip`	avoids flipping or rotating the image (important for stereo-PIV processing)
`-noip`	avoids image pre-processing options
`-norotate`	avoids flipping or rotating the image (important for stereo-PIV processing)
`-info`	provides feedback during processing of data
`-o<fname>`	stores output data in file <fname>
`-pco`	treats the input image as a PCO-double exposure image
`-speckle`	perform speckle shift processing, where the first image is considered the reference (unshifted) image.
`-wx|y`	specifies the interrogation window size. Overrides the value specified in the parameter file.
`-sx|y`	specifies the interrogation window step size. Overrides the value specified in the parameter file.
`-bx|y`	specifies the global image offset. Overrides the value specified in
`-mask<fname>`	uses specified mask image. Useful for batch processing with varying masks. Note: mask image must have the same size as PIV images.

DPIV3C

The program ***dpiv3c*** reads the specified stereo configuration and parameter files to perform complete stereo PIV processing using the given image set. This processing including:

- image pre-processing (filtering, background subtraction, etc.)
- image back-projection using projection maps (including disparity correction)
- correlation analysis for both view (particle image shift extraction)
- data validation
- merging of the two views
- conversion to velocity

The result is stored in a netCDF file such that it can be read by other PIVview programs. Use ncdf2tec to convert the data to a Tecplot-readable format. Unless specified with the -o option the output file name is determined from the first image name (View A).

Calling procedure:

```
dpiv3c <cfg_file> <imageA1> <imageA2> <imageB1> <imageB2>
dpiv3c –pco <cfg_file> <imageA> <imageB>
```

Parameter description

`<cfg_file>`	(input) *PIVview3C* generated stereo configuration file (netCDF-format).
`<imageA?>`	(input) PIV image pair for view A
`<imageB?>`	(input) PIV image pair for view B

Command line options

`-align`	perform camera disparity correction
`-def`	performs second-order accurate image deformation PIV
`-mg<fact>`	performs multi-grid (pyramid) PIV, initial de-sampling factor `<fact>` (default=3)
`-info`	provides feedback during processing of data
`-o<fname>`	stores output data in file `<fname>`
`-noip`	avoids image pre-processing options
`-pco`	treats the input images as a PCO-double exposure image (both images must be PCO images)
`-wx|y`	specifies the interrogation window size. Overrides the value specified in the parameter file.
`-sx|y`	specifies the interrogation window step size. Overrides the value specified in the parameter file.
`-bx|y`	specifies the global image offset. Overrides the value specified in
`-mask<fname>`	uses specified mask image. Useful for batch processing with varying masks. Note: mask image must have the same size as PIV images.

IMAGEPRE

This utility program reads the specified image and performs image pre-processing (filtering, background subtraction, etc.) as specified in the parameter file.

Calling procedure:

```
imagepre <par_file> <imageIN> <imageOUT>
```

Parameter description

`<par_file>`	(input) PIVview generated parameter or data file (netCDF-format) with image pre-processing information.
`<imageIN>`	(input) original image
`<imageOUT>`	(output) pre-processed output image

Command line options

`-noflip`	avoids flipping or rotating the image (important for stereo-PIV processing)
`-norotate`	avoids flipping or rotating the image (important for stereo-PIV processing)
`-info`	provides feedback during processing of data
`-pco`	treats the input image as a PCO-double exposure image and generates two output images with the extensions .ima, .imb
`-pco2`	same as the -pco option, but stores the resulting image pair in a single PCO-double expsure image file.

NCDF2TEC

The program reads the specified *PIVview* data file and generates a *Tecplot*-formatted ASCII or binary output file.

Calling procedure:

```
ncdf2tec <fileIN> <fileOUT>
```

Parameter description

`<fileIN>`	(input) netCDF data file as generated by PIVview
`<fileOUT>`	(output) *Tecplot* formatted output file

Command line options

`-asc`	creates ASC-II data file
`-bin`	creates *Tecplot* binary data file
`-vel`	writes out the velocity data contained in the input file if it is available. This is the default output option.
`-disp`	writes out the pixel (image) displacement data contained in the input file.
`-piv`	writes out the pixel (image) displacement data contained in the input file.
`-mag`	also writes out either velocity magnitude or pixels shift magnitude depending on which option was set.
`-raw`	skip post-processing of data after loading (i.e. validation)
`-diff`	stores differentials (implies `-vel`)
`-dvort`	stores vorticity data (implies `-vel`)
`-dshear`	stores shear strain data (implies `-vel`)
`-dnstrain`	stores normal strain data (implies `-vel`)

-s<num> sets output stride to <num>, that is only every <num>th point is stored.

-sx<num> sets horizontal output stride to <num>.

-sy<num> sets vertical output stride to <num>.

-z stores Z-coordinate

-z<num> stores user-specified Z-coordinate

-info provides feedback during processing of data

NCDUMP

The NCDUMP program reads the specified data file and writes the contents onto the command (shell) screen.

Calling procedure:

ncdump <fileIN>

Parameter Description

<fileIN> (input) any *netCDF*-formatted data file

-h (option) shows only variable and attribute definitions and their values.

-help (option) shows all available options for ncdump.

NCGEN

The NCGEN program reads the specified raw CDF data file and generates a netCDF (binary) data file. The makes it possible to convert the ASC-II output obtained from *ncdump* back to *netCDF*. The resulting data file is written to the screen unless a file name is specified with the -o option.

Calling procedure:

ncgen <fileIN>

Parameter Description

<fileIN> (input) ASC-II formatted data file with variable and attribute definitions

-o <fileOUT> (option) stores the resultant netCDF data in the specified output file. Otherwise data is written to stdout (screen).

-help (option) shows all available options for ncdump.

POSTPROC

This program first builds a list of files from the first and last file provided and then performs post-processing (i.e. validation, conversion, filtering, etc.) on each PIV displacement data set. The results are placed in new files whose names are determined from the common file stub of the input files. It is useful when only post-processing of previously calculated PIV displacement data is necessary.

Calling procedure:

postproc <PARfile> <dataIN_1> <dataIN_N>

Parameter description

<PARfile> (input) first file in sequences to be processed.

<dataIN_1> (input) first file in sequences to be processed.

<dataIN_N> (input) last file in sequences to be processed.

Command line options

`-prefix<stub>`	overrides the output file stub to the name provided
`-A`	use parameters associated with camera view A, if available
`-B`	use parameters associated with camera view B, if available
`-info`	provides feedback during processing of data
`-tec`	store result in *Tecplot* ASCII file
`-plt`	store result in *Tecplot* binary file.

STEREO

The program reads the specified *PIVview* data files supplied for each camera view and reconstructs the 3-C velocity field using the geometry information specified in the parameter file. Use the *StereoGeom* module to specify the geometry information.

Calling procedure:

```
stereo <CfgFile> <fileA> <fileB> <fileOut>
```

Parameter Description

`<CfgFile>`	(input) Stereo project file as generated by *PIVview3C* and/or stereo modules.
`<fileA>`	(input) PIV data set for view A (*netCDF* format required)
`<fileB>`	(input) PIV data set for view B (*netCDF* format required)
`<fileOut>`	(output) PIV data with reconstructed 3-C velocity data (default = *netCDF* format).

Command line options

`-info`	(option) gives feedback during processing.
`-plt`	(option) writes out the data in *Tecplot-binary* format.
`-tec`	(option) writes out the data in *Tecplot-ASCII* format.
`-A`	use grid from `<fileA>` as output grid (If the grid from view B does not coincide then this data is interpolated)
`-B`	use grid from `<fileB>` as output grid (If the grid from view A does not coincide then this data is interpolated)

Shortcut keys in PIVview

F2	region-of-Interest selection (if enabled)
F4	PIV parameter menu (also with right-mouse button on image)
F5	start PIV evaluation
F6	show correlation plane
F7	show 2-D scatter plot (histogram)
F10	redraw current view
B	image brighter
D	image darker
I	show / hide image after evaluation
L	change pseudo-color look-up table
Shift+L	show previous pseudo-color look-up table
P	open plotting parameter menu
C	show / hide scalar image after evaluation
V	show / hide vector field after evaluation
+	increase image magnification (zoom in)
–	decrease image magnification (zoom out)

CTRL+i	image pre-processing menu
CTRL+L	hide / show LUT bar
CTRL+M	open mask editor
CTRL+O	open file dialog for loading images
CTRL+P	print currently displayed data or image
CTRL+Q	quit PIVview
space-bar	toggle between images of image pair
CTRL+Space	overlay images of image pair

Mouse ShortCuts & Actions

Left click on image pair
– single-point PIV evaluation using current parameter settings.

Right click on image pair
– opens context-sensitive menu

Double-click on evaluated image
– opens a data monitoring window showing statistics for each point currently captured by the mouse.

Supported File Formats

Supported Image Formats

Tagged image file format (TIFF)

at 8-bit/pixel and 1-bit/pixel including compression (Not supported are LZW-compressed TIFF images on which Unisys holds a patent. If you plan to use LZW-TIFF images use a image converter such as IrfanView to convert the images to another supported format). Color images are converted to 8bit grayscale.

Windows Bitmap (BMP)

1, 4 and 8 -bit/pixel, color images are converted to 8-bit grayscale.

JPEG Color JPEG's are converted to 8-bit grayscale.

Portable Network Graphics (PNG)

Color images are converted to 8-bit grayscale.

Portable Bitmap Graphics (PBM, PGM, PPM)

This includes various formats from a collection of ASCII based bitmap types: PBM, PGM and PPM. PBM (Portable Bitmap format) is a 1-bit, black and white bitmap type, PGM (Portable Greymap format) is an 8-bit greyscale bitmap type and PPM (Portable Pixelmap format) is a 24-bit full colour bitmap.

PCO-B16 a 16-bit/pixel image format used by PCO's camera acquisition software

B32 an extension of PCO's B16-format to 32-bit/pixel

LaVision Images (IMG)

a 16-bit/pixel integer and 32-bit/pixel floating point image format used by LaVision's DAVIS software. Not supported is LaVision's proprietary, compressed IMX file format.

Note: The command line utilities such as *dpiv* only support the following image formats:

- TIFF - all except LZW-TIFF and 24-bit color
- BMP - 1 and 8 bit/pixel, uncompressed
- PCO-B16
- LaVision-IMG

Image naming and numbering conventions

Generally PIVview automatically determines the image name of the second image using the name of the first. Several rules are used to determine the second image:

ima → imb If the first image has the extension 'ima' then the program will look for a file where the extension changed to 'imb'
Example: (1st image: `myImage.ima`) → (2nd image: `myImage.imb`)

a. → *b.* If the first image has the letter 'a' before the extension then program will look for a file changed where 'a' is replaced by 'b'
Example: (1st image: `myImage_a.tif`) → (2nd image: `myImage_b.tif`)

(n) → (n+1) If the images are sequentially numbered the program will look for the file with the next highest index.
Example: (1st image: `img099.tif`) → (2nd image: `img100.tif`)

Excepted from these rules are images loaded in the speckle or autocorrelation modes, as well as images that are loaded as self-contained image pairs (e.g. PCO-B16 double images).

Supported Output File Formats

ASCII Plain ASCII data can be generated by PIVview which can then be read by other programs without much effort. A short header specifies the number of points in the data set along with a description of each column's content.

Tecplot PIVview data can be exported to be compatible with the TecPlot graphics package (AMTEC Engineering, Inc., www.amtec.com), Version 7.0 and higher). Style files for both displacement and velocity data are generated to ease the data presentation with TecPlot.

netCDF is a self-describing, platform-independent data file format frequently used in the scientific community. NetCDF data generated by PIVview is aimed to be compatible with the layout utilized by PivNet/EuroPIV cooperation projects.

Since NetCDF is an open format, additional variables can be added without interfering with a predefined layout. Further information on NetCDF can be found at Unidata (www.unidata.ucar.edu).

Two separate utilities are redistributed with PivView that allow NetCDF file viewing (ncdump) as well as NetCDF file generation (ncgen). In principle these utilities allow the user to edit a NetCDF file by first converting it to a text file with ncdump and recompiling it after modification using ncgen .

Parameter Files

The current parameter settings are generally stored in the system registry when the program exits. Once the program restarts these parameters are restored. However, the most important parameters, especially those regarding evaluation, conversion and post-processing can also be stored in a separate file which has the same name as the image and the extension .par. These files are formatted in NetCDF (see above) and are compatible with the existing UNIX-based PIV software of the German Aerospace Center (DLR) as well as with the specifications defined by the EuroPIV / PivNet activities.

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