# HANDbook

VidPIV 4.6

## Particle Image Velocimetry Software Brochure

**Measurement Principle**
**What is VidPIV ?**
**An Overview of the VidPIV Interface**
**Data Management**

ILA
Intelligent Laser Applications GmbH

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**Easy navigation. Check links.**

# 1. Measurement Principle

Particle Image Velocimetry (PIV) is a non-intrusive optical technique for the measurement of flow velocities. All the velocity vector components (u,v and w) are measured simultaneously over an two-dimensional flow area.
The PIV technique follows an intuitive principle: particles in motion, suspended in the flow, are imaged digitally at two points in time close to each other. These points are defined precisely using short pulse illumination to "freeze" particle motion on each of the two images. In the time interval between light pulses, the particles move a short distance. Their displacements are then calculated statistically over a grid, for each grid cell area. Knowing the pulse separation and the image scale, the displacement field can be converted into a velocity vector field. The result is an immediate snapshot of the flow.
PIV is applicable in many variants depending on experimental goals and conditions.
ILA's VidPIV software supports a range of implementations of the technique, shown in the table below:

| PIV Implementation | Type of Flow Measurement |
|---|---|
| 2 D | Planar two-component velocity field |
| 3 D Stereo | Planar three-component velocity field |
| Micro | Microscopic scale planar velocity field (two or three components) through microscope optics |
| High-Speed (also called Time Resolved) | High rate of capture (typically kHz) planar velocity field, two or three components |
| PIV / LIF (LIF: Laser Induced Fluorescence) | Planar velocity fields in two-phase flows, using fluorescent particles |
| Liquid LIF (Laser Induced Fluorescence) | Planar concentration fields in liquids, using fluorescent dye |

# 2. What is VidPIV ?



VidPIV is the common software interface and the central component for all ILA PIV and LIF systems. Through a highly intuitive graphical user interface, it gives the user full control of hardware components for illumination, image acquisition and synchronisation taks.

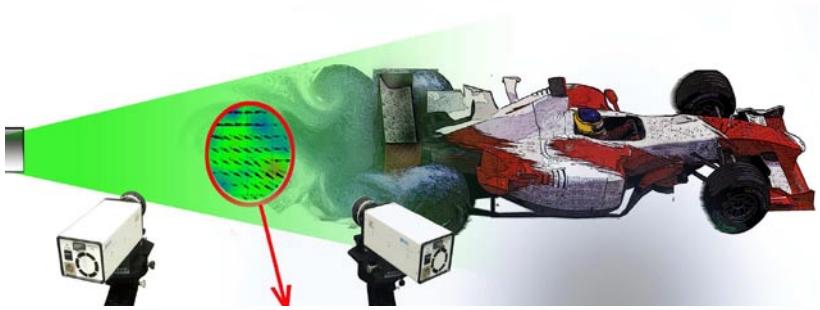
## What is VidPIV?

VidPIV combines in a single software package all the aspects of PIV and LIF measurements:

- ✓ Image acquisition
- ✓ Synchronisation of system components, such as laser and camera
- ✓ Synchronisation of the measurement with the experiment
- ✓ Structured Data storage and retrieval
- ✓ Image and vector map display
- ✓ Image processing and analysis
- ✓ Post-processing and export of results
- ✓ Automation of measurement and analysis sequences

The visual tree architecture is used to acquire and analyse image data provides full access to all configuration parameters and intermediate results, yet simplifies the learning process to the maximum. It is not uncommon for new users to look at their first meaningful results within a couple of hours of using VidPIV.

# 3. An Overview of the VidPIV Interface



Unbenannt
- Session
  - ILA PIV Synchronizer
  - PCO SensiCamQE Acquisition
  - Regular Timing
  - Image Annotations
  - Photogrammetric Mapping
  - Photogrammetric Mapping 1
  - Noise Reject
    - Contrast Enhancement
      - Cross Correlation
        - Grid Description
        - Signal to noise filter
          - Window Velocity Filter
            - Velocity Filter (Local Median)
              - Interpolate Outliers
                - Adaptive Cross Correlation
                - Grid Description
                - Window Velocity Filter
                - Velocity Filter (Local Median)
                - Interpolate Outliers
                - Average
                - 2D Vectors to 3DVectors
                - Vz Filter

1 **Running Hardware**

2 **Calibration**

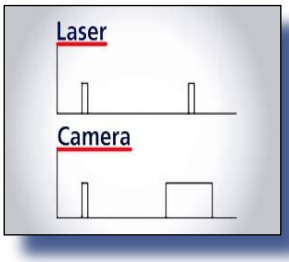
3 **Preprocessing of Images**

4 **Correlation Algorithm**

5 **Filters**

6 **Interpolation**

7 **Calculation of Third Component**

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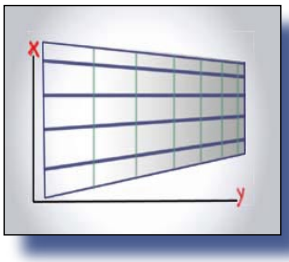


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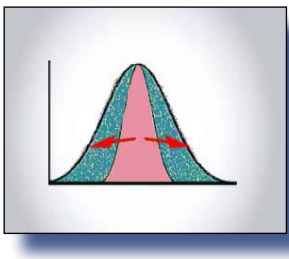

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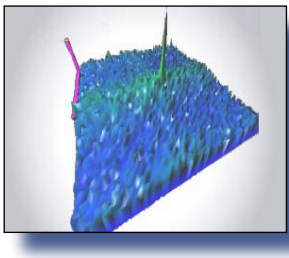

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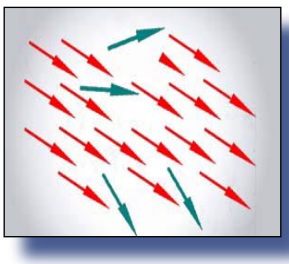

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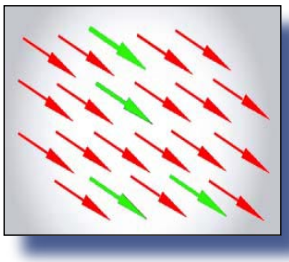

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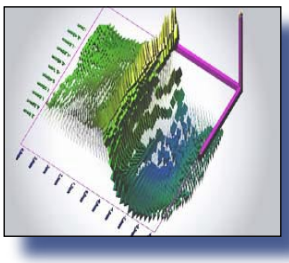

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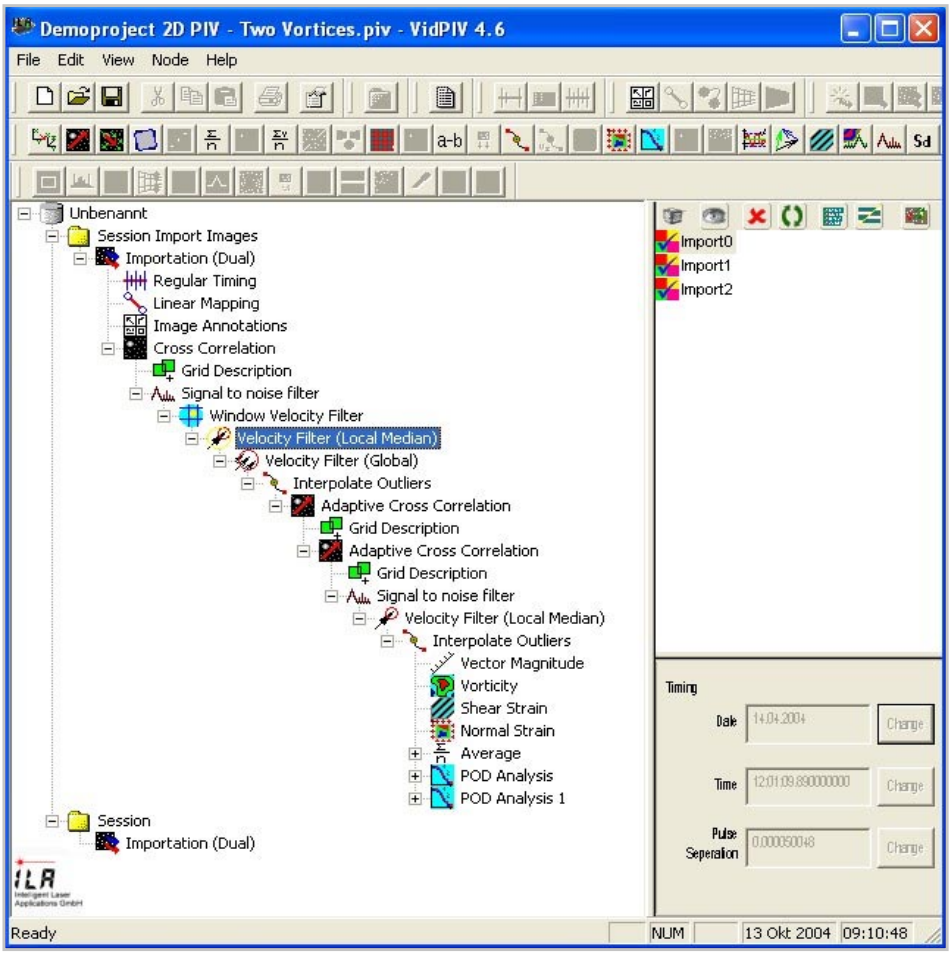
# 4. Data Management



VidPIV uses a sophisticated data management system that handles through a single interface all the aspects of data acquisition, processing and storage. To achieve this VidPIV uses highly structured project files organised in hierarchical fashion. Project files appear as tree structures where all the data, measurement parameters and links between processing operations are stored. The tree-structured presentation of the interface has several key advantages:

## 4.1. User Interface

In VidPIV, data management is handled through a single interface window. All the hardware controls, image processing and analysis parameters, images and flow maps are accessed directly from this single interface, avoiding the confusion of multiple document windows.
The right-hand-side area, called Node View shows a list of all the image or derived data available to the currently selected node and includes powerful batch editing and export tools.



### 4.1.2 Project Files and Tree-Structured Data Storage

A VidPIV project regroups all the image sequences, results, configuration and processing data related to a given experiment or series of experiments.
This data is stored in Project Files that can be saved, opened and edited at will. Inside a Project File, the original data and results are organised in a tree structure that encapsulates all the project information and operations applied to the images (e.g. data source, acquisition, analysis and filtering options).
The tree structure represents the project information graphically in a flexible and intuitive way, using icons to visualise each operation.
This representation has several key advantages:

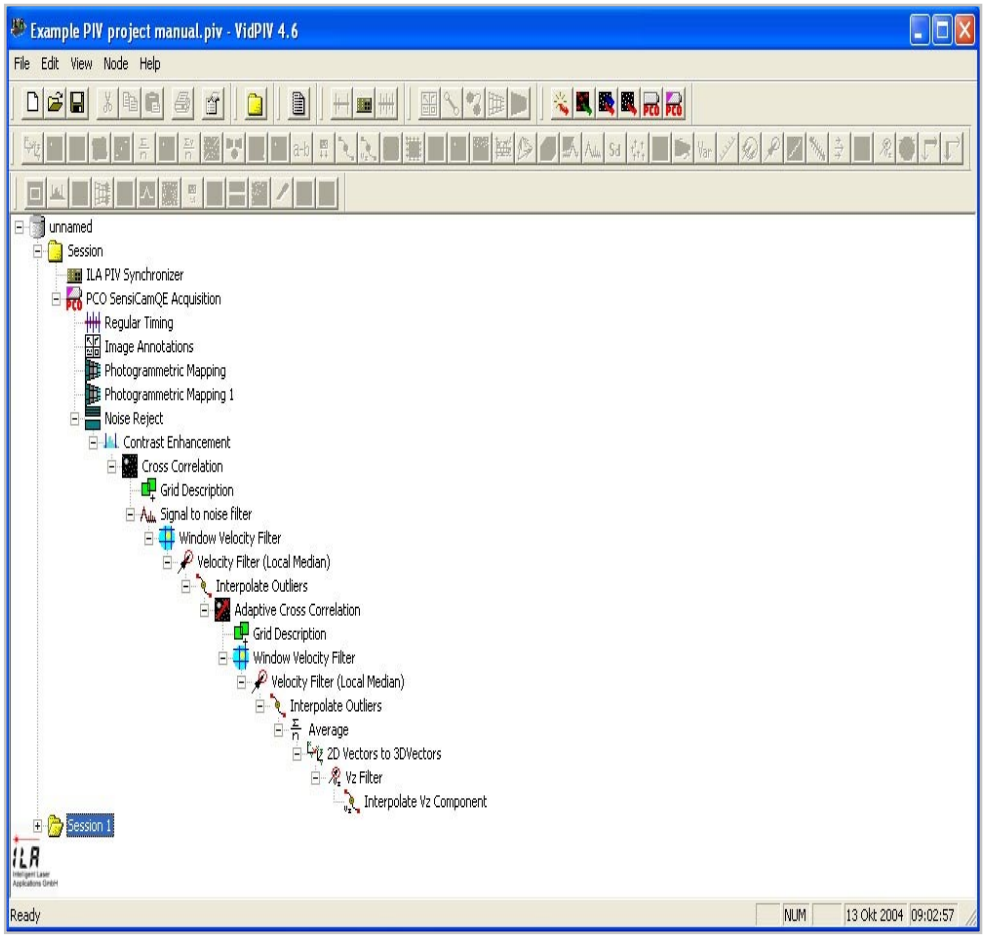
**Key Advantages of Project Files**

- ✓ Project files make the organisation and manipulation of the data transparent and flexible
- ✓ All the experimental parameter settings are documented so a project, in addition to being a data container, acts very much like an electronic lab-book
- ✓ Multiple parallel analysis sequences, using different algorithms or parameter settings, can be executed on the same original datasets and results easily compared for optimisation purposes

### 4.1.3 Project View

The left-hand-side area of the VidPIV interface, called Project View, displays the tree structure corresponding to the open project file.
This structure corresponds to an ordered sequence of operations that are applied to the image data and visualises the different steps of the acquisition and analysis process, where each operation is symbolised by a node icon.
Users can start with a blank project view and build their own project tree, or edit an existing one, or extend it using simple cut and paste techniques. Each node can be configured or executed from the project view with a few mouse clicks.

See graphics next page.




### 4.1.4 Node View

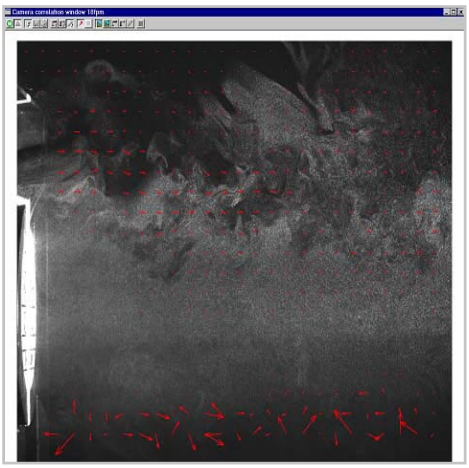
Nodes are the elementary building blocks that are used to create image acquisition and analysis sequences in VidPIV. They are accessed via buttons or menus in the project view.

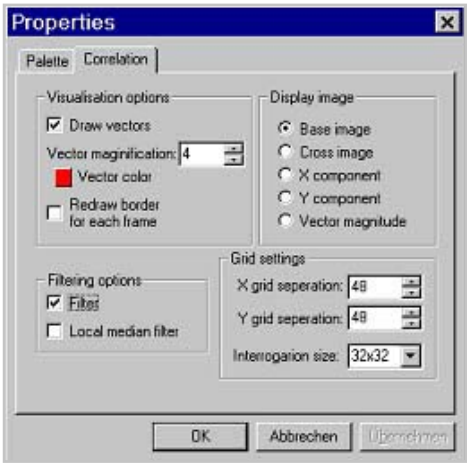
At any point on the tree, Intermediate results or configuration parameters can be visualised in the node view by bringing a node into focus in the project view. The right-hand-side of the VidPIV interface, called Node View, displays the data to which the in-focus node applies, together with status information, or in some cases configuration information relating to that node (calibration, analysis, hardware control). Node View functionalities are summarised in the table below.

| Node View Functionalities | |
|---|---|
| ✓ Synchronising the Equipment | ✓ Analysis |
| ✓ Aquisition of Images | ✓ Export of Data to other Applications |
| ✓ Deleting Images or Calculations | |

### 4.1.5 Online Cross Correlation Viewer

When the online processing option is activated, flow images are processed on the fly without being saved and the display window is continuously refreshed, in real time but reduced frequency (between 1... 2 Hz), with velocity vector maps. This feature is particularly useful to optimise the PIV system settings – e.g. laser pulse separation, image focus and contrast seeding density – before acquiring large amounts of image data. The results of experimental adjustments can be seen immediately and appropriate action taken, saving valuable time.






### 4.1.6 Saving Configuration Information

All the critical information relating to a project file – mappings, annotations can externally saved for re-use in other project files. This feature also offers additional protection against erroneous actions or data corruption.

## 4.2 Data Input

Images are VidPIV´s primary input material. They are acquired either directly via cameras that are controlled from the project viewer, or by importing sequences of external image files.

### 4.2.1 Import

Images are imported into VidPIV either individually, in batches or as AVI movies. Both single images and cross-correlation pairs are recognised by the software. All common image formats are supported:

| Supported Image Formats | | |
|---|---|---|
| ✓ BMP | ✓ PCX | ✓ B16 |
| ✓ TIFF | ✓ JPEG | ✓ AVI |
| ✓ DCX | ✓ EPS | |

### 4.2.2 Camera Support

Native support is available for camera ranges from PCO and Redlake MASD. Full camera control is achieved via the VidPIV camera nodes, which offer the same level of functionality as included in the camera manufacturer's own software. Synchronisation is provided for most – if not all – scientific CCD and CMOS cameras used for PIV, standard and high-speed, including but not limited to:

| Supported Cameras | | |
|---|---|---|
| ✓ IDT | ✓ Vision Research (Phantom Range) | ✓ PCO |
| ✓ Photron | | ✓ Redlake MASD |
| ✓ Hamamatsu | ✓ Sony | ✓ JAI |

## 4.3 Pre-Processing

Experimental constraints such as the presence of reflective obstacles in the measurement plane sometimes limit the quality of flow images that can be acquired. In these situations, image pre-processing may be useful or necessary. In this case of reflective objects for example, the background subtraction node can be used to good effect to remove unwanted reflections from images prior to cross-correlation analysis. VidPIV includes a range of image pre-processing functions, including:

| Pre-Processing Functions | |
|---|---|
| ✓ Contrast Enhancement | ✓ Speckle Removal |
| ✓ Edge Detection | ✓ Image Sharpening |
| ✓ Image Peak Finding | ✓ Image Subtraction |
| ✓ Noise Rejection | |

## 4.4 Timing

VidPIV includes a comprehensive range of control functions for synchronising the operation of all the PIV system components. These functions pass timing parameters to the ILA synchronizer, from where trigger signals are sent to the camera(s), laser(s) and any other opto-electronic device at the appropriate times. Additionally, the laser pulse separation can be entered for imported or acquired images using the timing node.

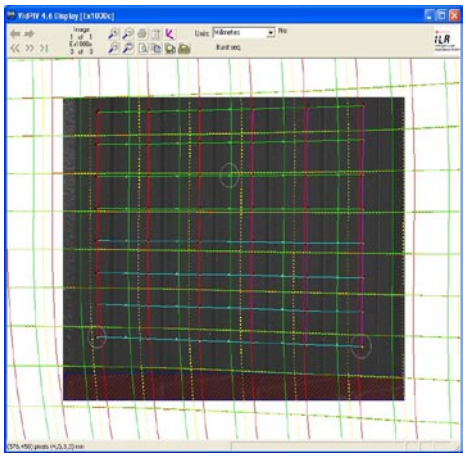
## 4.5 Mapping

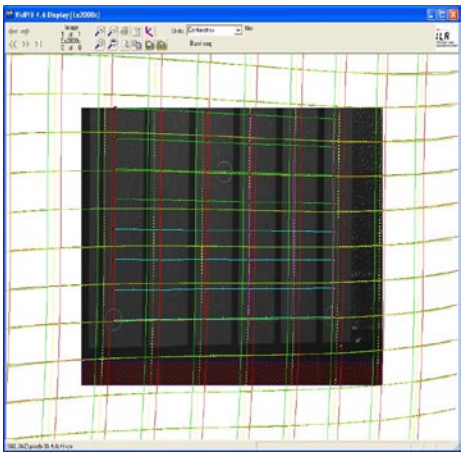
Mappings are an essential part of PIV image processing, since they establish the dimensional correspondence needed between the sensor plane and the

measurement plane that is needed to express the measured velocities in physical units. The quality of their implementation has a strong effect on the overall accuracy of the measurements, and as such cannot be overemphasized. VidPIV offers a comprehensive range of mapping options, including:

| Mapping Options | | |
|---|---|---|
| ✓ | 2D Measurements: | linear and perspective |
| ✓ | 3D Measurements: | photogrammetric |

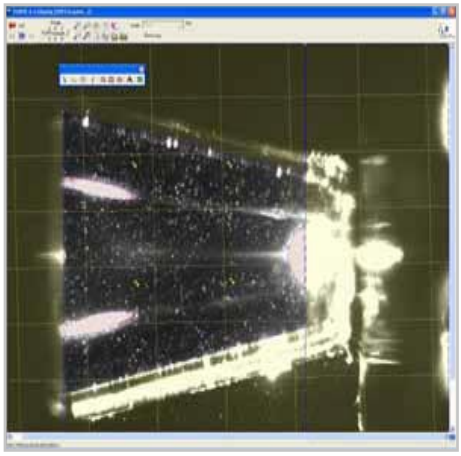
These mappings are implemented in a general and mathematically rigorous form. In addition, the choice of algorithms yields mapping tools that are inherently robust and tolerant of inaccuracies on input datum points.





## 4.6 Annotations

PIV images often contain areas where there is no flow, that need to be excluded from the analysis. In addition, marker drawing and text tools can help enhance the visual information contained in the images.



To this end VidPIV provides a series of common resources called Annotations, that can be shared by all image processing nodes in a processing tree to single or all images. They include:

| Annotations include | | | |
|---|---|---|---|
| ✓ | Definition of excluded areas - solid or dashed | | |
| ✓ | Lines | ✓ | Text |

## 4.7 Cross Correlation Analysis

In PIV, velocity vector fields are calculated from pairs of flow images, using spatial cross correlation method combined with peak-finding and peak interpolation features.
VidPIV includes ILA´s adaptive multi-pass technique for cross correlation analysis reflecting the latest advances in algorithms published in the PIV community.

### 4.7.1 Adaptive Cross Correlation

Adaptive Cross-correlation (CC) is an iterative method that allows multiple CC passes. The first pass always uses a standard cross correlation node.

| Standard Cross Correlation Features |
|---|
| ✓ Velocities are calculated in a single pass |
| ✓ Window size from 8 to 128 pixels in square |
| ✓ Origin and window overlap are adjustable. Selectable units. |
| ✓ Use for one-pass analysis or as the first pass for advanced adaptive cross-correlation. |

At each analysis pass, adaptive CC uses the vector map generated by the previous pass to refine the search for matching particle images**,** until convergence is achieved over the whole velocity field. Adaptive CC has many advantages over standard one-pass CC, in terms of dynamic range, tolerance of velocity gradients, and reduced peak-locking.

| Standard CC versus Adaptive CC |
|---|
| ✓ Compared to the standard CC method, |
| ✓ Adaptive CC can handle larger velocity dynamic ranges |
| ✓ Adaptive CC can remain accurate in areas where there are strong local gradients |
| ✓ Adaptive CC node makes use of subpixel offset shift image interpolation to reduce peak locking. |

#### 4.7.1.1 Advanced Cross Correlation-Algorithm

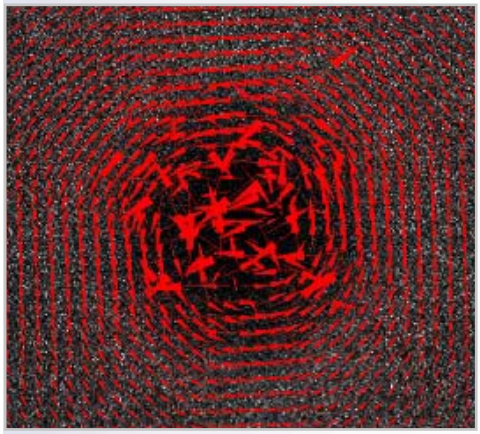
Often images are less than ideal (small particle images) or the flow of interest has strong local velocity gradients and vorticity. In these cases adaptive cross-correlation needs further sophisitication to achieve good accuracy. ILA's Advanced CC algorithms were developed to answer this requirement. Using a

window deformation technique, they minimise peak-locking, adapt to locally strong flow variations and produce accurate results in the most challenging situations.

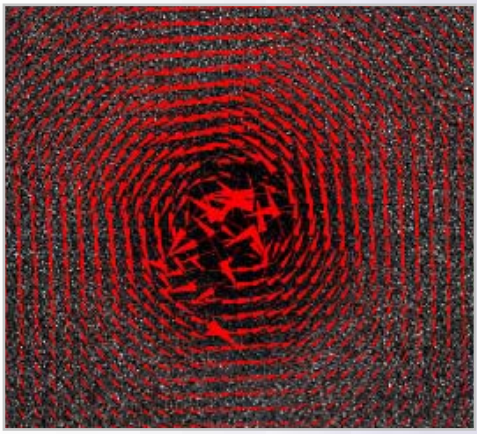
#### 4.7.1.2 Window Deformation

VidPIV' s advanced adaptive cross-correlation uses a window deformation technique to take into account the effect of flow gradients on particle image distribution. The method is iterative: at each pass, the flow gradient resulting from the previous iteration is used as predictor to deform the interrogation spot in the first and the second image. Due to the image deformation which needs data at non-discrete points, a subpixel grey value interpolation scheme is required to generate grey values at any spatial location in the image. Interrogation spot deformations can be linear or quadratic. The scheme is applied until convergence is reached, and the final result is a velocity map that is accurate to a small fraction of a pixel even in high flow gradient areas.

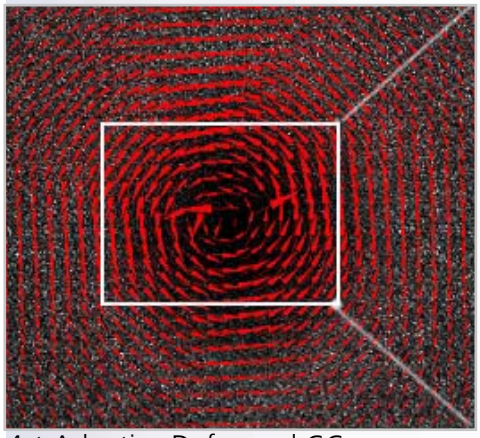
**Adaptive CC Node Results**



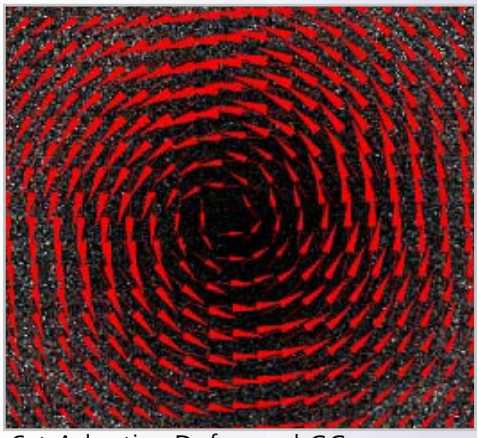
Standard CC 32 x 32



1st Adaptive Deformed CC



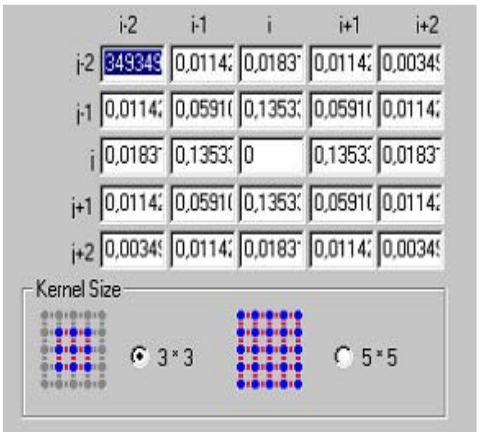
4st Adaptive Deformed CC



6st Adaptive Deformed CC

## 4.8 Post Processing

VidPIV includes comprehensive post-processing functions for outlier filtering and vector interpolation.
Interpolation: an advanced second order interpolation scheme is used to replace isolated outliers or whole groups with vectors that are consistent with the local valid vectors. Additional post-processing operations include flow field subtraction and re-referencing.

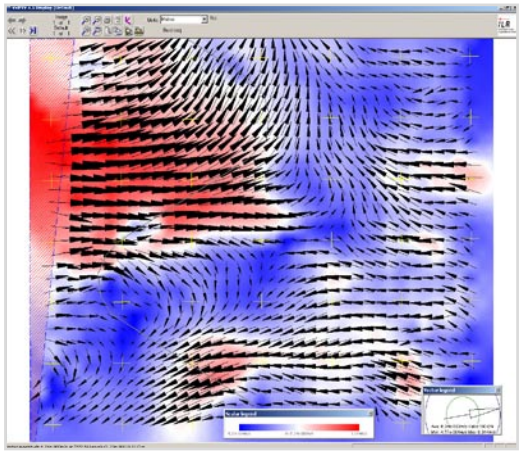



**Post Processing: Filters**

- ✓ Window
- ✓ Global
- ✓ Local Median
- ✓ SNR

## 4.9 POD Analysis

The purpose of POD (Proper Orthogonal Decomposition) analysis is to extract from PIV data dominant flow structures with the most energetic components. When POD is applied to experimental data, it eliminates the low energy components of the flow that obscure the main energetic features. The POD analysis is useful in many applications where the standard Reynolds approach of looking at average and turbulent intensities is not satisfactory.

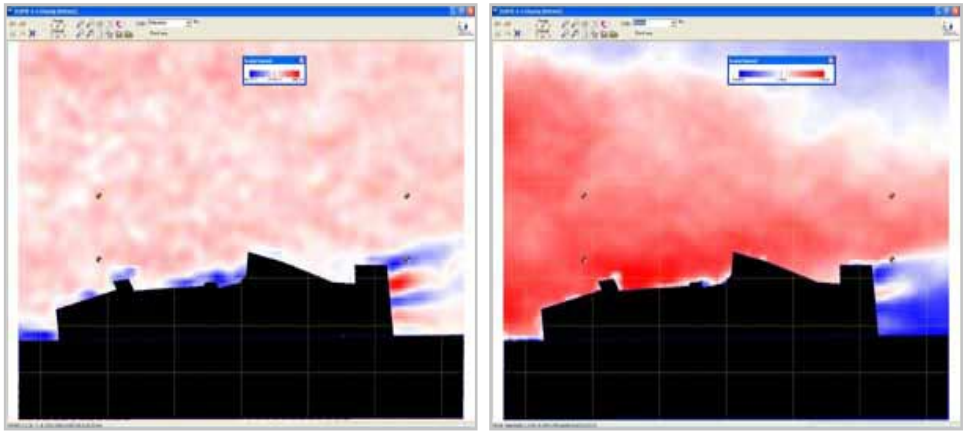


## 4.10 Scalar Quantities

Scalar quantities, e.g. vorticity or strains, provide an often-needed additional insight in the behaviour of the flow unter investigation. In VidPIV, scalar derivations can be calculated, superimposed onto vector maps for display and exported as text files. Nodes to calculate the following scalars are part of the standard VidPIV package:

| Scalar Quantities | |
|---|---|
| ✓ X Component | ✓ Shear Strain |
| ✓ Y Component | ✓ Normal Strain |
| ✓ Velocity magnitude | ✓ SNR |
| ✓ Vorticity | |

A choice of colour palettes is available to visualise the scalar intensity maps.



## 4.11 Flow Statistics

With Ensemble Statistics nodes, series of velocity fields can be grouped into ensembles over which the following quantities can then be calculated:

| Quantities | |
|---|---|
| ✓ Average | ✓ Variance |
| ✓ Average magnitude | ✓ Standard deviation |
| | ✓ RMS |

## 4.12 Data Export

In the VidPIV environment, data and results can be exported selectively or as a whole after acquisition or at any stage of a processing sequence.

| Data Export Images | | |
|---|---|---|
| ✓ TIFF | ✓ BMP | ✓ DCX |
| ✓ JPEG | ✓ PCX | ✓ FSP |

**Data Export Vector and Scalar Maps**

- ASCII files

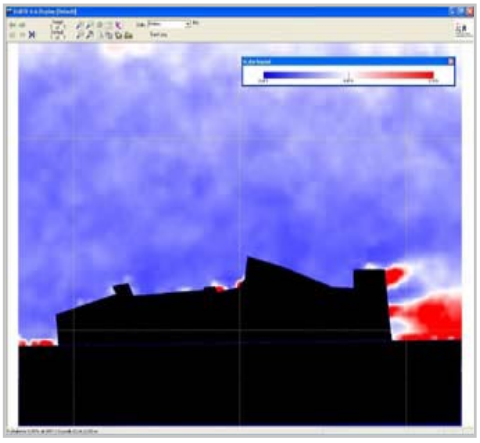
**Data Export Movies**

- AVI

## 4.13 Saving a Project Configuration

All analysis parameters and experimental information at session level, such as mappings and annotations, can be saved in separate files for re-use in other projects.

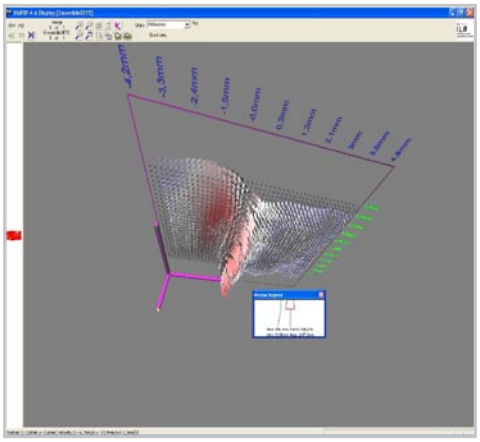
## 4. 14 Turbulence and RMS Node



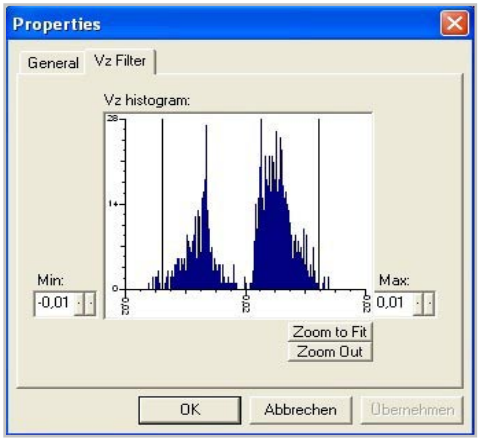
For the investigation of unsteady flows, VidPIV 4.6XP provides a series of nodes to characterize flow fluctuations. The Standard Deviation, Variance, RMS Value and Turbulence Index can all be calculated from an ensemble defined in the VidPIV post-processing nodes and directly exported as a bitmap image or AVI animation for reporting or presentation purposes.

## 4.15 3D Stereo VidPIV

3D stereo PIV allows the measurement in a plane of all three velocity components. Stereo pairs of flow images are recorded by two cameras viewing the measurement plane from a chosen angle. To analyse stereo image pairs, a calibration relationship needs to be established between the sensor plane and the measurement volume. Calibrated images can then be analysed using one of the standard cross correlation algorithms. The resultant perspective vector maps are then recombined to obtain a 3D vector map. VidPIV includes all the necessary tools



to perform these operations, including: photogrammatric mappings, Stereo mapping correction, 2D-to-3D vector recombination node and filtering and interpolation of out-of-plane component.

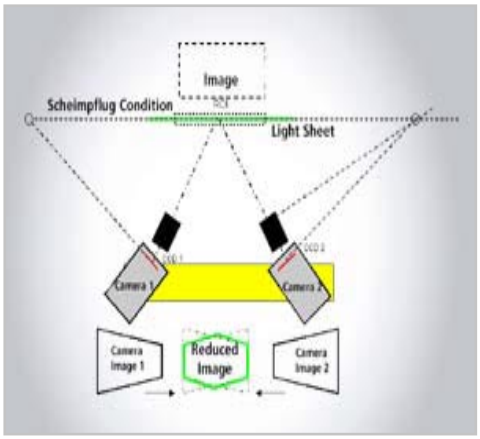



**3D Stereo PIV Nodes:**

- ✓ Photogrammetric mappings
- ✓ Stereo mapping correction
- ✓ 2D to 3D vector recombination node
- ✓ Filtering and interpolation of out-of-plane (Vz) velocity component

### 4.15.1 Stereo Mapping Correction

One of the main sources of error in stereo 3D setups is the misalignment between the laser lightsheet and the target used in the calibration procedure. VidPIV stereo mapping correction nodes help minimise this error by correcting the mapping functions of the cameras for this misalignment. This correction results in a smaller overall measurement error and can be retro-actively applied to existing sets of stereo data.




### 4.15.2 Vz Filtering and Interpolation

Filtering and interpolation of out-of-plan (Vz) velocity component: provides the means of filtering vector outliers following the recombination of vector fields from the left and right perspective images. The valid range of Vz magnitude can be selected from a histogram of the Vz component. Advanced interpolation can then be applied to the filtered vector field using the Vz Interpolate node.

## 4.16 Tracking

In sparsely seeded flows, particle tracking algorithms perform better than those based on cross-correlation. Two particle tracking nodes are included:

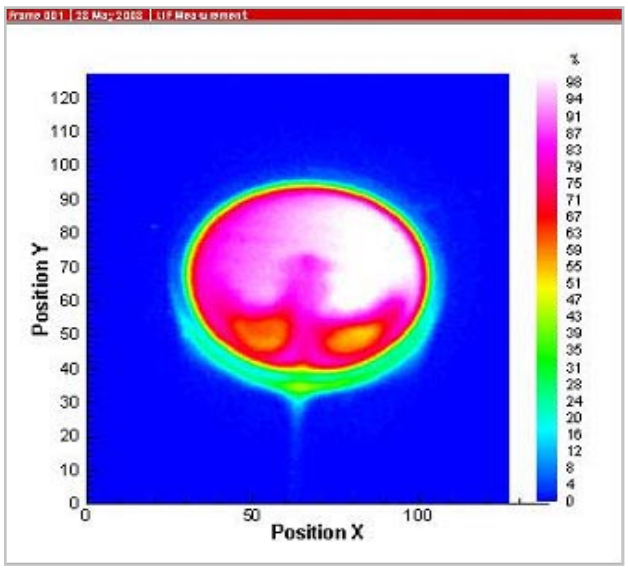
| Particle Tracking Nodes |
| --- |
| ✓ Standard |
| ✓ Adaptive: i.e. where one or several cross-correlation operations are first performed to orient the search for individual particles. |

## 4.17 Particle Counting

Determining the spatial distribution of dust or aerosol concentrations in air is of interest for a range of industrial and research studies. The particle counting node is a tool for the measurement of particle counts per unit area or particle concentrations. Particle counts or concentration values are measured inside a thin volume illuminated by a laser light sheet. Effects such as intensity variations in the light sheet and variations in particle visibility as a function of their size are taken into account by a calibration process performed prior to the experiments.

## 4.18 Laser Induced Fluorescence (LIF)

Laser Induced Fluorescence (LIF) is a measurement technique well suited to the study of two-phase flows, mass transfer and mixing phenomena in liquids. Whith a fluorescing dye added to one of the flow phases or liquids to be mixed, fluorescene images can be recorded under exitation of the dye substance by a planar laser light sheet. In these images, the grey-level intensity patterns on the image are related to spatial variations in dye concentration. Once calibrated using samples with known concentrations , the LIF node in VidPIV allows the user to convert these images into quantitative concentration maps.



### 4.18.1 Export Feature in LIF Node

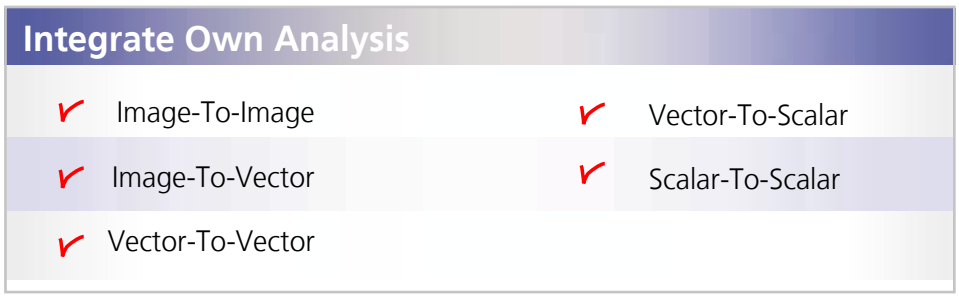
Scalar LiF data can be exported to create presentation-quality output, using the Export Data function. A smoothing function can be optionally applied to the grey-level pixel data to enhance their visual continuity. A Tecplot header option allows users to load the grey-level intensity data directly into Tecplot, the industry-standard scientific presentation package.

## 4.19 Java Script Batch Processing

Processing significant numbers of large image datasets is now a common requirement among PIV users. Configurable batch-processing efficiently answers this need by providing a simple means of automating large-scale processing tasks. VidPIV´s Javascript-based batch processor is an external add-on that allows the user to control the operation of VidPIV from outside by Java Script or using OLE. A processing sequence is first designed and stored as a project file. Once this is done, simple command line syntax lets the user construct batch processing files that control the import, analysis and export of multiple image datasets from and to specified directories. Once started, the process runs to completion without user intervention.

## 4.20 Software Developement Kit

VidPIV is primarily a research and development tool, and as such needs to be flexible and adaptable. To fulfill these requirements, a C/C++ Software Development Kit (SDK) offers users the possibility of integrating in the VidPIV environment their own analysis, processing or post-processing algorithms as processing nodes. Source code templates are provided with instructions and examples covering the different types of nodes that can be developed:




Coding is performed in the Microsoft Visual Studio environment. Compilation is with the Microsoft Visual C++ 6.0 compiler. Nodes made with the SDK are used in exactly the same way as native nodes and benefit from the same environment functionalities.

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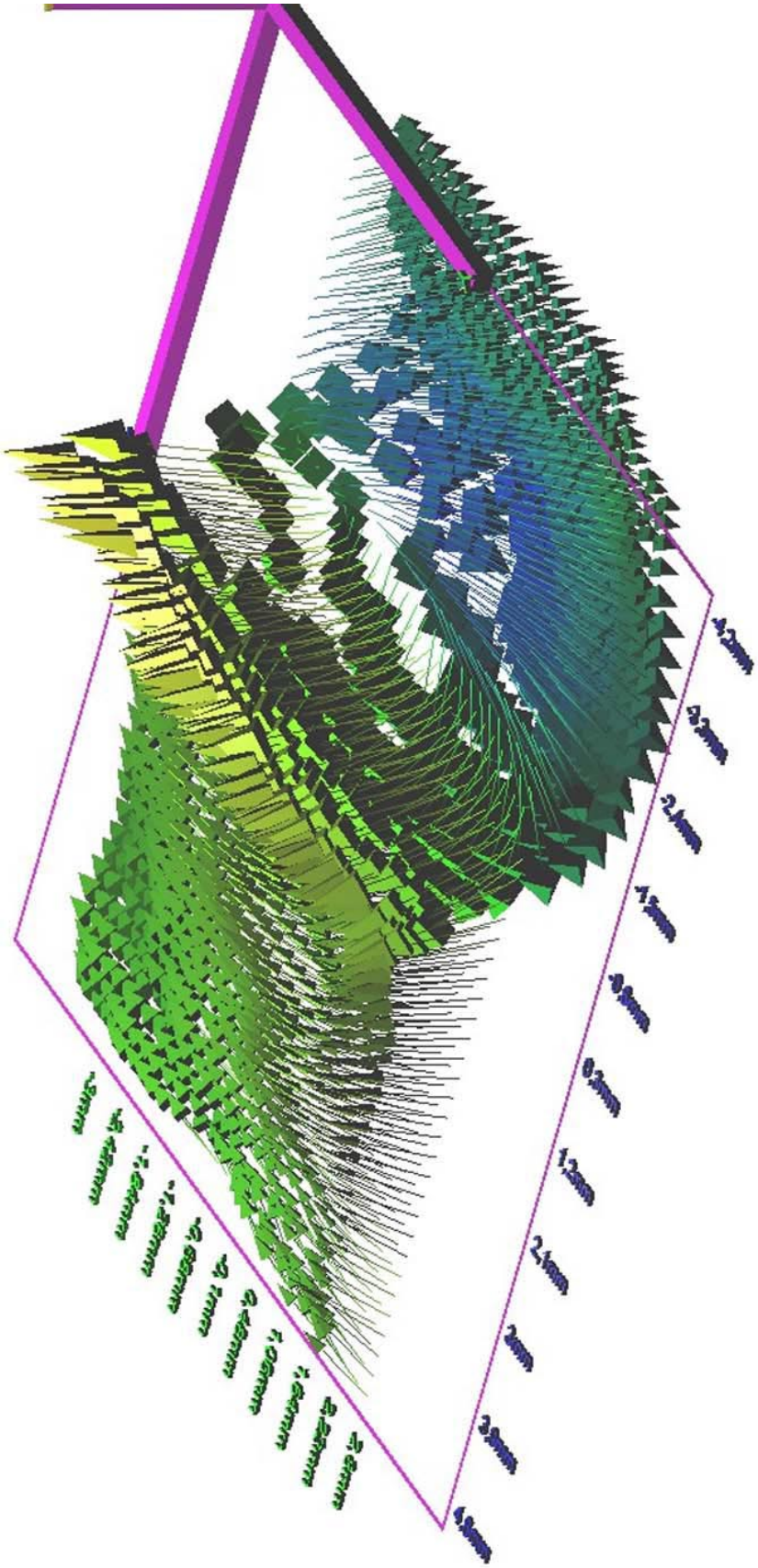
# 6. Appendix



Coloured Vectors in 3D View for Stereoscopic PIV.
Brilliant open GL. The palette can be assigned to magnitude or z-component.

# 7. Contact

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