MICROVEC PIV

Operator's Manual

Microvec Pte Ltd

http://www.piv.com.sg

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Chapter I Brief Introduction

About Microvec and Microvec PIV systems:

With almost 20 years of technical collaborations with multiple universities, including the Institute of Fluid Mechanics of Beijing University of Aeronautics and Astronautics, Department of Mechanics of Tsinghua University, University of Minnesota, Jiaotong University and Zhejiang University, Microvec has developed multiple PIV systems on a world class level. Researchers from many other academic institutions in the US, UK, Australia and Germany have collaborated on some of the software components of the systems by implementing the newest algorithms and techniques. In addition, Microvec has selected some of the most advanced and reliable hardware components from the USA, (cameras, frame grabbers and lasers), Japan (cameras), Germany (cameras), Korea (cameras), UK (lasers) and France (lasers). Optical components are sourced from Japan and Germany.

Microvec offers various PIV systems which are intended to meet different requirements. Microvec has successfully developed multiple PIV systems, for example:

- 2D and 3D PIV systems used for macroscopic flow field tests;
- MicroPIV systems used for microscopic flow field tests;
- MiniPIV systems used for research and educational purposes;
- Tomographic PIV with multiple algorithms available;
- Pressure PIV;
- Artificial Intelligence (AI) PIV

To offer fully integrated systems, Microvec has also designed proprietary hardware such as the "synchronous timing controller" and the patented Scheimpflug device. Based on its core technology, Microvec has created not only complex PIV products, but has also provided complete equipment applications for the majority of PIV users, including affordable systems for educational purposes.

Microvec was the first in the world to have launched a PIV system with a 16 Megapixel resolution camera. It offered the first PIV system that uses a 500mJ high-energy PIV pulsed laser. It was also the first manufacturer that launched a synchronizer with a 250 picoseconds jitter, making it the most accurate at that point in time. It was the first to apply 64 PCI-E technology (more than 2GB/s bandwidth) with analysis software that was developed by using the latest third-generation multi-threaded parallel PIV algorithm.

Microvec has over 300 installations worldwide used for various applications such as two-phase flow image analysis modules, large field test analysis modules, burner flow field analysis modules, particle field (particle size analyzer/momentum field) analysis modules, concentration field analysis modules, temperature measurement modules and many others.

Microvec

1.1 Introduction

Microvec Inc. developed a particle image velocimetry (referred PIV) system (computer software copyright registration numbers 2003SR0083 2003SR12905 2010R11L076296; patent registration numbers: 200 910 162 651, 200 720 140 441, 200 720 143 783, 200 920 144 898) with independent intellectual property rights. The company employs engineering personnel highly qualified in advanced hardware and software development as well as fluid control, strong technical development abilities and diligent after-sale customer service support. The PIV system can easily and reliably interconnect different hardware. It works together with multiple components sourced from the best high-tech companies, and combines them into fully integrated products to meet customers' requirements for their experiments. Besides using the most advanced hardware, Microvec's software offers a full-featured, unique base system and data analysis tool modules (e.g. particle size statistical analysis for different particle sizes and particle displacement tracking/momentum measurements, and spatial concentration fields, scalar field analysis functions, etc.) combined with different experimental requirements. The final Microvec product offers a comprehensive PIV solution, maintaining the flexibility of using the customer's preferred/existing solutions or hardware combinations to maximize the potential of the customers' laboratory equipment and provide powerful and effective protection for customers in their research and development.

Microvec system models supported in this manual include:

2D system	3D system
SM-2M100	DM-2M100
SM-4M200	DM-4M200
SM-5M200	DM-4M200
SM-8M380	DM-4M380
SM-11M380	DM-11M380
SM-29M500	DM-29M500

E-mail: info@PIV.com.sg
Company website: www.PIV.com.sg

1.2 Hardware and software installation

The PIV system developed by Microvec consists of hardware and software. The hardware system standard configuration includes: a laser, synchronizer, high-speed digital camera, frame grabbers and computer. The software system includes: an integrated particle image velocimetry system, particle image tracking velocimetry system, concentration field analysis system, particle size analysis system and digital camera control system.

To install the entire particle image analysis system, first install the hardware system by connecting the corresponding signal lines and the synchronization control lines. Lasers should be placed in accordance with the manual and require a suitable experimental site, then connect the synchronizer trigger cable. All hardware total power requirements are 220V 50Hz (or 110V 60Hz) for the 10A three-wire AC power supply and require reliable grounding. For detailed hardware installation steps, see Chapter II. After installing the appropriate software and hardware, start the computer running the appropriate installer for the first time. In addition, Microvec provides a hardware key (dongle). Dongle installation is explained in Chapter III.

1.3 Notes and Practice

All hardware systems should have reliable ground connection and connected signal cables before powering on. You should not connect non-Microvec-provided third-party hardware. This system needs to go through a Microvec Trained professional engineer before operating and running the system.

Man-made damages resulting from the system being used by operators who are not licensed and Microvec-trained are not covered by the Microvec free warranty service.

Complete PIV equipment environmental requirements include an ambient temperature of 10-30 degrees Celsius, humidity less than 80%; camera sensor chips and associated optics noting moisture and dust, an area that avoids direct sunlight, no direct laser irradiation camera lenses and related sensors. Laser light can burn and damage the sensor easily if exposed to the laser light.

Based on the above hardware, particle image analysis systems with integrated Microvec V3 software will allow for appropriate hardware control and real-time signal processing functions. Do not access software source code for software debugging or compilation.

(It is recommended that the user manual be prominently placed in the laboratory).

Chapter II Introduction of the hardware system

2.1 Composition of the hardware system

The PIV test equipment hardware system developed by Microvec includes an illumination laser, synchronizer, frame grabber (placed inside the computer), high-speed digital camera(s) and a computer (see Figure 2.1):

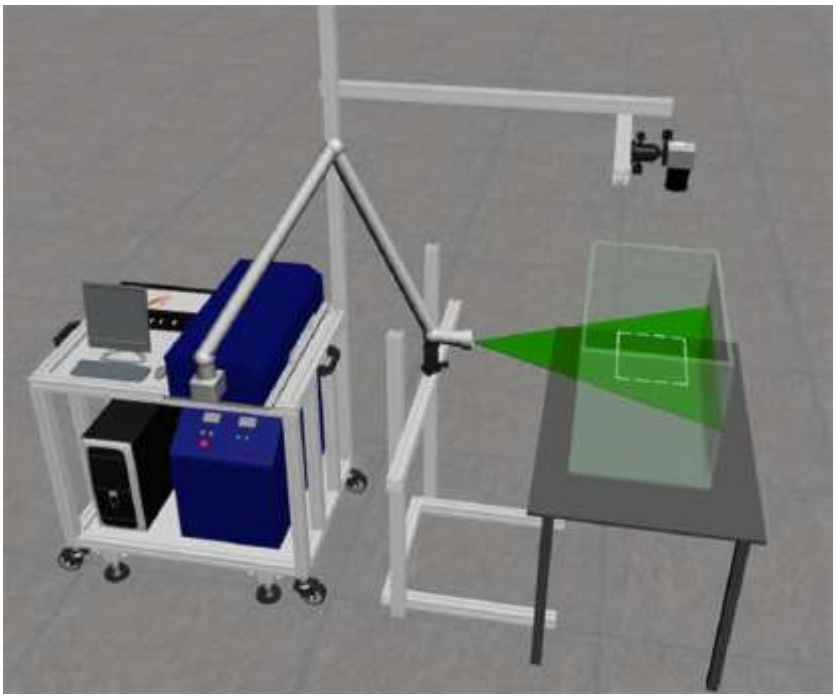


Figure 2.1 PIV System Descriptions

The illumination laser is shown in Figure 2.2. Usually a Nd:YAG double pulse laser (also known as PIV laser) is used as a light source. It uses two pulse lasers and sends out laser beams through an optical beam combiner and a light path exit. Usually a combination of a guide arm and sheet optics are used to expand the laser into a plane first and the plane onto a thin sheet, resulting in the pulse sheet light source illuminating the flow field.

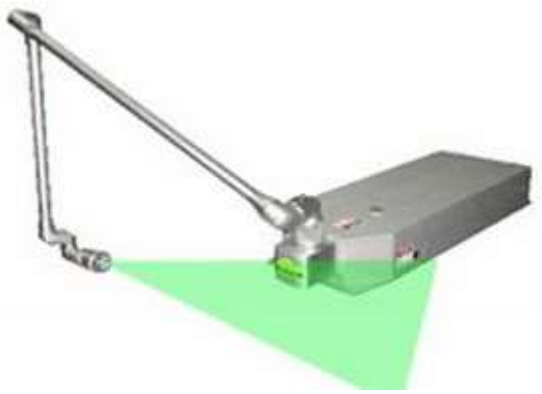


Figure 2.2 Nd: YAG double pulse laser

The digital camera (see Figure 2.3) captures two images using a double exposure mode which is synchronized with the double laser pulses. The capture is started by an external trigger. Both captured images are then sent in real-time to the computer memory through the frame grabber. Trigger signals are provided by a synchronizer to be fully synchronized with the double pulsed laser.

Figure 2.3 PIV dedicated digital camera

The synchronizer (MicroPulse725) (see Figure 2.4) generates cycle pulse trigger signals through the internal time base, simultaneously producing multiple delayed trigger signals through internal time-delay channels. The synchronizer is used to control the laser, digital camera(s) and frame grabber, so that all of them operate in perfect synchronization, and ensures perfect coordination of all these various parts.

Figure 2.4 Synchronizer

A computer is used for storing image data that is passed through the frame grabber. It is then used to calculate, display and store the velocity field in real-time through the particle image velocity measuring system software.

2.2 Use of the hardware system

The PIV system uses a laser as an independent lighting device which can be used with or without the synchronizer. If the synchronizer is not available, the internal synchronization of the laser can be used

during the setup of the optical path and laser energy (for the detailed steps please refer to the user manual of the laser).

The frame grabber takes up a standard PCI slot (PCI-E) of the computer. The interface of the acquisition board is mainly a 26-pin CamLink standard digital camera connection interface. The Microvec PIV system uses digital cameras with a standard CamLink interface. It uses three 10 meter signal lines to connect to the frame grabber, keeps trigger signals to make the digital cameras synchronize with the pulse laser, and then connects with the synchronizer's output interface through the coaxial signal cables via TTL trigger, which interfaces with the camera.

When the synchronizer is available as part of the PIV system, the laser must be set in the external synchronous mode (where the 4-way delay signals of the synchronizer are output to controls of the corresponding two sets of the laser flashlamp and Q-Switch of the laser) while the digital camera is set to "PIV work mode." See Figure 2.5.

Figure 2.5 Double pulse PIV laser wiring

Specific wiring is as follows:

T1, T2, T3, T4 of the synchronizer are connected to four channels of the laser's flashlamp 1 (F1), Q switch 1, flashlamp 2 (F2) and Q switch 2. T5 and T6 are respectively connected to two CCD camera signals (see figure 2.6 below), and the T7 channel is reserved for future use. More details can be found in Chapter 8.

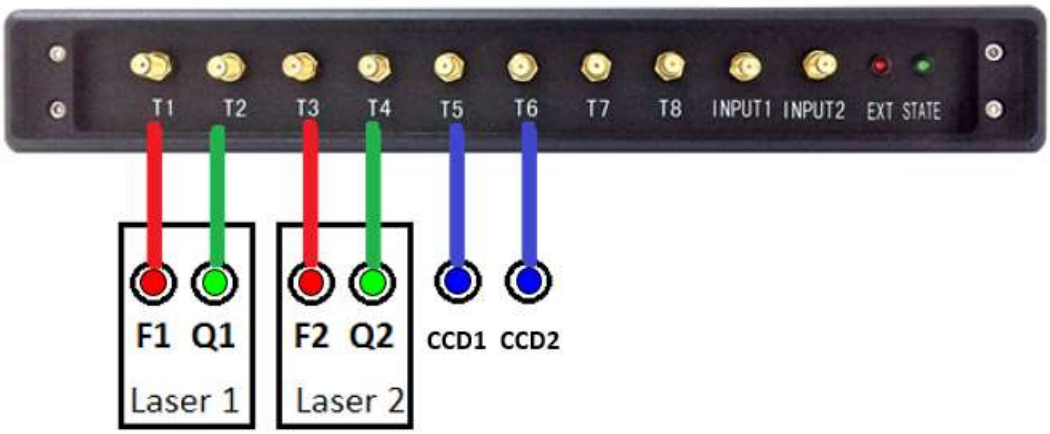


Figure 2.6 Wiring diagram of the laser and cameras.

The laser system has three operation modes, based on whether the timing of the flashlamp and Q-Switch trigger signals are controlled internally or controlled from external sources.

1. Internal mode: Both flashlamp & Q-Switch are set to internal mode. This mode is used for starting up the laser system and when undertaking any kind of diagnostics or fault detection.

2. External mode: Both flashlamp & Q-Switch are set to external mode. This mode is applied when the laser system is completely controlled by an external control system. This is the model used when Microvec software takes control over the laser system and synchronizes the laser with the camera.

An example of 2D PIV system setup is shown in Figure 2.8:

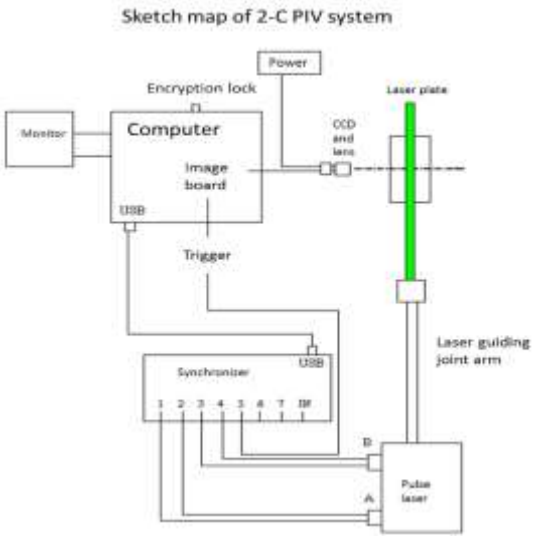


Figure 2.10 Setup of 2D PIV system

In the 3D (stereo) System, there is a certain angle between the camera and laser plane where the captured image can be clear (Figure 2.11) as long as the camera chip plane, the lens plane and the

image plane captured meet the Scheimpflug optical conditions. The Scheimpflug condition is the geometric rule that describes the orientation of the plane of focus, the lens plane, and the image plane of an optical system (such as a camera) when the lens plane is not parallel to the image plane.

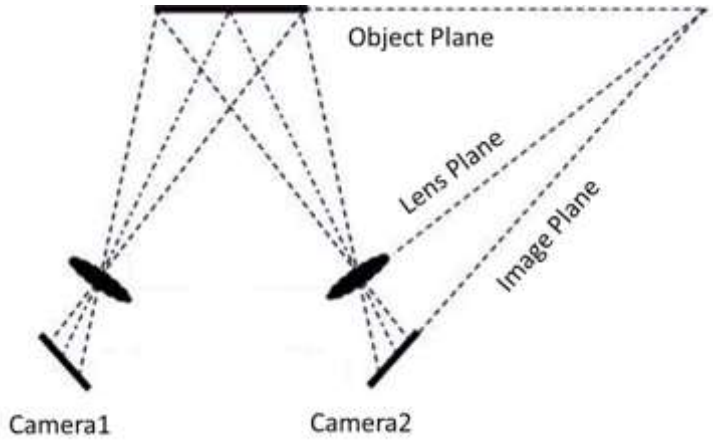


Figure 2.11 Schematic of 3D (Stereo) PIV system

Each digital camera is fixed on a 3D stereoscopic mechanism and camera lenses are fixed on the fixed panel in front of the 3D stereoscopic mechanism. An example is shown in Figure 2.12.

Figure 2.12 Example of 3D stereological adjustment mechanism

There are two ways to configure your 3D Stereo PIV setup: an angular configuration and the translational configuration.

Figure 2.13 shows the various components of the stereo camera and the stereological adjustment mechanism. The following are steps to install the camera and lens on the stereological adjustment mechanism:

First, remove the connection rings and lens from the camera, fix the removed connection rings on the frame seat (fixed with the positioning holes 7, 8 and positioning holes on the other side

through the top wire), and then mount the lens with the connection rings; afterwards, connect the CCD camera with the camera frame seat with screws through holes 1, 5 and 2, 6. Finally, you have the camera frame seat connected to the turntable through holes 3 and 4 with rotary tables and translation tables connected to the base plate via threaded connection. The base plate of the 3D stereoscopic mechanism can be fixed in the standard aluminum rails provided by Microvec.

Depending on your necessities, you can have both of the cameras on one side of the light sheet with different intensities or have the cameras on different sides of the light sheet with the same intensities. You want to make sure your setup uses the correct angles since it can change the light intensities. The angular configuration consists of rotating the cameras at an angle and having their axes intersect at your object plane. This causes a distortion and different magnifications. The complexity and flexibility of this configuration allows it to be used for many different applications. In the translational configuration, the two cameras are facing parallel to the subject and can be placed close together. You don't get a lot of perspective distortion and your magnification is constant. However, when the angles start getting higher, this type of configuration can cause issues with the results. Therefore, it's not ideal for many situations.

During the test, the angle of the CCD camera can be adjusted simply by using the angle knob. In order for the camera chip plane, lens plane and laser plane to meet the Scheimpflug optical conditions, make sure to secure those planes with lock nuts after determining the angle. **(Note: When adjusting the angle knob on the camera frame seat, the knob must be rotated and adjusted slowly to prevent damage to the rack).** As seen in Figure 2.14, you will start off with a partially sharp image with other parts being blurry. Then you will use the tilt knob on the lenses to shift the lens until the entire image is sharp, as seen in the image on the right of Figure 2.14.

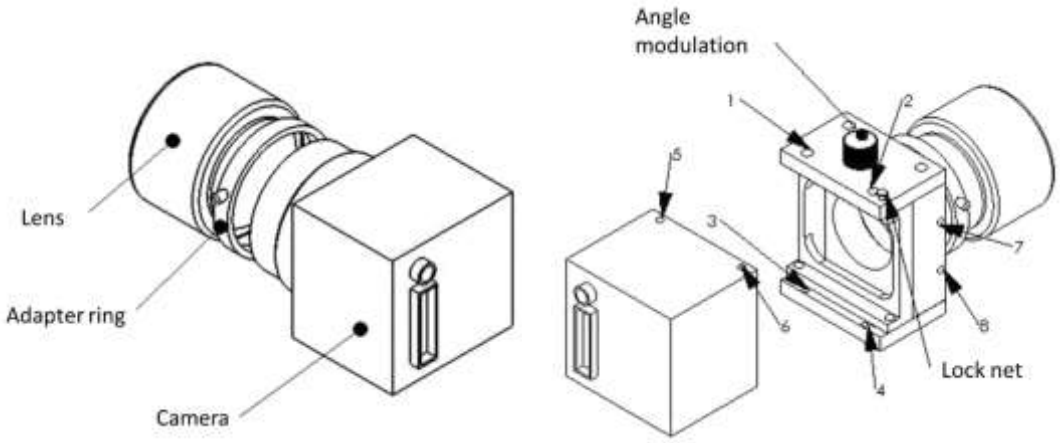


Figure 2.13 Camera disassembly diagram for 3D system

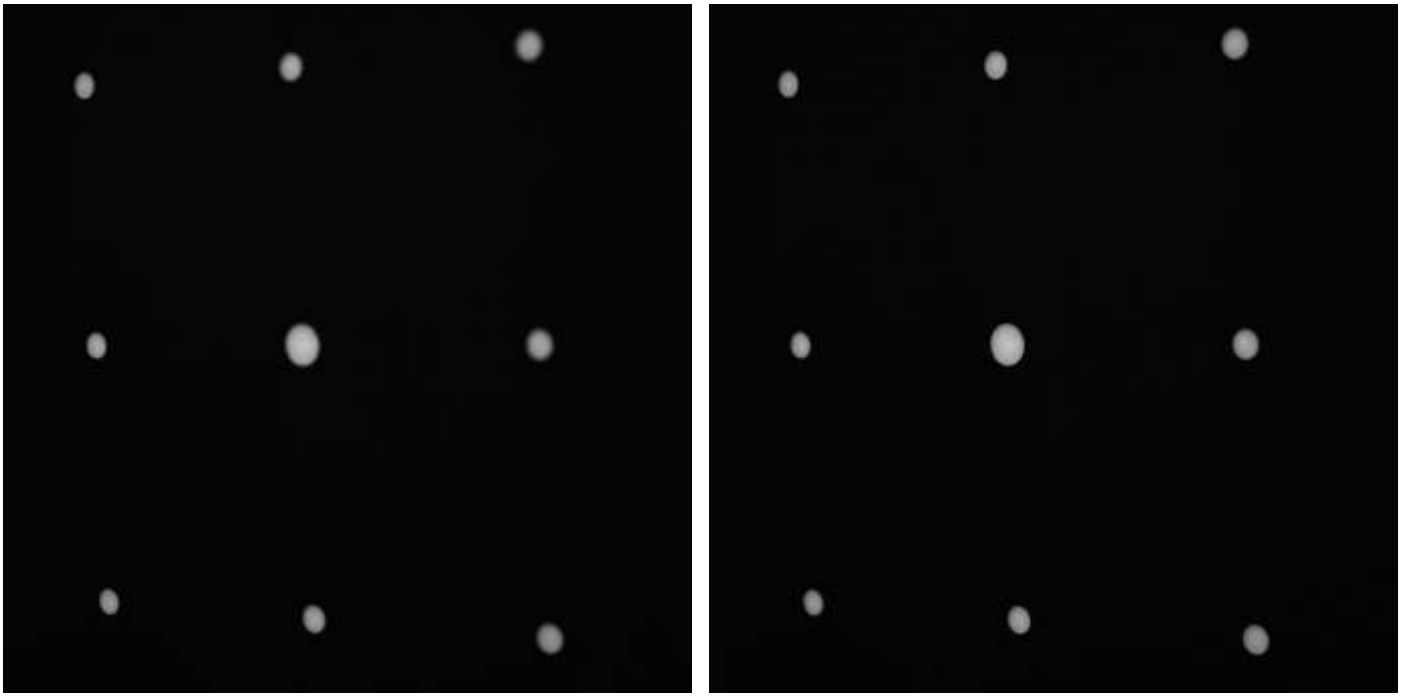


Figure 2.14 Use the tilt/shift lens to adjust the image until it is sharp

Setup of 3D system is shown in Figure 2.15:

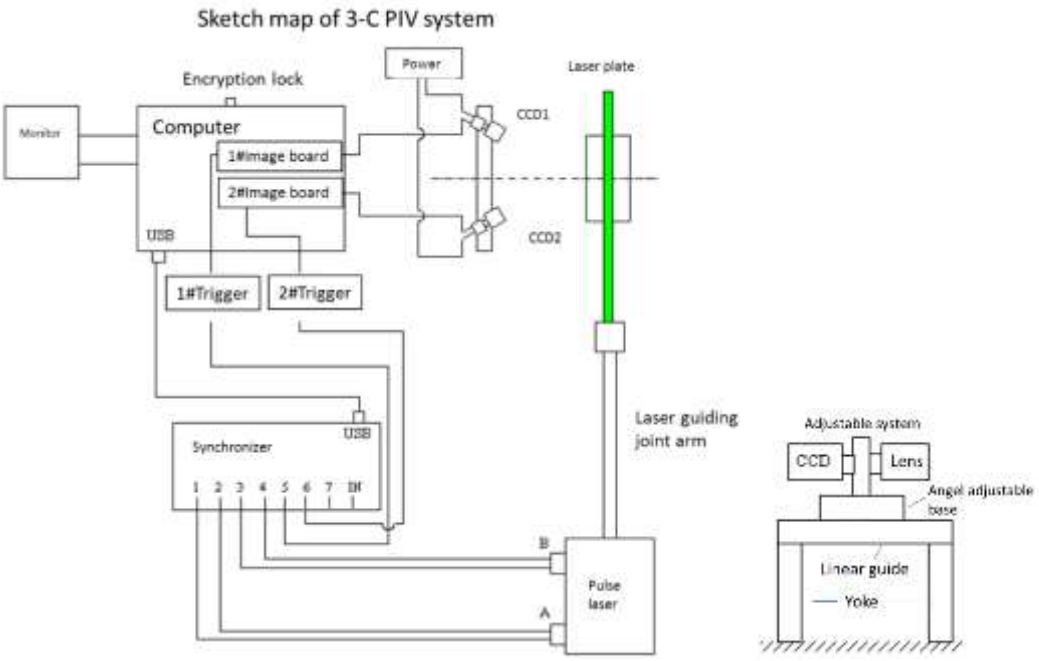


Figure 2.15 Sample 3D PIV system

From the system diagrams of the two systems, one can see the scalability of the systems. A 2D PIV system can be enhanced into a 3D PIV system and vice versa. Note two important points during

such a conversion: sheet light thickness needs to be different (see Figure 2.16) as well as the camera layout (see Figure 2.17):

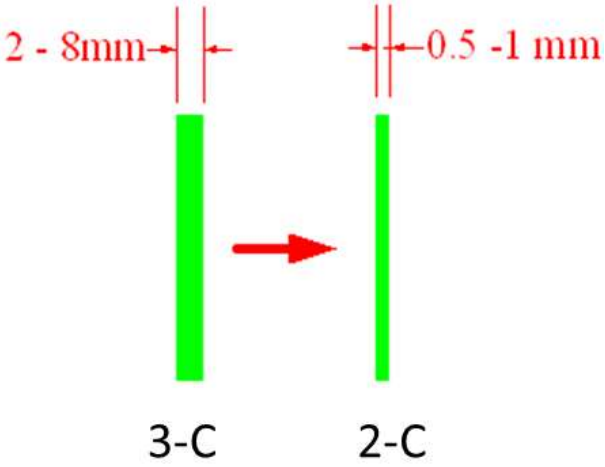


Figure 2.16 3D light sheet thickness variation

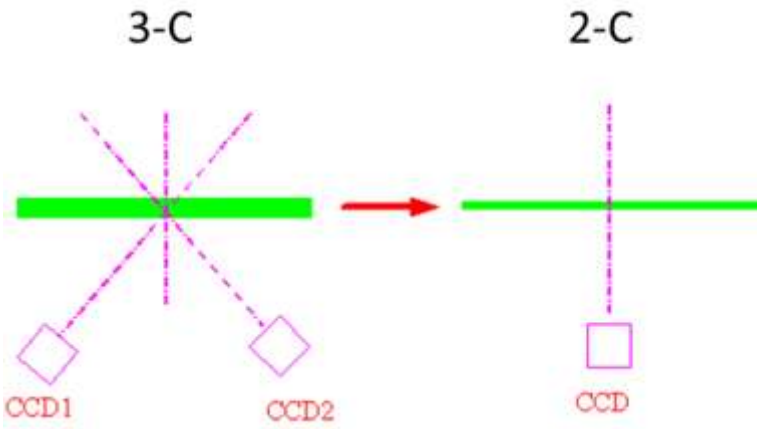


Figure 2.17 3D system camera layout difference

2.2.1 Mechanical Setup of the Cameras on a Rail

With the quick release plate (with 1/4-20" & 3/8"-16 threaded screws), and by using the “1/4-20" threaded screws”, we can connect the camera with the 3-way, geared pan-and-tilt head, as shown below:

Figure 2.18 Manfrotto 3-Way, geared pan-and-tilt head

Usually we set the head on Aluminum guide rails by using a special bolt, but since the head installation position is higher than the lowest knob, we have to add a shim between the head and the aluminum guide rails, and then the head can be fixed properly and the direction can be adjusted.

Figure 2.19 Special bolt

Aluminum guide rails

When we perform the 3D calibration by using the Nikon Tilt/Shift lenses to adjust the Scheimpflug condition, the 3D calibration target needs to use the translation mechanism, as show in the picture below.

Figure 2.20 3D Calibration plate and translation mechanism

2.3 Use of Tilt/Shift lenses for 3D PIV Systems for Scheimpflug adjustment.

As compared to traditional 3D PIV systems, which normally use Scheimpflug adapters, Microvec PIV systems also use Tilt/Shift lenses, which are suitable for Scheimpflug adjustment in the majority of cases. See Figure 2.21 for a typical Tilt/Shift lens sample.

Figure 2.21 Example of Tilt/Shift lens: Nikon 45mm f/2.8D PC-E

Besides our own patented Scheimpflug adapter, we offer tilt/shift lenses instead because we believe that they are much better for the reasons explained below.

The standard Scheimpflug mount normally has limited adjustment for lens orientation, only tilting and rotating, no shifting. The adapter has a soft cover (rubber cloth) at the rotation part to cover the leaking light from the gap, which might cause an uncomfortable experience during the adjustment. Also, with an additional adapter, the distance between the lens and the CCD sensor is changed, which means that the camera is not working on the optimized condition and could cause some distortion during the imaging.

The Tilt/Shift lenses we offer have a full angular adjustment. They have shifting, rotating and tilting adjustments to make any orientation of the lens to satisfy the Scheimpflug condition, without worrying about the issue of leaking light and the distance between the lens and the CCD sensor.

Additionally, the mount of the Scheimpflug adapter is not a welcome component for the setup due to some potential mechanical problems and easy contamination of the sensor (!). Therefore, we now offer Tilt/Shift lenses solution for all our 2D3C (Stereo) and Tomographic (Volumetric) PIV systems.

2.3.1 Stereo 3D PIV System Principles

When using two cameras, the Scheimpflug condition, which describes the plane of focus of a camera when the lens plane is not parallel to the image plane, needs to be implemented. Perspective error will occur when moving particles are projected onto a 2D plane. When the lenses are altered, it will allow all the particles to be in focus as opposed to only a certain portion. The addition of a second camera, will provide a second perspective on the particles allowing more equations that can be used to solve the 3D information.

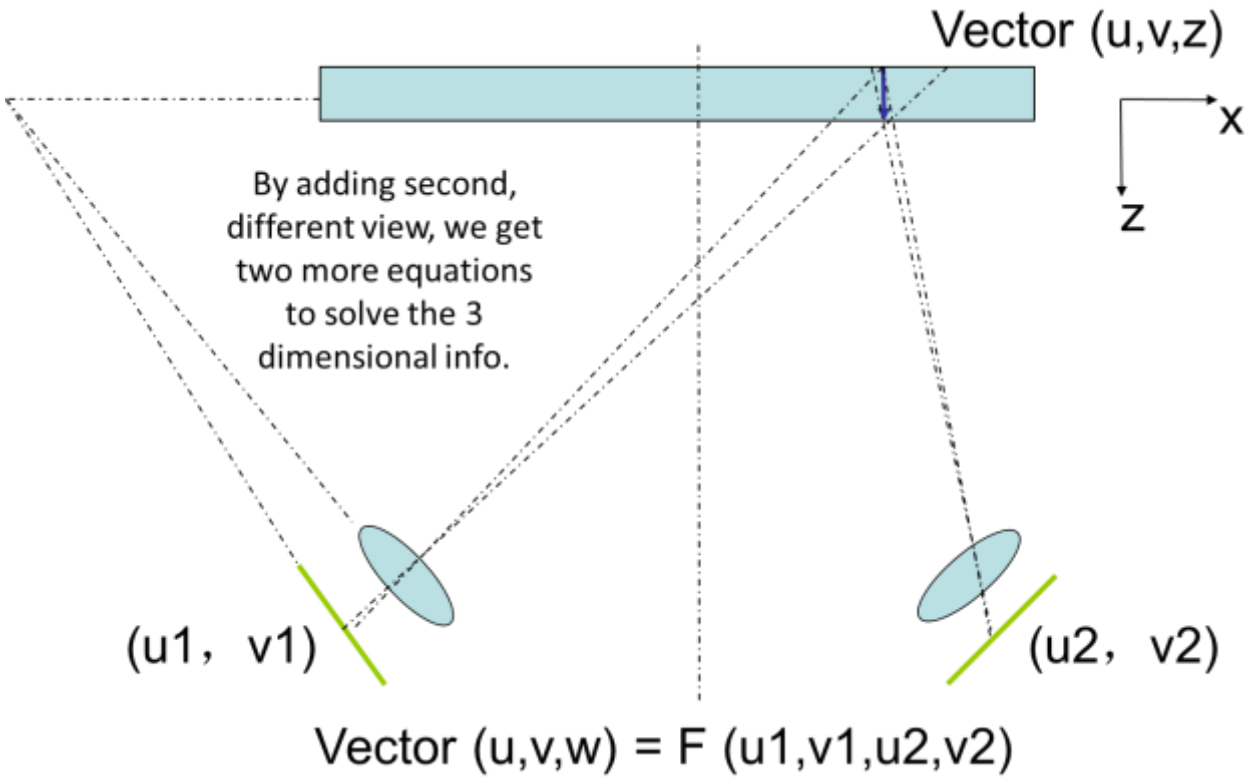


Figure 2.22 Principle of Stereo (3D) PIV

2.4 Safety precautions

WARNING: LASER RADIATION

MOST LASERS USED IN MICROVEC PIV SYSTEMS ARE CLASS 4 LASER DEVICES AND ARE CAPABLE OF EMITTING LEVELS OF BOTH VISIBLE AND INVISIBLE RADIATION THAT CAN CAUSE DAMAGE TO THE EYES AND SKIN. IT IS THEREFORE IMPERATIVE THAT THIS MANUAL IS FULLY READ AND UNDERSTOOD PRIOR TO USING THE PIV SYSTEM WITH THE ACCOMPANIED LASER.

OVERVIEW

The Microvec PIV systems use lasers, which are CLASS 4 laser devices and should be operated with due care and attention paid to the safety practices outlined in this manual. Whilst these lasers have been designed to comply with all necessary legislation pertaining to safety and electromagnetic compatibility, if used incorrectly, harm to the user or others may result.

Safety Terms used in this manual:

Danger

Indicates an imminent / immediately hazardous situation which, if not avoided, will result in death or serious injury.

If you do not take note of this warning and avoid this hazard it is extremely likely to result in death or serious injury.

Warning

Indicates a hazardous situation which, if not avoided, could result in death or serious injury.

If you do not take note of this warning and avoid this hazard it could result in death or serious injury.

Caution

Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury. *It is also used to alert the user against unsafe working practices that can potentially result in damage to the equipment.*

If you do not take note of this warning and avoid this hazard it could result in minor or moderate injury. If not noted and checked when using or maintaining the laser system it could result in damage to the laser system that is not warranted.

2.4.1 General Laser Safety

The operation of PIV lasers should always be in accordance with the procedures described within this manual. As the laser output is potentially harmful, the user and those in the same room, or optical proximity to the laser should be aware of its operation and the potential hazards. In order to minimise the danger posed by the laser output, there are several steps that the user can take.

These include, but are not limited to:

• Never operate the laser in a room where light can escape through windows or doors. If possible, interlock the door(s) giving access to the room using the external interlock connector on the power supply unit.

• Always ensure that adequate and proper protective eyewear is provided for all persons who may be exposed to radiation from the laser during its operation.

• If possible, mount the laser below eye level.

• Assume that all reflections pose a danger and never knowingly look at a reflecting surface even when wearing protective eye-wear.

• Be aware of back reflections from energy monitors and dump them safely.

• Keep the intra-cavity safety shutter closed whenever the output is not needed and if possible, stop the laser.

• Always dump the beam safely onto an absorbing target. Be mindful of the fact that the target will increase in temperature and may pose a fire hazard.

• Always post appropriate CLASS 4 laser warnings on all entrances to the room where the laser is used.

• Try to ensure that the beam path is shrouded, to avoid any radiation escaping.

• Always ensure the laser is secured suitably so that it cannot be moved during operation.

• Always ensure the connections to the laser head and power supply are secured and do not pose a tripping hazard.

2.4.2 Operational Laser Safety

All PIV laser systems are equipped with a full suite of interlocks. The function of an interlock can be either:
1. To shut the laser down when further operation in the current state may cause damage to the system **or**
2. To prevent the system being operated in an unsafe state that could result in harm to the user.

The function detailed in point 1 also acts as a self-check during laser start up and operation. In addition, all interlocks are latched so that if a transient fault occurs (such as opening and closing a door connected to the external interlock), the user can readily see the cause for the system shutdown. This is an important diagnostic tool.
Never operate the laser with the covers removed from the laser head and interlocks defeated.
• Never operate the laser with the covers removed from the power supply, lamp connections, and lamp. Lethal voltages are present that may cause death or serious injury.

2.4.3 Optical Laser Safety

Laser emissions from PIV lasers are sufficiently intense to cause blindness. Blindness may result not only from direct incidence of the beam on the eye, but from any type of reflection either diffuse or specular. As the radiation emitted is invisible, the danger may not be obvious. It is absolutely necessary that protective eyewear, with a sufficiently high optical density at the wavelengths emitted by the laser, is worn at all times when operating the laser.

WARNING: LASER RADIATION 

PROTECTIVE LASER GOGGLES MUST ALWAYS BE WORN WHEN OPERATING THE LASER. THE GOGGLES MUST PROTECT AGAINST ALL WAVELENGTHS THAT CAN BE EMITTED INCLUDING HARMONICS. THESE WAVELENGTHS ARE 1064nm AND MAY INCLUDE, DEPENDING UPON THE MODEL, 532nm, 355nm, 266nm AND 213nm. ALWAYS AVOID DIRECT EYE OR SKIN CONTACT WITH ANY RADIATION, BE IT LASER OR COLATERAL.

The emission indicators on the laser head and power supply unit warn of laser emissions. It should be assumed that a hazardous emission exists if either of these is illuminated. The emission indicators are of a colour that can be viewed through all protective eye-wear appropriate to the operation of this device.
Most PIV laser systems are supplied with an intra-cavity electronic safety shutter that is electronically verified. When the laser is turned on, the shutter is automatically closed so that the system will not start up in a condition where lasing can occur. If the shutter is not in the verified position then the laser will not start.

2.4.4 Electrical Laser Safety

It is necessary to the operation of a flashlamp pumped pulsed Nd:YAG PIV laser, or systems of this type, that high voltages and large stored energies are required. The cover of the power supply should never be removed. There are no user serviceable parts within the power supply and any fault should be reported to Microvec, which will, if necessary, arrange for the unit to be serviced by a qualified person.
Equally, high voltages exist within the laser head. When removing the cover from the laser head always remove the power from the mains to the power supply unit and wait at least 5 minutes for all capacitors within the power supply to have fully discharged.

DANGER: ELECTROCUTION

HIGH AND POTENTIALLY LETHAL VOLTAGES AND STORED ENERGIES ARE PRESENT WITHIN BOTH THE POWER SUPPLY AND LASER HEAD DURING OPERATION AND STANDBY. ALWAYS ISOLATE THE POWER SUPPLY FROM THE MAINS AND WAIT AT LEAST 5 MINUTES BEFORE REMOVING THE COVER TO THE LASER HEAD. NEVER REMOVE THE INNER COVER TO THE POWER SUPPLY.

2.5 Camera Sensor Protection

CCD or CMOS sensors used in digital cameras are light-sensitive devices. Direct or reflected radiation from PIV lasers can damage the CCD or CMOS sensor of the camera. This may happen with or without power to the camera and with or without the lens mounted. Therefore, when setting up and aligning for measurements, take extreme care to prevent this from happening.

Laser damage may turn up as white pixels in the vertical direction, or as isolated white pixels anywhere in the image. This shows up clearly when acquiring an image with the lens cap on.

The CCD and CMOS manufacturer has identified all sensor defects into classes. Often the character and location of all defects are on record. Additional defects arising from laser-induced damage may void the sensor warranty.

Precautions

• Cap the lens whenever the camera is not in use.

• Cap the lens during set-up and alignment of the light sheet. Before removing the cap, make sure that reflections off the surface of any objects inside the light sheet do not hit the lens by observing where reflections go.
• As general precautions to avoid eye damage, carefully shield any reflections so that they do not exit from the measurement area. You must wear appropriate laser safety goggles during laser alignment and operation.
• Start measurements with the lowest laser power and a small aperture of the camera lens.
• Increase laser power step by step and check the intensity on the corresponding image. Make sure that the sensor does not run into saturation.
• Bright parts in the experiment, like reflections on walls or big particles, will limit the maximum laser power. Modify the optical arrangement of your setup in order to remove bright reflections from the camera image.

2.5 General System Considerations

• When the power is on, please don’t connect or disconnect any cables.

• In the event of unknown failures and/or the hardware system not working properly, you should first put on the lens cover of the digital camera and then turn off the laser’s operating xenon lamps and Q-Switch controller.

• It is not advisable to connect signal output ports of the synchronizer with any high voltage power supply, or to shorten the output ports. The synchronizer can be damaged.

Chapter III Introduction of the software

3.1 Composition of the software

The particle image analysis system, Microvec V3 image control system, has been developed by Microvec, to be used on Windows 10 Professional 64-bit operating systems. It has an object-oriented software architecture. Microvec V3 has integrated many modules for PIV, PTV, analysis of concentration field and particle size, etc.

Hardware controls include: real-time control of the digital cameras, laser control including laser energy, control of the frame grabber and the synchronizer.

Software modules include: General digital image display and processing; calculation of real-time particle image velocimetry (PIV); particle tracking velocimetry (PTV); speed of partial area and the entire image area in the cross-correlation calculation image; batch processing of large numbers of images; set partitions with automatic calculation; support vector single-point correction / single-point assignment / vector filtering / fixing all vectors; grayscale adjustment, filter, flip, reading, blur, zoom, contrast adjustment and other general-purpose digital image processing functions; real-time analysis of the particle size distribution in the image, including: particles' equivalent circular diameter, spatial position coordinates, equivalent rectangular parameters, particle cross-sectional area and other parameters; include analysis tools of gray density field: analysis changes in the spatial distribution of image gray level to get the relative concentration distribution and achieve measurement of non-linear absolute concentration field through the calibration; include tools to analysis particle number concentration distribution: real-time analysis of distribution of the number of particles in different diameters in various areas; compatible with Tecplot flow field analysis mapping software; compatible with other mathematical analysis software. (For detailed functions of the software please refer to Chapter 5).

3.2 Use of the software

The software installation consists of three parts: installation of the frame grabber control software, installation of Microvec V3 software and the dongle driver.

3.2.1 Microvec Software

Installing Microvec V3

Step One: Right click on the installation file, titled "MicroVec-365 EN," and select "Run as administrator." If a window pops up asking if you would like to allow the program to make changes to your computer, select "Yes."

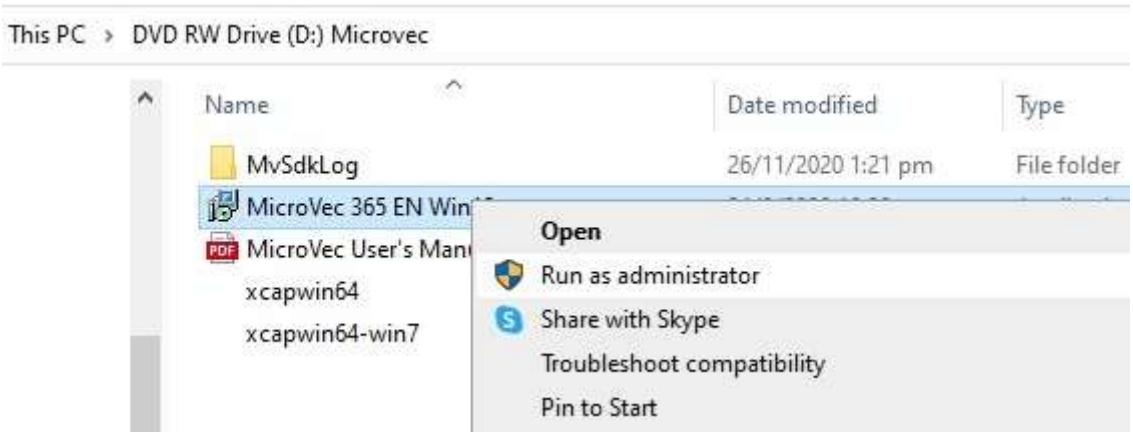


Figure 3.1 Installation of Microvec V3

Step Two: When the setup window appears, click the “Next” button to begin the installation process.

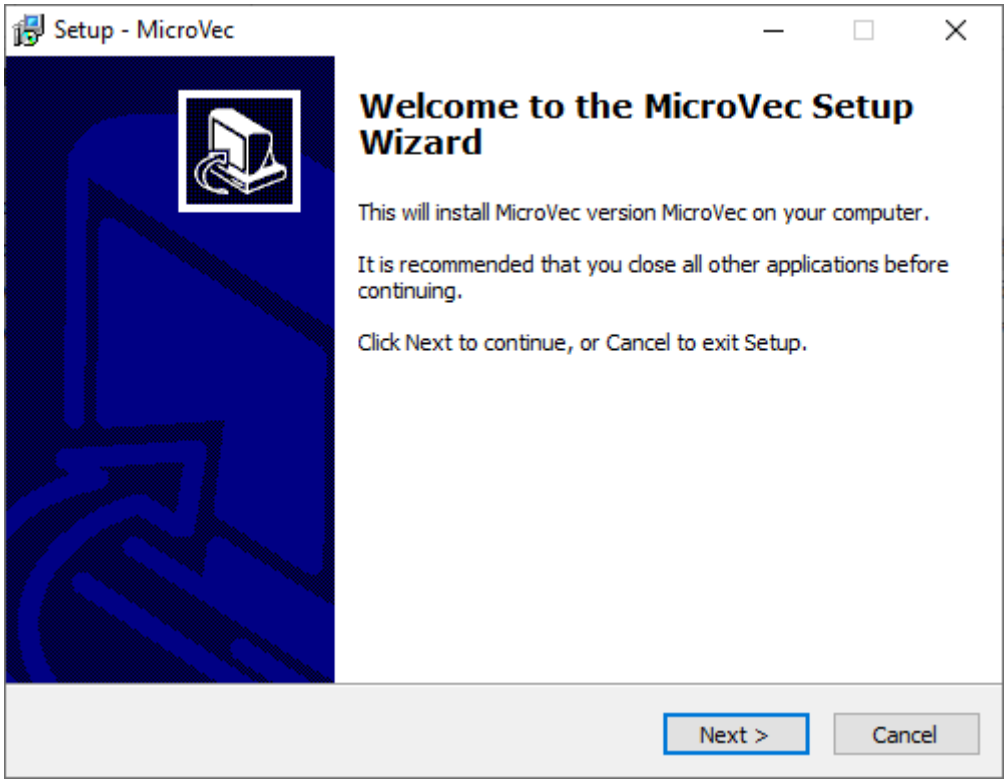


Figure 3.2 Installation of Microvec V3

Step Three: You will be taken to a window asking you where you would like to install the program. We recommend leaving the default location to install it on your C drive. If you would like to change the location, click the “Browse” button to choose the folder you would like to use. Click the “Next” button to move on to the next step.

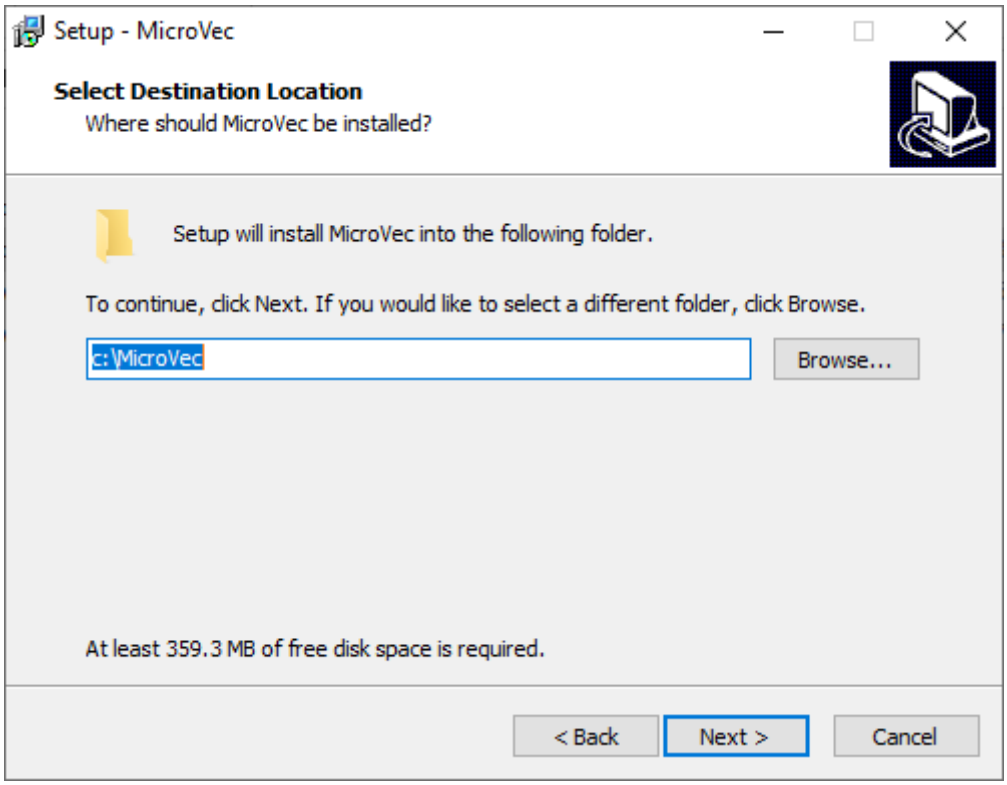


Figure 3.3 Installation of Microvec V3

Step Four: We recommend using the default Start Menu folder to create a shortcut in. If you would like to change the location, select the “Browse” button to choose a different folder. Click the “Next” button to move on to the next step.

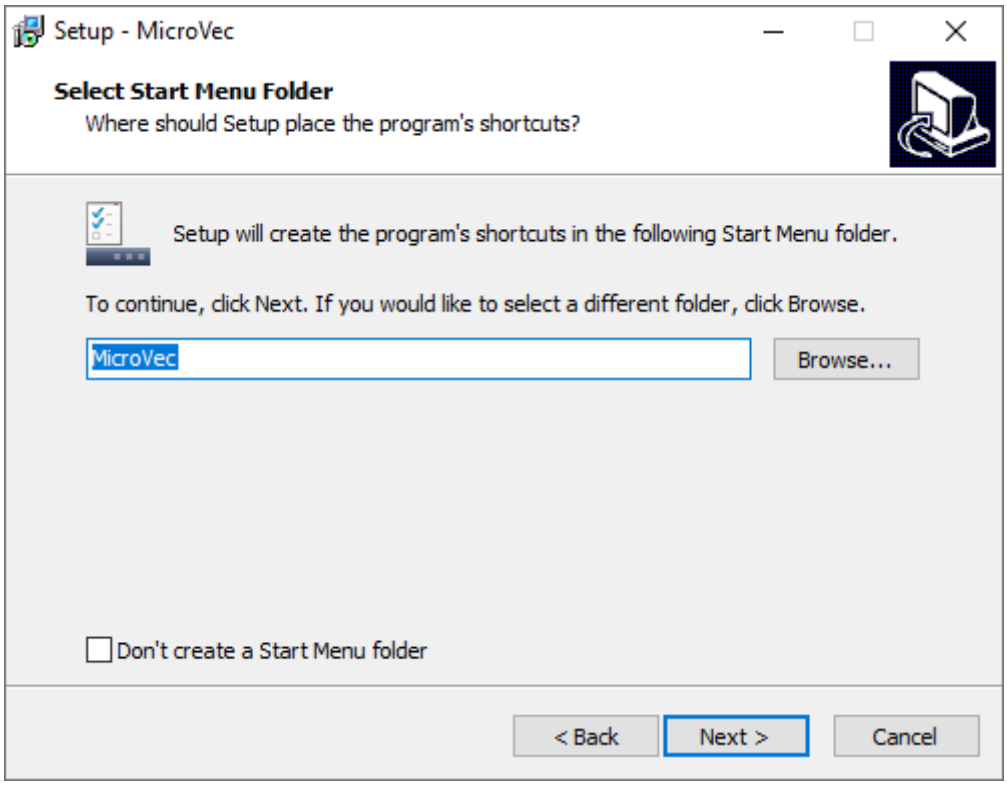


Figure 3.4 Installation of Microvec V3

Step Five: To create a desktop icon, check the box to the left of the option. Then, select the “Next”

button.

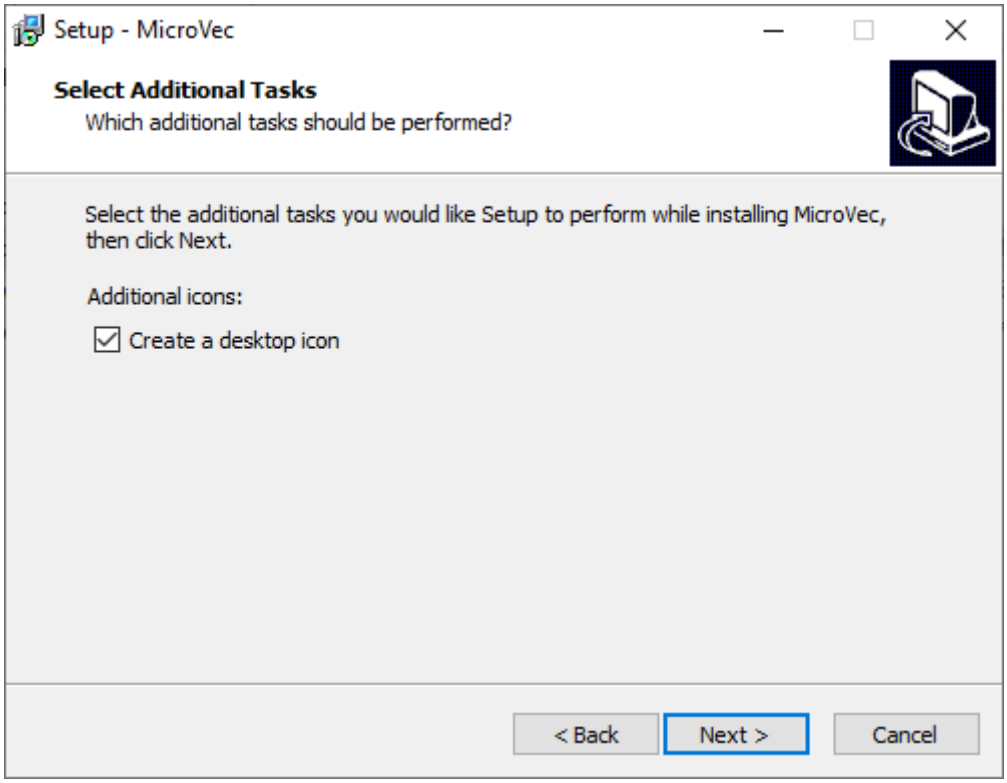


Figure 3.5 Installation of Microvec V3

Step Six: A window will show all the options you've selected so far in the installation process. Once you've reviewed everything and ensured it's all correct, click the "Install" button to install the program. If you would like to change anything, select the "Back" button to go back to previous steps and make changes.

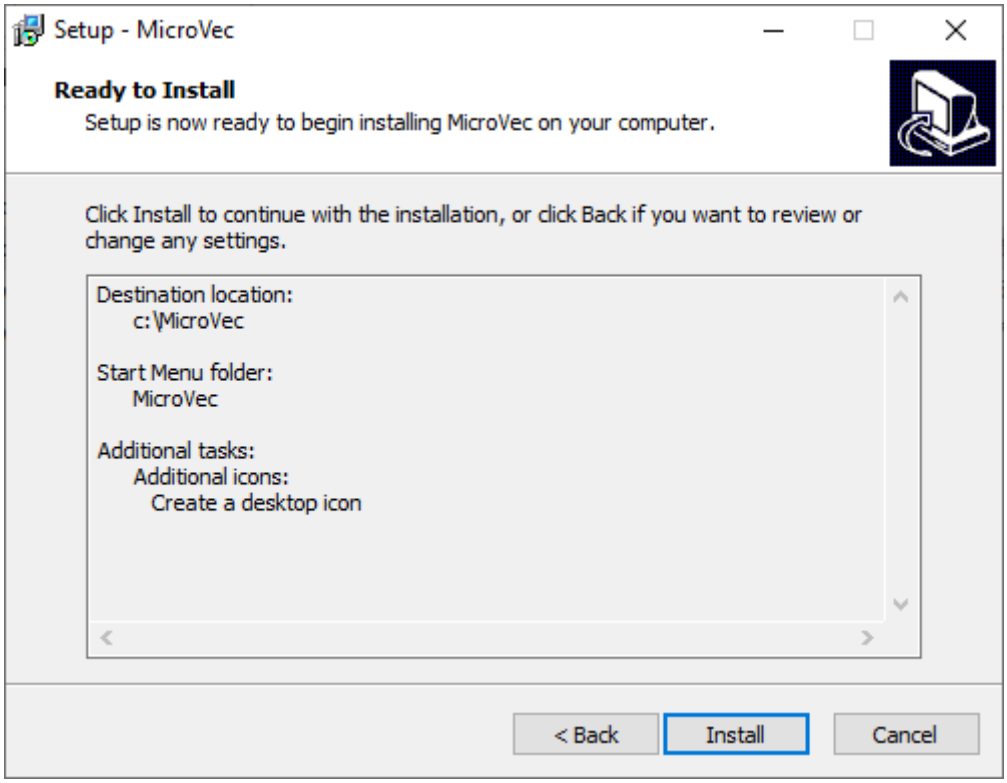


Figure 3.6 Installation of Microvec V3

Step Seven: Once the program has completed the installation, you will be given the option to launch the Microvec program immediately. Click the "Finish" button to complete the installation process.

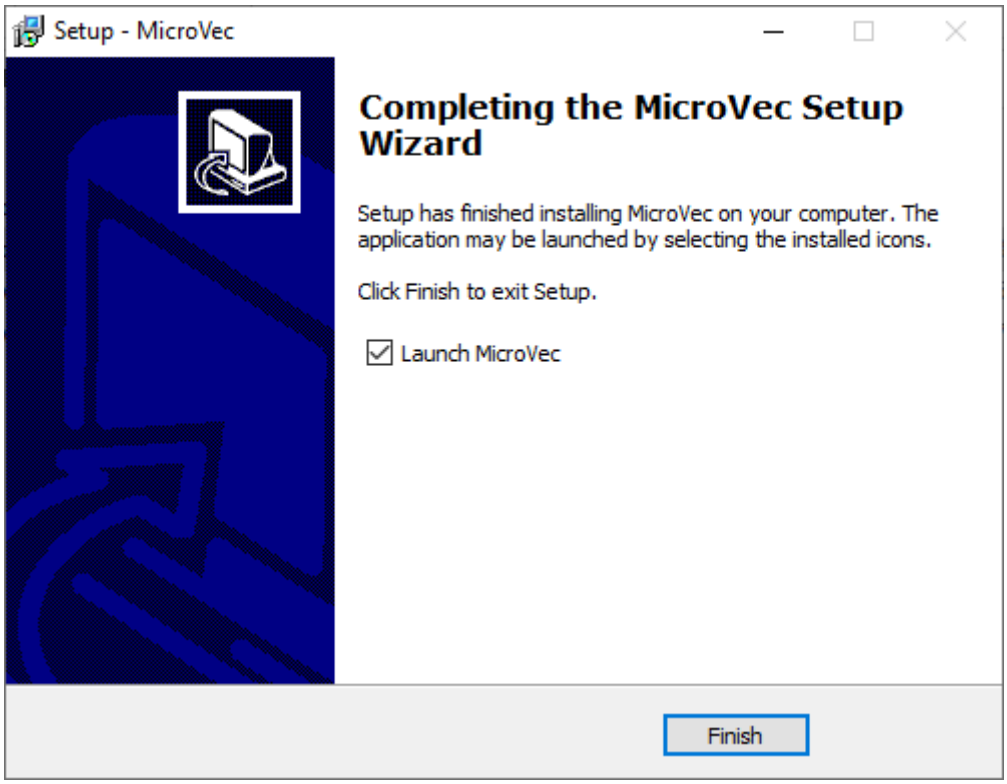
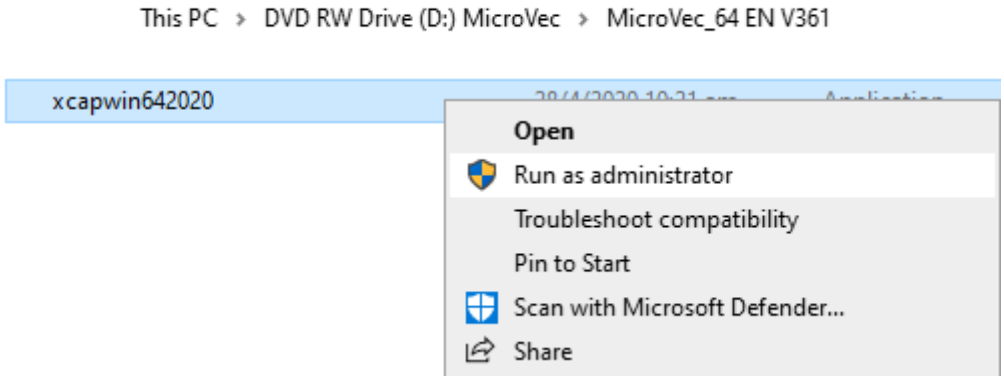


Figure 3.7 Installation of Microvec V3

Installing XCAP

Step One: Right click the installation file for XCAP and select "Run as administrator." If a window appears asking you if you would like to allow the program to make changes to your computer, select "Yes." When the installation window appears, click the "Next" button to begin the installation process.



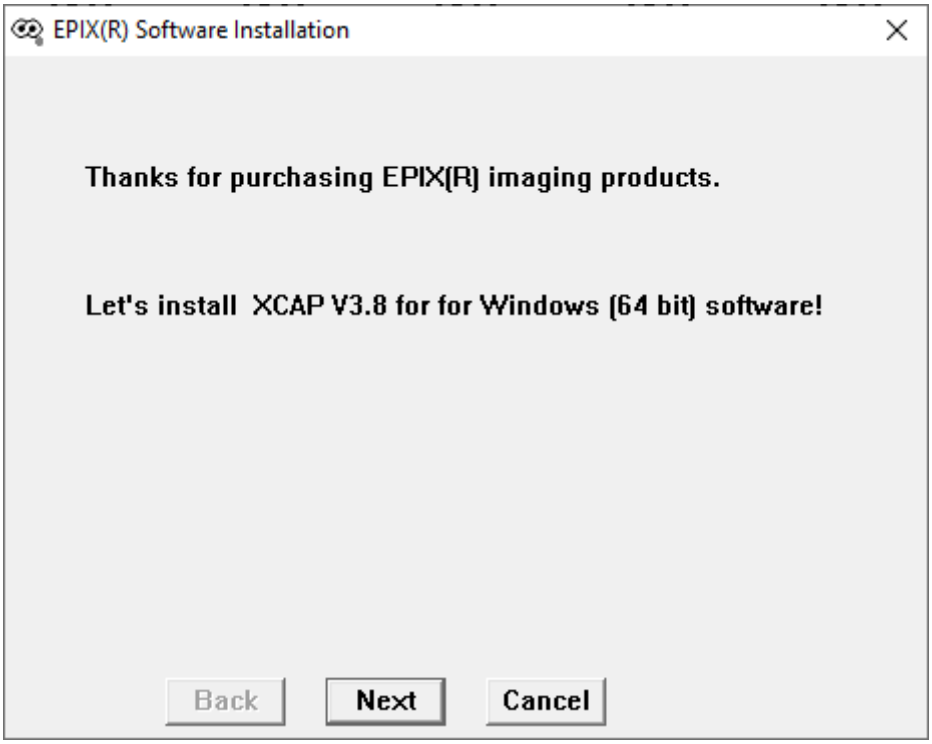


Figure 3.8 Installation of XCAP

Step Two: You have two options for who you would like to allow to use the program - all users on the computer, or only one user. Select the checkmark box beside the option you prefer. Click “Next” to move to the next step in the installation process.

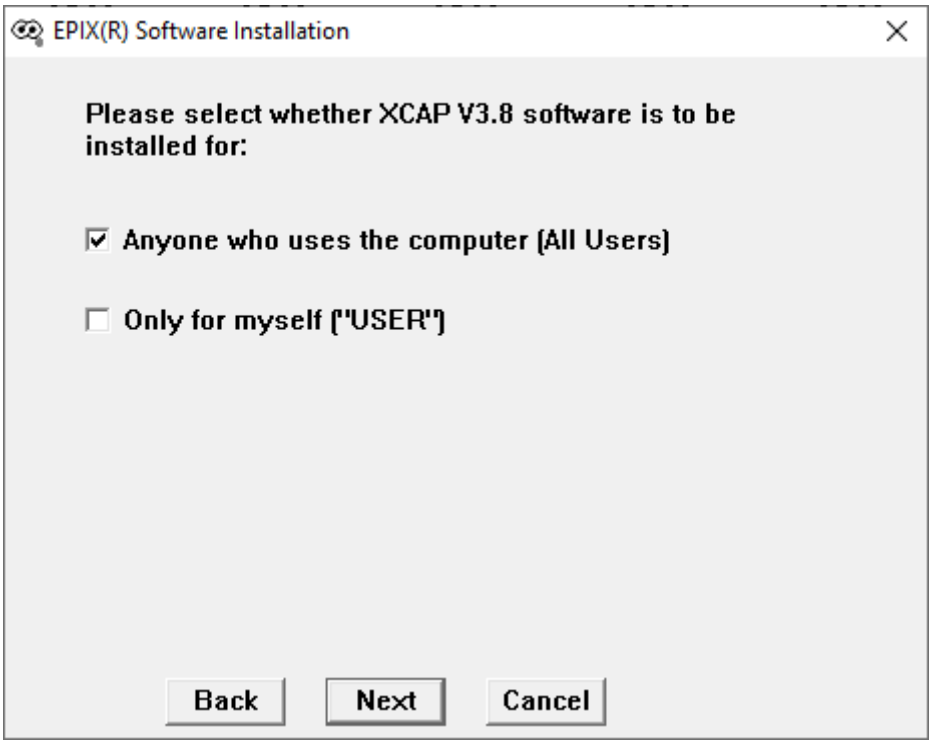


Figure 3.9 Installation of XCAP

Step Three: This step will ask you to select the drive and folder where you would like to install the program. We recommend selecting Drive C and the default location in the C drive Program Files folder. Click “Next” to move on to the next step.

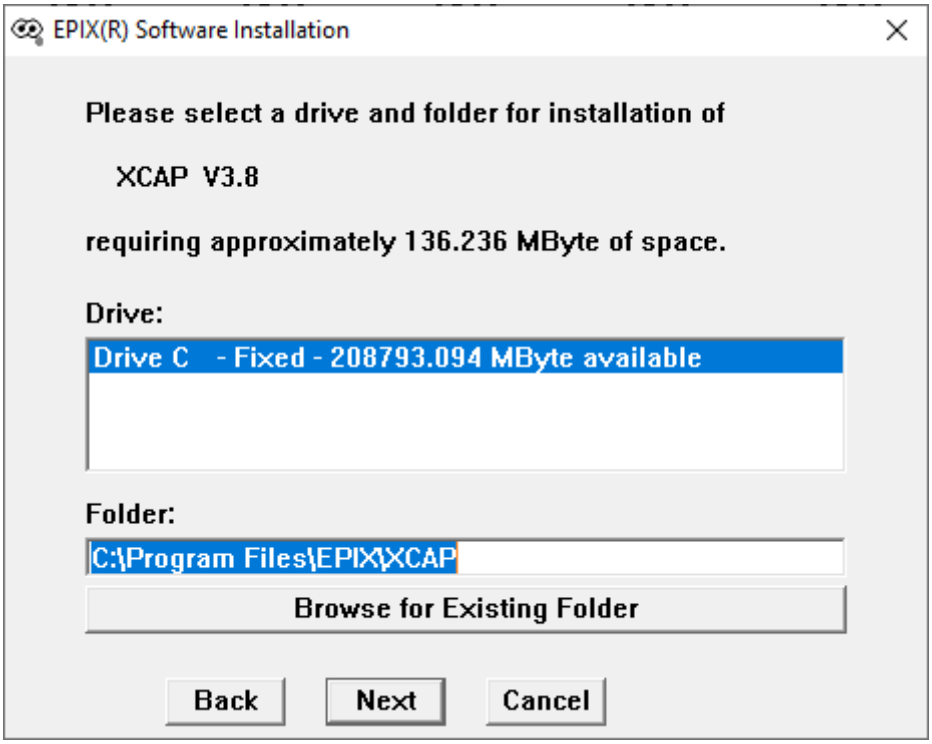


Figure 3.10 Installation of XCAP

Step Four: Select a location where you would like to automatically save the images produced by the program. We recommend keeping the default folder in the user's Documents folder. Click the "Next" button. The necessary files will then be installed.

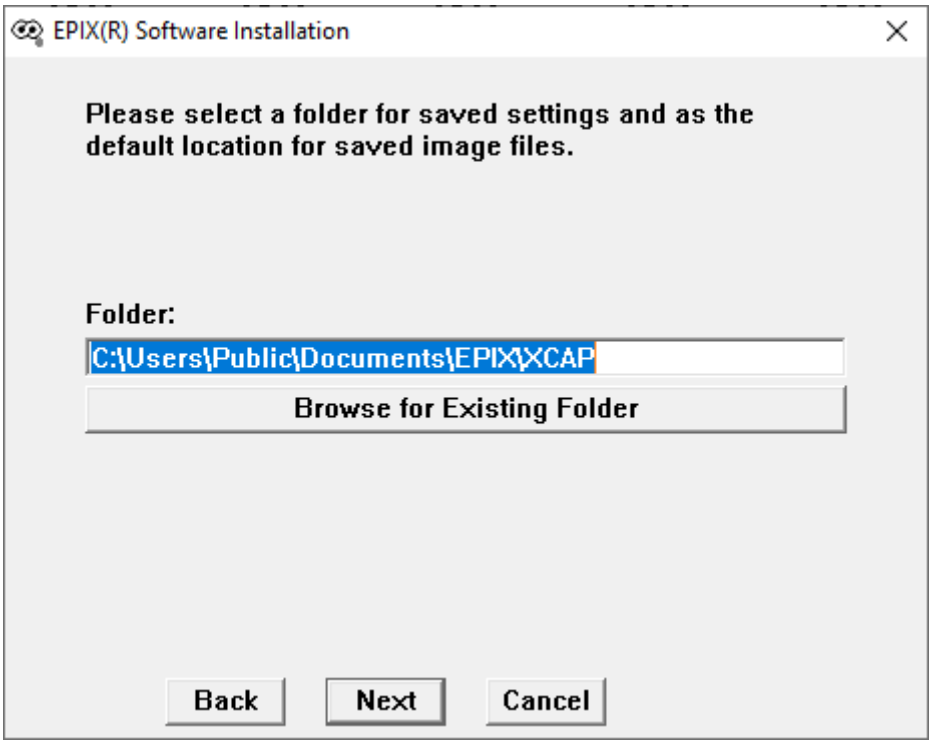


Figure 3.11 Installation of XCAP

Step Five: Once the files are installed, you will be given the option to browse the installation notes. Click "Next" to move on. You will then be given the option to create a shortcut on your desktop. Select either "Yes" or "No."

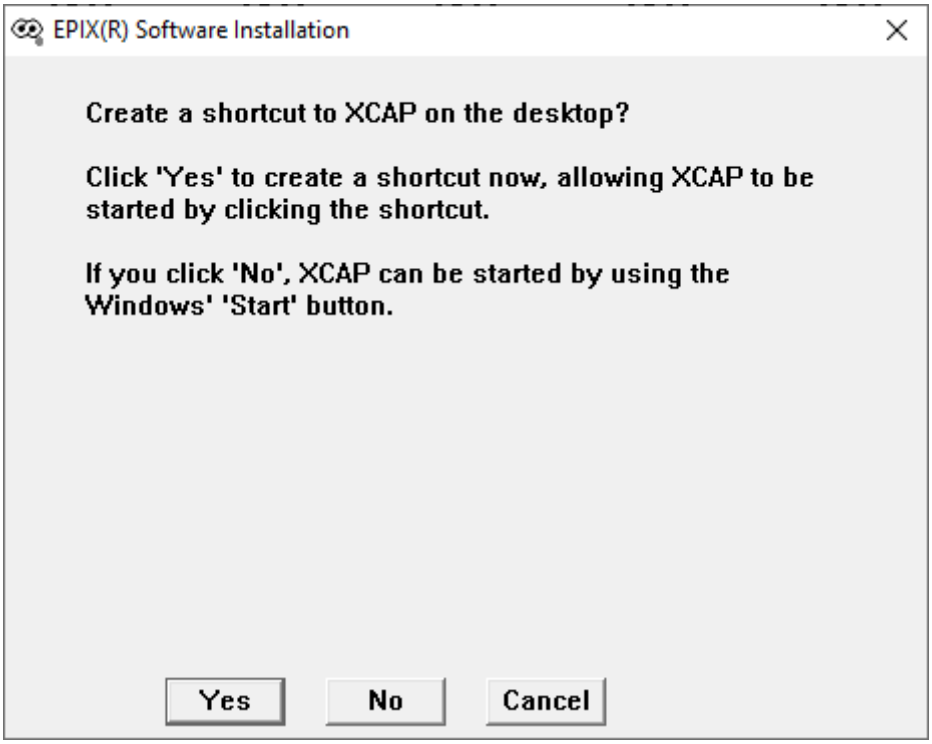


Figure 3.12 Installation of XCAP

Step Six: To finish the installation process and start the XCAP program, select the “Yes” button.

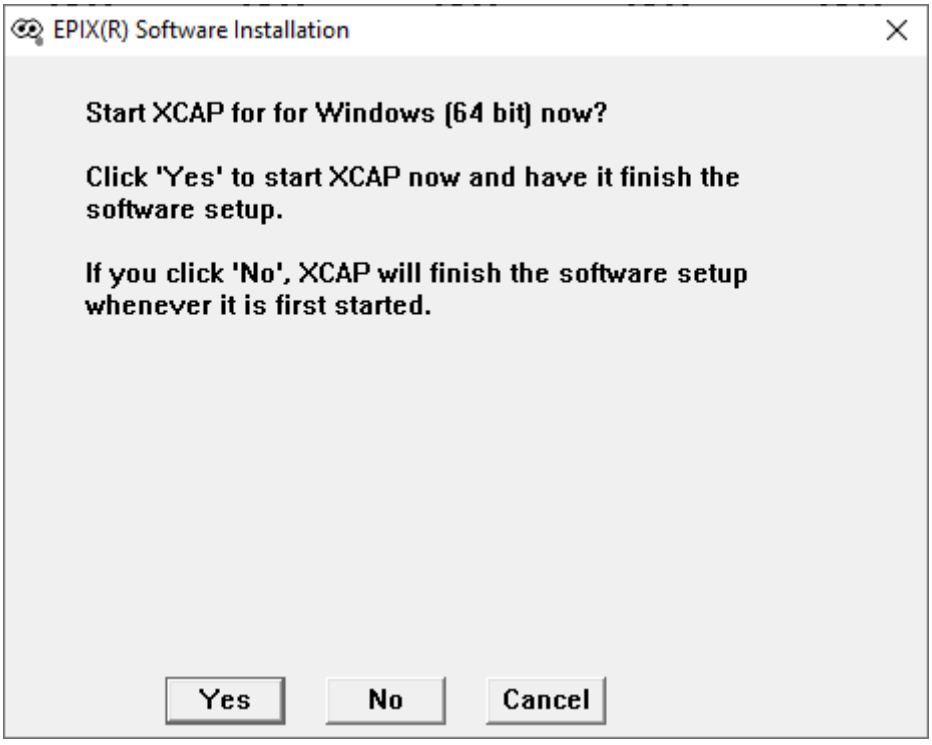


Figure 3.13 Installation of XCAP

Step Seven: The license agreement for EPIX XCAP will appear. Review the terms of the agreement and click on the “Agree” button.

Figure 3.14 Installation of XCAP

Step Eight: The window will ask you to authorize the software by providing a license key. In the first input section, “Enter Software ID with format,” type in the following license key: 53HR/25A4/NKZU and click the “Submit” button. Then, click “OK” to move on.

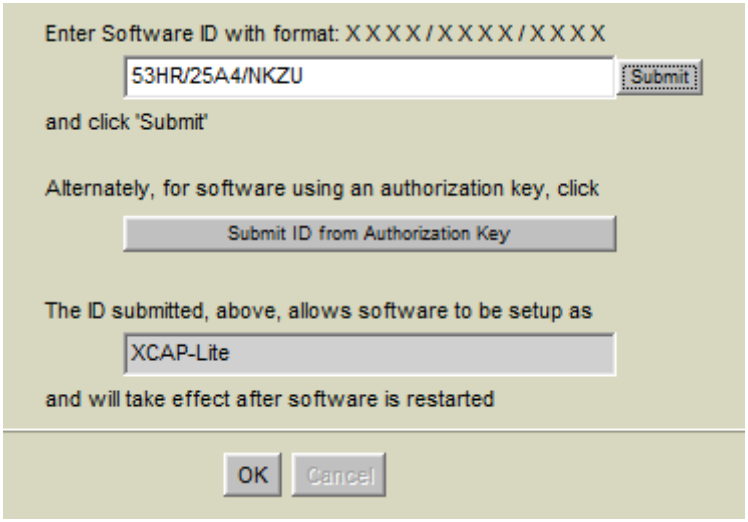


Figure 3.15 Installation of XCAP

Step Nine: You will now have a window appear saying that the installation is complete. Click “Yes” to start XCAP after closing the installation window. Then reboot the computer.

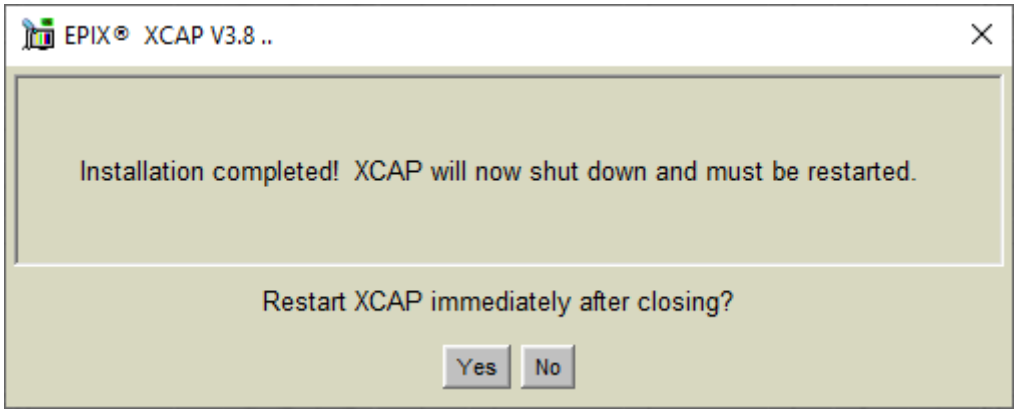
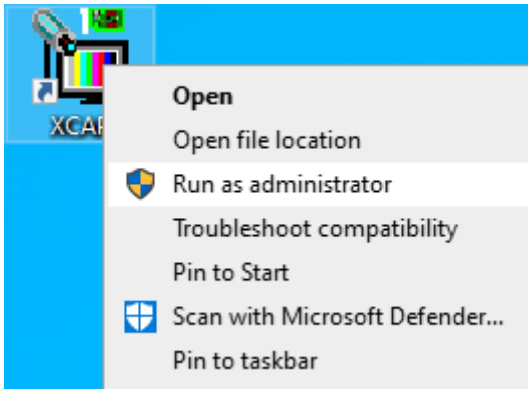


Figure 3.16 Installation of XCAP

Step Ten: Right click the XCAP desktop shortcut and select “Run as administrator” to open the program. A welcome message will appear. Click “OK” and a new window will appear in the program.



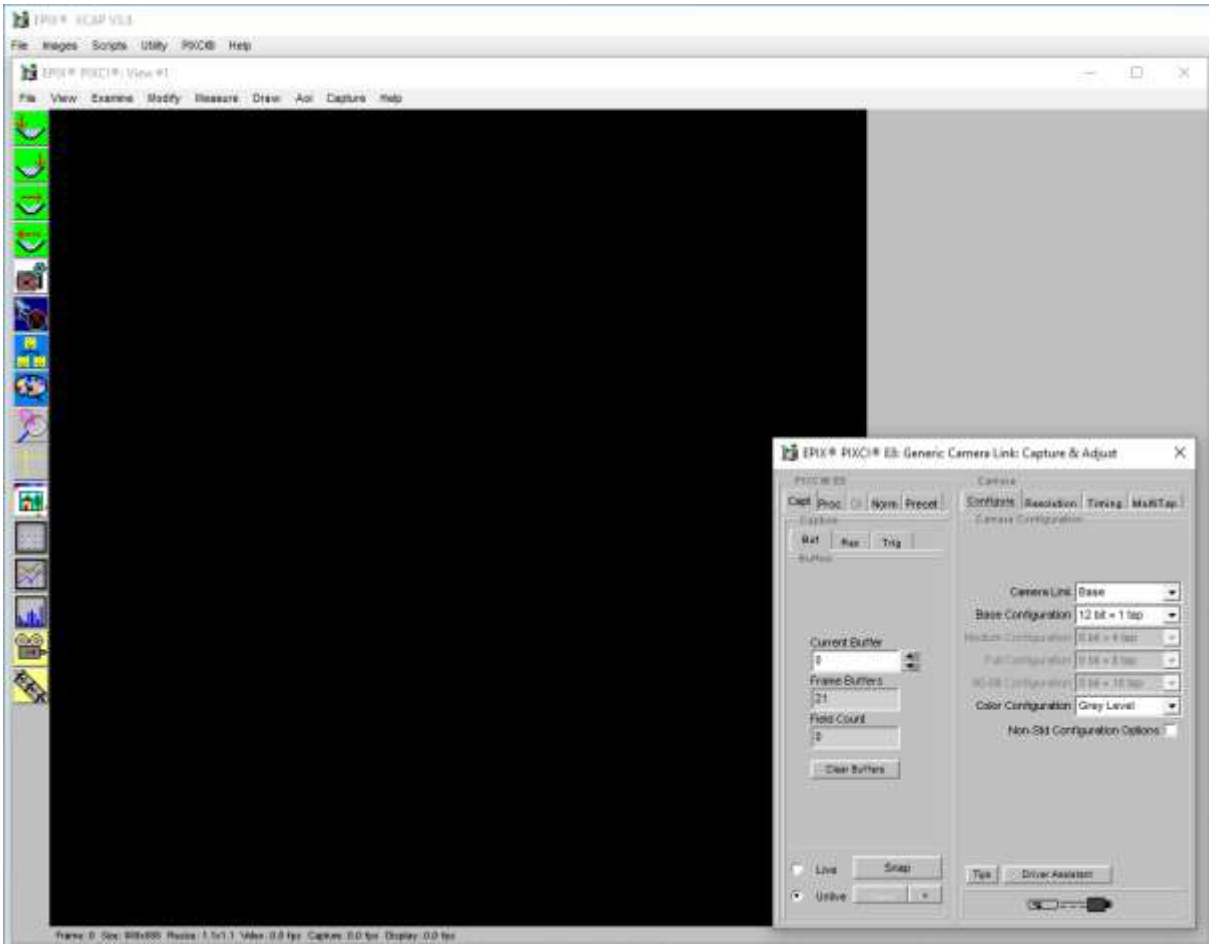
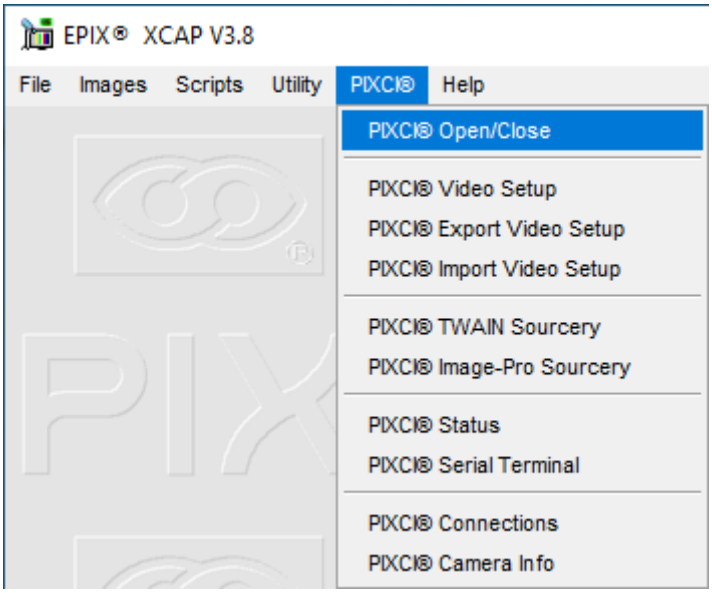


Figure 3.17 Installation of XCAP

Step Eleven: Select “PIXCI” in the toolbar and click on the “PIXCI Open/Close” option. This will cause a small window to pop up with multiple options. If most of the buttons are greyed out and unclickable, click on the “Close” button. This will activate the buttons.



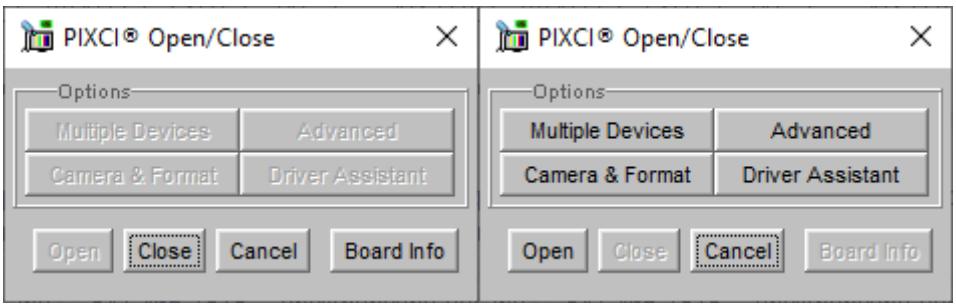
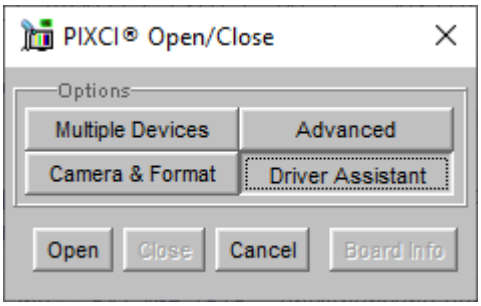


Figure 3.18 Installation of XCAP

Step Twelve: Click on the “Driver Assistant” option. This will open the PIXCI Driver Assistant window. Select the “Set PIXCI Frame Buffer Memory Size” option on the left. Under PIXCI Configuration, select “Request Normal Frame Buffer Allocation.” Under “Memory Requested for Frame Buffers” input 8000.00 MBytes. Click the “Apply” button.



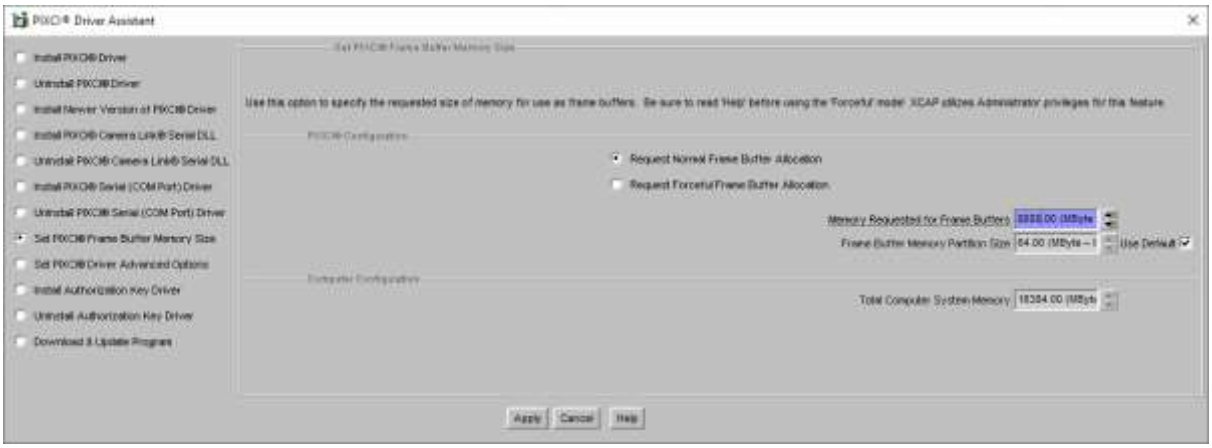


Figure 3.19 Installation of XCAP

We recommend selecting the "Request Normal Frame Buffer Allocation," which is referred to as "Normal" in the program. On "Memory Requested for Frame Buffers," select a memory of 8000 (MByte). This will cause the computer to reboot directly into the Windows system. This option will assign a small amount of buffer space to the image system. The number of recordable pictures is restricted, but the program has the advantage of having a high management efficiency of the imaging systems and is very fast with image manipulation. The specific number assigned should correspond with the actual physical memory of the computer system (meaning the sum of the two options cannot exceed the computer's memory capacity). Leave the default value in the third setting.

What does this memory allocation mean for the user? In a system using single-mode capture, a memory portion of the Normal 8 GB is allocated to the image. For example, for a CCD camera

with a resolution of 2048 × 2048 pixels, the size in 8bit is: 2048 × 2048 = 4194304 = 4MB x 2 (dual exposure mode saves 2 frames); therefore, the share in the computer memory is 8M. For 8 GB memory allocation, the total number of images saved can be 8000/8 = 1000. In this case, the software will be able to save and display 1000 acquired image pairs.

If the computer has a much larger physical memory, e.g. 32 GB, the user selected "Memory for Frame Buffer" will be 16 GB, "Memory for Windows" will be set to 16 GB (it's recommended that the Window System be higher than the reserved memory 512MB), the image buffer can be continuously saved and set to display 16 GB worth of image sets. For the CCD camera above, it result in 16000/8 = 2000 image pairs.

Windows operating system allocates memory to the image buffer. There is a number of differences between 32-bit systems and 64-bit systems. 32-bit Windows supports up to 4GB memory. In order to not affect the high-speed computing, 32-bit system memory allocation for the image buffer should not exceed 512MB.

64-bit Windows supports up to 128GB memory. In order to not affect the high-speed computation ability of the system, the image buffer memory allocation required should not exceed 16GB. Using US-made CCD cameras from IMPERX as an example (model VGA210), with a resolution of 640 × 480 and recording at 200 frames per second (fps) in 8-bit gray scale, a Windows 32-bit system will have the maximum recording time (into the memory of the PC) of 50 seconds. The number of results for the velocity field can be up to 10,000. Using the same camera as an example, with a Windows 64-bit system, the maximum recording time is up to 2000 seconds and the number of velocity field results can be up to 400,000!

Step Thirteen: A new window will appear telling you that the frame buffer memory request has been set. Click "OK." When you are asked whether you want to reboot, click "OK." Your computer will be rebooted.

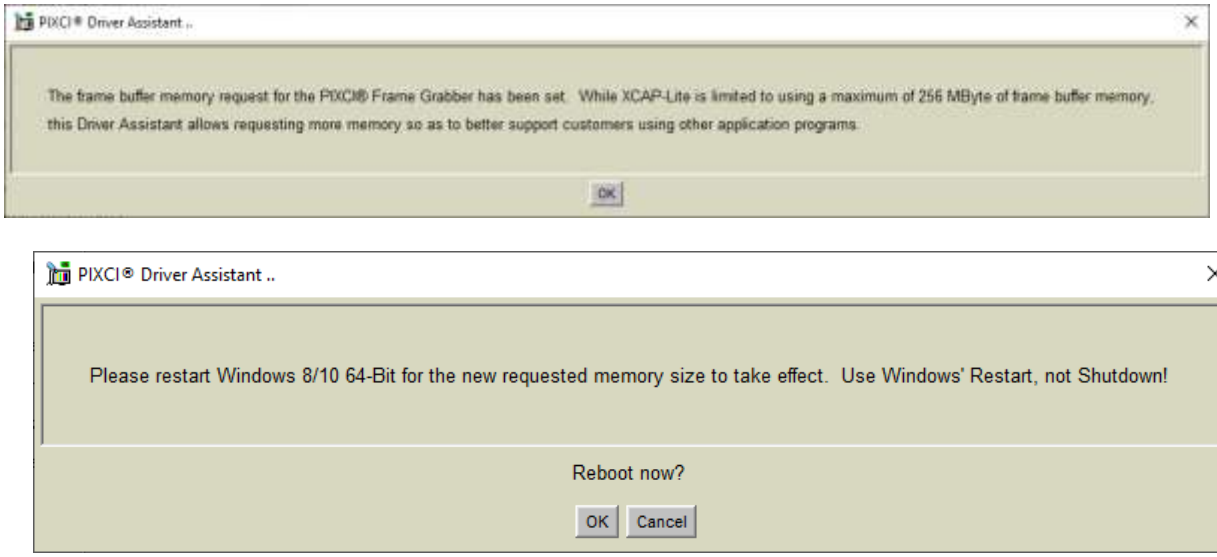


Figure 3.20 Installation of XCAP

3.2.3 Synchronizer

The synchronizer connects to the host computer through a USB cable. Microvec software installation includes all the software needed to run it. Therefore, there is no need to install the driver separately, Windows OS will automatically identify and install the appropriate driver.

After the software driver installation is completed successfully and the MicroPulse725 synchronizer is connected to the computer's USB port, the synchronizer will be seen in the 'Universal Serial Bus controllers' section of the Windows system hardware device list. See Figure 3.21 below.

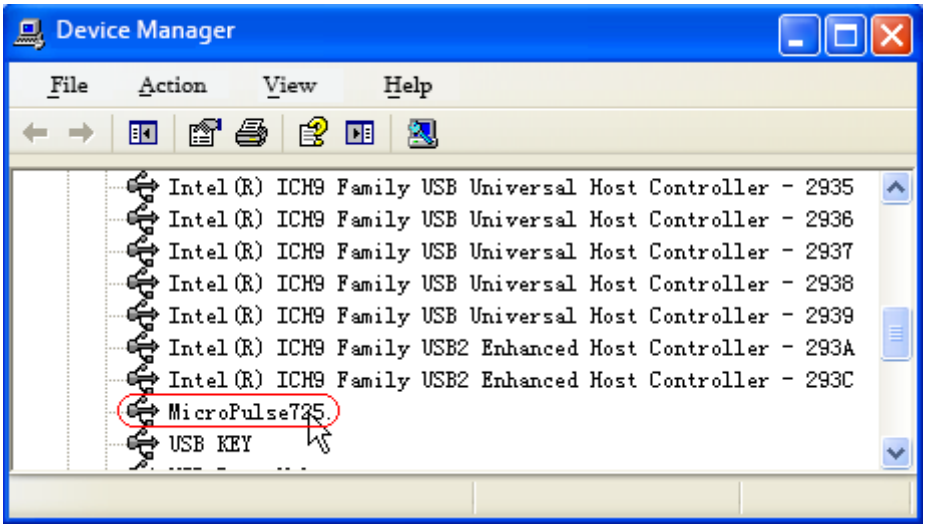


Figure 3.21 Synchronizer installation complete

Installation Notes:

When the MicroPulse725 reconnects to the computer's USB port, if the connection port is the same with that of the last connection, the Windows system will automatically recognize the device and will continue to use MicroPulse725.

3.2.4 Hardware Key (Dongle) Installation

Insert the USB key into the computer. Your computer will automatically start setting up the new device, as you'll be able to see by a notification on the bottom right of your screen. Once the computer is done setting it up, you will receive another notification stating that it's ready for use. This will allow Microvec V3 to function properly.

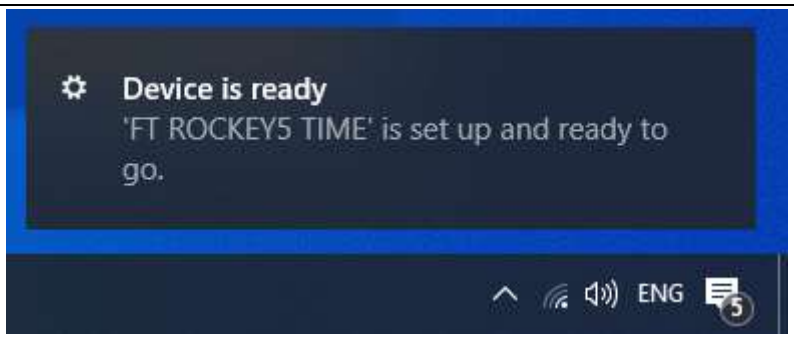


Figure 3.22 USB Key driver installation complete

3.3 Configuration files of the software

The Microvec installation directory (C:\Microvec) has a system configuration file named "Microvec.fmt". This file contains information about the parameters of the entire system's software and hardware.

Microvec 3.6.5 Initial File	Meaning of the parameters
[System]: 64_2D	There are 4 choices: 32-bit 2D and 3D system, 64-bit 2D and 3D systems
[CCD]: 51,0.0,0.0,0.0,0.0,2,12	7 figures represent the following: Range 0-55, type of the camera supported; camera 1 gain (negative value indicates left channel gain is greater than that of the right channel, a positive number means that the left channel gain is less than that of the right channel (cameras 2,3 and 4 are consistent with this); cameras 2 gain; cameras 3 gain; cameras 4 gain; camera channel settings (1 - represents single channel, 2 - represents dual channel); camera bit depth (8-12 bit)
[MICROPULSE]: 4,	Range 0-4; synchronizer version
[PARAMETER]: 0,0,50,0,0	The first parameter range 0-1 represent whether to enable the "Image right key menu responding"; second parameter range 0-1, represents the ability to enable the "image overlay displays message"; third parameter is to set the amount of memory when the GPU is computing; the fourth parameter range 0-1 represents whether to display vector nodes; fifth parameter range 0-1 represents whether to enable "Image store contain vector files."
[Laser]: 220.000, 220.000,236.000,235.000,233.000,233.000， 100.000,100.000,200000.000,0.000 100.000, 100.000,100.000,100.000,100.000,100.000,100.000,10,1,0,0,0	Representative of the various numerical orders (time units are μs): laser 1 light-Q delay parameter; lasers two lights-Q delay parameter; synchronizer Channel 5 in advance at the time of the laser Q1; channel 6 in advance of the laser Q1 Time; Channel 7 in advance in laser Q1 time; Channel 8 in advance in laser Q1 time; two laser cross-frame delay (computing speed time parameters); lasers senior set light threshold; lasers duplication cycle; lasers two light time relative to the laser is a light ahead of time The amount of time; Synchronization Channel 1 output pulse width, pulse width channel 2, channel 3 pulse width, channel 4 pulse width, pulse width channel 5, channel 6 pulse width, pulse width channel 7, the laser frequency limitation, the laser light-Q

	divider value, divided by the laser light-Q flag, laser Channel 2 locking channel 7 logo, external input trigger signal reverse (negative transition).
[DIRECTORY]: C:\Microvec, C:\Program Files\TEC360 2010\Bin\tec360.exe C:\Microvec\Help\MicrovecManual.chm ; C:\Microvec\PostPrecess\MicrovecPost.exe.	Contains three directory information: The first one is the system working directory; second is the Tecplot startup path (if after completing the installation of Tecplot, it can't start properly from the Microvec software, please check the path and file name, to see if they match)； third is the English language help document path; fourth is post-process software.

Microvec software reads and saves the system information in the following format (see specific parameters below):

3.4 Precautions

The above-mentioned particle image analysis system software requires Windows 10 Professional 64-bit operating system. Computer motherboards require Intel series chipsets with independent graphics to support and a minimum memory configuration requirement of 2GB. Minimum Hard Disc size should be 400GB.

The PIV image system requires a power ground line with reliable grounding. In the case of poor ground, static electricity or electromagnetic pulse interference to the camera or the synchronizer might be generated, affecting the high-speed image acquisition system. If the above phenomenon appears, you need to improve the overall system power ground connection and restart the entire system. I**n case of serious adverse ground, there might be damage to corresponding components; such damage is not covered in the warranty service range provided by Microvec.**

The above software needs 2 hardware components to operate: the EPIX frame grabber (Microvec software uses included XLIB digital processing library) as well as the USB hardware key (dongle). Both are provided by Microvec systems.

Chapter IV Summary of PIV

4.1 PIV Fundamentals

Particle Image Velocimetry (PIV) is an optical method of flow visualization used in education and research. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles (like smoke in the air or small hollow beads with the same density as water) in the flow field which is illuminated by the laser to illuminate the particles and make them visible in order to capture images of them to tack them. The sequential images with tracker particles in motion are then processed for cross correlation to calculate the speed and direction (the velocity field) of the flow which is being observed. Further processing can be done with flow vortices, flow lines and speed lines, and flow field parameter distribution. A typical PIV system configuration consists of a digital CCD or CMOS camera, a laser with an optical arrangement to limit the physical area to be illuminated, a synchronizer to act as an external trigger for control and timing of the cameras and laser, the seeding particles and the fluid under investigation. A laser light arm may be used to connect the laser to the lens setup, which then converts the beam into a line or sheet. PIV software is used to process the optical images. The sample system is shown in Figure 4.1:

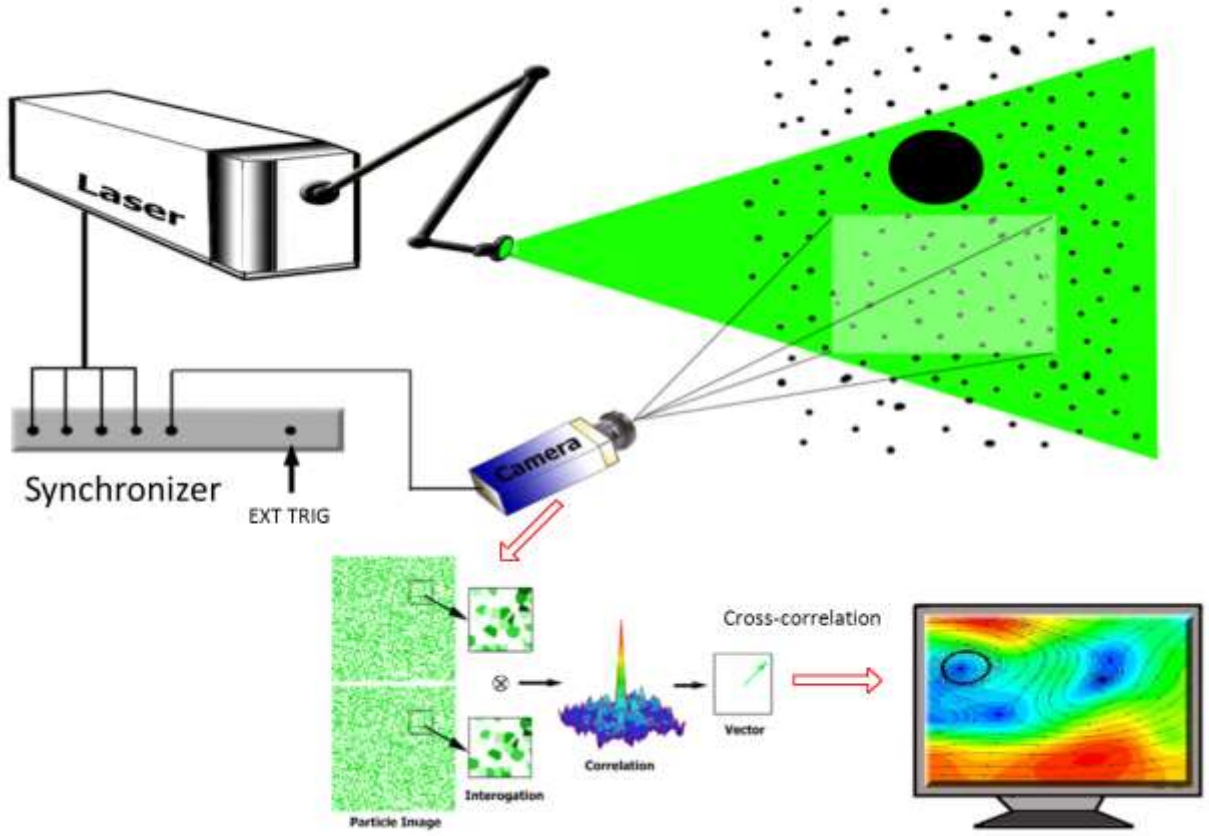


Figure 4.1 Sample PIV System

Within the known time interval Δt, the tracer particles following the movement of the fluid are emitted by the pulsed laser, and the sheet light illumination by the lens group records the instantaneous position of the particles on the CCD chip. If we know the displacement change of the same particle micelle at the two times t_1 and t_2, from the recorded particle image, the velocity of the particle group at t_1 can be obtained according to the definition of velocity, as in the formula (4-1), shown below.

$$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} \tag{4-1}$$

In general, there are three assumptions in PIV technology:

1. Tracer particles follow the fluid motion.

Since the PIV technique measures the velocity of fluid movement by measuring the speed of movement of the tracer particles, this requires that the tracer particles have good followability with respect to the fluid. Tracer particles with a diameter d ≤ 10 μm are better than fluid followability.

2. Tracer particles are uniformly distributed in the flow field.

If the tracer particles are not uniformly distributed in the flow field, a significant error vector is likely to occur at a particle concentration that is too large or too small. Partial error vectors can be removed by implementing vector correction, but if there are too many error vectors, they cannot be completely removed.

3. The interrogation window has a unique speed.

4.2 Cross-correlation theory

In the analysis of the acquired image, it is first necessary to clarify the concept of "interpretation area." It refers to a square image of a certain size in a certain position in the image, and the speed can be obtained by performing signal processing on the interpretation area.

Suppose the system acquires Figures 1 and 2 at two times, t_0 and $t_0+\Delta t$, respectively. Obtaining two interpretation areas f(m,n) and g(m,n) of the same size in the same position in FIGS. 1 and 2,

(m, n) represents the relative position of f and g in Fig. 1 and Fig. 2, respectively. The corresponding displacement s of the interpretation area can be obtained by processing f and g, as shown in Fig. 4.2:

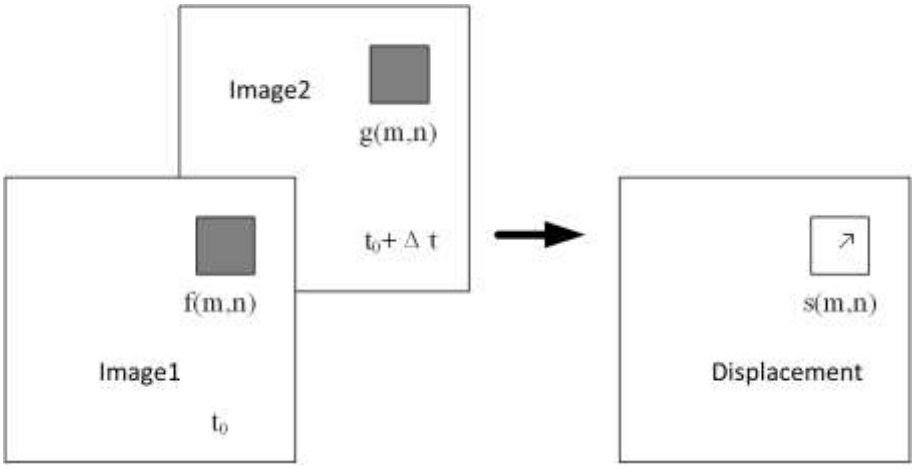


Figure 4.2 Cross-correlation calculations Schematic

The relationship between the digital signal transfer function between the interpretation areas f, g and the displacement vector is shown in Figure 4.3 (the uppercase letters in the figure correspond to the lowercase Fourier transform):

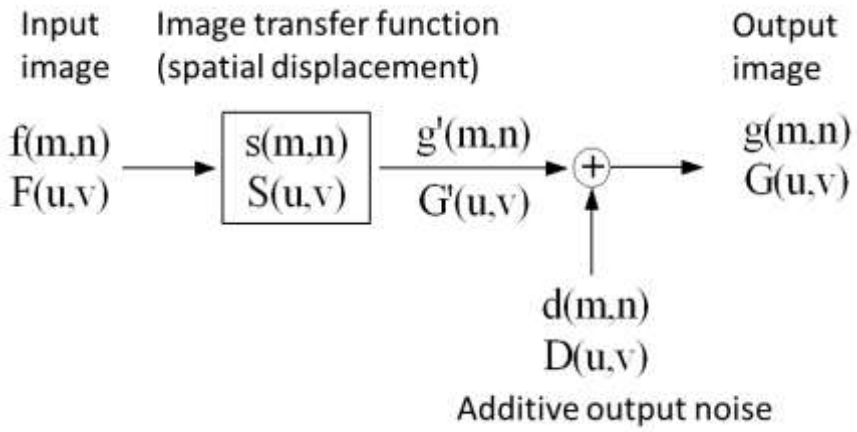


Figure 4.3 Cross-correlation analysis of the transfer function diagram

In Figure 4.3, f(m,n) represents the system input, g(m,n) represents the system output, s(m,n) represents the spatial displacement function (corresponding to the impulse response of the system), and d(m,n) represents the additional noise caused by the particles leaving the edge of the interpretation zone or the particles entering the screen due to three-dimensional motion. Of course, the original samples of f(m,n) and g(m,n) must also contain noise.

The main task of PIV image analysis is to calculate the spatial displacement function s(m,n), but the appearance of noise, d(m,n), complicates the problem. The entire system working relationship is:

$$g(m,n)=[f(m,n)*s(m,n)]+d(m,n) \tag{4-2}$$

* indicates the convolution operation of f and s. The time interval Δt at which the bit is removed to obtain the two images is the average displacement of the interpretation zone.

Assuming that the noise signal can be neglected, the Fourier operation on each side of (4-2) can be obtained by:

$$g(m,n) \approx f(m,n) * s(m,n) \Leftrightarrow G(u,v) = F(u,v)S(u,v) \quad (4\text{-}3)$$

The uppercase letters represent discrete Fourier transforms of the respective lowercase letters. The approximate result of S(u,v) can be obtained through the equation (4-2). If the effect of d(m,n) is negligible, the inverse transformation S(u,v) can restore the displacement function s(m,n). In order to accelerate the above-mentioned step operation speed, the fast Fourier transform (FFT) is used to speed up the operation when the discrete Fourier transform is performed, and the process of obtaining the speed from the image analysis by the PIV system is as shown in Fig. 4.4:

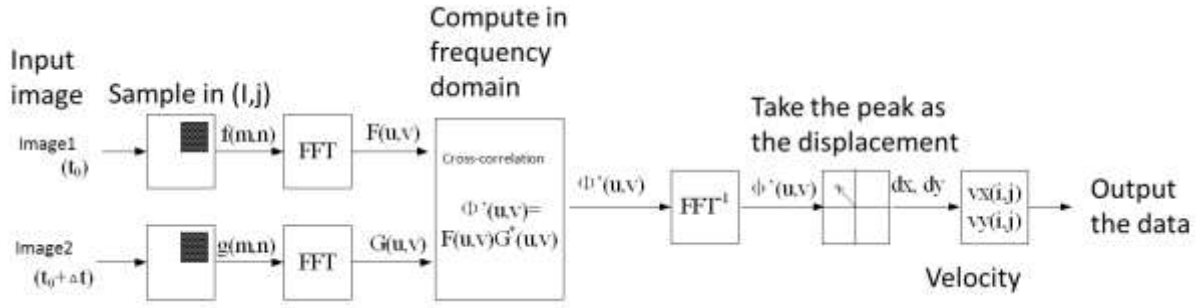


Figure 4.4 Cross-correlation calculation step diagrams

In the figure, dx and dy are the changes of the maximum value of the result in the two directions of x and y with respect to the center position after the Fourier inverse operation, respectively, vx=dx/Δt, vy=dy/Δt. References:

Willert CE, Gharib M. Digital digtal image correlation . Experiments in Fluids, 1991, 10: 181 ~ 193

4.3 Fluid Parameter Description

1. Vorticity

Physical meaning: The basic form of fluid micelle movement has translation, deformation and rotation. The vorticity marks the rotation of the fluid micelle. The vortex motion and the spinless motion are classified according to whether the vorticity is equal to zero. The square matrix composed of the spatial rate of change of velocity can be decomposed into a symmetric square matrix and an anti-symmetric square matrix. The anti-symmetric square matrix represents the volute tensor. The vorticity is a vector that is a function of spatial coordinates and time. Its spatial distribution determines the vorticity field.

Equation:

$$\Omega = \nabla \times u = \begin{vmatrix} e_x & e_y & e_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial_z} \\ u_x & u_y & u_z \end{vmatrix} = (\frac{\partial u_z}{\partial y} - \frac{\partial u_y}{\partial z})e_x + (\frac{\partial u_x}{\partial z} - \frac{\partial u_z}{\partial x})e_y + (\frac{\partial u_y}{\partial x} - \frac{\partial u_x}{\partial y})e_z$$

2. Amount of pulsation fluctuation

Physical meaning: The process of variation of pulsation quantity specifically reflects the irregular variation of random quantity. The formula is as follows: $\xi' = \xi - \overline{\xi}$

Where ξ represents the instantaneous value of the random variable and , $\overline{\xi}$ represents the time average of the random variable.

$\overline{\xi} = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} \xi dt$ 。

3. Shear strain rate

Physical meaning: the rate of change of shear strain or velocity in a certain direction per unit of time Equation: du/dy， dv/dx， $du/dx, dv/dy$， dw/dz.

4. Turbulence

Physical meaning: Turbulence is a parameter that represents the degree of disturbance in the incoming flow. The formula is: $N = \frac{\sqrt{\overline{u'^2}}}{u_\infty} = \frac{\sqrt{\frac{1}{3}\left(\overline{u_x'^2} + \overline{u_y'^2} + \overline{u_z'^2}\right)}}{u_\infty}$ Wherein $\sqrt{\overline{u'^2}}$ To u' Rms, represents u' The standard deviation, u_∞ For the incoming flow velocity, u' As u pulsation volume, u_x'， u_y'， u_z' For the three coordinate axis direction to flow velocity fluctuations.

5. Turbulent kinetic energy

Physical meaning: the turbulent kinetic energy characterization of fluid turbulence intensity.

Equation: . $k = \frac{1}{2}\rho\overline{u'_i u'_i} = \frac{1}{2}\rho\overline{(u'^2_1 + u'^2_2 + u'^2_3)}$

6. Reynolds stress

Physical meaning: the Reynolds stress [$-\rho\overline{u'_x u'_y}$] Can be explained by the plane perpendicular to the x-direction and y-direction per unit volume of fluid momentum. $\rho u'_x$ Said unit time on a plane

normal to the x mass per unit area, by u'_y After the unit time per unit volume of fluid momentum y direction, the [$-\rho\overline{u'_i u'_k}$] is due to the turbulence caused by the average momentum flow.

Equation: . $$\overline{\tau_{xy}'} = \begin{bmatrix} -\rho\overline{u_x'u_x'} & -\rho\overline{u_x'u_y'} & -\rho\overline{u_x'u_z'} \\ -\rho\overline{u_y'u_x'} & -\rho\overline{u_y'u_y'} & -\rho\overline{u_y'u_z'} \\ -\rho\overline{u_z'u_x'} & -\rho\overline{u_z'u_y'} & -\rho\overline{u_z'u_z'} \end{bmatrix}$$

4.4 Sub-pixel fitting

Since the minimum unit of the CCD chip recording the experimental image in the current PIV system is 1 pixel, the above cross correlation calculation result error is ±1 pixel.

Generally, for the interpretation area of size N=64 pixels, according to Nyquist's sampling law, the calculated displacement does not exceed N/2. At this time, the error is about 1/(64/2)=3.13%. This kind of error occurs when the speed of extracting from the image is not acceptable. Therefore, researchers have used the curve fitting method to improve the accuracy of the calculation results to ±0.1 pixel precision (i.e. sub-pixel precision), which can reduce the error to about 0.3%.

There are three main methods for sub-pixel fitting: center fitting, parabolic fitting, and Gaussian fitting. Three-point Gaussian fitting is the most widely used, and this fitting method is used in the company's development software. The Gaussian fitting formula is:

$$f(x) = C\exp[\frac{-(x_0 - x)^2}{k}] \qquad (4\text{-}4)$$

4.5 Error correction vector

In the real world, the image acquisition is not able in each local region to meet the requirements of uniform particle distribution; therefore, the correlation calculation result often includes a small error vector. A fast way of calculating a correction method is often essential.

The basic idea of the software correction of the error vector is: the fluid continuity equation, a calculation points around the difference between speed and cannot be too large, as shown in Figure 4.5:

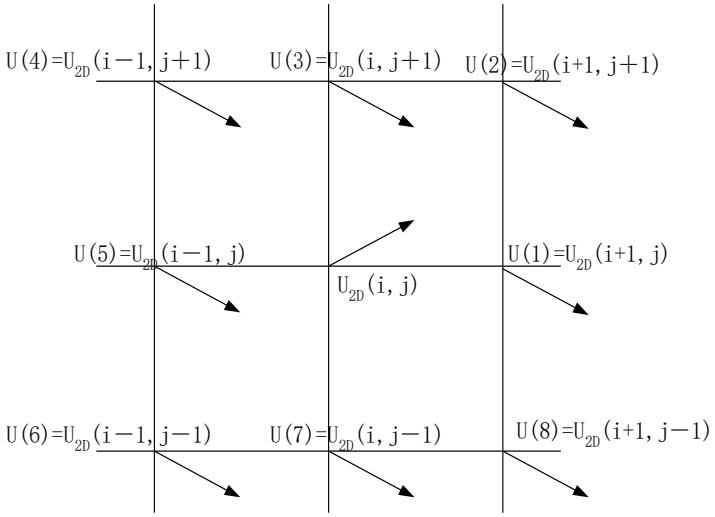


Figure 4.5 Schematic error vector corrections

U 2D (i, j) represents the calculated result, U (1)-U (8), respectively, results in around 8 results.

The Microvec3 software error vector used in the correction formula is:

$$\left|\vec{U}_{diff,n}\right| = \left|\vec{U}_{2D}(mean) - \vec{U}_{2D}(i,j)\right| < \varepsilon_{thresh} \qquad \varepsilon_{thresh} > 0 \qquad (4\text{-}5)$$

Among $\vec{U}_{2D}(mean)$ The U (1)-U (8) averages the eight speeds. To determine the threshold value, ε_{thresh}. (4-5) is expressed as $\left|\vec{U}_{diff,n}\right|$ Greater than the threshold value. ε_{thresh} , demonstrates that the calculated result is erroneous results, given the removed and median filtering algorithm with the calculation results instead of $\vec{U}_{2D}(i,j)$.

Median filtering algorithm: the calculation result of the surrounding adjacent U (1)-U (8). These eight results are sorted according to magnitude and the sorted intermediate values used to replace the calculation of this error.

4.6 Image Bias

Because PIV uses statistical cross-correlation to determine local flow velocity (see Section 4.2), inherent errors arise from finite tracer particle numbers, sample volume size, and image resolution. Normally the same position is selected for the interrogation window and used for cross-correlation calculation. The errors occur mainly because of out-of-boundary particle motion, correlations occurring between unmatched particle pairs, particle overlap, non-uniform particle distribution, and variations in image intensity. Image bias is mainly based on the assumption that the cross-correlation calculation results will show where there is a corresponding displacement of fluid particles. Therefore, rather than using the same position for selecting the second interrogation window, the calculated vector displacement can be used to calculate a new position of the second interrogation window

(bias image) – see Figure 4.6. Using the cross-correlation calculation on a bias image will generate more accurate results.

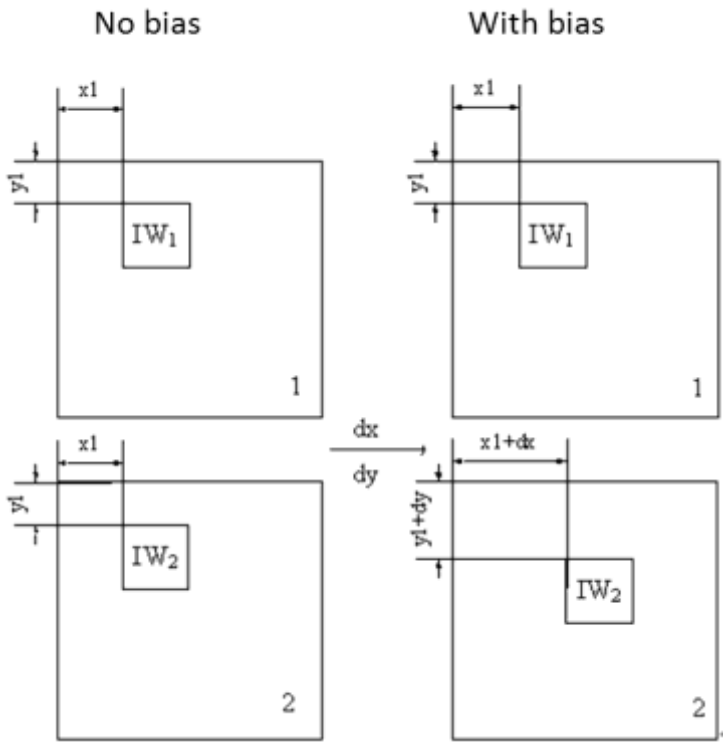


Figure 4.6 Bias illustration image

Reference:

Westerweel J, Dabiri D, Gharib M. The effect of a discrete window offset on the accuracy of cross-correlation analysis of digital PIV recordings. Experiments in Fluids, 1997, 23: 20 ~ 28

4.7 Iteration algorithm

As can be seen from the figure, the image bias algorithm can improve the signal to noise ratio of the cross correlation calculation. If we reduce the size of the interpretation area based on the previous calculation and then introduce the image bias algorithm, an iterative algorithm can be formed. Due to the combination of cross-correlation calculation and image biasing technology, the iterative algorithm results are more accurate than those without iteration, but the iterative calculation process is time consuming. An iterative algorithm is added to the Microvec3 software, and the number of iterations can be set.

Interpretation of the corresponding cell size (in pixels) iteration can be changed to: 128 → 64 → 32 → 16 → 8 → 4.

Second iteration follows (using large interpretations of the last calculation result of the cell, as the interpretation of a small cell next predicted values calculated using the predicted values of the image offset calculated cross-correlation):

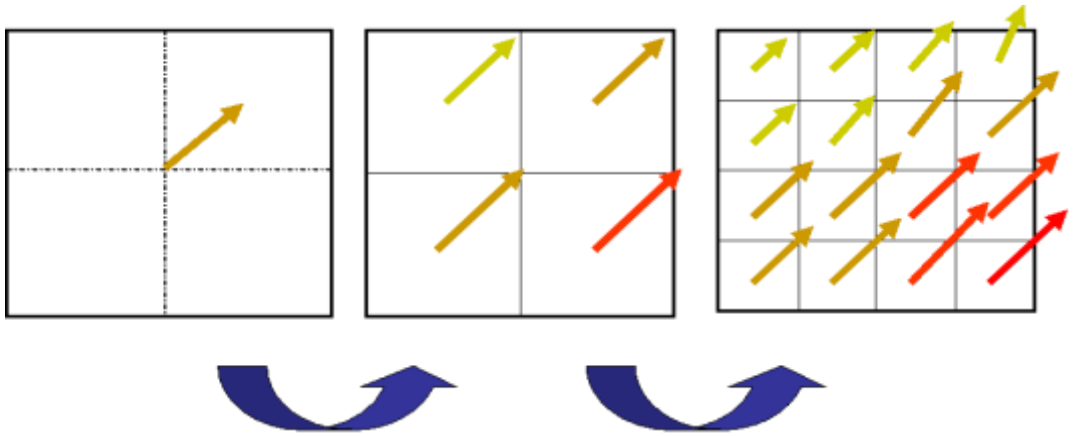


Figure 4.7

The iteration algorithm used by the interpretation of a small cell size of a large amount of displacement is calculated (over interpretation cell size) as possible.

4.8 Window deformation algorithm

For a relatively large vortex or a convective velocity gradient with a relatively large velocity gradient, the calculation result can lead to a loss of accuracy and the production of erroneous vectors. These erroneous vectors arise due to the inability of the algorithm to correctly identify particle pairs in consecutive images. The above shortcomings of the standard algorithm can be addressed by various improved algorithms including windows deformation algorithm, where the deformation process is based on the continuous image.

Correcting for this error requires an interpolation of the interrogation images that is based on the measured displacement field in the previous interrogation analysis.

In order to determine the image deformation, it is required to obtain estimates of the special gradients of the measured displacement field. These are typically obtained from the previous iteration. For each iteration it is necessary to re-interpolate the image data.

As an end result iterative windows deformation can offer an improvement in peak detectability and reduction of measurement error.

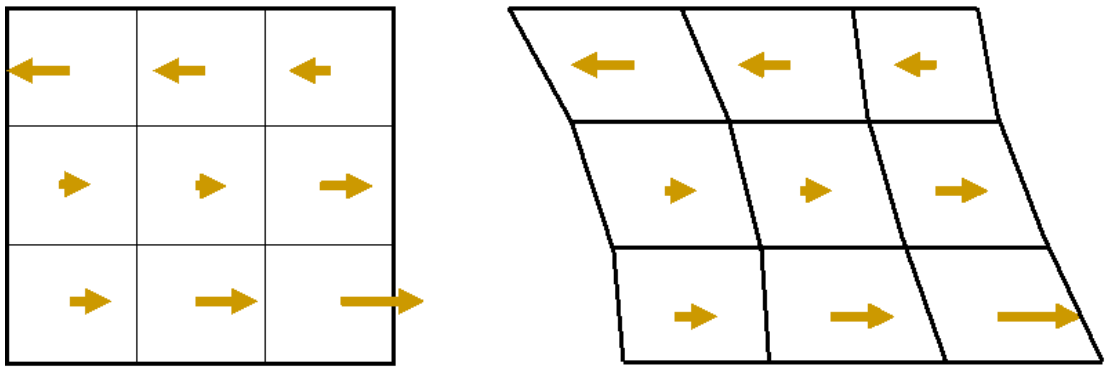


Figure 4.8

The Microvec system, through a combination of the above algorithm is effective to achieve high-precision measurement technology for PIV experiments to improve the overall system test measurements for different applications and reliability.

4.9 Measurement Accuracy

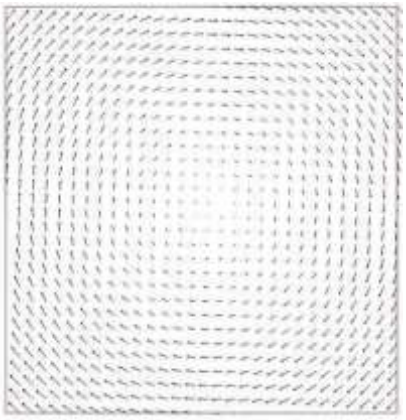


Figure 4.9 Artificial rotational velocity field results

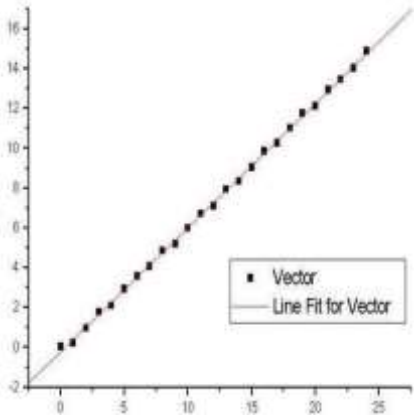


Figure 4.10 Analysis of the velocity field over the center curve

The error analysis of the particle image calculation result of artificial rotation 1.5 is shown in Figure 4.9 and Figure 4.10 (the calculation area is 32 × 32 square pixels, the calculation result is not corrected).

Figure 4.10 shows the velocity distribution along the radial direction of the center point and the linear fitting straight line. After linear fitting, the linear correlation of the actual calculation results is 0.99964, and the standard deviation of all the results is less than 0.1 pixels.

If the range of the actual measurement is 10 pixels, the relative error of the software system is less than: 0.1/10=1%.

The above simulation method is a typical numerical simulation and The measurement accuracy of the entire PIV system was measured by the 1.2-meter low-flow water tunnel of the Water Hole

Laboratory of BUAA. The turbulent flow field of the entire water hole was measured to be less than 1%, and the water hole motor was measured. The linear correlation between speed and flow rate is higher than 99.98%, which provides accurate standard parameters for high-precision testing of water tunnels and can only measure a major aspect of the measurement error of the PIV image system. In general, the measurement error analysis of the PIV system can be derived from systematic and random errors. However, in the actual PIV system, due to the existence of complex optical systems, laser systems, synchronous controllers, software calculations, etc., it is difficult to clearly distinguish between systematic errors and random errors; Therefore, in the actual evaluation of the total measurement error of the PIV system, the general method is to adopt the method of measuring deviation and uncertainty. At the same time, the PIV system can be used as a measuring instrument and can also be marked with a nominal error.

Moreover, in the actual measurement, the PIV system can be calibrated using a water hole with a good flow field quality. In addition, for many years, Monte Carlo simulations have been used to systematically analyze PIV image systems.

After many practical experiments, analyses and demonstrations, the measurement error of the PIV system is mainly related to the following aspects:

a, the particle size of the particles in the particle image;

b, the actual displacement size of the particles in the particle image;

c, the concentration of particles in the particle image;

d, particle image gray level;

e, particle image background noise;

f, the velocity gradient in the flow field;

g, particle loss caused by the motion of the sheet perpendicular to the sheet;

h, stability and consistency of the external triggering of the double pulse laser;

i, the trigger signal accuracy of the synchronous controller;

j, PIV system software parameter selection and processing methods;

k, PIV system experimental design.

Chapter V Microvec Software Overview

The Microvec V3 software developed by Microvec integrates the following functions: hardware control of the particle image analysis system, real-time digital image displaying and processing, real-time data acquisition and analysis, synthetic particle image velocimetry - particle tracking velocimetry (PIV-PTV), particle concentration, real-time particle size analysis. Lastly, the software provides a function module for measuring and analyzing the flow field and comprehensive experimental measurement solutions.

Overall user interface is shown in Figure 5.1:

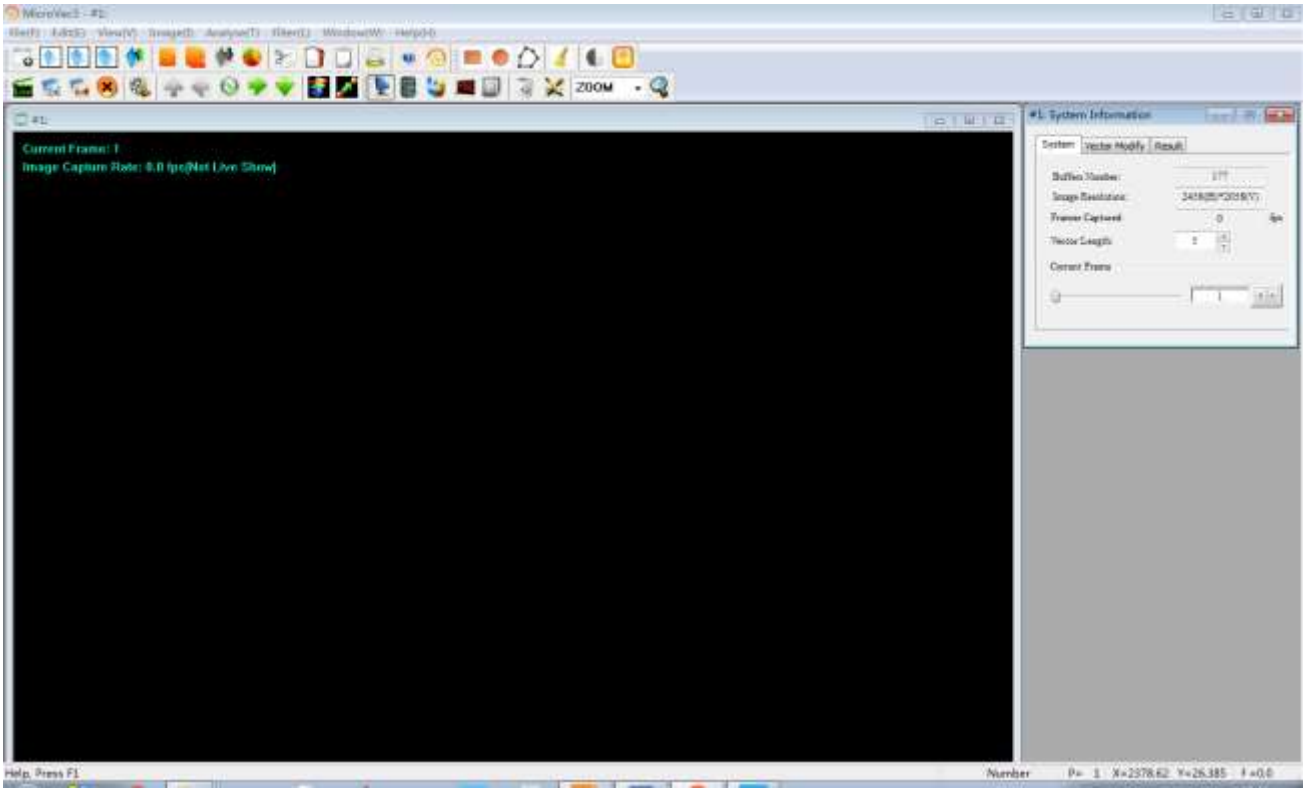


Figure 5.1 Overall view of the user interface

The interface is divided into four parts: the menu area, toolbar area, the image display area and the operating window area. The main functions of each part are as follows:

Menu area: Selection of menu commands;

Toolbar area: Displays shortcuts to commonly used commands;

Image Display: Displays images and the calculated vector maps;

Operating window area: Place for various operating windows.

Microvec V3 software's main functions are described below.

5.1 File Menu

The file menu includes open and store operations of versatile digital images and the velocity vector data file. Specific functions are described below:

5.1.1 New

 Open New Workspace command:

This command creates a new workspace, and prepares to initiate the image space. After a proper image board initialization, this command is greyed out. In the 3D system, this command can be used to open the corresponding image # 2 image board display area.

5.1.2 Open

 Open command:

This command opens an image (.BMP), and displays the image in the current image buffer. Image file formats supported are: BMP / JPG / TIFF / AVI / RAW / BIN. If the image has not been saved in the standard calculation size (currently supported camera spatial resolution), the image will be stretched into a standard calculation size for display.

For image files in RAW or AVI format, an image flip function can be used to browse pictures in the different frames of corresponding files. When the file size in these two formats exceeds the total size of image buffer, input image buffer position number needs to be browsed in the image buffer position of the system Information window. If a higher number of pictures than the total number of the picture buffer is required to browse, the image display window needs to be refreshed with the right key. At this point you may click flip function of the system Information window, and then return to the original picture browsing mode.

5.1.3 Command to open the image pair

 Open Image Pair command:

This command opens a pair of images. The two images are stored in the current and the next image buffer, and the first image is displayed.  Image board window specifies the current image buffer number.

Figures in these image files' names must be continuous. For example: Image008.bmp and Image009.bmp. If the current image buffer is specified as 2 in the  Image board window, the image Image008.bmp is stored in image buffer 2. In the main window display, image Image009.bmp is stored in image buffer 3.

If the image is not saved in a standard calculation size, the image size that is larger than the current image is scaled down to a standard size for display of the entire image. If the image is smaller than the current default size, the image opens and displays in its original size at the upper left corner of the window. The blank area is filled with black.

5.1.4 Command to open image sequences

 Open image sequence command (see Figure 5.2):

Open image sequence dialog box appears. Open the image series (.BMP) and start from the current image buffer to display the image series.

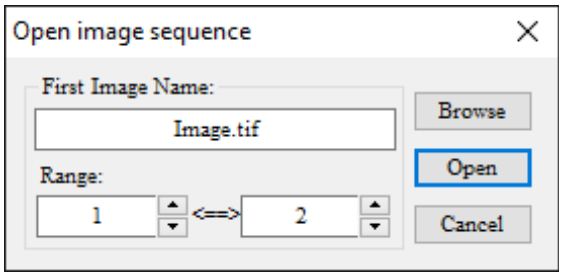


Figure 5.2 Open Image Sequence interface

If the image is not saved as a standard calculation size, the picture is scaled to a standard calculation size.

Range setting is used to set the image file you want to open, the starting point of the buffer (left input box) and end point (right input box).

Browse is used to select the path and name of the file you want to open (the name of the first file you want to open is displayed in the First file name).

Open button is used to open the corresponding image files into the image buffer, each file is sequentially stored in the image buffer according to the number in the file name.

5.1.5 Save

Save command saves the current image(s) from the image buffer according to the default name, path, and format.

5.1.6 Close

Close command closes the current workspace and image space.

5.1.7 Save as

 Save As command saves the current image buffer image as a new image file.

5.1.8 Save Image Series

Save Image Sequence command (see Figure 5.3):

This command prompts the Save Image Sequence dialog box to set the scope of the buffer in order to save the image, and to generate a number of new image files.

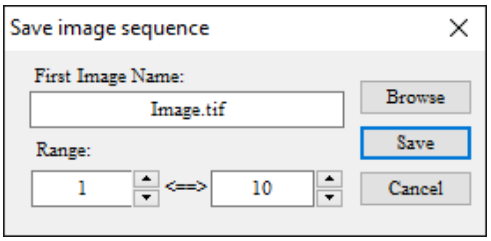


Figure 5.3 Sequence Interface stored images

Range setting is used to define the image series to be saved from the buffer based on the entered starting and ending points.

Browse is used to select the file path and name you want to store the images in (displayed in the First Image Name).

Save button is used to save the image from the image buffer to the corresponding image files, and each file is automatically saved in the name of the first image name with an added digital file number. Supported formats to save image files are: BMP / JPG / TIFF / AVI / RAW / BIN. If the AVI file format is selected, a dialog box with parameters would be displayed in the system settings command window.

5.1.9 Vector File Setting

Vector File Setting command (see Figure 5.4):

This command sets vector data in the current image buffer zone will be saved as a vector file (.dat) data format.

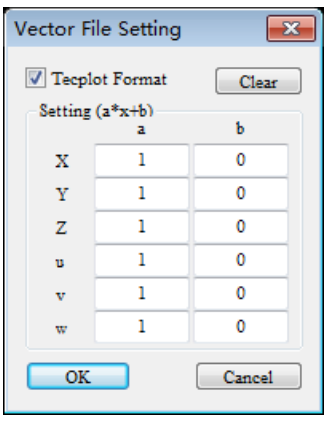


Figure 5.4 Vector file parameter setting interface

The parameters are defined as follows:

Tecplot Format	Tecplot data format as the output format (this is the default software format), you can open and display output data files directly in the Tecplot software.
XYZ	Used to set the display coordinates' magnification and panning effect.
u, v, w	Used to set the calibration and correction of PIV calculation result vector data.
a, b	Used to set the magnification ratio (a) and translation values (b) of all parameters.
Clear	Clear imported images and speed magnification data, restore the default value parameter.

When stored as a vector file, various parameters (coordinates, vector components and vortices) of data in the vector file here are multiplied by the corresponding parameters. The parameter settings are used to calculate the resulting image in pixels of the particle displacements. Then, it incorporates the exposure time yields velocity field results which are saved. These parameter settings also facilitate the binding characteristics of the original data size into dimensionless results (the calculation method is such that all data components are stored in the data file in the form a * x + b).

For definitions of specific import parameters, refer to the Ruler calibration process.

5.1.10 Open the vector file

 Open vector file commands:

This command opens a vector file (.dat) and displays it in the current image buffer.

Microvec vector file must be generated by the software, and saved in the Tecplot format. Corresponding calculation information is enclosed at the end of the file. It must be noted that the set parameters in the  vector file must be consistent with the calculation information appended at the end of the vector file. Any inconsistency may affect the display of vectors.

5.1.11 Save Vector File

 Save Vector File command:

Vector data in the current image buffer zone is saved as a vector file (*.dat) in the Tecplot format.

Vector file includes the following essential sections:

Header file: content and parameters compatible with the Tecplot file format.

Vector data: list of vector data files, each row provides the position coordinates of vectors (x, y, z), the three vector components (u, v, w), magnitude of the vectors, and vortices weight perpendicular to the image plane.

Calculated parameters:  This calculates major calculation parameters, which are used in the calculation window image and the original image file information, as well as  parameters in the vector file setting are saved here.

5.1.12 Vector File Flatten

 Merge Vector File command:

This command takes a number of PIV result data files in different regions and automatically matches them into a single data file (similar to the flatten command in Photoshop). when opening PIV result files at multiple different regions, it avoids the flow line incoherence or flow line cross errors phenomena. Figure 5.5 explains the functionality of this command.

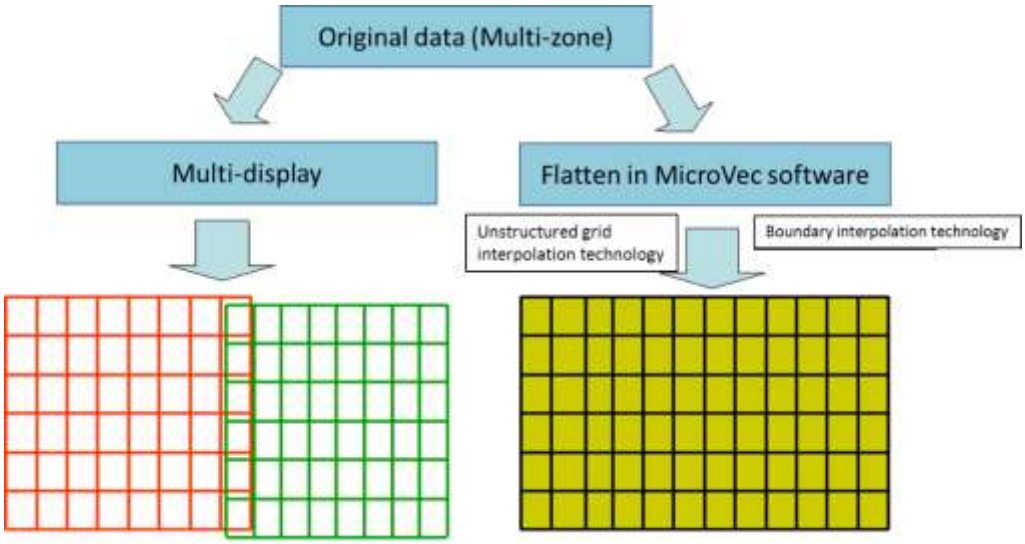


Figure 5.5 Vector File Flatten function

Operation sequence: First, the user has to click the Combined vector File command in the File option, and then select the data files they want to flatten (they must be included in the same directory, refer to Figure 5.6)

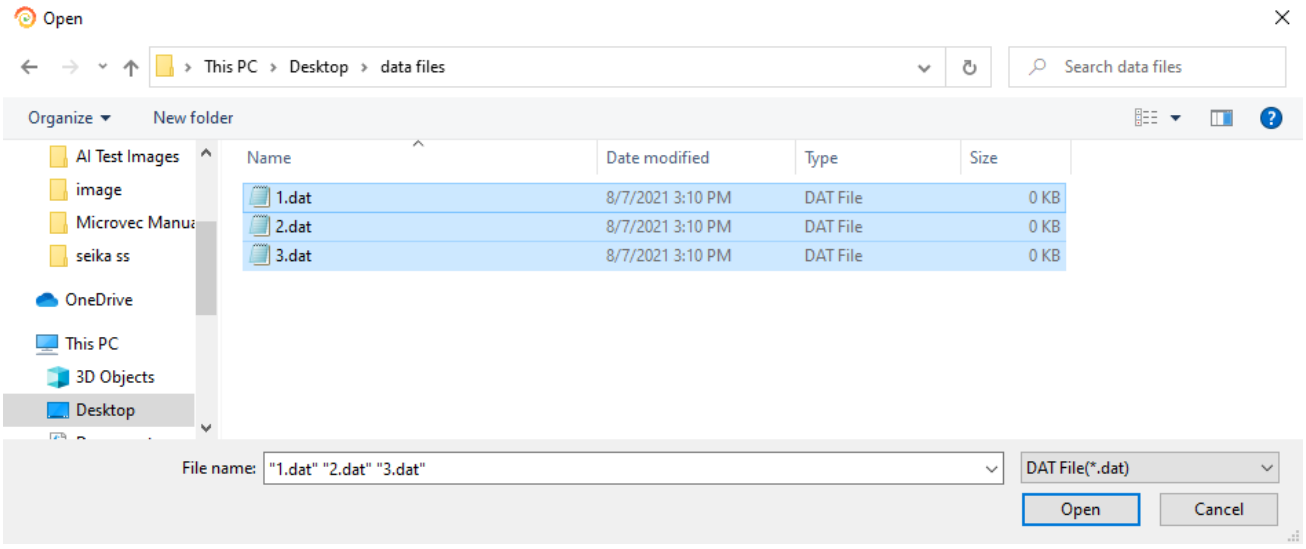


Figure 5.6 Interface to select the desired data files to be flattened

Upon clicking OK, a "Save As" dialog box will pop up to allow storing of the flattened result in a new file.

5.1.13 Exit

Exit command:

This command displays the exit dialog box, and the user can choose whether to exit the PIV software.

5.2 Edit Menu

Undo command:

This command erases the last change performed to the current image buffer. And vector calculation results are reverted back to its older state.

 Cut command:

This command extracts the currently displayed image (image becomes black background) in preparation for copying and pasting.

 Copy command:

This command copies the currently displayed image in preparation for pasting into another image buffer.

 Paste command:

The extracted or copied image is pasted into the current image buffer.

5.3 View Menu

View Menu brings up the most frequently used software and hardware control dialog windows and the corresponding shortcut toolbar of the Microvec3 software.

5.3.1 Toolbar

Toolbar is a shortcut toolbar which can be used to show and hide the most commonly used file operations (see Figure 5.7).

Figure 5.7 Toolbar shortcut toolbar

5.3.2 Status Bar Toolbar

The Status Bar Toolbar displays the coordinates of the current mouse position, image position and the progress bar of velocity calculations (it must be noted that this only shows in the iteration calculations or 3D calculations) in the PIV software view area (see Figure 5.8).

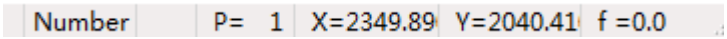


Figure 5.8 Status Bar

The parameters have the following meaning:

P	Buffer number corresponding to the currently displayed.
X, Y	Current mouse pixel coordinates (coordinate origin is in the upper left corner).
F	Acquisition rate (frames / sec).

5.3.3 Image Control Toolbar

Image Control Toolbar displays image control buttons in the view area of PIV software, and sets the check characters in the menu (see Figure 5.9 and Figure 5.10):

Figure 5.9 Image Control Toolbar

The icons have the following meaning:

	Real-time display images acquired by the camera
	Capture an image into the current image buffer
	Capture a pair of images to the current image buffer and the next image buffer
	Stop running camera and capturing images
	Hardware control window (including camera control, laser control and image recording window)
	Display the first image in the image buffer
	Display the last image in the image buffer of the current position
	Alternating display between the current and next image in the image buffer of the current position
	Display the next image in the image buffer of the current position
	Display the last image in the image buffer

Figure 5.10 Image control bar 2

The icons have the following meaning:

	PIV calculation window
	PTV calculation window
	System information window
	Image information window
	Histogram window
	Grayscale analysis window
	Vector calculation result window
	Clear vector window
	Digital ruler window
	Image magnification window

5.3.4 Image Analysis Toolbar

Image Analysis Toolbar displays image analysis buttons in the view area of the PIV software (see Figure 5.11), and sets the check character in the menu.

Figure 5.11 Image analysis toolbar

The icons have the following meaning:

	System parameter setting window
	Image Correction window
	Output analysis result window
	Particle analysis window
	3D PIV-PTV calculation window
	Multiple directory automatic calculation window
	Gray stretch window
	Image blur window
	Contrast adjustment window
	Image flip window
	Image calculation window

5.3.5 PIV Calculation

 PIV Vector Calculation window shows and sets the parameters for cross-correlation calculation (see Figure 5.12). The methodology used for the calculation is the cross-correlation algorithm explained in Chapter IV. This window sets the parameters for automatic PIV batch computing and for the 3D PIV calculations.

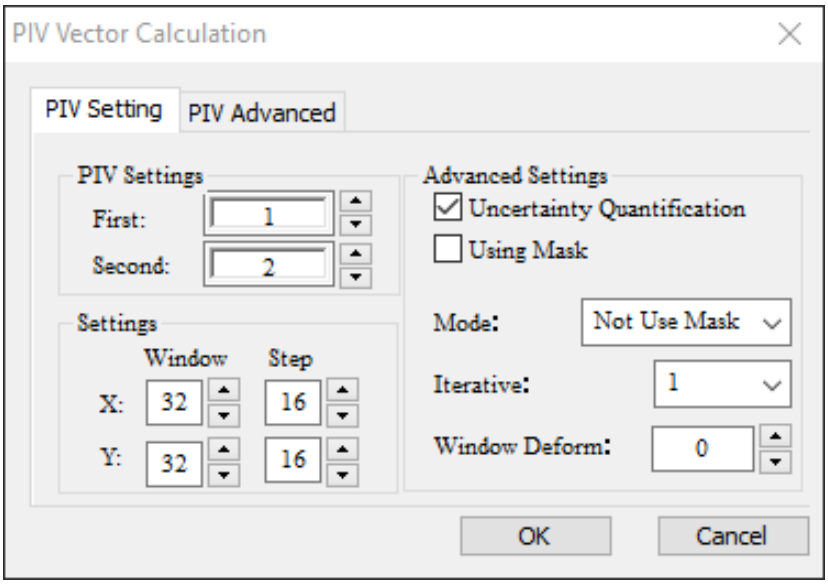


Figure 5.12 Vector Calculation Window

The parameters in the window have the following meanings:

PIV Setting	first	Select the serial number of the first image frame in the image buffer, which is used for the calculation.
	second	Select the serial number of the second image frame in the image buffer, which is used for the calculation.
Setting	X, Y	Calculates the coordinate origin at the top left; X represents the horizontal direction, the positive direction is from left to right; Y represents the vertical direction, the positive direction is from the top down. When saving the calculation results to use in Tecplot software, this program makes the corresponding flip according to the Tecplot data format (Cartesian coordinate system.)
	Window	Selects the interrogation window size for the cross- correlation calculation by clicking the up and down directional buttons. Here, six choices in total can be chosen: 4, 8, 16, 32, 64, 128 (in pixels).
	Step	The calculated distance between two adjacent vectors (in pixels), which is the spacing of the vector grid (the recommended parameter is a half of interrogation window size) of the final calculation.
Advanced Settings	Iterative	Iteration Algorithm: this first calculates velocity vectors by using a rough pre-calculation function. Then, the algorithm uses the results to guide grid encryption calculation (interrogation window size exponentially decreases and meshes encrypt exponentially). In this way, the premise of increasing the number of vectors and narrow interrogation of calculating the window size, computing time can be significantly reduced.

		This algorithm has three iteration steps denoted as 1, 2, and 3. The first iteration corresponds to the rough calculation of the first interrogation window size which is 1-3 times the current settings, The second iteration step refers to the calculation results yielded by using a doubly reduced interrogation window size. The third and final iteration uses the actual settings of setup parameters. If the interrogation window, size of the final calculation should be used as an 8 × 8 window, then the user should select the number of iterations of the algorithm as 3. In this case, Microvec software may first use a 64 (8 × 2 × 2 × 2) window for the rough calculation, then use 32 (8 × 2 × 2), 16 until the interrogation window size reduces to 8 in the final calculation.	
	Enable Image Mask	Template using the image boundary detection area set calculation to calculate masked area will not be calculated. This feature first requires the image boundary detection function to be enabled. See more information on using masks in Chapter 5.4.17	
	Window Deformation	Enables use of the image distortion correction function in the cross-correlation calculation. After completing the complete general PIV calculation, it conducts multiple additional window deformation algorithm amendments, which are used to improve the accuracy of calculations. If a value is set here, Microvec completes the first general computation, and then conducts a number of additional calculation cycles based on the window deformation algorithm and adds the number of corrections. Each time, the system will automatically update the calculation results and amend the original values. Since this calculation takes a long time, we recommend that the default value should be no more that 2 or 3. This is a good compromise between the calculation time and the effectiveness of the revised calculations.	
	Mode	Disable vector mask	This method is different from the "Enable previous result". We will recalculate the image pair on the selected area, regardless of the result of the last result.
		Enable previous result	the current results of this calculation are corrected according to the last result
		Enable vector mask	you can import a result that has already been calculated (usually a small area where multiple iterations or window deformations are used), and then select new calculation parameters to calculate the selected area

Advance settings window is shown in Figure 5.13:

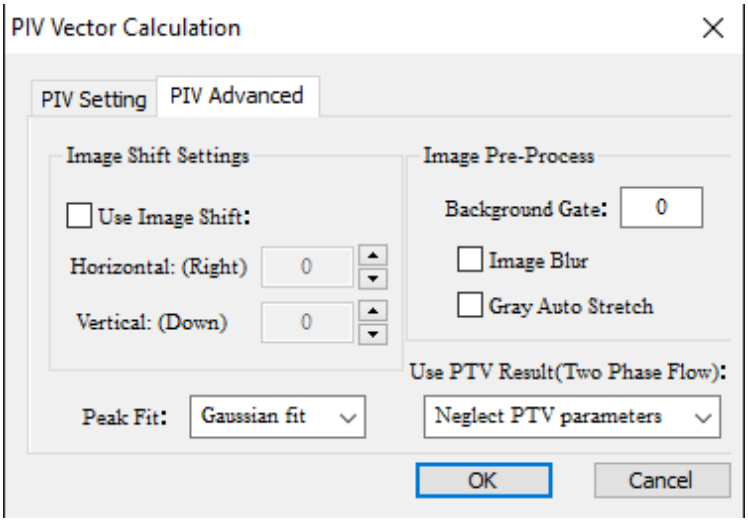


Figure 5.13 PIV vector calculation Advanced Settings interface

Compute with current vector	By this feature, a completed calculation result (typically a small area using several iterations or window deformation algorithms) can be imported, and then new calculation parameters can be chosen based on the selected area to be recalculated	
Prebias Setting	Horizontal (right)	The first frame before the calculation can be manually moved to laterally offset a set number of pixels.
	Vertical (down)	The first frame image can be calculated before the artificial bias longitudinal movement of a set number of pixels.
Background	When this parameter is non-zero, the system will calculate the actual first two images simultaneously before subtracting the value set. This function is used to subtract a uniform background light effect or residual noise common in CMOS cameras.	
Peak Finding	Cross-correlation analysis of the selected peak fitting algorithm, Gaussian fitting, parabolic fitting, and the center of gravity fit in three ways.	
Use PTV Result (two-phase)	Neglect PTV setting	Performing cross-correlation analysis is not considered when calculating the window particles PTV search parameters.
	Apply PTV setting	During cross-correlation analysis, PTV is calculated using the parameters in the search window particles for PIV calculation.
	Apply PTV Remove particles	During cross-correlation analysis, PTV is calculated using the parameters in the search window particles after striking out, and then PIV calculation.

5.3.6 PTV computation

Particle Tracking Velocimetry (PTV) is a non-intrusive optical measurement method which obtains each of the velocity vector by tracking individual particle. PTV uses singly exposed frames with a pulsed laser (or continuous laser for slow flows), and matches particle pairs from frame to frame. Particle velocities are then found by calculating the displacement between matched particle pairs and dividing by their displacement times. PTV offers the advantages of increased spatial resolution and decreased computational cost.

 PTV Calculation menu selection brings up the window corresponding to a set of parameters required for PTV calculation.

This window provides Particle Tracking Velocimetry function (PTV), seen in Figure 5.14. It identifies different sizes of particles and their spatial location, and calculates displacement of each particle through the adjacent image pair. Combining with the exposure time, information such as the spatial distribution of particle position and speed each particle is determined.

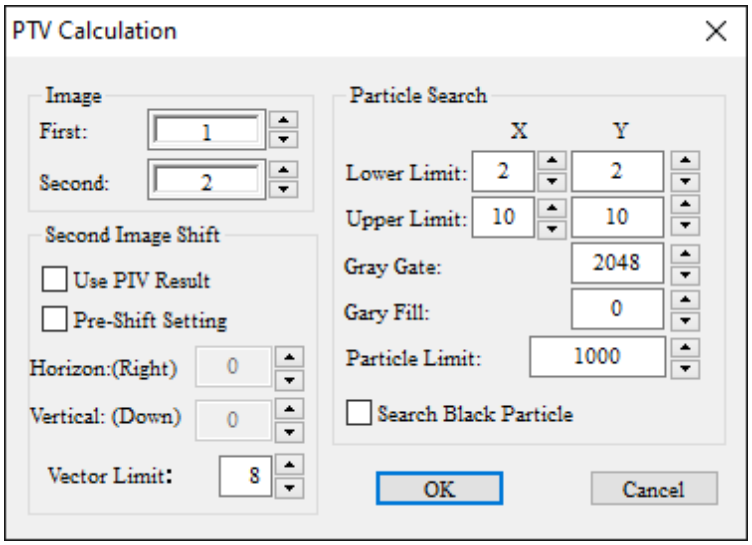


Figure 5.14 PTV Calculation Window

The definitions of these parameters are provided in the following table:

Image setting	First Frame	Frame number of the first picture in the image buffer involved in the PTV calculation.
	Second Frame	Frame number of the second picture in the image buffer involved in the PTV calculation.
Refer PIV Result	If the particle density in the images used for calculating PTV is relatively high, we recommend using the first image PIV function to perform PIV calculations, and only then use PTV calculation. Selecting this function to calculate high concentrations of particles can effectively improve the matching accuracy.	
Pre-bias setting	Horixontal (Right)	Transverse image pre-bias of the second picture involved in the PTV calculation.
	Vertical (Down)	Longitudinal image pre-bias of the second picture involved in the PTV calculation.
Vector Length	To search for setting the maximum particle displacement value (this value should be set to less than the maximum distance between the particles. If the distance between particles is too large lowering the exposure time between the images is recommended. This may narrow the limit of vector length. Otherwise, the probability of particle searching for matching error can be increased).	

Particle Data Setting	X	Lateral (positive direction from left to right)
	Y	Longitudinal direction (positive direction from the top down)
	Diameter (min.)	Set to search for the smallest particle equivalent length and width of a rectangle
	Diameter (max.)	Set to search for the maximum particle equivalent length and width of a rectangle
	Gray	Set the threshold to distinguish between the particles and the gray background for threshold binarization
	Gray Fill	Gray value to fill in the pixels in identified particles. This value should be lower than the gray threshold. The default value is 0.
	Number	Set the maximum number of particles to be searched
	Search Black Particle	If it is in the white background, the image of the black particles needs to use this option.

5.3.7 Real-time calculation result show

Demonstrates real-time calculation camera to particle maps and is continuously refreshed in real time. Before using this feature, the user has to conduct a 2D PIV calculation (here, it is recommended that an appropriately smaller window size should be used for a quick calculation and displaying fresh results).

5.3.8 System Information

 This dialog box displays system information (see Figure 5.15): The system information displayed includes system parameters, vector correction parameters and formation of calculated results.

System parameters displaying image board and system-related hardware information:

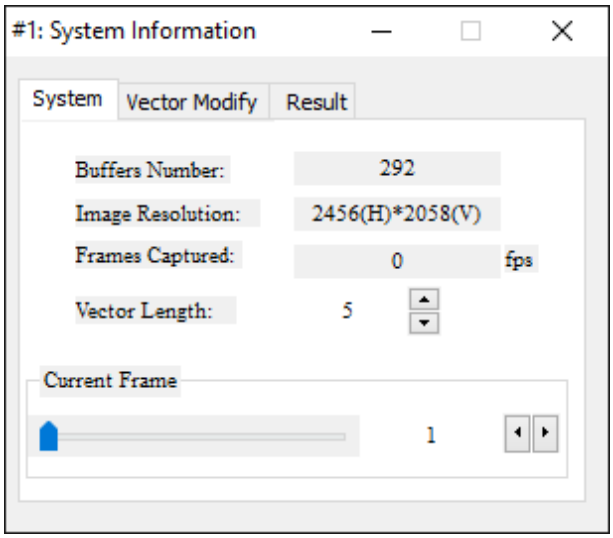


Figure 5.15 System Information window

The parameters have the following meaning:

Status	Buffers Number	This is the PIV software memory allocated to image buffer which underlines the total number of images that can be stored (For specific image buffer partitioning methods, refer to the Chapter corresponding to the introduction of the software).
	Image Resolution	Show the camera Image Resolution (pixels).
	Frames Captured	The number of images per second acquisition system (frames / sec).
	Vector length	Magnification of displaying vector length, which can help to better visualize distribution of vectors.
	Current Frames	Currently displaying image in the image buffer location, ranging from 1 to the number of images being displayed in the image buffer.

Filter: This displays the window used for correcting velocity vectors (see Figure 5.16). When keeping this window active, and right-clicking on the resulted vector image window, the user can click from the vector value at the recent correction window of velocity vector U, V and W values. And when left-clicking on the result vector image window, the velocity vectors can be corrected according to the vector correction parameter values entered. The options on the vector result correction.

While keeping this window active, but also on PIV batch, the multi-dimensional PIV catalog automatic batch and vector calculations automatically corrected.

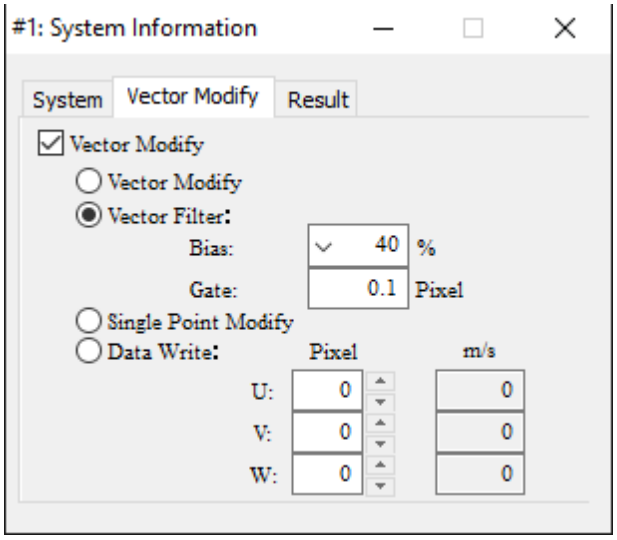


Figure 5.16 Vector modify window

The parameters have the following meaning:

All Point	Correct all vectors obtained by calculation.
Vector filter	Left-click anywhere on the velocity vector results. "Vector Bias" filters out errors in the calculation point (see the Section on algorithm for correcting vector errors in Chapter IV and relevant sections). The "Vector Bias" used in a predetermined cross-correlation calculation ranges from the average, a figure of 10% means that less than 10% deviations of calculated vectors are considered correct vectors. This parameter ranges from 10-80%, and if the fluctuation of velocities expected is not very dramatic, it is recommended you use more than 40% of the option. Otherwise, the flow field could be smoothed out. "Filtering threshold value" calculation is used to determine whether a vector correction is intended. Only if the calculated vectors are greater than the set threshold do the vectors need to be corrected.
Single-point	The selected point from the left mouse button with the recent velocity vector averages around eight velocity vectors, and then with this value to the value instead of the original synthesis. Synthesis point value is replaced to the original values occupy the center of gravity of the weight values.
Data Write	U, V, W, are horizontal, vertical, and the out-of-plane velocity components of the UV plane, respectively. Right click on a vector to get its pixel displacement (the “Pixel” is the pixel displacement) and actual velocity (the “m/s” is the actual velocity).

Information: This tab of the system information dialog box displays information on estimated parameters (see Figure 5.17):

This window displays information corresponding to the most recent results such as the calculation of time and the number of estimated velocity vectors. It should be noted that this window may be displayed only after the end of calculating velocity vectors.

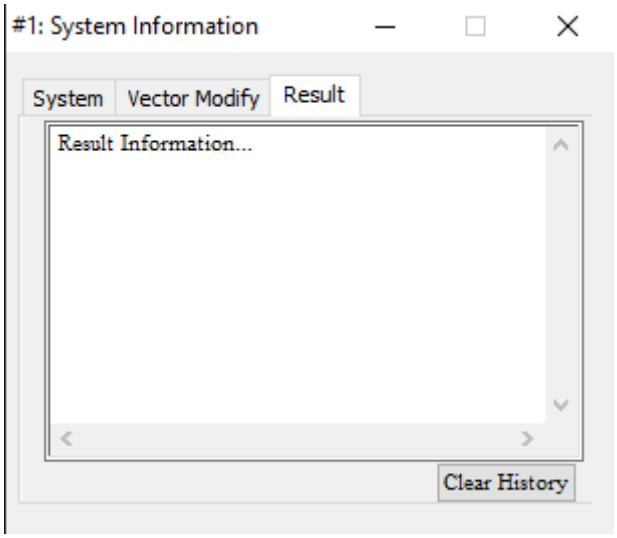


Figure 5.17 Result information window

5.3.9 Image information window

 Image Information window. Click this command and click the left mouse button on the image, then display a 9×9 pixel window which represents the gray value of 81 points around the selected position and mark a rectangle at the corresponding position in the image display window .

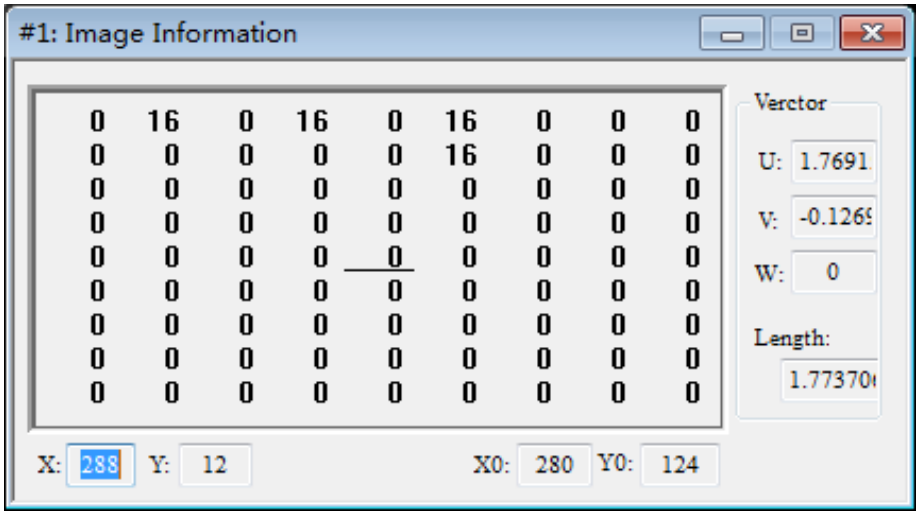


Figure 5.18 Image information window

The parameters have the following meaning:

X	Horizontal x-coordinate of the selected point
Y	Longitudinal Y-coordinate of the selected points
X0	x-coordinate of the velocity vector, which is the nearest from the selected point
Y0	y-coordinate of the velocity vector, which is the nearest from the selected point
U	Horizontal component of the velocity vector
V	Vertical component of the velocity vector
W	Velocity component in the third direction perpendicular to the XY plane (out-of-plane component)
Length	Size of the velocity vector

5.3.10 Histogram window

 Histogram window displays the histogram distribution (see Figure 5.19):

A histogram is a measure of the amount of digital image exposure standard characteristic values; the figure window shows the gray map images from left to right which represent the number of pixels in the darkest to the brightest statistical distribution of the number of pixels.

This window displays the current image pixel grayscales from 0 to 1023 (10 bit) of the statistical distribution. Move the illustration of two triangles, then press the "Apply" button so the calibration data can be modified according to image gray value distribution. Carrying out this operation allows the entire image contrast to be deepened. The ruler of this command is often used in the shooting; the right of the recovery command can automatically restore the most recent changes in imaging applications.

If the histogram distribution of emphasis is on the left side of the window, it indicates that most of the pixel gray values is small, which means that the image brightness is dim; conversely, if the histogram distribution is on the right side, the image brightness is categorized as bright. Therefore, for proper image exposure histogram distribution, there should be emphasis on the middle and it should be more evenly distributed.

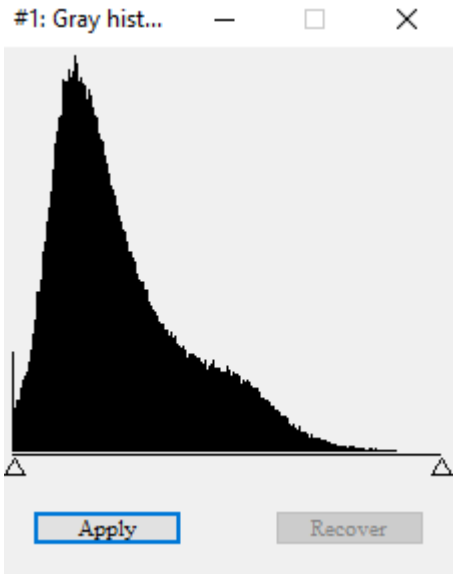


Figure 5.19 Gray histogram window

5.3.11 Grey Analysis

 Grey Analysis displays a grayscale analysis window (see Figure 5.20):

Online grayscale analysis window consists of two main parts: the left area displays each pixel of the image in the main window on the line intensity distribution; characteristic parameters are displayed on the right side.

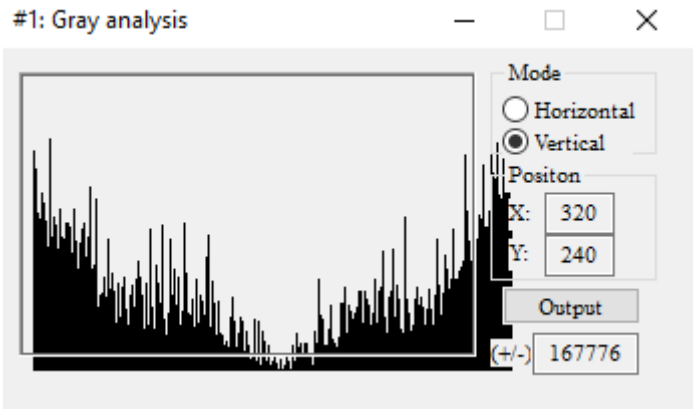


Figure 5.20 Gray window

The parameters have the following meaning:

Horizontal	In the main window, click the left mouse button and draw a horizontal line.
Vertical	In the main window, click the left mouse button and draw a vertical line.
X	x (horizontal) coordinate of points selected by the left mouse button.
Y	y (vertical) coordinates of points selected by the left mouse button..

(+ / -)	Image gray value on the line parity line contrast, the greater the contrast, the sharper the image, the higher the value.

5.3.12 Vector result

Vector result shows the vector result list window (see Figure 5.21):

This window displays the calculated numerical values with vector file formats. The results shown in this window have the following columns from the left to right: u-direction coordinate, v-direction coordinate, w-direction coordinate, u direction speed component, v direction speed component, w direction speed component, velocity magnitude, vorticity field results, u direction velocity standard deviation , v direction velocity standard deviation, w direction velocity standard deviation, standard deviation of velocity magnitude, and the standard deviation of vorticity.

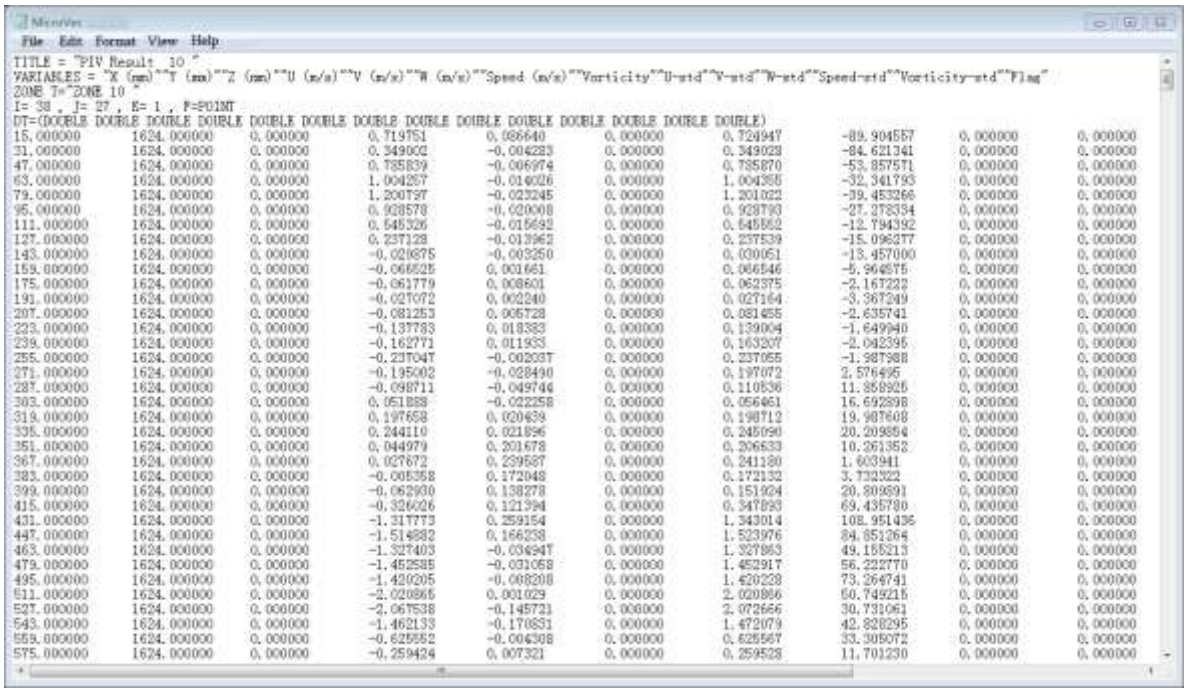


Figure 5.21 Vector results window

5.4 Image menu

Image menu includes a digital camera control command, the buffer and the main image display control commands.

5.4.1 Real-Time Display

Real-Time Display command:

The image data from the digital camera is continuously fed into the current image buffer area and the image being displayed is continuously updated in real time.

5.4.2 Capture an Image

 Capture an Image command:

This command captures an image to the current image buffer area, and displays the image.

5.4.3 Capture Image Pair

 Capture Image Pair command:

Captures a pair of images into the current and next image buffers and displays the image in the current image buffer.

5.4.4 Stop Running

 Stop Running command:

This command stops various tasks on the image board to freeze the current image in the image buffer.

5.4.5 Hardware Control

 Hardware control (see Figure 5.22) includes camera control, laser control and image recording. If the synchronizer is also connected, the window shown in Figure 5.22 is prompted. If it is not connected, an error message may pop up saying: No MicroPulse 725 V5 synchronizer! Please check your computer's USB port is connected to the controller and synchronizer! (MicroPulse controller software driver is in a file in C:\Microvec\synchronous drive directory). Note: do not use a USB extension cord of the synchronizer, because it can lead to a communication control error (as the extended USB cable is too long and is likely to cause interference in signal transmission).

Camera Window:

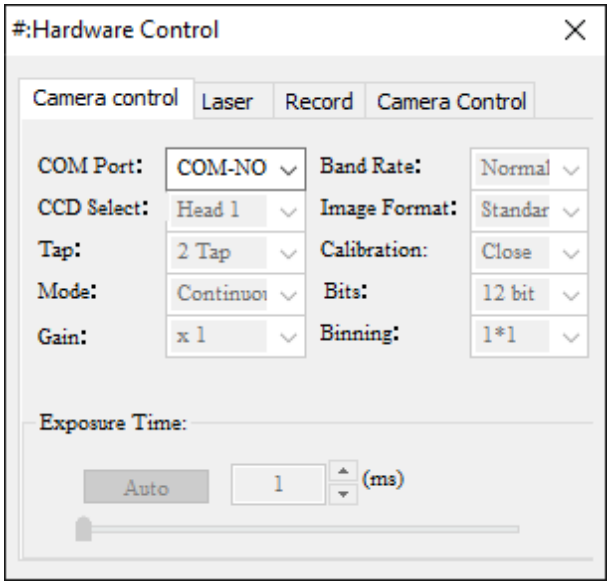


Figure 5.22 Camera control window

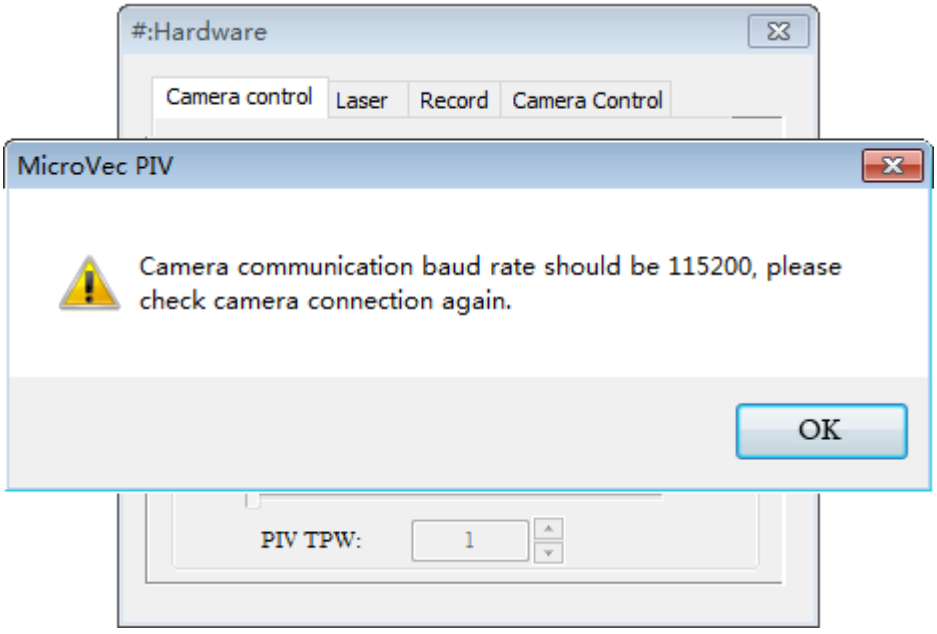


Figure 5.23 Camera communication error

Camera Control window is used to detect and set the frame grabber to connect to a digital camera in working condition. First, the "Port" should be set to the "CamLink" option to initialize the camera, and to detect the camera and its working conditions. The detection will be shown in the camera control window. If not detected, the error message shown in Figure 5.23 will pop up. In that case, the user needs to check the appropriate hardware connections (including signal lines and power lines), but you can plug the camera power on the camera software reset, but not hot-swappable Camera data cable.

Camera malfunction troubleshooting: If the camera does not work properly, you can detect if the camera itself has failed or if it is a signal failure. In continuous mode, using real-time display function, check that the camera acquisition rate and the image display is working normally. If this is not the case, the camera itself has failed. Check the power cable and/or CamLink cable to see if they are

properly connected. If the continuous mode is normal, then the camera is ok. In this is the case, select the PIV mode and click “RUN” to see if the camera can capture frames. If it cannot, check the synchronization of the camera to see if the BNC cable is connected correctly or if it is faulty. You can also check the output signal of the synchronizer (available via a synchronous control laser, check the normal laser light to determine whether the sync signal is ok).

Speed		The camera's clock frequency can be fine-tuned. This will affect the digital camera acquisition rate.
Mode	Continuous	Set the camera to operate at maximum continuous acquisition mode, the camera will automatically use the highest sampling rate and operate in continuous image acquisition mode to acquire images into the buffer. The exposure time for each image is based on parameters set by the exposure time.
	Trigger	The digital camera is synchronized to the external TTL trigger input signal, the exposure time for each image is based on parameters set by the exposure time.
	Control	The digital cameras TTL inputs the external trigger signal synchronization, the exposure time of each image corresponds to the external input trigger signal pulse width settings.
	PIV mode	PIV mode allows two events (two images) to be captured in rapid succession using a single trigger pulse. Upon receiving the trigger signal, the camera starts integration for the first frame, completes the integration, transfers the information to the vertical registers and then captures the second image. While capturing the second image, the first one is being read out. The minimum time between the frames is around 200 ns. In PIV mode, there are two important points: 1. If a continuous light source is used, you will find the first image partially dark, because the second image exposure time (milliseconds) is much larger than the first image exposure time (microseconds). 2. When a double pulse laser is used for lighting and the images are different, it is because the pulsed laser light intensity is not the same and the light intensity for pulses needs to be adjusted accordingly.
	FPS Control	Set the image rate for the camera and the camera will capture images continuously. The exposure time for each image is set by the exposure time.
Binning		The process of combining the data in a group of pixels into a single pixel, such as a 2×2 to increase the brightness of the combined pixel by factor 4.
Gray Output		This feature allows the user to change the group of bits sent to the camera output and, therefore, manipulate the camera brightness. The user can implement up to 7 bits left or right digital shifts. The internal camera processing of the data is 14 bits. If the camera is set to output 10 bits of data, then the four least significant bits are truncated. In some cases, the user may need to convert from 14 to 10 bit by preserving the 4 least significant bits and truncating the 4 most significant ones.

Laser Control window (see Figure 5.24):

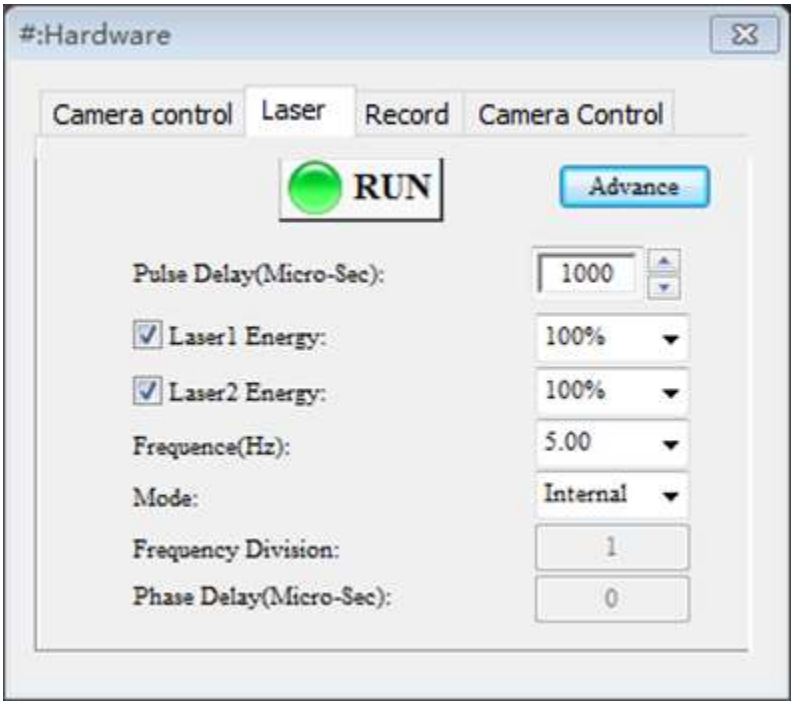


Figure 5.24 Laser control window

Buttons corresponding to the following meaning:

Run / Stop	Run the system by setting parameters - laser emits laser work / stop operation of the current system
Advance	Set the system to run detailed parameters

Note: If you want to change the normal working hours laser operating parameters, read below:

Click the "Stop" button to stop the system operation;

After setting the parameters, click the "RUN" button. The computer will change the settings in the associated hardware device and the system setup parameters will run with the new setting values.

Window parameters have the following meaning:

Pulse Delay（Micro-Sec）	The value defines the separation between the two laser pulses and it is also determining the time between two exposures of the camera Δt.
Frequency	Sets the PIV system frequency indicating how many image pairs are captured per second.
Mode	Sets synchronization mode. Internal: sets the synchronization of the entire PIV system based on the PIV set frequency. External: sets the synchronization of the entire PIV system based on the external input signal which is connected to one of the synchronizer INPUT ports.
Frequency Division	This mode is active only when External synchronization is selected. It sets the frequency division (for example: a 1KHzperiodic external trigger signal can be set to a frequency of outer portion 100, so that the entire PIV system will operate in1K/100 = 10Hz).

	You can use software trim to control the intensity of laser output pulse.
Phase delay (Micro-Sec)	When the lasers are operating in external sync with the outer gate, the lag time on the outside of the trigger signal will show.

Click the "Advance " button, you can see the following time parameter setting window (Figure 5.25):

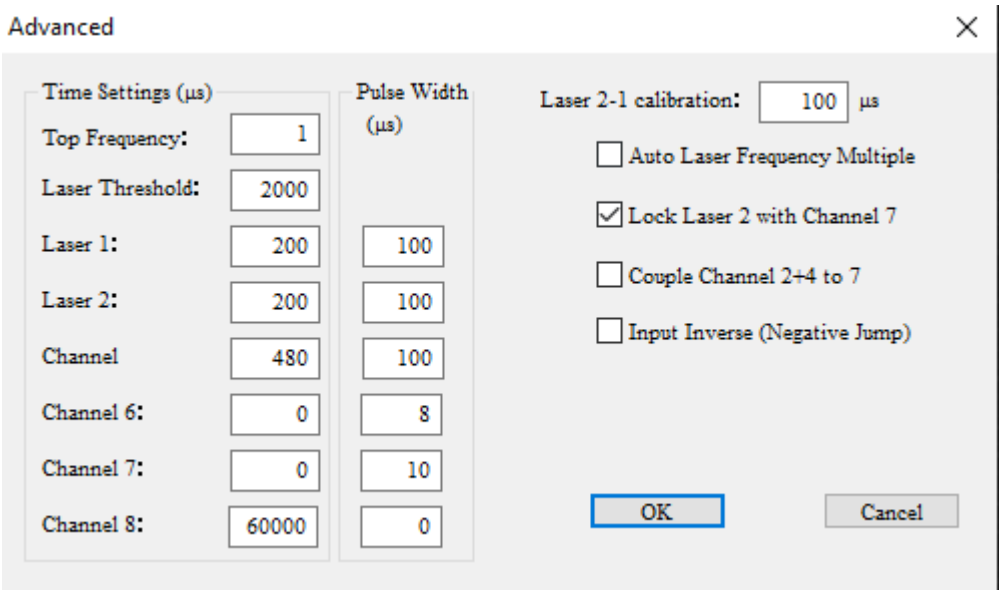


Figure 5.25 Advanced settings window of laser control

The parameters have the following meaning:

Top Frequency	Limits the operating frequency of the laser, which is determined by the camera synchronizer, laser systems such as hardware parameters are then notified of the decision. When the actual operating frequency is set outside the range of the software you will be given a warning.
Laser threshold	Regulates the laser's internal adjustment parameters, which means that the Q-switched laser is higher than this value after at least open to the laser. This parameter is available only on the software to adjust the laser output energy work and does not affect other functions.
Laser 1 and 2	Adjusts the laser's internal adjustment parameters (discharge flashlamp and Q-Switch delay between the trigger signal, see details in the laser manual).
Channel 5, 6, 7	Working out the camera trigger or PIV mode, the laser light before (200 microseconds) to open the double-pulse laser capture (camera work out for different trigger condition, it is recommended parameter is 100 micro-seconds). Note: In the TR-PIV system, the signal output channel 7 is channel 2 and channel 4 signals or outputs coupling.
Lasers 2-1 Calibration	B Q-switched lasers trigger the signal ratio of channel A Q-switched laser trigger signal advance or delay time.
Auto Laser Frequency Multiple	When using this mode, the laser discharge flashlamp will automatically multiply to integer multiples of the operating frequency, then it will be less than equal to the Advanced Settings inside the maximum operating frequency.
Lock Laser2 with Channel 7	The second channel and the seventh channel are locked to operate at the same frequency and phase.

Couple channel 2+4 to channel 7	The second channel and the fourth channel signal is coupled with the channel VII which uses a two-way channel that can be completed on the laser control (mainly used in the TR-PIV).
Input Inverse (Negative Jump)	The external trigger signal to reverse high into low or low rpm to high. Also a corresponding conversion between rising and falling edges.
Pulse width	The trigger signal pulse duration, which is the duration of each trigger signal.

Image recording window (see Figure 5.28):

Recording window allows for a continuous recording of digital image data by a digital camera and the image buffer according to the preset number and serial saving mode. The image buffer according to the serial number can be set to a display mode and displays an image sequence.

When recording images to the selected image board, this function mainly takes into account the above two frame grabbers present in the system, and flexible settings can be made.

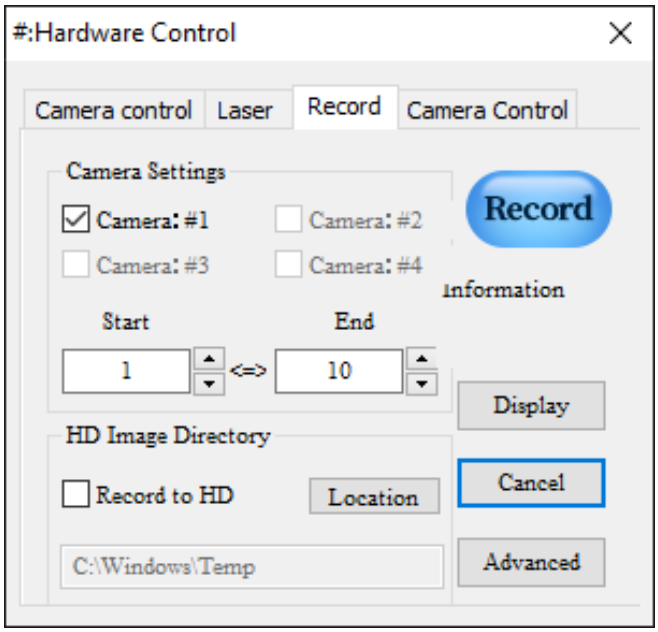


Figure 5.28 Image recording window

The parameters have the following meaning:

Frame Grabber	Select the image acquisition card using the corresponding image space. The two CCD being used need to be chosen and tested using a single CCD default to the 1st image board.
Start and End	Images captured by digital cameras are sequentially stored in the buffer area by the image start position to the end position (the total number of images). System Information windowhas a limited number of image buffer.
Advanced	Advanced image acquisition and display configuration options (see Figure5.29).
HD Record	In the image acquisition process, the images are saved directly to the hard drive. As it relates to hard disk operations. In order to ensure continuous recording speed, we recommend using a disk

	array system or reducing camera image acquisition rate, but recording extra image sequences. When the digital ruler window is active, this function saves only the selected image area Ruler.
Record	In accordance with a pre-set serial number. Saves the image buffer method to collect images.
Live	In accordance with pre-set serial number. Saves the image buffer in continuous display images.

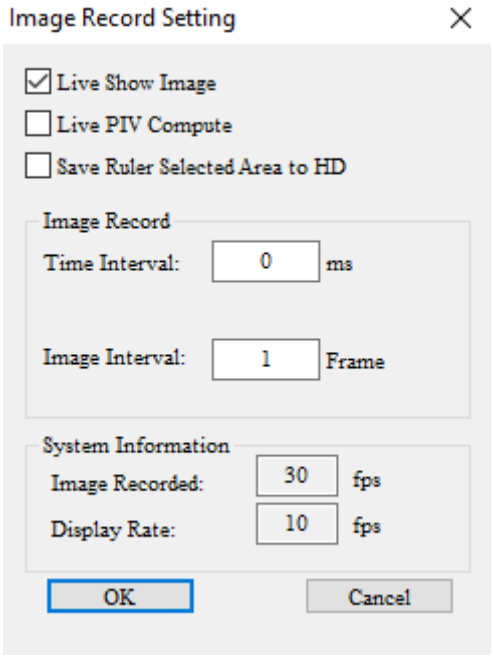


Figure 5.29 Image record parameter setting window

The parameters have the following meaning:

Record With Display		In the process of image acquisition, the screen displays the current image capture and record keeping and is refreshed in real-time.
Live PIV Computation		In the image acquisition process, the results are displayed in real-time, preferably with the GPU functions.
Ruler Region Recorded to HD		When the camera is obtaining images, it will only save the selected region to the HD
Record Setting	Time Interval	Set adjacent to two consecutive images captured during an image acquisition time interval, the parameter set to zero indicates that the camera works with the highest collection rate.
	Odd-even Interval	Set the image on the two-image acquisition time interval. In this case, the time interval between two adjacent images means the time interval between the images.
	Image Interval	Captures images acquired with a number of images skipped between.
System information	Record Speed	System acquisition rate.
	Display Speed	System displays rate.

Note: Use the images recorded directly, if you want to record only a part of the image area, the image area to be recorded should be selected by opening the digital gauge panel, and then the user can click on the recorded image. If the digital gauge window is closed, the image recording mode records the entire image.

5.4.6 Pulse delay settings

If the user has no clue what the Pulse delay time should be, Pulse Delay time needs to be calculated after the calibration using the “Straddle Time Estimate.”

PIV experiments carried out across the frame delay setting require a critical parameter. Setting it incorrectly can make image post-processing troublesome; thus, the user should take all precautions to set this parameter correctly. If the fluid flow rate can be controlled or can be estimated, the software itself can be used to provide cross-frame interval estimation functions.

First, the digital gauge must be selected, and then a rectangular area check-box opens the scale image. Afterwards, the nominal dimensions must be chosen, which correspond to the length of the input values.

Secondly, click on the Zoom Rate followed by the Straddle Time Estimate. Then, fill in the maximum flow velocity of the actual flow field at the “Velocity Max.” Finally, click “Straddle Time” to obtain the estimated value of the pulse delay time, then you can fill the time in the “Pulse Delay (Miro-Sec)” (as shown in Figures 5.26, 5.27).

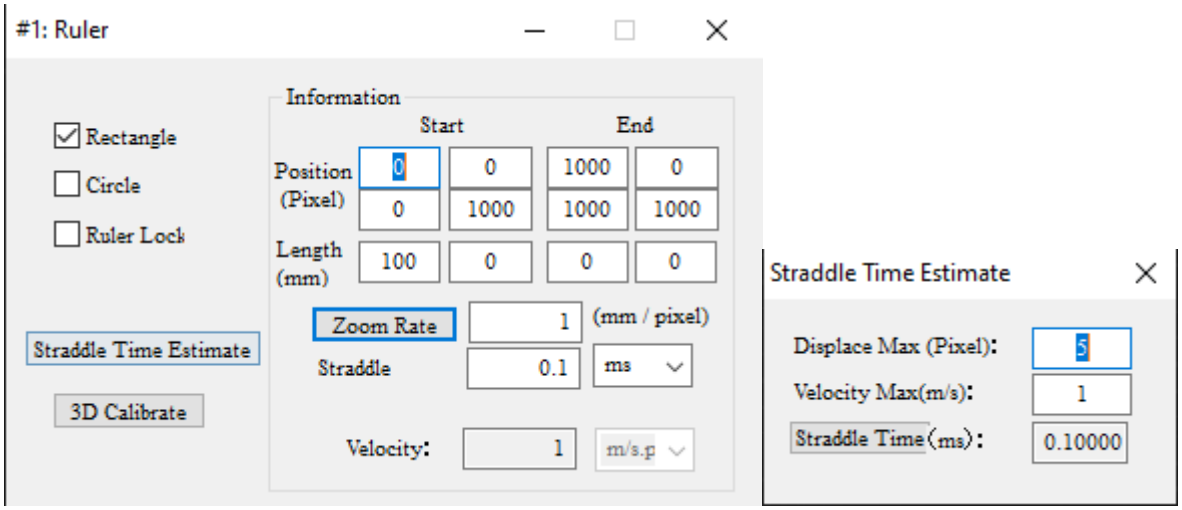


Figure 5.26 Exposure time estimation

$$\delta t = \frac{\delta d \frac{D}{R}}{V_{Max}} \qquad (5\text{-}1)$$

: Pulse delay time (Second)

: The maximum displacement of two images does not exceed 1/4 of the interrogation area. For example, when the interrogation area is 32*32 pixel , δd is less than or equal to 8 pixel.

: Camera shot of the flow field area (m)

R: Camera resolution (pixel)

: The actual measured flow field maximum flow rate. (m/s)

E.g., the interested flow field area is D * D = 70.40 mm*58.99 mm; Camera resolution is R*R=2456*2058 pixel: The maximum pixel displacement between two frames of particle images is 8 pixels. According to the formula, calculated Pulse delay time is $\delta t = 29\mu s$.

(5-2)

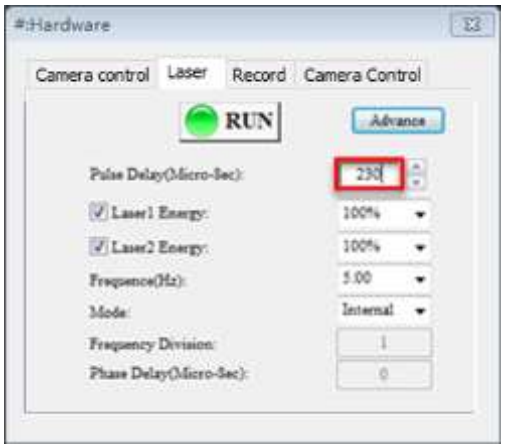


Figure 5.27 Pulse Delay settings

The estimate by the inter-frame time may not be the most suitable cross-frame delay in order to achieve good test results. Thus, it is necessary to adjust the estimated inter-frame time. If the estimate is slightly out of the inter-frame time and is increased or decreased to shoot some pictures of the vector correction, then select the image of the local rough calculation, calculation after calculation information window view, if the fix rate of 30% or less can basically meet the test requirements; correction lower but if the length of the vector is smaller, by a slight increase to increase the inter-frame time to reduce the length of the vector calculation error, to a certain extent if the adjustment vector correction ratio exceeds 30%, the inter-frame time is slightly smaller then the test tone; if flow conditions is unknown, can experience a number of experimental set: inter-frame delay for supersonic test can be set to 1-2us; tunnel at wind speeds of several meters to the range of tens of meters can be set within the range of 10-500us, normally set to tens of microseconds; tunnel experiment fluid flow is usually a range of a few centimeters to several meters, the frame delay setting range across several the range of microseconds to several milliseconds, you can usually set a few hundred microseconds to several milliseconds; these reference values according to the above principles to follow to make the appropriate adjustments, until you find the best parameters so far.

Note: The exposure time estimate function only estimates Pulse delay time. Sometimes, the actual Pulse delay time needs to be adjusted according to the particle images or calculation results.

5.4.7 Show first image

 Show first image command:

The first image is set to the current image buffer, and displays the image in the image buffer.

5.4.8 Show previous image

 Show previous image command:

The current image buffer zone on an image is changed to the previous image buffer, and displays the image in the image buffer.

If the current image is the first image buffer, the command becomes invalid and still displays the first image in the image buffer zone.

5.4.9 Show next image

 Show next image command:

The next image is set to the current image buffer, and displays the image in the image buffer.

If the current image as the last image buffer, the command is invalid, still displays the last image in the image buffer.

5.4.10 Display two images alternately

 Display two images alternately can alternately display the current image and the next image in the image buffer. This can be used to assist manual identification of two images.

5.4.11 Show last image

 Show last image command:

The last image is set to the current image buffer, and displays the image in the image buffer.

5.4.12 Show image

Show image command:

This command should only be chosen to display the image. Otherwise it is just a black background (Cancel image display can show more clearly the results of vector distribution).

5.4.13 Image average

Image average command:

Average command is used to capture an image of an image sequence in gray scale. This is done by considering image intensity values at positions and super-positioning those values to get the spatial average. Thus, this command generates a new image after the last image on the system buffer as shown in Figure 5.30.

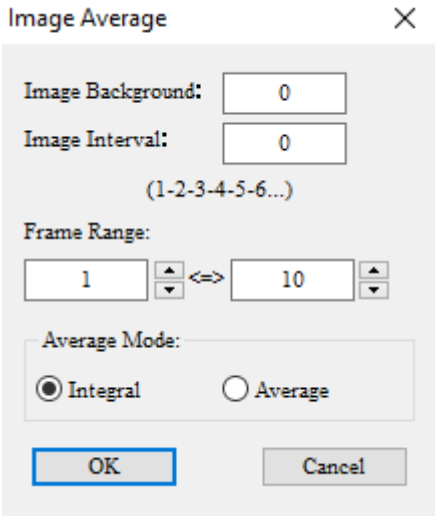


Figure 5.30 Image average window

The parameters have the following meaning:

Image (interval)		The image needs to be averaging interval 0 - means no interval, one -on behalf of every one reprocessing one, and so on.
Image (background)		For the image averaging process to subtract a background value.
Image buffer		Expresses the need to calculate image processing buffer average starting and ending locations.
Compute Mode	Integral average	Image buffer used for setting an image gray value for each point stacking process, and taking the average.
	Equalization	Setting an image gray value of each point to accumulate integral calculation value exceeding the value of the highest grayscale, all set to the maximum gray value.

5.4.14 Image Fill

Image Gray Fill window is used for filling a selected area in the image or the entire image with gray values. In the absence of a digital gauge for a selected area, this command automatically fills the entire image with gray values (Filled gray value from small to large corresponding with images from dark to light).

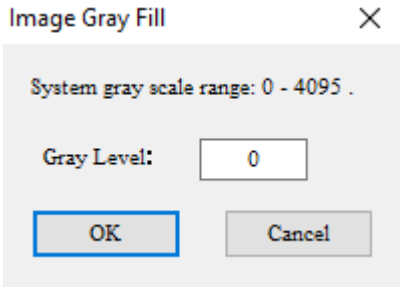


Figure 5.31

5.4.15 Clear Image Buffer

Upon clicking on this command button, the image stored in the buffer is fully cleared.

5.4.16 Image output

Image output contains four functions: One Image Output, Sequence Image Output , One Screen Image Output and Sequence Screen Image Output.

One Image Output (see Figure 5.32): the current buffer of some or all of the output image. Select the range of the output image (you can use the digital gauge choice), click on "Browse" to select the storage location, and then click the "Output" button.

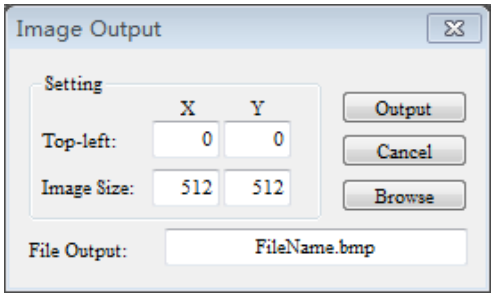


Figure 5.32 Single image output

Output Series (see Figure 5.33): output of the selected area can follow a series of images. Select the output image buffer range, click on "Browse" to select the storage location, and then click the "Save" button.

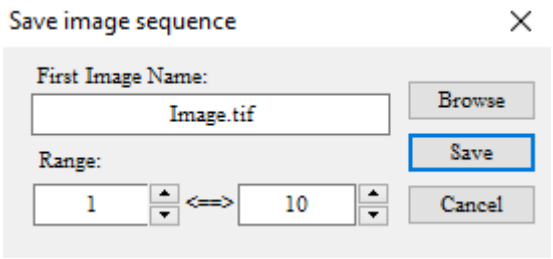


Figure 5.33 A series of image output

Output Screen single: display area of the window within the scope of the current buffer image screenshots and output.

Output Screen series: can be a window in the selected area of the image display area of a series of screenshots and output.

5.4.17 Image Mask

Mask including image boundary detection function consists of two sub-functions: Mask Preview and Mask Setting. Masks can be created in two ways: by defining areas with a composition of geometrical forms like filled rectangles, circles and polygons from the menu (see the details below) or by applying an existing mask created in another software which is subsequently stored at a hard disk.

Mask Preview feature:

Current settings are automatically displayed in the template image of the last image buffer.

Mask Setting feature:

The system sets the currently displayed image as the PIV calculation template. Microvec software can you the current image in the buffer and use the detection boundary algorithm to generate a mask. You can also use your own image generated in another image tool software like Adobe Photoshop. User generated mask image needs to be saved in BMP or TIFF format with 8-bit and greyscale.

Creating a Mask in Microvec software:

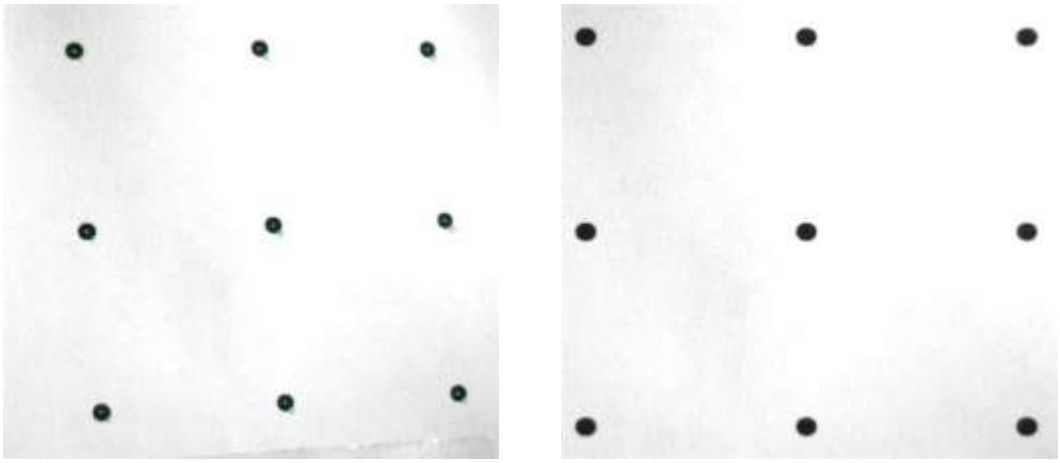
1. Once you have the image you would like to use open in the active window, open the image mask polygon tool  on the toolbar.
2. Use the cursor and left click on the points you would like to connect to create the shape of the mask. Once all the points are connected, and there are no gaps in your shape, you will see that the shape will be filled in and outlined in red.
3. Click on the Save button on the toolbar  and select the location and the name which you would like to have the file saved as.
4. Click on the Clear button  on the toolbar to clear the image.
5. The same sequence can be performed using rectangle  and/or circle  tool from the toolbar.

Using the Mask

1. In a separate buffer, open the mask file that you have created in the active window. You will then see the mask shape appear in the window.
2. Go to Image > Mask > Mask Setting. A window will appear asking whether you would like to use the image boundary detection template. Select Yes.
3. Use the green arrows on the toolbar to go to the first buffer. Then, select the Open Image Sequence button to select the images you would like to use.
4. Use the ruler tool  to select the area which you would like to calculate and change the appropriate settings.
5. Click on the PIV Compute button. Under the “PIV Settings” tab, under “Advanced Setting”, check the “Using Mask” option. After you click the OK button, you will see that the PIV calculation was only performed in the area within the boundaries of the mask.
6. Go to Analyse > PIV Batching > PIV Batching Compute. Alter the settings to fit your experiment and click OK. You will then see that the mask has been added to the calculation in each image in the series.

5.4.18 Image Calibration

 Image Calibration command (see Figure 5.34):



Before correction After correction

Figure 5.34 Image of image correction plate

Display image correction window (the figure uses the corrected calibration plate image as an example). The user should select an image in the calibration plate consisting of 9 calibration points. The points are in the real space coordinates corresponding to the input of the physical space coordinates. The create image function can be used to calibrate images to the specified image buffer.

Actual corrected image space of a standard calibration plate has 3 equally spaced rows and 3 columns consisting of 9 dots (if the dot is black, the background needed should be bright white; if the dot is white, the background needs to be black). The use of the Image Correction window button

initiates an automatic calibration, and the software automatically finds the nine dots. Then, the user can then open the corresponding need to calibrate the image, and the correction calculation button can be used to generate a new image after calibration.

This function is non-integrity software correction because the images captured by the camera may contain distortions caused by non-linear changes and image magnification.

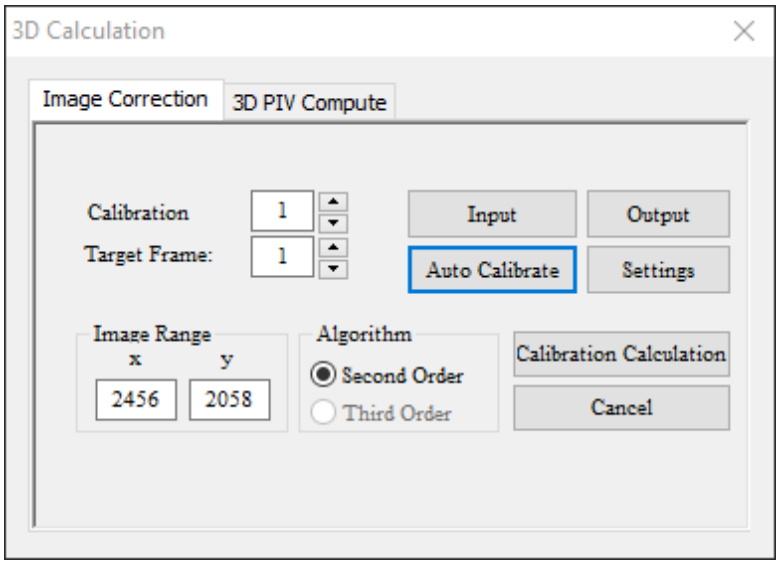


Figure 5.35 Image Correction Window

The parameters have the following meaning:

Current	The number of calibration points selected on the current screen.
Target image	After calibration this will generate an image storage buffer number.
x, y	Marker position in the object space. (Coordinate origin in the upper left corner of the screen, x forward and backward from left to right, y positive direction from top to bottom).
X, Y	Marker position in the image plane. (The coordinate origin and the pros and cons to above).
Range	The maximum recording surface of the object plane on the image plane corresponding to the maximum size.
Input	With the existing files *. rul), nine markers point coordinates are transferred.
Output	The nine marker coordinate data stored in the *. rul) file.
Automatic calibration	In accordance with the information given with the nine markers automatic calibration, and calibration information appears in Figure 5.35, otherwise it will not be an image distortion correction. This will require further adjustments to the calibration setting parameters.
Correction Setting	Set calibration point to search for the size (specifically see below).
Correction computation	Correction calculation according to the set parameters causes the image to be stretched into a square.
Correction algorithm	Select the correction algorithm.

"Correction Setting" button in the corresponding window shown in Figure 5.36 (Figure dimensions are in pixels). If the auto calibration function does not work, it becomes necessary to manually adjust the calibration parameters in this window (which affects calibration point search results):

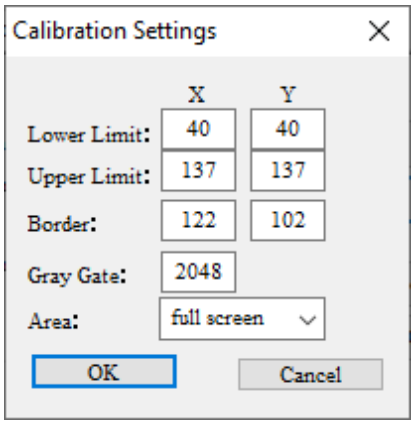


Figure 5.36 Calibration parameter settings window

The parameters have the following meaning:

	X	Y
Lower limit	Horizontal rectangle containing the minimum calibration point	Vertical rectangle containing the minimum calibration point
Upper limit	Maximum horizontal rectangle containing calibration points	Maximum vertical rectangle containing calibration points
Boundary setting	The leftmost and rightmost calibration point distance from the left and right borders	Uppermost and lowermost calibration point distance from the upper and lower boundaries
Gray Threshold	Search grayscale calibration point threshold (this value must be able to distinguish between the calibration points and background intensity threshold, the general point can be set to standard values and background gray middle value)	
Region	Because of the different imaging system (2D and 3D systems), the search area uses different calibration points. For the ordinary 2D system one can use a full search, while with the full 3D display system, one should only select the left half or right half.	

5.5 Analysis Menu

Analysis menu contains a variety of image analysis tools such as velocity vector field and 3D velocity vector field measurement tools.

5.5.1 System Setting

 System settings command (see Figure 5.37):

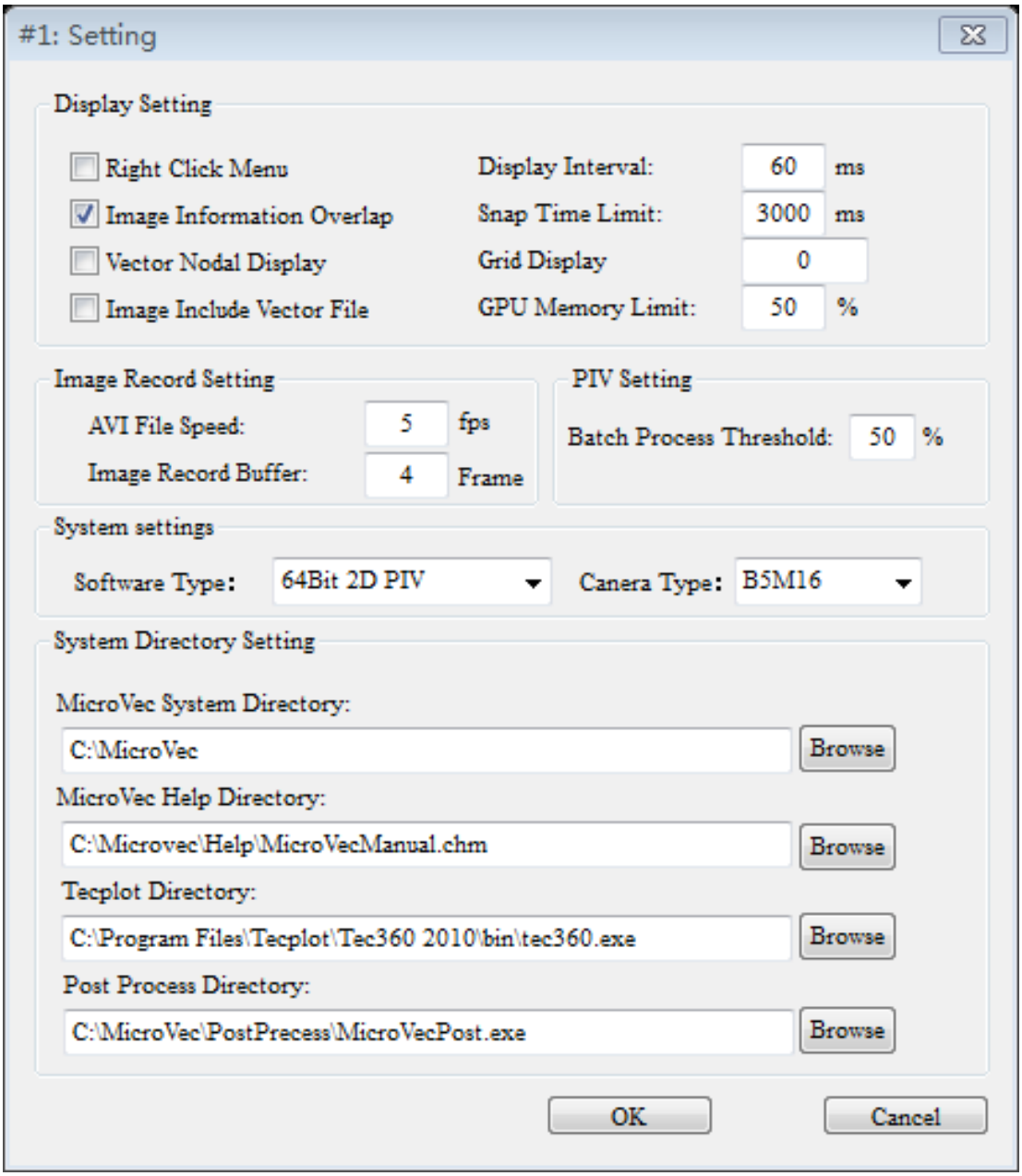


Figure 5.37 Parameter settings window

The parameters have the following meaning:

Right click menu	Set the main window, right-click on the pop-up screen image control menu functions.
Image information overlap	Determines whether the image display area will show "before image buffer when the number of" or "image acquisition rate."
Vector Nodal display	Manner with which each vector dot node is represented.
Image include vector file	Enable this option to save or open the image sequence, it will automatically save or open the corresponding file / file name data files.

Display interval	Real-time display showing the digital camera captured images, the image on the computer screen refreshes according to the time interval.
Snap time limit	During this time, if the system does not capture the image, then it automatically resets.
Grid display	When this value is not 0, the system will be in the image window in accordance with the actual figure (pixels) interval to display horizontal and vertical grid lines and positioning for target analysis.
GPU memory limit	Set using GPU algorithms determining the amount of memory used.
AVI file speed	The number of consecutive images saved as AVI files. AVI files set realistic rates.
Image record buffer	After the image is recorded onto the hard disk, this is used for the continuous recording of the image buffer memory number. According to the actual system image buffer number, this number can be increased.
Batch process threshold	In a multiple batch, if the data correction results file exceeds this value, the system will calculate the multi-information file in the directory and the corresponding entries in this file are added a "*" character display to show that prompting the data results exceeded vector correction rate settings (where there arepossible image quality problems).
Software Type	Select software type. 64Bit 2DPIV、64BIT Stereo PIV
Camera Type	Select Camera Types
Microvec system directory	Set Microvec system working directory (this directory must be exactly the same as the Microvec installation directory).
Microvec help directory	Set Microvec help document path.
Tecplot directory	Select Tecplot installation directory for the start directly from Microvec.
Post process directory	Set post-process analysis paths.

5.5.2 Digital Ruler

 Digital Ruler command (see Figure 5.38):

This command is available in the main window. The digital ruler can be used to drag and draw a straight line. With the image of the calibration plate in the actual length (length of input parameters), the magnification of the captured image can be estimated.

In addition, according to the maximum flow velocity to be measured and the calibrated image magnification, the experimental parameters, such as the exposure interval of the two images to be set for calculation, can be estimated.

Having the digital ruler in the open state and the selected area in the other system commands, Microvec functions automatically. These include PIV calculation, PTV calculations, image grayscale fill, particle size analysis, image output, the concentration field analysis, the scalar field analysis, PIV batch

processing, and PTV batch processing. Please note that the numbers in the above operation ruler window are open.

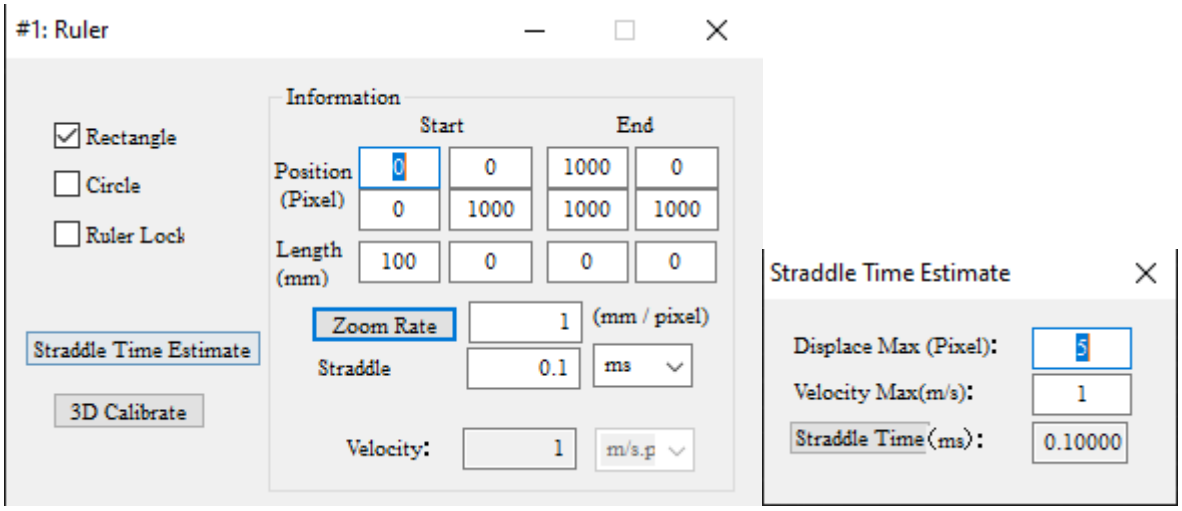


Figure 5.38 Ruler

The parameters have the following meaning:

Rectangular	The current image's rectangular computational domain (see Figure 5.39 to Select this option. To cancel this option see Figure 5.40).
Circle	Set the current image in the calculation of a circular area (Figure 5.41) which can enter the circular shape of "start" and "end point" to manually set the coordinates.
Ruler Lock	Lock set the size of the computational domain. The successive calculations are performed with the calculation of this size area.
Start	Image plane left mouse button pressed selected location.
End	Lift the left mouse button on the image plane in the selected location.
Length	Users enter in this column object space and the corresponding start and end point coordinates of the point.
Zoom Rate	Each pixel in the image corresponds to the actual length.
Straddle (pulse delay)	In pixels, difference between the speed and the actual speed conversion relationship.
Velocity	Each pixel velocity in the image corresponds to the actual velocity.
Straddle Time Estimate	Can be measured according to the flow rate. The estimated time interval the two pulses of light.
3D Calculate	According to 3D calculation results of the calibration window. Automatically estimates the various 3D magnification parameters.
Displace Max	Settings vector length calculated value (exposure time interval for the estimate).
Velocity Max	The flow field to measure maximum flow rate.
Straddle Time (ms)	Estimate the associated measurement set by the two image exposure time interval. Directs laser control of cross-frame delay parameters.

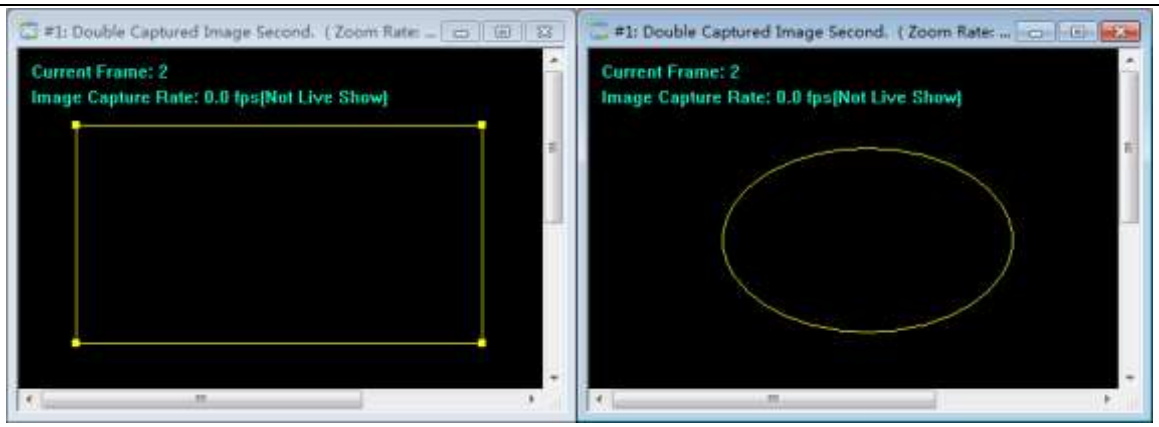


Figure 5.39 Select " Rectangular Region Show " Figure 5.40 Cancel " Round Region Show."

When the "Display a rectangular area" option is cancelled, click the left mouse button and drag a straight line (see Figure 5.40). Clicking and dragging the mouse can also be done from left to right or right to left; from the top down, or from the bottom up; or dragging along a diagonal direction.

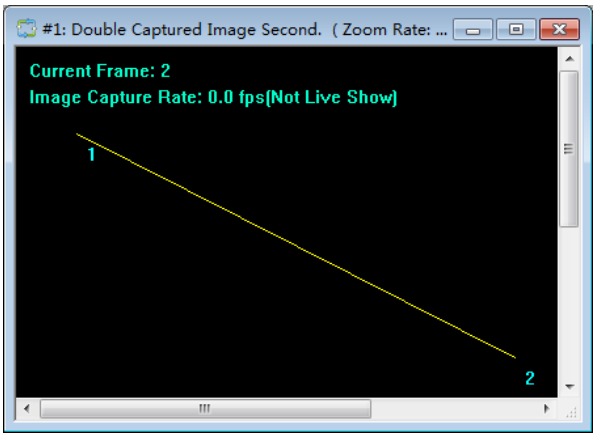


Figure 5.41 Select "Line Show " option

5.5.3 Analysis Result Output

 Analysis Result Output command (see Figure 5.42):

This window is used together with the digital gauge window, with a Ruler in the start point and end point to define the start and end line data analysis position. Analysis of each component of the velocity vector line data is stored in the specified file. Line velocity vector at each point of the model is the point around which the recent four velocity vector interpolation fitting determines. This window is only completed and effective in the calculation of the velocity vector. The "vector of step size" is defined data analysis line direction in the x and y coordinates of the step size.

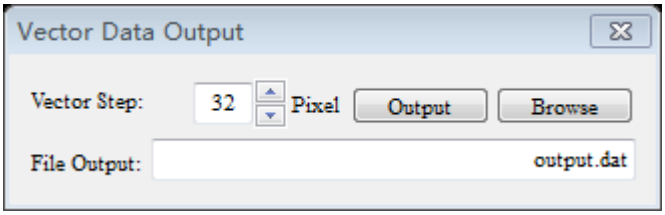


Figure 5.42 Analysis result output window

Parameters in the analysis results have the following meaning:

Number	Analysis of the data is the number of nodes
X	X-axis
Y	Y axis
U	Velocity component U
V	V velocity component
W	W velocity component
Speed	Closing speed
Vorticity	Vorticity results
Speed-r	Radial velocity of the line
Speed-t	The tangential velocity of line
U-std	Standard deviation of the velocity component U
V-std	The standard deviation of the velocity component V
W-std	The standard deviation of the velocity component W
Speed-std	Closing speed of the standard deviation
Vorticity-std	The standard deviation of vorticity
Speed-r-std	Radial velocity of the standard deviation line
Speed-t-std	Tangential line speed of the standard deviation

5.5.4 Particle analysis

 Particle Size command (see Figure 5.44):

The particle size analysis window provides real-time statistical analysis of the particle size of the captured particle images. The analysis results include: the number of eligible particles, the number of unqualified particles, the space position coordinates of the searched particles, the position of the center of gravity, and the particles area, equivalent circle diameter, equivalent rectangle size, relevant statistical analysis, etc. After the particle search is completed, the searched particles will be marked with a red mark in the current image cache.

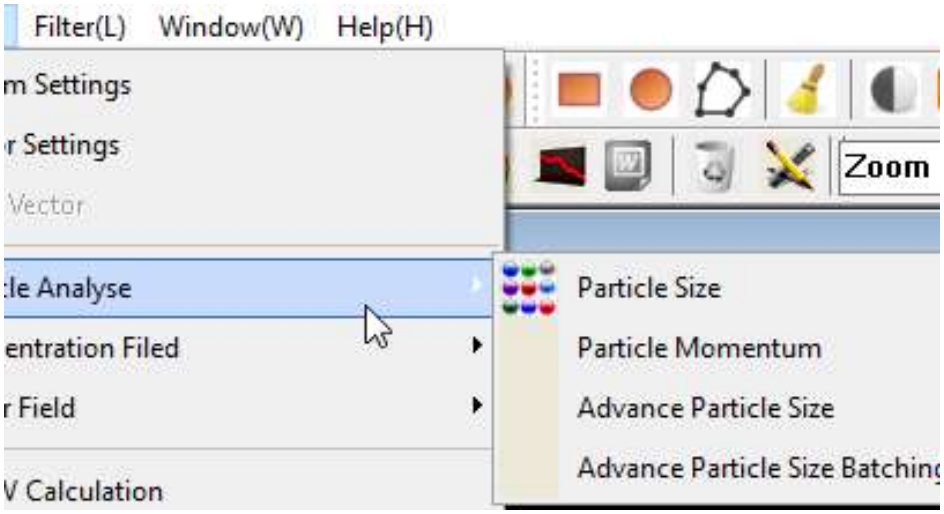


Figure 5.43 Particle size analysis software interface

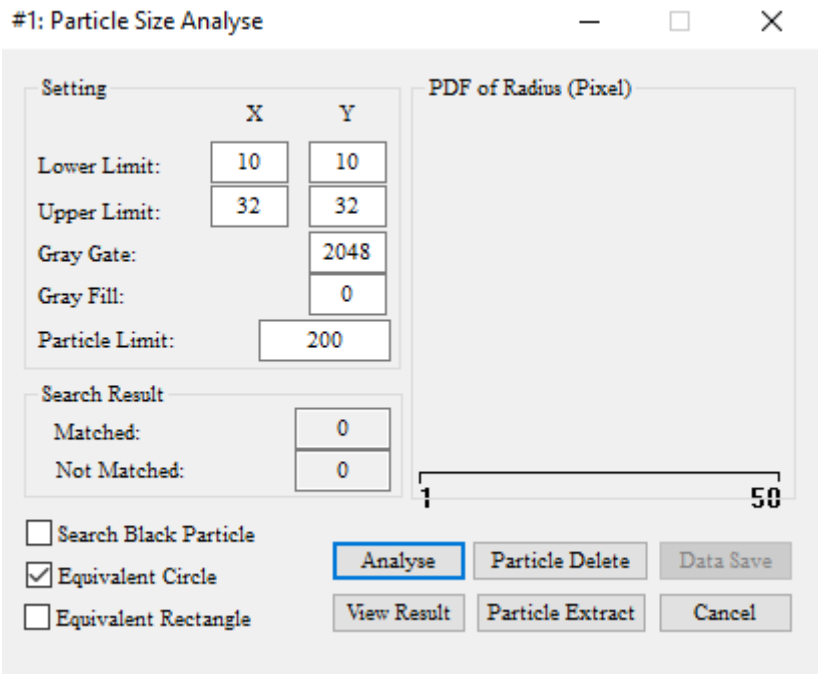


Figure 5.44 Particle size analysis window

The parameters have the following meaning:

Starting point	Set the position to start searching from in the image.
Lower Limit	Set the horizontal and vertical lower limit (minimum) of the particle size to be searched.
Upper Limit	Set the horizontal and vertical upper limit (maximum) of the particle size to be searched.

Gray Gate	Set the threshold of the grayscale brightness of the eligible particles (the grayscale value that can distinguish the particles from the background).
Gray Fill	After the particles are found, they are filled with this gray scale.
Particle Limit	Set the upper limit of the number of searched particles.
Matched	The number of eligible particles actually searched.
Not Matched	The number of unqualified particles actually found.
Equivalent Circle	By default, the obtained particles are elliptical.
Equivalent Rectangle	By default, the obtained particles are rectangular.
Analysis	Run the statistical analysis of particle size under the above set parameters.
Store results	Store the analysis result and save it as a .DAT data file.
Particle segmentation	Separate the two particle images that are glued together.
Image export	Export the searched result image as a separate image (remove the background).
Search for black particles	You can search for a white background and black particles.

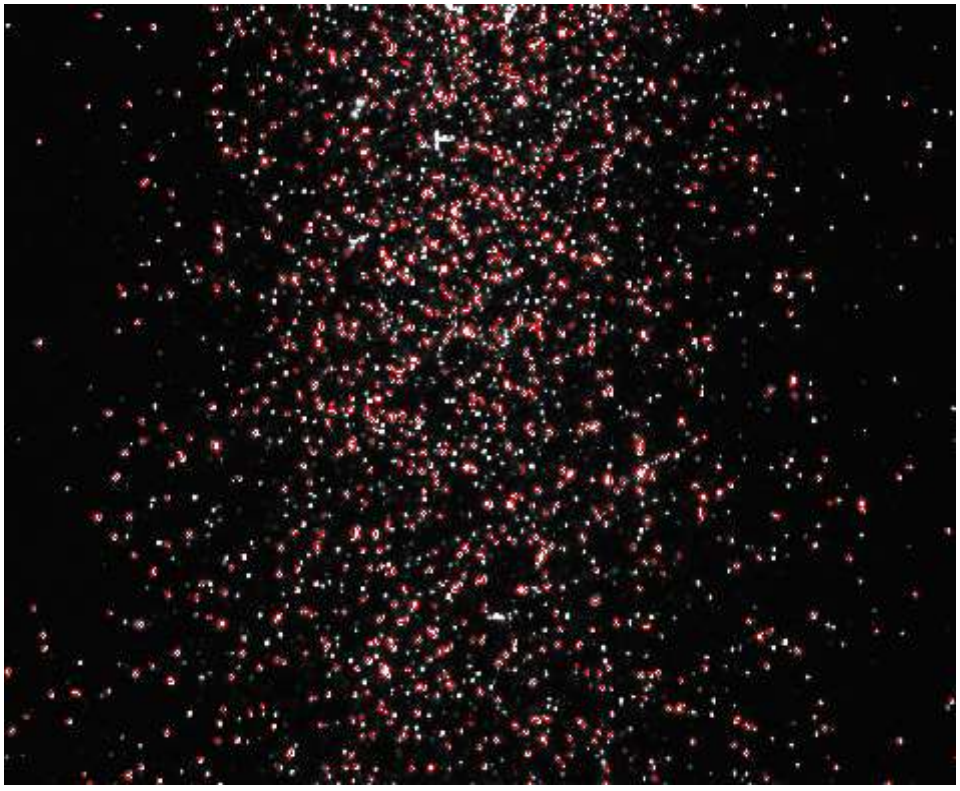


Figure 5.45 Particle size analysis results

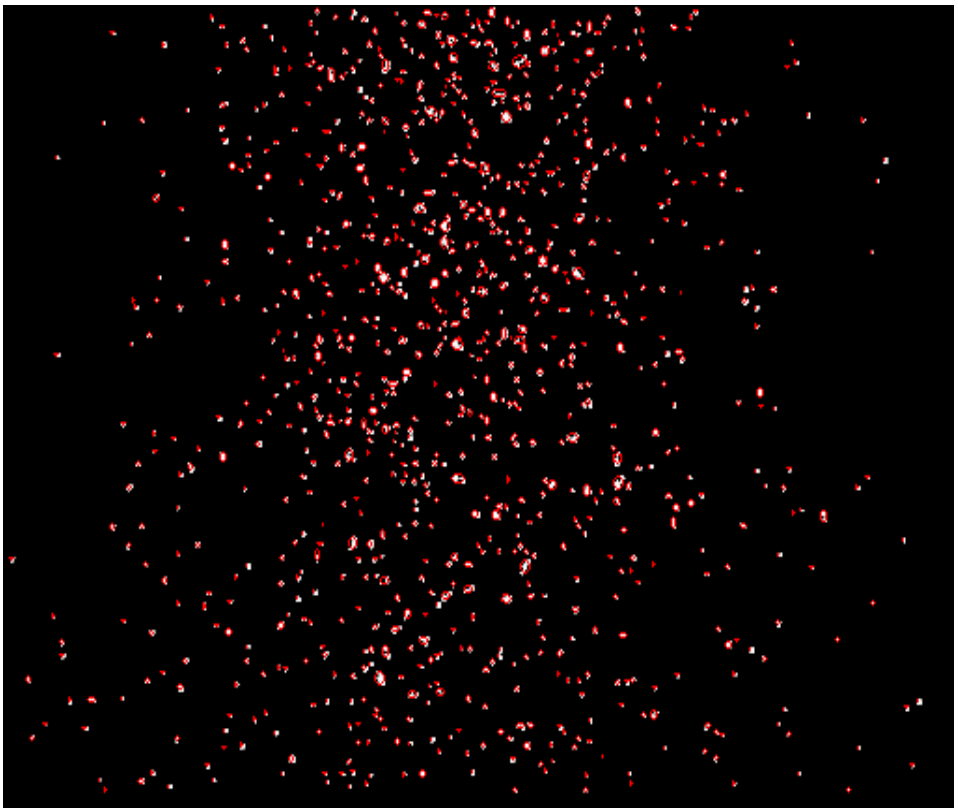


Figure 5.46 Particle extraction results

```
PARTICLE SIZE (mm)
VARIABLES = "N""X(mm)""Y(mm)""Hor(mm)""Ver(mm)""Size""Diameter(mm)"
ZONE T="ZONE 001"
I= 985 , F=POINT
DT=(DOUBLE DOUBLE DOUBLE DOUBLE DOUBLE DOUBLE DOUBLE)
0       19.918317       65.073018       0.338897        0.211810        0.046658        0.121868
1       22.231611       65.114729       0.169448        0.127086        0.017945        0.075579
2       24.005170       65.115199       0.169448        0.127086        0.016151        0.071701
3       27.857662       65.086549       0.338897        0.169448        0.041275        0.114622
4       21.565549       65.045320       0.211810        0.169448        0.023329        0.086174
5       24.412199       64.954812       0.296534        0.381259        0.071782        0.151158
6       24.998913       65.020473       0.127086        0.127086        0.014356        0.067600
7       16.210550       64.890210       0.169448        0.254172        0.026918        0.092565
8       20.236358       64.953753       0.169448        0.169448        0.017945        0.075579
9       21.856001       64.932572       0.211810        0.211810        0.026918        0.092565
10      26.095031       64.974934       0.127086        0.169448        0.017945        0.075579
11      12.043861       64.918234       0.211810        0.169448        0.023329        0.086174
12      20.873907       64.933101       0.338897        0.169448        0.028713        0.095601
```

Figure 5.47 Data result file

Particle Momentum command:

Momentum field analysis is based on the PIV calculation result of the particle field, combined with the particle size analysis result (calculating the particle mass), and outputting the momentum field analysis result of a particle.

The analysis process is as follows: first calculate the corresponding velocity field from the two particle field images, then use the particle size analysis function to search for particles in the second image, and convert the searched particle size to calculate the particles in each cell. You can use this command to store the currently searched particle momentum field information in the specified data file (*.dat).

Advanced Particle Size Module command:

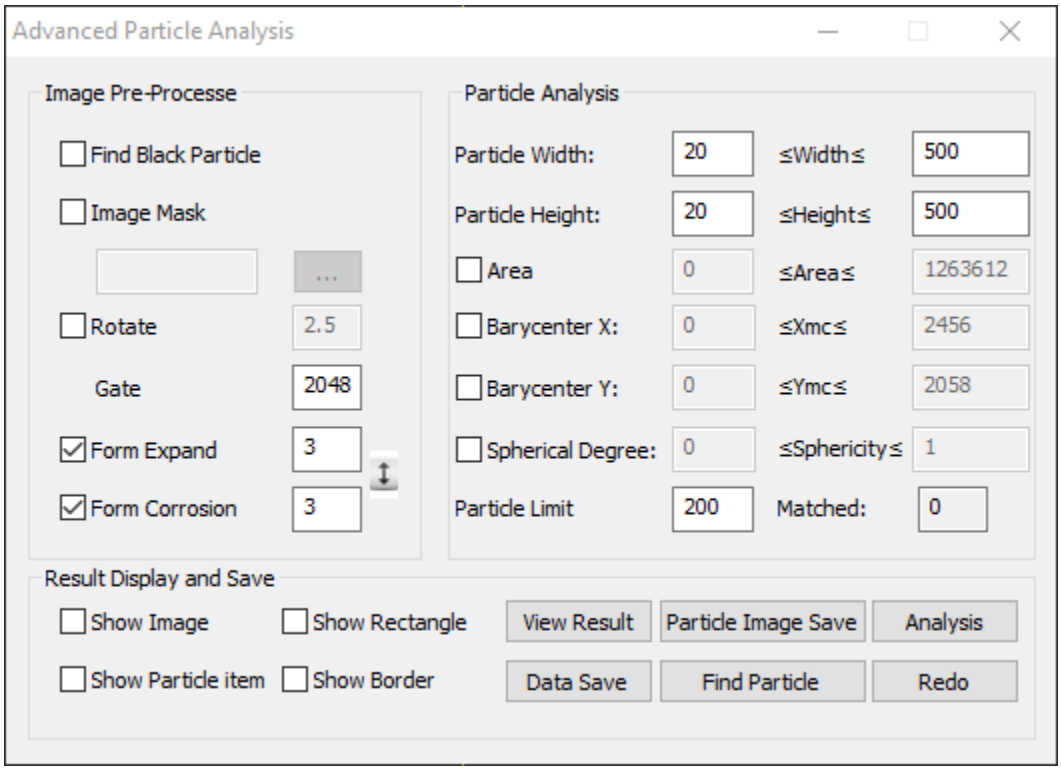


Figure 5.48 Advanced Particle Analysis Interface

	Image Pre-Processing
Find Black Particles	Set to search for white background and black particles.
Image Mask	Set the mask image template
Rotate	Set image rotation
Gate	Set the threshold of the grayscale brightness of the eligible particles (the grayscale value of the particles and the background can be distinguished)
Form Expand	Set morphological expansion
Form Corrosion	Set Morphological Corrosion
	Particle Analysis and Screening
Particle Width Range	Set the particle width range
Particle Height Range	Set the particle height range
Area	Set the particle area range
Center of mass coordinate x	Set the center of mass coordinate range of the particle in the x direction
Center of mass coordinate y	Set the center of mass coordinate range of the particle in the y direction
Spherical Degree	Set sphericity range
Particle Limit	Set the upper limit of the number of search particles.
Matched	Set the number of particles that meet the conditions actually found.
	Result Display and Save
Overlay the original	Set the original picture to be superimposed

picture	
Display particle number	Set display particle number
Show Rectangle	By default, the obtained particles are rectangular.
Show circumscribed ellipse	By default, the obtained particles are elliptical.
View Result	View result data
Particle Image Save	Particle image storage
Analyse	Run the statistical analysis of particle size under the above set parameters.
Data Save	Store the analysis result and save it as a .DAT data file.
Find Particles	Separate the two particle images that are glued together.

Particle Size Batching

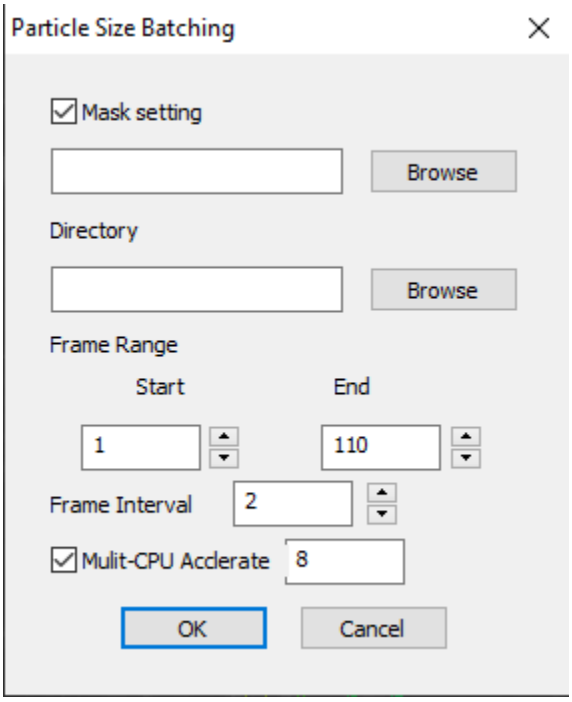


Figure 5.49 Particle Size Batching Interface

Specify Analysis Template	Browse the DAT file of the selected particle analysis
Specify the Save Directory	Set the path where you want to save the results
Frame Range	Set start and end frame
Frame Interval	Set the number of image intervals
Multi-CPU Accelerate	Set the number of CPU threads

5.5.5 Concentration Field Tool

 Concentration Field Tool command (see Figure 5.44):

The particle concentration distribution of the output image data file (*. dat) format.

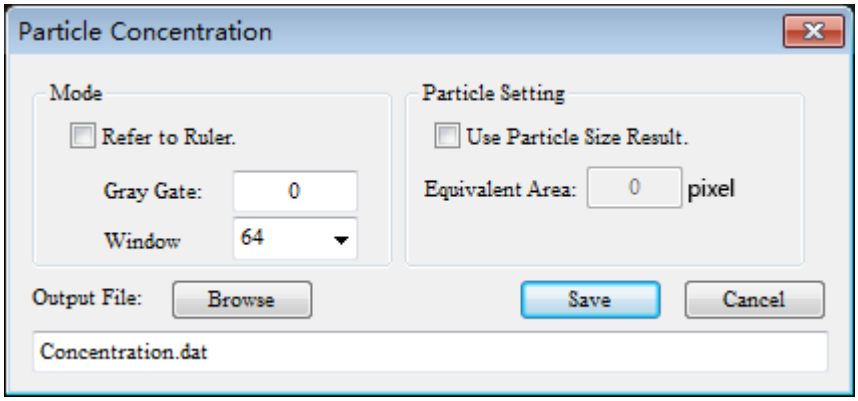


Figure 5.50 Particle concentration analysis window

The parameters have the following meaning:

Gray Gate	Concentration of the conditions set in accordance with the brightness and gray threshold (background gray threshold).
Window	Setting calculates an area averaging window size (also forming a grid step size).
Equivalent area	If you set options using the particle size analysis, particle size analysis results will be used to partition the concentration analysis. An equivalent area will be obtained by dividing the number of particles in the calculation of the window (if the value is zero, the direct output of the number of search statistics will ignore particle size).

Concentration field calculation results shown in Figure 5.51 (This picture is colorful only in the electronic version or the online help documentation):

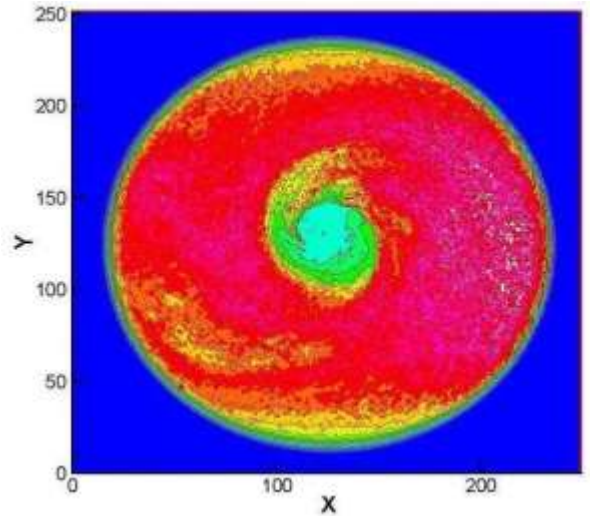


Figure 5.51 Calculation result of concentration field

Concentration field batch process command: Based on the above analysis of the concentration field, parameters are set for multiple image analysis using the concentration field command for processing.

5.5.6 Scalar Field Tools

Scalar measurements: The principle of planar laser-induced fluorescence is based on the fluorescence intensity of a fluorescent substance. When the laser energy is much less than the saturation energy, the fluorescence intensity of S can be expressed as:

$$S = \eta V c na f(T) BI g(vL, va) F / (F + Q)$$

Where η is the overall collection efficiency including the optical path and the detector; na molecular density; f(T) is the percentage of the ground state density of the absorbing molecular laser coupled to the total density of the probe molecules. In thermally equilibrium conditions, it is subjected to glass Shields MAN distribution law. The ratio F / (F + Q) stands for the generation efficiency of fluorescence; BI represents the pumping efficiency of the laser, wherein B represents Einstein absorption coefficient and I represent the power density of the laser; g (vL.va) represents the laser Spectral line gL and the collision. The Doppler frequency shift and temporal broadening causes such as absorption lines superimposed linear coefficient ga.

With other experimental conditions unchanged and through good pre-calibrated flow field information (flow calibration using images shot six times), you can post captured images of the flow field and the look-up table to be calculated to obtain the corresponding flow-field images.

The quantitative results:

This tool can be used with a digital gauge setting a specific area to be measured, or turn off the digital gauge so the whole area of the image can be calculated and measured.

The following example describes the use of this function module for a temperature field:

When each test device is ready, set the grid step size (measured flow field formed by meshing interval, the default value is 64), starting with 10 times the calibration sequence number value of 1 (calibration first image). Click the Start button calibration, and set the current image acquisition to the appropriate image buffer fill calibration parameters (temperature measured here, you need to fill out the thermometer to measure the temperature of the flow field that is known). Click on the calibration calculations. The calibration number will increase to 10 2. While waiting for the actual flow temperature to reach the second calibration parameters, fill in the calibration parameters in the second calibration parameters, click on the calibration calculations ..... and so on, until all of the 10 calibration images. Then enter into the actual measurement phase, the actual shooting of the flow field image, and then click the resulting output. The captured image is stored as the current temperature field data file and you can use Tecplot software displays the results.

In the calibration process, pay attention to the 10 calibration parameters, which must be ordered sequentially from small to large, and try to be measured at equal intervals covering the entire range. Also note that, in the entire gray scale measurement, the range cannot appear too low or grayscale photographic exposure saturation phenomenon will occur. You might need to adjust the camera exposure time or laser energy recalibration 10 images, then get the actual measurement.

5.5.7 3D vector calculate

 3D PIV Compute command (see Figure 5.52):

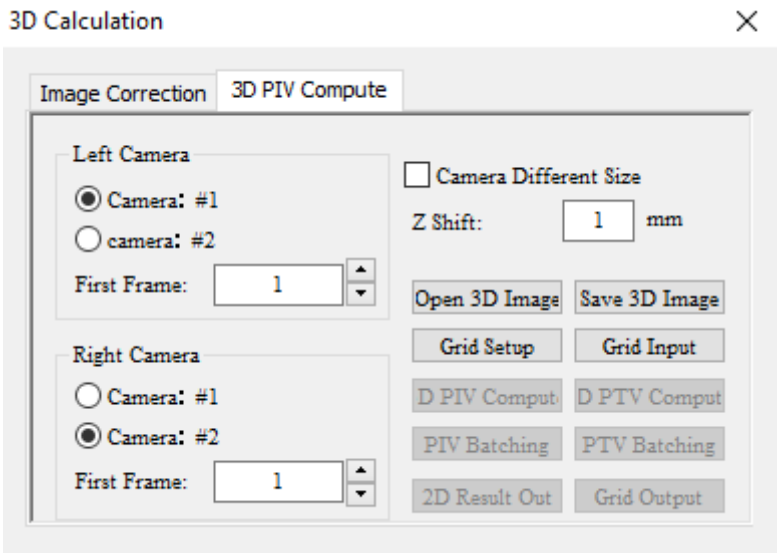


Figure 5.52 3D velocity measurement window

The parameters have the following meaning:

Left Camera	First Image	Place the first buffer corrected image.
Right Camera	First Image	Place the first buffer corrected image.
Camera Difference Configure		If the laser light sheet is placed in the middle of the physical layout of the two cameras, certain calculations will be used. If the laser in the two cameras is on the same side, you do not have this option.
Z-direction		Calibration process, each fine-tunes the CCD moving distance.
3D vector open		This feature automatically adds a picture (from left and right camera images to synthesize) split, and then places them in different positions corresponding with the image board buffer.
3D vector save		The left and right, respectively, captured by the camera at the same time (corresponding to the position of different image board) is synthesized into an image, and then stored in accordance with the order.
Grid Setup		Corrected image created from the acquired correction grid computing.
Grid data input		Previously calculated calibration parameters are applied to the current 3D setting and the process eliminates the need to establish the grid again.
Grid data Output		Establish that the parameters of the current grid settings are saved as a data file.

3D PIV	3D PIV calculations (for this command you need to perform a 2D PIV calculation to calculate initialization parameters needed to choose a 3D computational domain PIV calculation that were calculated for the entire image).
PIV batch process	Use "3D PIV computing" command parameters in the calculation of 3D images of a large number of experimental PIV calculations.
3D PTV	3D PTV calculation (for this command you need to perform a 2D PIV calculation to calculate the initialization parameters needed to choose the appropriate 3D computational domain PTV calculation which were calculated for the entire image).
PTV batch process	Use the "3D PTV computing" command calculation parameters in a large number of 3D image PTV calculation.
2D Output	Output the 2D result
Grid Data Output	Output the grid data

Ordinary particle image velocimetry systems can only be obtained within the 2D cross-sectional test results of the 2D velocity field. This does not yield the third component of the test section, i.e. the out-of-plane component. When the third component of velocity is large, the test results lead to significant 2D error, which greatly limits the experiments using PIV.

Stereo particle image velocimetry system is based on the original particle image velocimetry system and relies on the principle of binocular vision similar to biological stereo vision. In Stereo PIV, two digital cameras are mounted at a certain tilt angle to simultaneously capture images of the experimental area. Using the displacements observed by the two stereo cameras, the out-of-plane component can be determined which finally results in 3D velocity vector field. This is not only to make up for the original 2D particle image velocimetry system deficiencies and fixed-dimensional test results, but to measure the real 3D flow field velocity field results (see Figure 5.53):

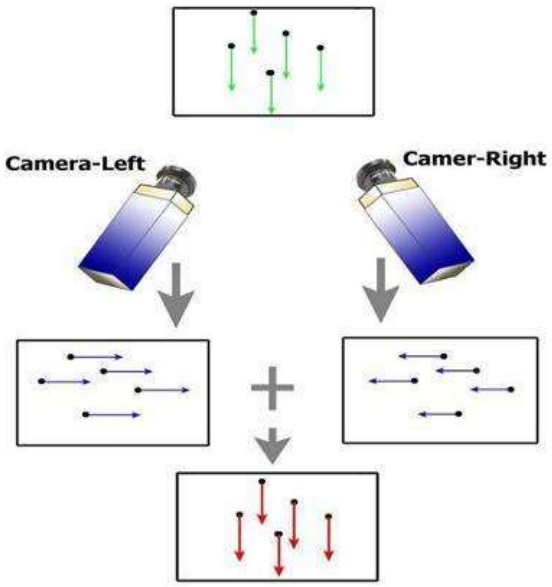


Figure 5.53 Schematic 3D velocity synthesis

Calibration points captured by two cameras are shown in Figure 5.54:

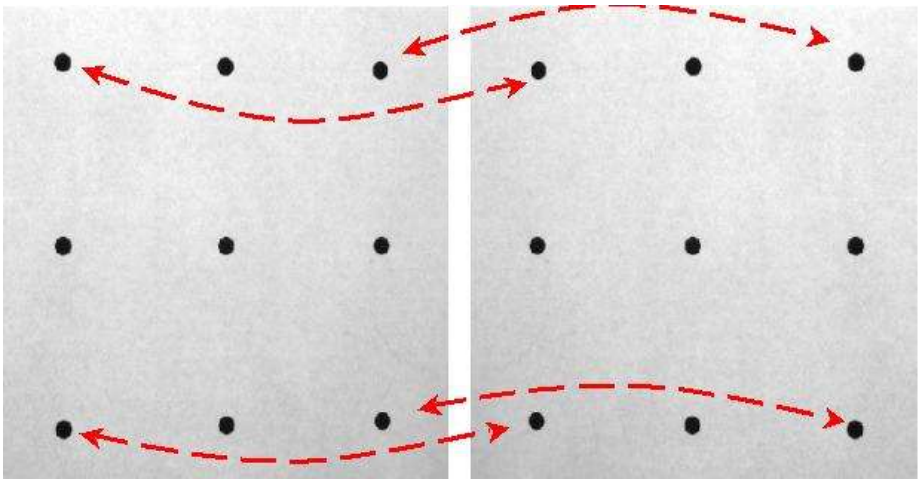


Figure 5.54 Calibration points corresponding to Figure

Spatial positioning of the calibration plate must be performed before performing 3D measurement.

First, make sure the two camera calibration standard maximum area is on the same point. With the left camera tilt calibration points, it is possible to determine the maximum area of the grid. With the right camera, you can determine if the maximum grid corresponds exactly (corresponding to the real space in the horizontal, vertical and whether they share the same number of calibration points around the camera which can determine the maximum corresponds exactly to the four corners of the grid).

In the adjustment and confirmation process for the camera's shooting calibration points, the second step is to move the spatial calibration point shooting position. The calibration standard fixed plane light sheet should be placed on the plane with respect to the direction of the camera from far to near, on-chip light moving within two intervals, each with about two cameras shooting three point calibration standard images (a total of six) (the existing system which has been replaced by the standard plate does not move, just move the camera this way). This six point calibration standards before and after moving the grid around the image must also meet the above standards.

After storing the captured image calibration, points can be calculated in the 3D velocity field window to create a grid and you can perform the actual experimental particle image capture. Different locations through the software automatically recognize calibration points on the grid, 3D calculation using the system tools can be directly calculated using 3D velocity vector result.

3D velocity field is calculated as follows:

1) To establish the spatial grid:

When choosing an image corresponding to the camera board, specify both captured images of a moving grid storage location (specified in the first buffer location for storing a moving image when shooting the first one index point, and then the actual location. The second and third shot amplitude calibration point increases sequentially next to the image stored in the image buffer specified in the first one back) in the **Z direction,** fill in the actual shooting moving image spatial position of the grid spacing. Click the "Grid establish" button to generate a 3D computational grid, if the image does not

meet the matching requirements around the grid, **the grid** will prompt the process **of establishing** the relevant error message.

Legend: the left three cameras were placed on the moving mesh image board # 1, 2, 3 in the buffer, the right side of the camera's three mobile grid images were placed on the image plate # 2 and in image buffer 4, 5 and 6 (two image board image buffer is independent), fill in the Z direction in the moving image plate spacing 1mm. Then click on the "Grid establish" button to generate a 3D computational grid.

2) 3D velocity field calculation:

3D calculation is to be carried out around the camera captured images into the appropriate image buffer. Left camera captured images inserted into the 3D velocity field calculation window are specified by the camera image on the left in the buffer. For the same shot into the right side of the camera image, click on the Calculate button 3D velocity field that can be used to generate a 3D grid in front of the camera about the synthesis of 3D velocity field.

Example: Using the previous grid parameters can be used for the camera image being placed into the image board #1 image buffer, the two images before and after the two moments into the image buffer 1 and 2, the window specified in Section and image parameter is 1. The right camera to the front and rear two images goes into image board # 2 buffer 1 and 2, a picture window, specify the first parameter is 1, and then click the button to calculate the 3D velocity field calculation 3D velocity field vector.

3) Store the results:

Right after the results of the 3D velocity field data are calculated, you can use the button functions for storage. Storage file types can choose to store the left and right cameras and the 3D velocity field after synthesis results.

4) Note:

Calibration standard for 3D image can be fixed using the printer to print in black on white paper calibration points and shot calibration point image, to ensure that the background is uniform and has high-brightness (background gray value close to the camera saturation brightness values).

Grid-image capturing images to black and white with the background gray uniform, can’t have a dark gray background camera exceeding 30% of the saturation intensity. You can properly adjust the digital camera's exposure time or the number of the lens aperture adjustment and, if necessary, use foreign ordinary light auxiliary lighting.

Regular intervals during the camera panning when shooting will have the captured image showing a change in movement, but the calibration points cannot appear to increase or decrease.

5.5.8 PIV batch process tools

 PIV batch process tools (see Figure 5.55):

This command contains three commands: PIV calculation batch, save the batch results, save the results and save radial direction results.

When conducting a PIV calculation using batch command parameters set on a large number of image cross-correlation calculations, you must keep in mind that, in calling this command, you need a large number of images to calculate a cross-correlation calculation parameters set, and then the batch will compute.

After the batch finishes computing, you will have just finished calculating the results of statistical averaging process, and to save the results averaged and displayed in the final image buffer.

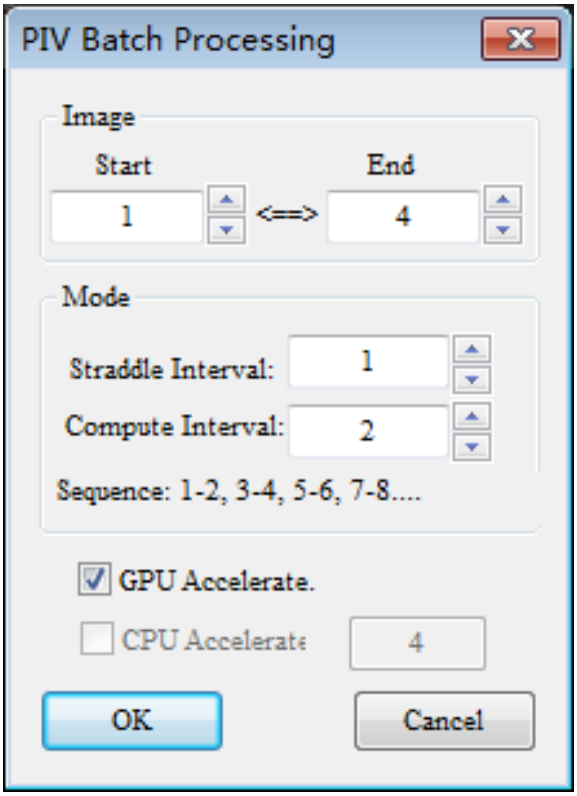


Figure 5.55 PIV calculation batch process window

The parameters have the following meaning:

Start	The first batch process image.
End	The last batch process image.
Straddle Interval	Batch process related calculations for the number of frames between pictures intervals.
Compute interval	Batch process A in the image of the frame spacing between the frame images.
GPU acceleration	Algorithm using GPU accelerated computing.
CPU Accelerate	Calculated using the CPU for parallel computing and set the set the number of threads.

Figure 5.49 in the cross-frame has an interval parameter set to 1, the calculation interval parameter is set to 2 and the calculated range is 1-400. PIV is calculated in batch process mode for image buffer 1 and 2 of the image cross-correlation calculation, then image buffer 3 and 4 of the image cross-correlation calculation, then image buffer 5 and 6 of the image cross-correlation count ... and so on, until the image buffer reaches 399 and 400 of the image after the end of the cross-correlation calculation.

Save batch processing results command (see Figure 5.56) will calculate every two PIV images that are saved after the implementation of a range of outcomes data files, file format, see Chapter VII corresponding introduction.

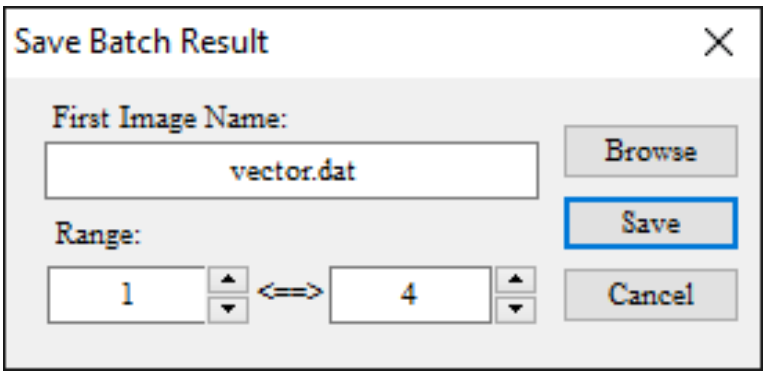


Figure 5.56 Save the batch process results

The parameters have the following meaning:

Browse	Set up a batch process result data file directory.
Save	Save the batch process result data file.
First File Name	Batch process data file name.
Range	The results need to be saved by batch process number, serial number and participation PIV. This calculation corresponds to the first frame image buffer number corresponds to the image.

Note: When batch process calculation is completed, save the image buffer in the final average results of the batch process software that need to manually save the vector function preservation.

Export radial results command corresponding digital gauge circular grid resulting data files. Follow the radial and tangential lines to store data files, V_r (radial velocity) and V_t (tangential velocity) Figure 5.57 provides positive direction show:

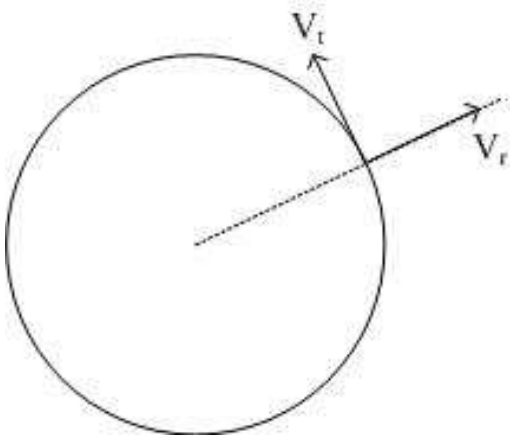


Figure 5.57 Illustration of radial results

5.5.9 PTV Batch Process tool

 PTV Batch Process tool:

This setting has two commands: PTV batch process and save the batch process results. These two commands and settings in the PIV calculation batch process use the corresponding commands and parameters.

5.5.10 Single-Point Process tool

Single point process：This command needs to be executed after a batch process PIV is carried out mainly on the calculation results of processing multiple vectors, including two commands:  Result Preview and Result Output.

 Result Preview command is used to give units of one pixel in the set area of all the curves calculated results (see Figure 5.58):

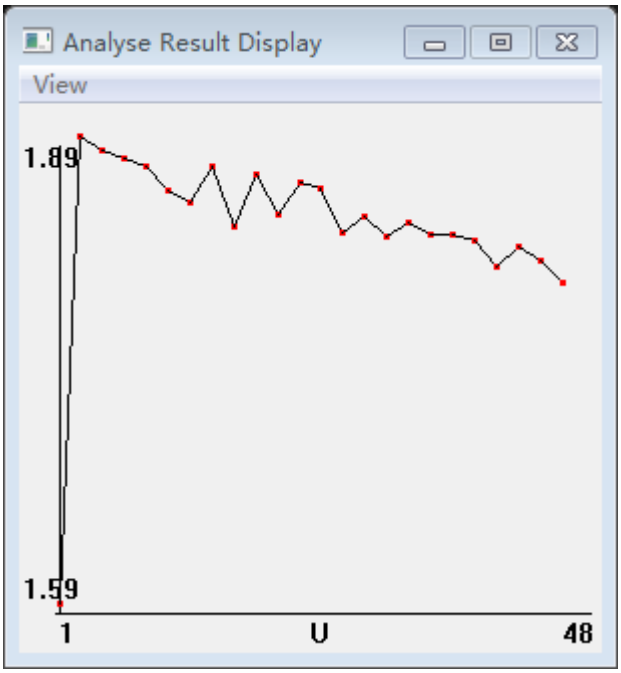


Figure 5.58 Result curve window

U	Average U of each velocity field in X direction
V	Average V of each velocity field in Y direction
W	Average W of each velocity field in Z direction
velocity	Average speed of each velocity field
vorticity	Average vorticity of each velocity field

Result Output will be followed by the results of the data stored in a given file, for more information on file format, see Chapter VII for instructions.

5.5.11 Data output

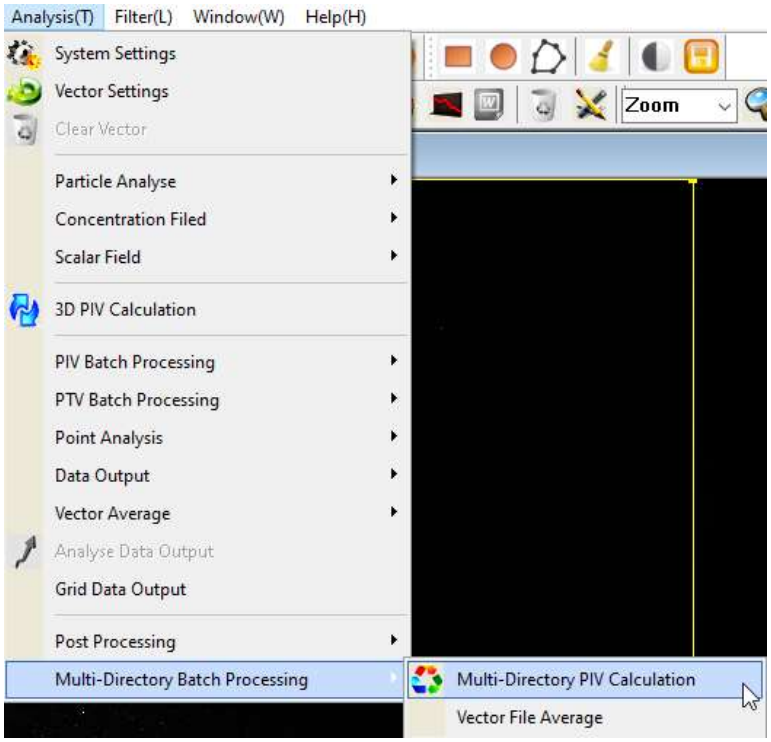
Exporting data is the result of the command data stored in a data file, retaining all data, and exporting data formatted according to the PIV / PTV results format (no file header information). This applies to the entire space and time variable data for statistical analysis.

5.5.12 Vector Average

Vector Average commands multiple PIV calculation results of each component of velocity vectors that show mean and mean vector distribution placed after the last image buffer.

5.5.13 Multiple directory batch process

Multiple directory batch process commands cannot limit the size of the image buffer to handle any number of hard disk directory PIV image data files. It automatically saves the file to the corresponding calculation results directory. Automatic batch process multiple directories can be calculated using parameters already stored data file format and can also be calculated according to the template files in the directory settings, as shown in Figure 5.59:



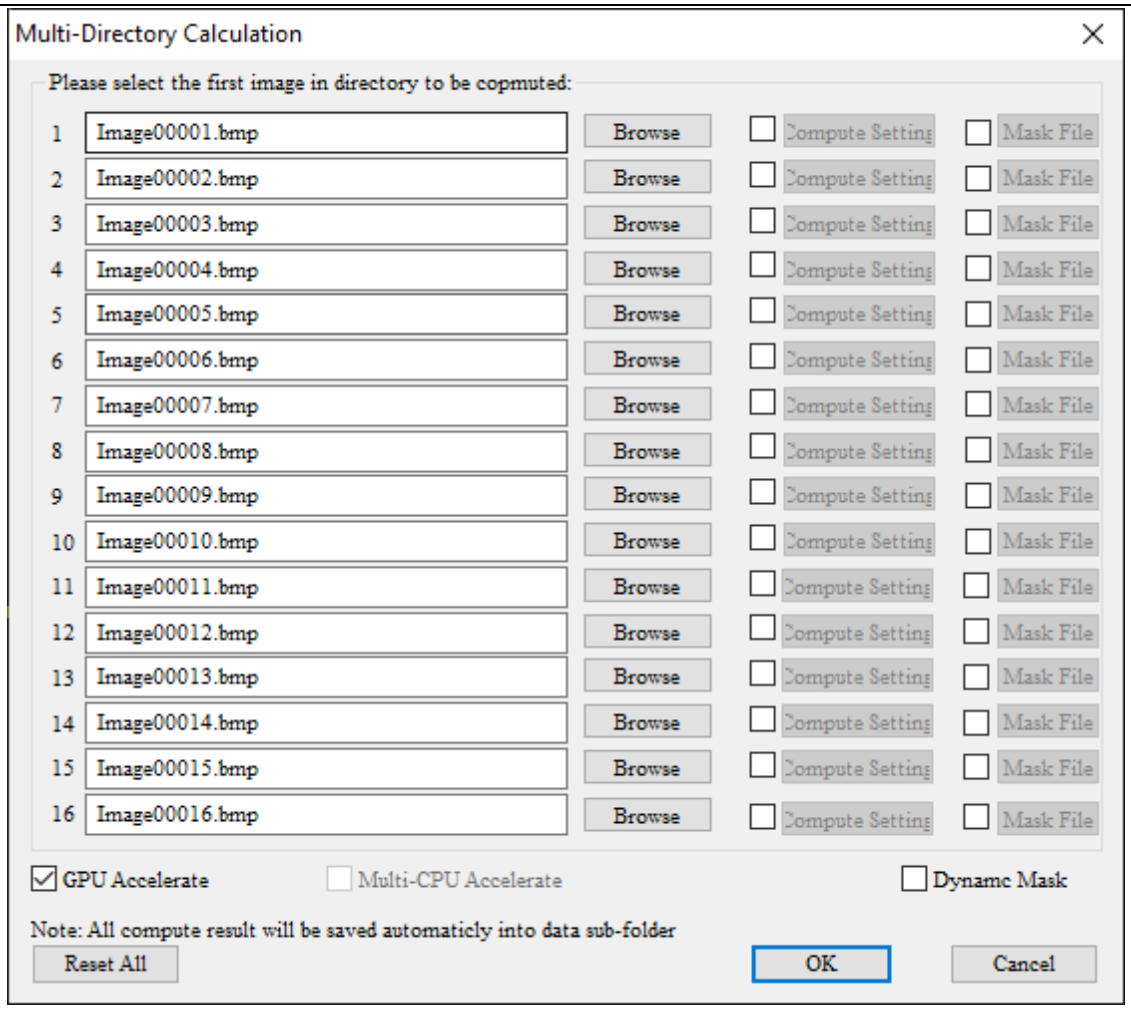


Figure over 5.59 Multi-directory automatic batch process window

Multi-directory PIV calculate commands can set 16 different automatic batch process file directories. Each directory can "browse" the selected image file to calculate the number of the first file. If you select the calculation parameters file, followed by the calculation of the batch process mode, the software will calculate based on the currently selected parameters in the parameter file batch process. if no file with calculation parameters is selected, the system will automatically use the most recent set of PIV batch process command mode calculations. The system will automatically select the first image file number, numbered sequentially in a cumulative basis, until it finishes with the numbering sequence of the image files. The results obtained and the average statistical average results are automatically stored in the corresponding memory image of the root directory.

Note: The use of multi-function automatic batch processing of data directory. If you want to speed up the computing speed, you can use the software GPU-accelerated computation or multi-threaded parallel computing capabilities. This parameter is set automatically during batch processing of multiple directories prior to conducting a manual batch processing. This batch process is set manually using the GPU accelerated computing, or multi-threaded CPU speed calculated parameters, so that later the directory will be set in accordance with good automatic batch process functions for data processing.

Mask setting: Each group directory calculations can be individually set to template file usage and calculation of the parameter file settings. Template function can be selected according to actual needs if you only need to calculate some irregular local image regions. In order to block out the rest of the region, it is necessary to set a template. The template is only counted after loading the software within the template image and the area outside the template will no longer participate in calculations. The template configuration steps are: the image buffer to the last template image → Open image→ Image menu → image mask → mask set, click OK to complete the template settings for PIV calculation template. You should check on the image boundary, as shown in Figure 5.60:

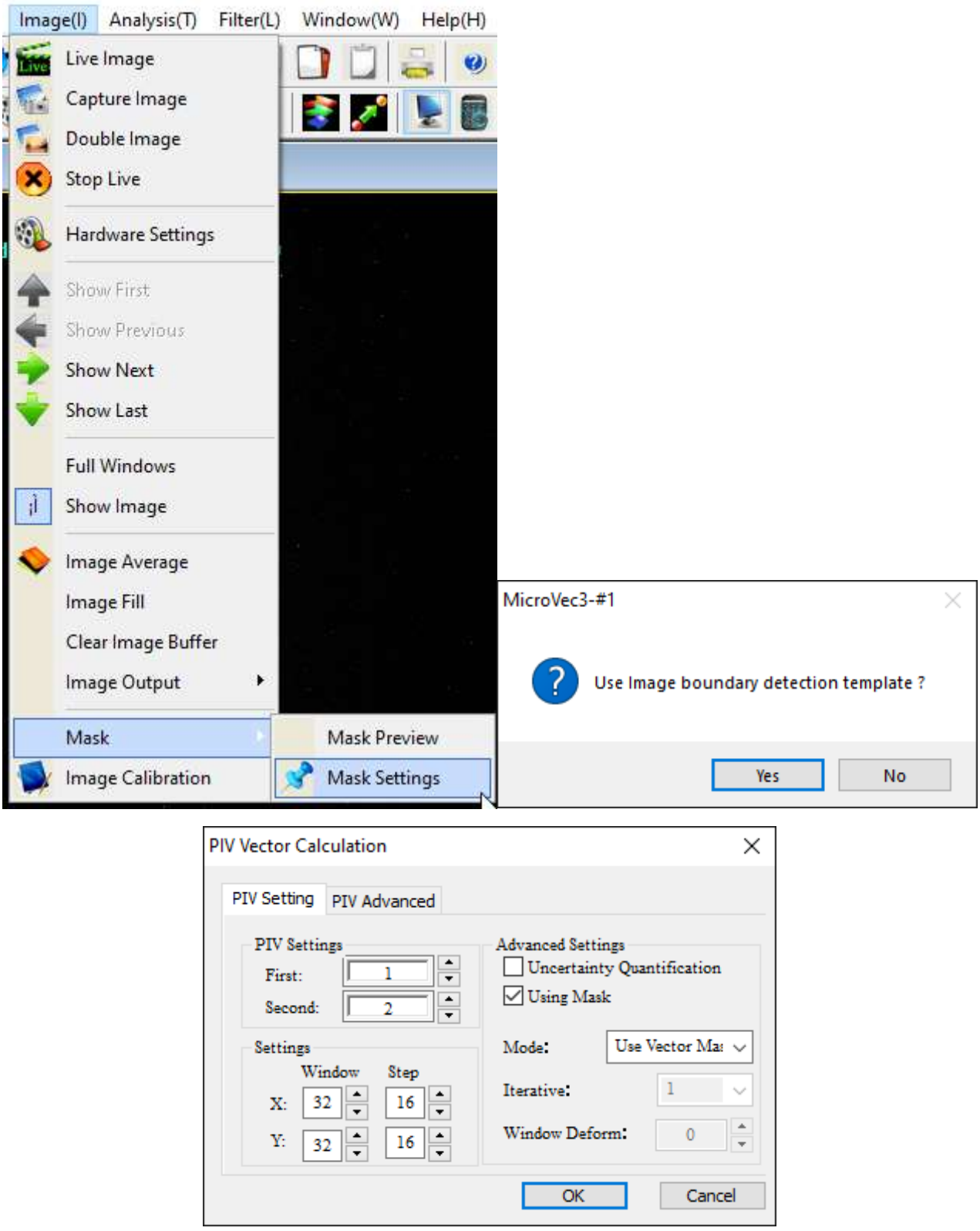


Figure 5.60 Operating procedures of graphical border template setting

Multi-directory PIV calculate operation process are: Analysis→ Multiple Directory Batch Process→ Multiple Directory PIV Calculate→ Browse (Select the calculated starting image) → Compute setting (Select sample data file) → Mask File (Select image template) → OK. After clicking

OK, the software will automatically calculate according to the relevant parameter configuration. The software integrates the monitoring function of the multi-directory automatic batch vector bias by setting the batch threshold. When the vector bias of a pair of image PIV data processing exceeds the set threshold, the data result will be saved. The setting process is: Analysis→ Parameters setting→Batch data threshold→Numerical setting, click on "OK". The parameter value can be selected according to the requirements of the actual experiment. The software default threshold is 50%.

You can average the vector which you have calculated. After using this function, the software will automatically generate a set of file names corresponding to the original data file containing the data file marked with -_HD_, with the newly generated data file is inside. Add to the Reynolds stress and turbulent energy corresponding to the flow field, and finally generate an average data file.

After selecting, the following dialog box will pop up, and the starting position of the data file needs to be averaged by browsing. In the following data file buffer settings, fill in the number of the starting point of the data file, usually the end position is slightly larger than the number of the data file, and then click to open the data averaging process.

When the result is averaged, the original data file is not changed, and the previously calculated average data file does not participate in the calculation. If there are different data files named in this data folder, the software only matches the selected data files with the same file name and different numbers for calculation. If some data files have a higher correction rate during the calculation that exceed the set threshold, the software will record in the automatically generated ErrorNote text file. The data file exceeding the threshold still participates in the calculation.)

When using multi-directory PIV calculation function, the following points should be noted:

1. When calculating the sample data file, the calculation process can refer to PIV data processing, and the computational domain selected must be locked after the ruler is used.

2. Template Selection Considerations: on the one hand, the software must support the template file format. On the other hand, the template must have a clear black and white contrast, which facilitates the calculation of the all-white area and all black masked area. Before using the software, you can use the software to open the image template to confirm whether the template meets the requirements.

5.5.14 Display of PIV data results

Microvec V3 shortcut panel can be directly connected to Tecplot software, which enables visualizing PIV data on the current buffer file. In order to use this feature, the following steps are required to follow: View → Enable Tecplot (see Figure 5.61) → Select Initial Plot (click OK) → Start Microvec (click) (see Figure 5.62). Then, the user can view a data file using the Tecplot interface. Procedure of using this function is depicted in the following diagrams.

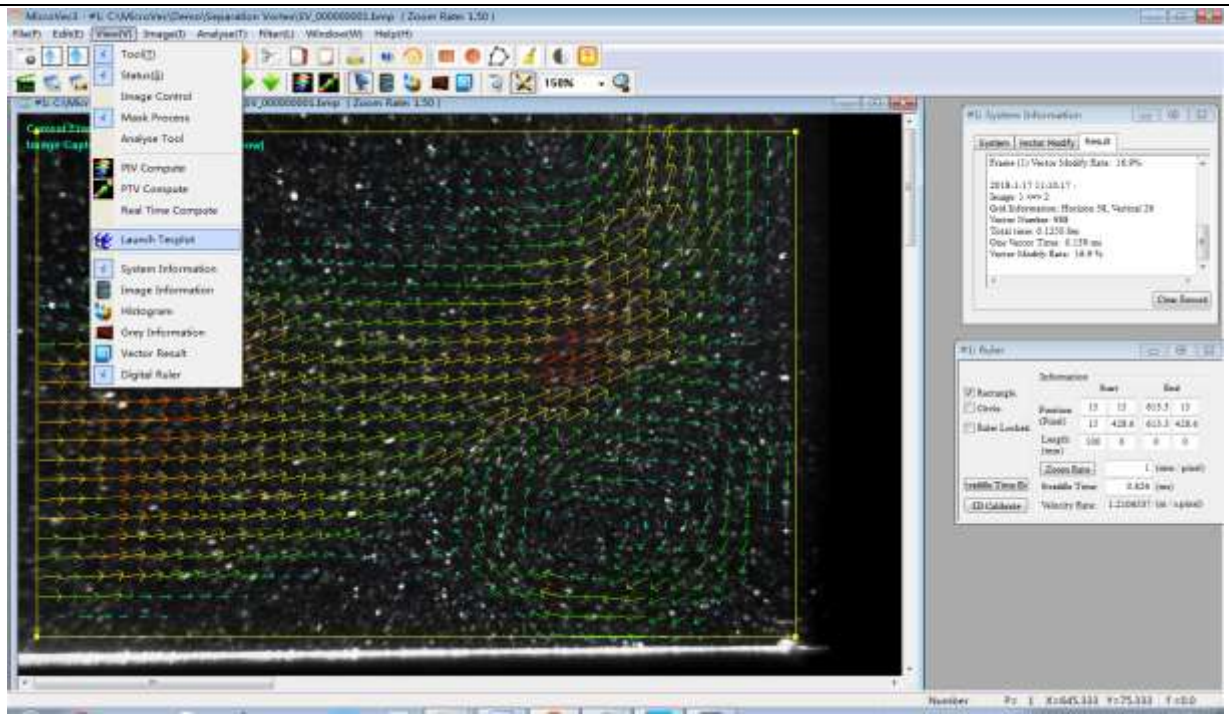


Figure 5.61 Start Tecplot

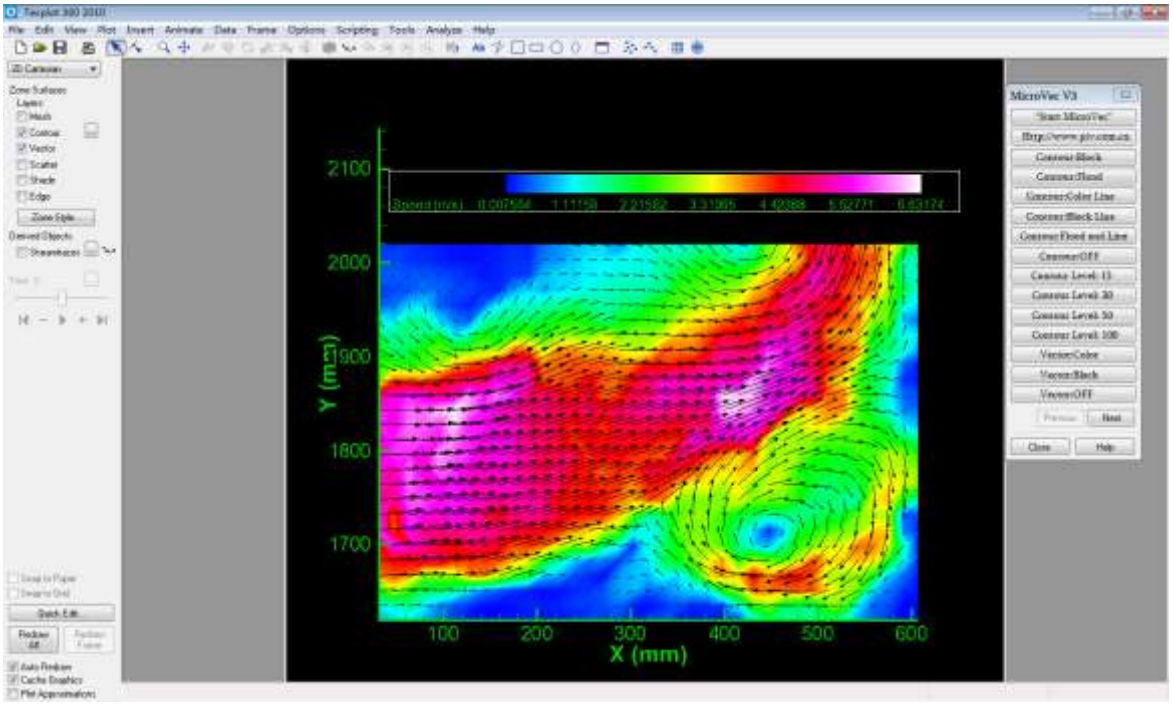


Figure 5.62 Start Tecplot macro commands

The user should pay attention when using this function: Tecplot software installation process must be carried out according to the default directory, and not with an artificially modified software installation directory. The main function of Tecplot software is to facilitate visualization of PIV flow field data results such as U, V, W components of velocity, vorticity, fluctuating volume and other related parameters.

Note that copying the Tecplot.mcr file in the Microvec directory and overwriting the original file in the Tecplot installation directory TEC100 can display the shortcut MACRO command panel.

5.5.15 Vector Clear

 Vector Clear

This command takes care of avoiding accidental deletion of vector results. For instance, in the current image, the entire image area or a delineated image area needs to be set to zero, and a message pops up to confirm the deletion. Upon clicking "Yes," the button executes the command (see Figure 5.63):If a certain region of the current image has been selected, the command deletes the calculated vectors corresponding to that particular region. If no specific area of the current image is selected, the command deletes all vectors.

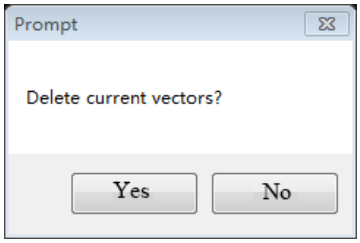


Figure 5.63 Confirm to clear vector window

5.5.16 Vector display setting

This feature can be used to set how the user intends to display resulted vectors. As shown in 5.64, several settings such as the window display color, length ratio, and the distribution of grid vectors can be adjusted to achieve the desired display of vectors. ANALYZE -> Vector Setting

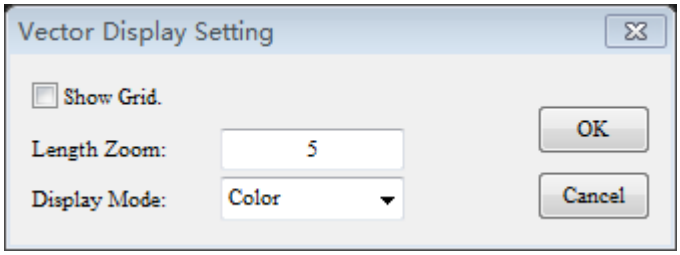


Figure 5.64 Vector display settings window

5.6 Filter menu

Microvec V3.6.5 provides a versatile digital image filtering and image conversion tool.

5.6.1 Gray stretch

Gray stretch: This can be used for digital image gray stretch and adjusting the digital image grayscale.

5.6.2 Image blur

Image blur: blur for digital image processing, fuzzy parameters can be set.

5.6.3 Contrast

Contrast: This can be used for digital image contrast adjustments and for making changes in light and dark-enhanced images.

5.6.4 Image roll

Image roll: This can be used for moving a digital image up and down, left and right or oblique axial symmetric reversal.

5.6.5 Image calculation

Image calculation: two images in the buffer according to a certain method of calculation to give another frame. Specific settings as shown in Figure 5.65:

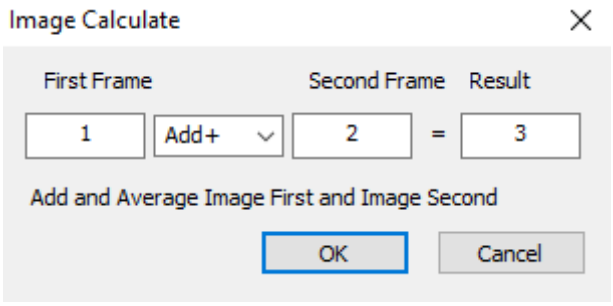


Figure 5.65 Image calculation settings window

First	Select the first image buffer location
Average	Calculation
Second	Choose to participate in the calculated position of the second image buffer
Result	Set the resulting image buffer location

Calculated by the following categories:

Average +	The two gray values together that are then averaged into the resulting image
Integration +	The two image gray values together (gray value results exceed the saturation value at saturation value processing)
Subtract -	The two gray value image subtraction (results take the absolute value)
AND	Two images at the same location as the gray value are large, the resulting image gray value at this position is large, otherwise the resulting image gray value smaller at this location
OR	Two images, the first image gray value in a certain position is large, the resulting image gray value at this position is large, otherwise the resulting image gray value at this position small.
XOR	If the two images in the same position is an image gray value, another frame gradation value is small, the result is the image gray value at this position large, otherwise the resulting image gray value at this position small.
Contrast	Depending on the first frame of image brightness, adjust the brightness of the second frame image
Difference	The difference of the two gray different parts of the resulting image (you can set the threshold gray involved in the calculation, as shown in 5.66)

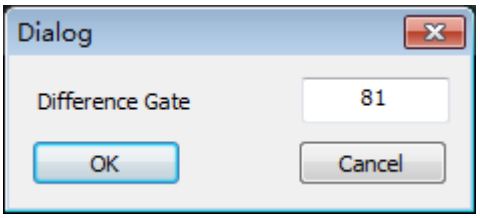


Figure 5.66

5.6.6 Image negative Gray

 Image negative Gray: This can be used for generating a new image with a gray value of the image size of rollover in the same position of the image frame.

5.6.7 Image Rotation

 Image Rotation: Rotate the image (Counterclockwise is the positive direction).

5.7 Window Menu

Configure Windows operating system interface window display: New windows, Cascade, Tile and Arrange Icons.

5.8 Help Menu

5.8.1 Help Topics

 Help Topic: Microvec V3.6.5 electronic online help file.

5.8.2 About Microvec

 About Microvec: Microvec V3.6.5 displays version information.

5.8.3 About www.PIV.com.sg

 About www.PIV.com.sg.: If the computer is networked case, you can link to the Microvec. home page for a visit.

5.8.4 USB Key Driver Installation

Dongle Driver Installation: Install the dongle drive, open Microvec3 and all its functional modules.

Chapter VI Application examples

In order to help users easily understand the particle image analysis system of Microvec and grasp the actual experimental techniques, this chapter will show the operation of the software system and the use of the hardware through the application of the different experiments.

6.1 Application of the 2D PIV system

6.1.1 System introduction

2D PIV system shown in Figure 6.1:

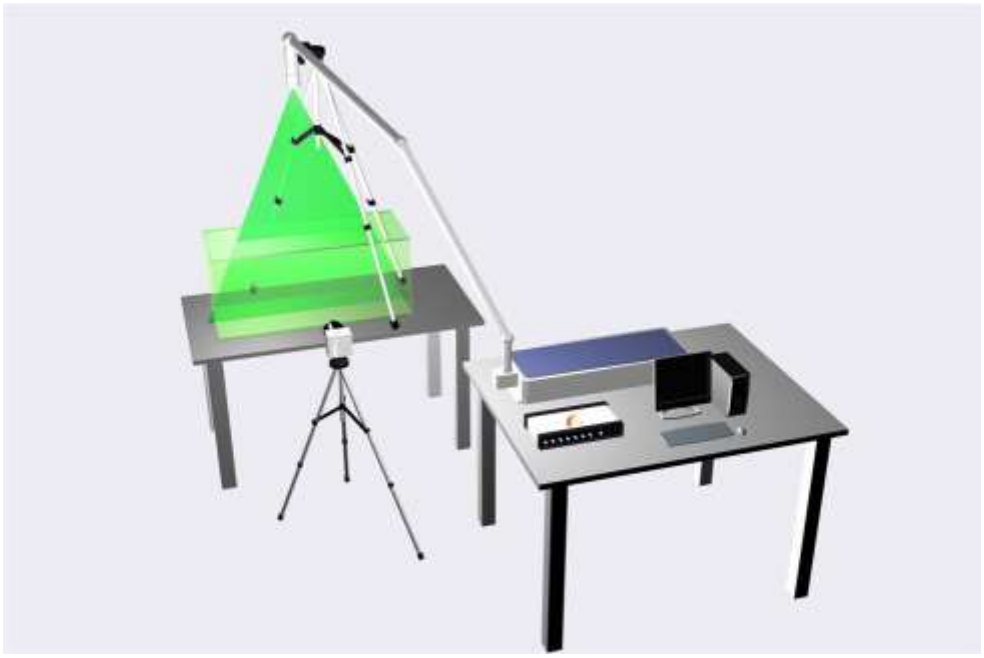


Figure 6.1 2D PIV system diagram

6.1.2 Recording image

This section describes the 2D images acquisition and the calibration process of the images.

1. Adjusting the laser sheet to the measuring field

Adjusting the thickness of the laser sheet to 1mm and illuminating the measuring field **(Note: refer to the lasers manual).**

2. Adjusting the camera frame to the appropriate position

The camera tripod is (tripod or coordinate frame) placed in the appropriate position and adjusted to an appropriate height to place the camera.

3. Installing CCD camera and lens

Install the lens onto the CCD camera, and fix it onto a tripod. Next, connect the power cable and the data cable. **Note: we must ensure the power is off. Cover the lens and the minimum aperture (the largest f-number), when installing the lens and CCD camera.**

4. Running the software

Run the software, Click on the "hardware control" command ("Image" menu "hardware control" command or ). In the "Camera Control" window, the communication port is selected as "CamLink" (see Figure5.22). When the detection is passed, we can carry out further work. If the detection is not passed, the user can reset the camera power, but avoid swapping camera data cables, and then re-work the detection. If the detection still can't be passed, then shut down the computer, turn off the power, and reconnect the power cable and the data cable.

5. Focusing

In the "Camera Control" window, make sure camera "mode" is selected as "PIV mode."

Add tracer particles to the experiment test section and run the experiment test section.

Click on the "hardware control" command ("Image" menu "hardware control" command or ), select "lasers" and click on the "Advanced Settings" and set the parameters.

If you complete the setting, click on the "Run" button.

Click on the "Live View image" command ("Image" menu "Live View image" command or ). Open the lens cover, adjust the aperture and focus it. Then, the measurement system focusing will be completed. Then, click on the "Stop" button to stop the laser work.

6. Recording the ruler image

In order to know the conversion relationship between the experimental segment size and the actual size in the picture, you need to use a ruler image.

There are two ways to record the ruler image: one way is to use the feature size of some experimental segment in the captured image, such as the known inner diameter or outer diameter of the pipe, or the actual length of an object in the experimental segment. These feature size object images can be saved as the ruler image (for the specific usage of the ruler image see next Section).

Another way is to place a ruler in the laser sheet (the laser energy is weakened, and the ruler can be illuminated with natural light, flashlight, etc.). As long as the scale of the ruler is clearly displayed in the captured image, the ruler image can be used.

7. Image calibration

To select the image of the buffer location, open the scale image ("File" menu "Open" command or ), The ruler of the intercepted image is shown in Figure 6.2:

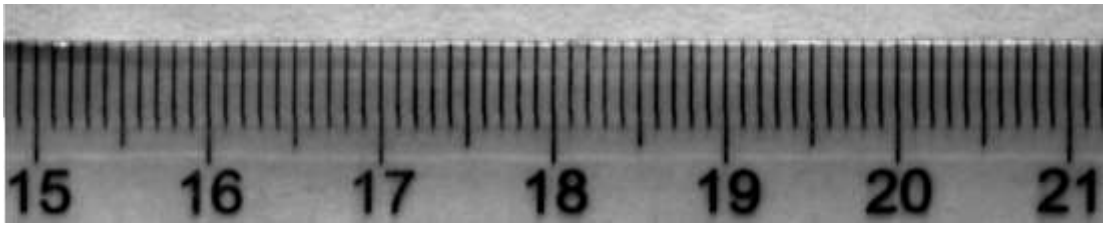


Figure 6.2 Scale image

The contrast of the ruler image can be adjusted with the "Histogram" command ("View" menu "Histogram" command or ) (Figure 6.3), Shown in Figure 6.3, the ruler image is darkened overall and you can click the left mouse button to drag the lower right triangle from right to left, then the contrast of the image will be changed.

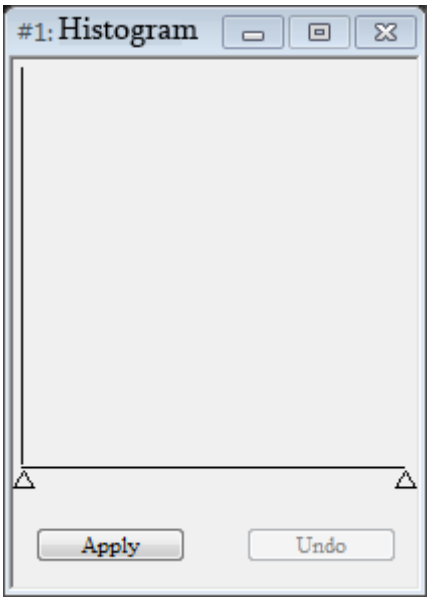


Figure 6.3 Gray histogram

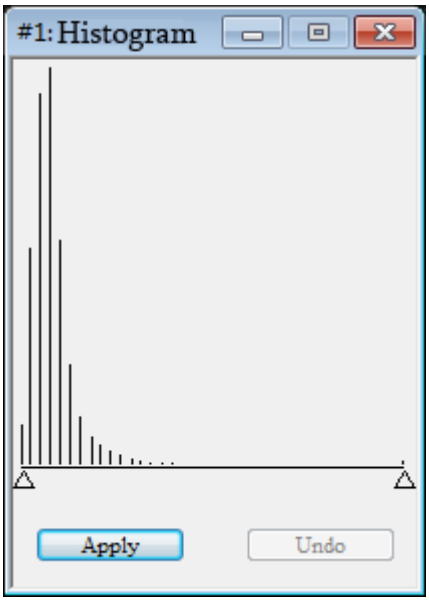


Figure 6.4 Grayscale distribution adjustment

Figure 6.5 is the new ruler image by adjusting the contrast of Figure 6.2:

Figure 6.5 The ruler image after adjusting grayscale distribution

Click on the "Ruler" window ("View" menu "Ruler" command or ). Cancel the "Rectangular Region Show" option, press the left mouse button in the image to draw a line along the tick mark (Figure 6.6):

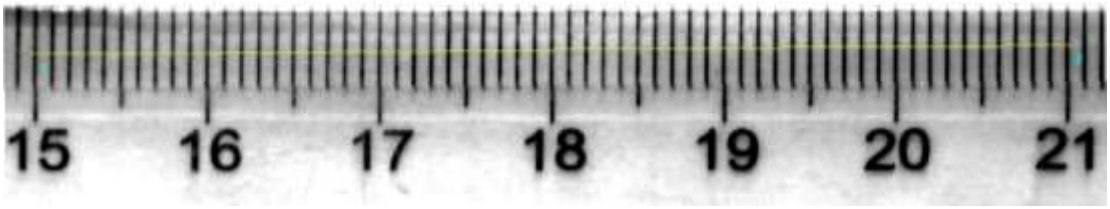


Figure 6.6

The software automatically recognizes the actual length of the line drawn in Figure 6.6(the actual length is 59.98mm), and automatically calculates the image magnification (the image magnification is 0.0556936).

It is worth noting that if the quality of the ruler image is poor, or you use other non-standard rulers/objects (such as the model size used in the experiment) to calibrate, you need to manually enter the actual length of the drawn line under the "Length" column, then click on the "Zoom Rate" button.

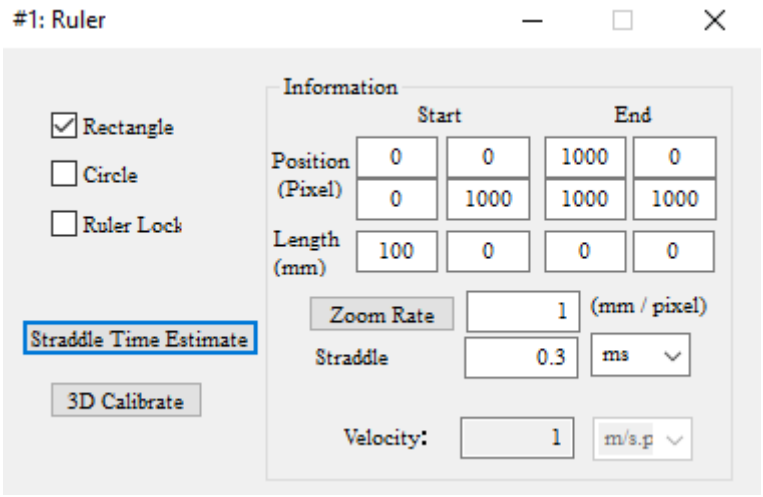


Figure 6.7

8. Confirm Pulse Delay

Click on the “Straddle Time Estimate” (Figure 6.7). As seen in Figure 6.8, fill in “Velocity Max” with a number (this number is the max speed of the flow field), then click the “Straddle Time” button. The number will be equal to Pulse Delay (**Detailed reference can be found in section 5.4.6**).

Note: The exposure time estimate function only estimates pulse delay. Sometimes the actual pulse delay time needs to be adjusted according to the particle images or calculation results.

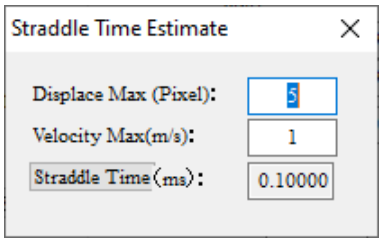


Figure 6.8 Estimate Pulse Delay

9. Recording images

For adjusting the laser energy, clicking on the "Hardware Control" command ("Image" menu "hardware control" command or ), and enter numbers into the “Start” and “End”, for example, for "Start" input 1, for "End" input 100. This indicates that 100 images captured will be saved in the image buffer 1-100.

Click the “RUN” and “Live show”(), you can observe the flow field, then you can click the “Record” command to record particle images when need to **(Note: The images are saved in RAM and not the hard disk).**

10. Evaluation of the particle images

Evaluation of the image is divided into two steps. First, the user needs to ensure that the particle distribution in the image is even. The main characteristics include that there are enough particles in an interrogation window, and the distribution is relatively uniform.

Preliminary calculation of the filtered image after the first step:

Click the "Ruler" command ("View" menu "Ruler" command or ).

Select the calculation area of the images, and click the "PIV Compute" command ("View" menu "PIV calculation window" command or ) to set PIV calculation parameters and calculate.

If the calculated vector distribution is smooth, the obvious error vector is small, or the corrected result is satisfactory, the acquired image meets the experimental requirements.

If you are not satisfied with the particle images, repeat steps 9 and 10 to capture the particle images.

11. Save images

Click the "Save Image Series" command ("File" menu "Save Image Series" command or ). Click on the "Browse" button to set the directory where the image is saved. When the image sequences are automatically being saved, the images are numbered. The default label is 000000001-000999999, so it is recommended to use the form "100us-" to name the files as shown in Figure 6.9, When naming the first image, add a "-" in the middle to make the subsequent image number and the front part of the file name easy to distinguish.

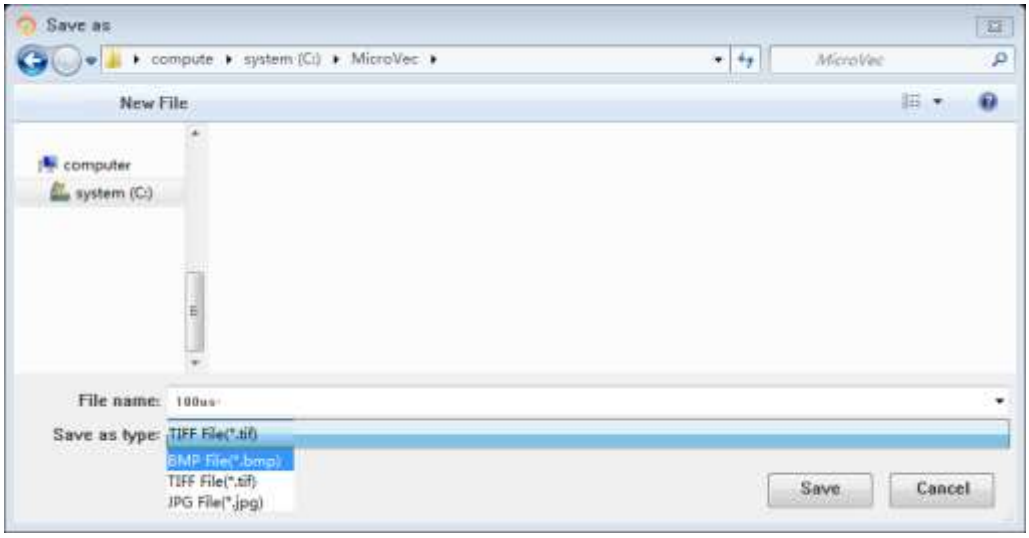


Figure 6.9 Save image series

Flow diagram of 2D PIV experiments is shown in Figure 6.10:

Flow diagram of 2D PIV experiments

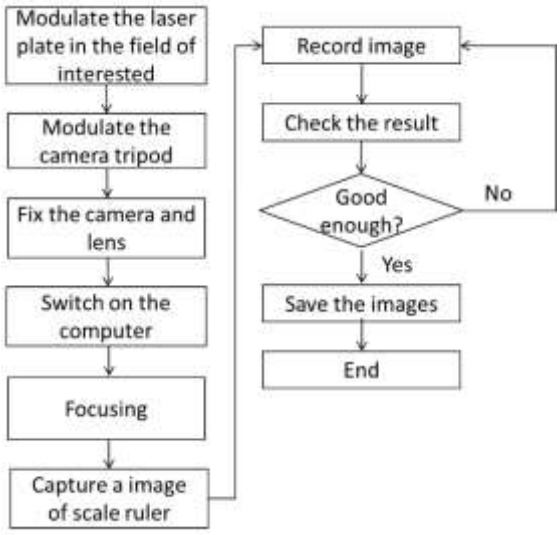


Figure 6.10 Flow diagram of 2D PIV experiments

6.1.3 Analysis of experimental images

An analysis is not always possible for each captured image. This section will describe how to achieve best results.

When we are doing the experiment, we can`t specifically analyze all images.

Take a pair of images as an example, the analysis steps are as follows:

1. Import the ruler image and calculation.

2. Import the particle images.

Click the “Open Image Sequence” command ("File" menu "Open Image Sequence" command or ) to import the image sequence.

3. Analysis of a pair of images

Before performing PIV batch processing on a large number of images, you first need to perform a calculation on a pair of images to set calculation parameters for batch calculation and vector correction.

Select the calculation area. In actual experiments, sometimes a partial area of the particle image is better, or there is no need to calculate the entire image. In this case, the calculation region needs to be selected. Click the "Ruler" command ("View" menu "Ruler" command or ), select the calculation area and lock the "Ruler Lock" option (Figure 6.7). The function of the “Ruler Lock” command ensures the software will calculate this area of all the images when batch processing.

Click the "PIV compute" command ("View" menu "PIV calculation window" command or ), and perform PIV calculation according to the set parameters. If you are not satisfied with the current vector result and the corrected result, you can delete this result and re-select the calculation parameters or different areas for calculation ("Analysis" menu " Current vector Clear" command). Click the "OK" button in the pop-up window to delete the calculation result.

Select the appropriate magnification scale to display vector. If the calculated vector is too small, you can adjust the length of the display vector by changing “Vector Length” ("View" menu "System Information" command or ) (Figure 6.11):

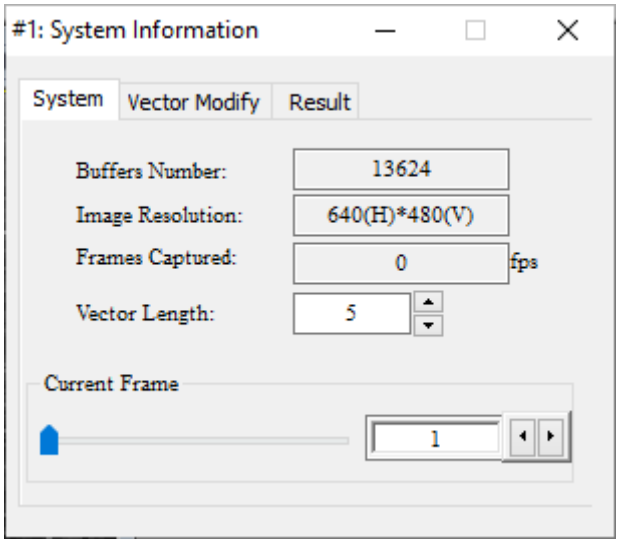


Figure 6.11 Selecting the vector display length

If you notice that the vector display is not clear enough, you can select "Show Image" in the "Image" menu to display only the vector image.

Click the “Filter” option and set vector correction parameters. Another function of the "Vector Correction" option is: when the software calculates image batch processing, it will use this function to correct the vector.

4. PIV image batch process

Click the "PIV Batch process" command ("Analysis" menu "PIV Batch process Tool" and "PIV batch process" command), and set up the image that needs to be batched (Figure 6.12). “Start” indicates the image buffer number that starts batch processing. "End" indicates the image buffer number that ends batch processing. In general, batch processing uses the default calculation parameters. Click on the "OK" button and the software will automatically calculate the image according to the previously set parameters and will automatically correct results according to vector correction parameters. The calculated vector is displayed in 1, 3, 5 ..... in the image buffer.

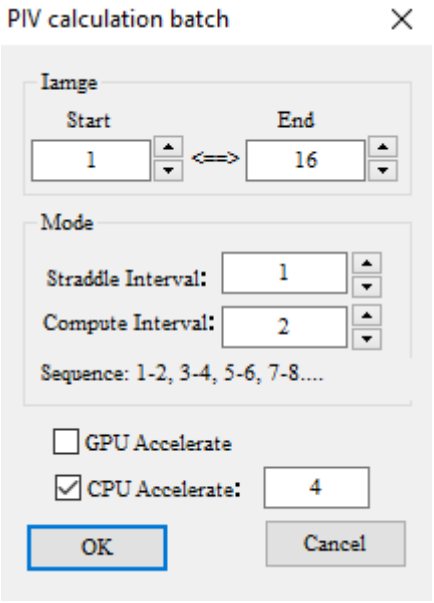


Figure 6.12 PIV calculation batch process

5. Save the calculation results

Before saving the calculation results, you first need to browse the batch results. Unsatisfactory results may exist among all calculation results. For such calculation results, there are two ways to solve the problem: opting not to save this result, or resetting parameters to calculate them.

After the mentioned work is completed, you need to save the calculation results. Click the "Save Batch process Results" command ("Analysis" menu "PIV Batch process" and "Save Batch process result" command) and set the file name and the range of calculation results that need to be saved. It should be noted that if the batch processing adopts the first calculation method (Frame Straddle:1, Compute Interval:2), half of the calculation data file name will be 000001, 000003, 000005...

6. Further processing

The data processing is completed at this stage, the user can use Tecplot, Origin and other software to do further analysis.

The flow diagram of 2D PIV image analysis is shown in Figure 6.13:

Image analysis

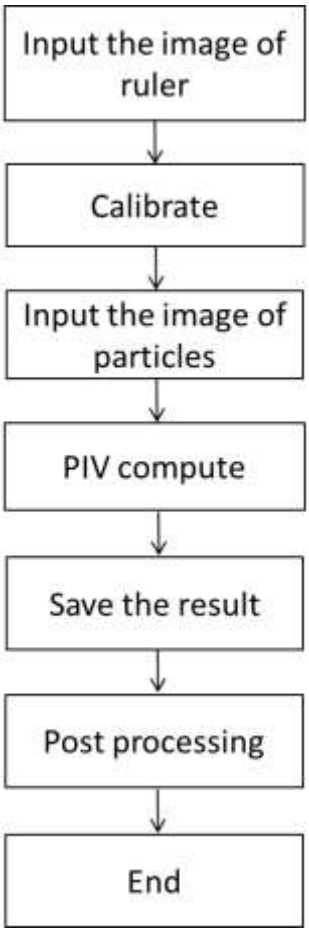


Figure 6.13 Flow diagram of 2D PIV image analysis

6.2 TR-PIV Application Examples

6.2.1 Continuous mode (without using synchronizer)

Continuous mode of the TR-PIV system is applicable for measuring the flow field, which has a flow rate below 0.5m / s. The experimental arrangement is shown in Figure 6.14:

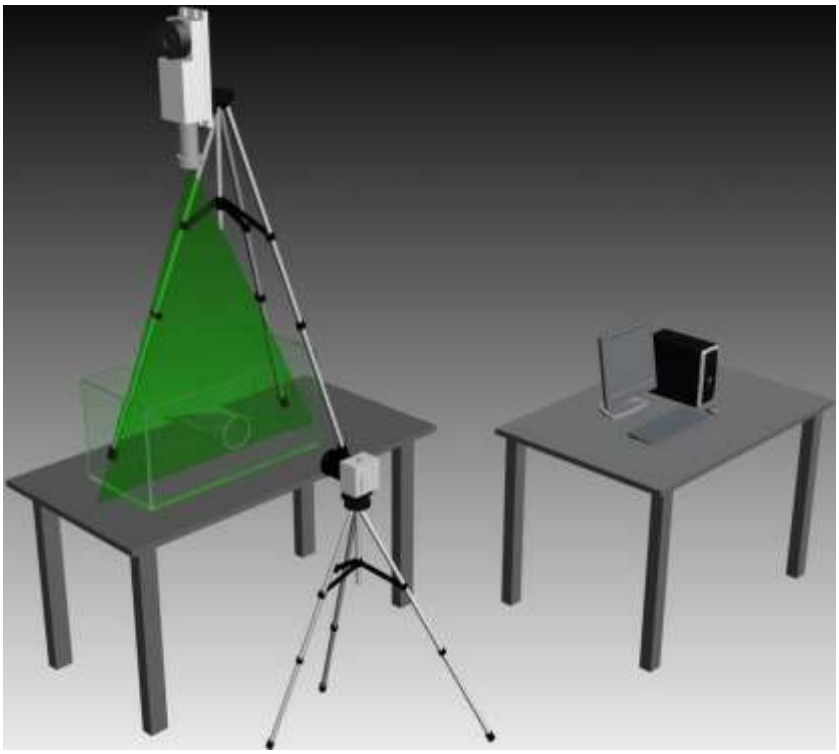


Figure 6.14 TR-PIV system continuous layout mode

PIV technique is an extension of PIV and includes the capturing of frames at a high speed of hundreds or thousands of frames per second usually with the use of high-speed cameras. Images are recorded at a series of time intervals and are subsequently processed to extract velocity information based on the time between the frames.

The Time Resolved PIV (TR PIV) system with a continuous mode timing diagram is shown in Figure 6.15.

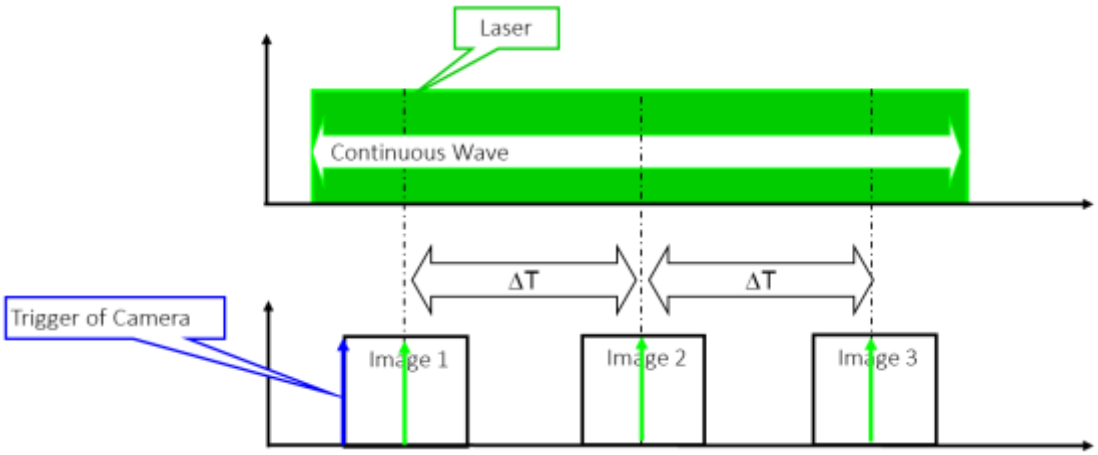


Figure 6.15 Timing diagram of TR PIV system in continuous mode

The following section describes specific steps of the TR PIV system in continuous mode:

i. Test data collection

1. Adjust the light sheet measuring position

The laser modulation mode should be switched to "TTL +". The laser light sheet should be adjusted to a light sheet thickness of about or below 1 mm and should cover the entire intended Area of Interest (AOI). **For more details see the laser manual.**

2. Adjust the camera to the appropriate position

The camera stand (tripod or coordinate frame) should be placed in the proper position and adjusted to a suitable height to place the camera.

3. CCD camera and lens mounting

Attach the lens and make sure the CCD camera is fixed on the rack. Connect the power cord and the CCD and image space between the data lines.

Note: During the installation, turn off the camera's power. Don't remove the lens cap and keep the lens aperture to the minimum number (largest f-number).

4. Running the software

When running the software, bring up the "hardware control" window ("Image" menu "hardware control" command or ). Then select the "Camera Control" button in the Camera Control window and select the port "CamLink." When the test has passed, the "Camera Control" window Camera "mode" should be selected for "continuous" Mode. If the camera can't be connected, the user can plug the camera's power after performing a reset, but not with a hot-swappable camera data cable, and then re-working the detection. If it is still not working, then shut down the computer, turn off the power supply, and remove the CamLink cable and power cable.

5. Focus

After adding tracer particles (it's recommended to follow a ton of water particles in the proportion of 10 g), run the experiment test section.

Use the "live show image" function ("Image" menu, "Live show image" command or). Open the lens cover, and adjust the lens aperture to fit small to large sizes. If the aperture adjustment to the maximum figure is still very dark, the particles can be improved through the laser current adjustment knob laser energy, or the "Camera Control" window can be used to increase the value with the "Electronic shutter" column. Photos of light irradiation area particles will display real-time image adjustment clearing. Thus, the measurement system focusing is completed. Stop the camera work ("Image" menu "stop all" command or).

6. Image calibration

The ruler image can be obtained in two ways, one is by using some experiments in the captured image feature size segment, such as the known pipe diameter or diameter size, or using the experimental section of the actual length of an object. The size image of the object can be saved as a yardstick image.

7. Open ruler image.

Select the image of a buffer location and open scale image ("File" menu, "Open" command or). The ruler of the intercepted image is shown in Figure 6.16:

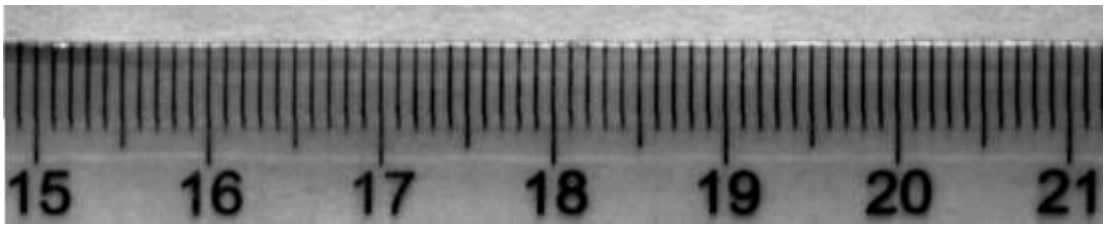


Figure 6.16 Scale image

For the ruler image in the acquisition, if there is not enough illumination to see the image clearly, you can open the "Histogram" window ("View" menu, "Histogram" command or) (See Figure 6.17). The histogram plots the number of pixels in the image (vertical axis) with a particular brightness or tonal value (horizontal axis). Our Histogram dialog box allows you to visually adjust the brightness value of each pixel and to dynamically display the results as adjustments are made. Improvements in picture brightness and contrast can thus be obtained by dragging the triangle pointer with the mouse click to the left. As a result you can see a much better histogram equalization and the image with the particles will appear much brighter than before as shown in Figure 6.18:

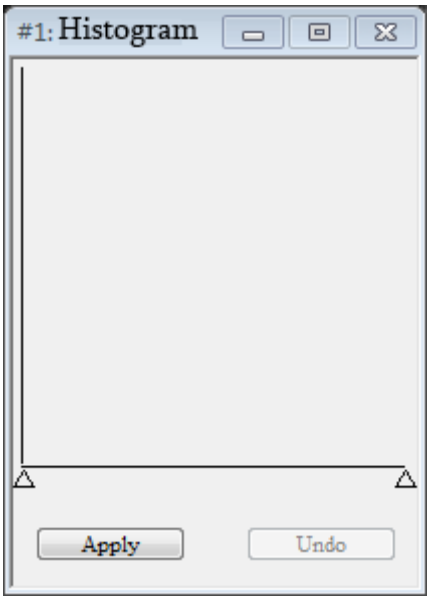


Figure 6.17 Grayscale histogram

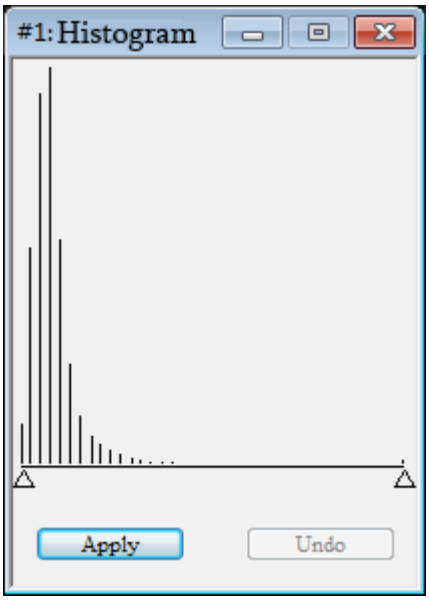


Figure 6.18 Grayscale histogram equalization

In this case, as shown in Figure 6.19, the scale image is shown as a much brighter and clearer picture as before and the selection of the known scale can be made easier:

Figure 6.19 Scale image after grayscale distribution adjustment

Bring up the "Ruler" window ("View" menu, "Ruler" command or ). Uncheck the "rectangular region show" option, and, while pressing the left mouse button in the image, draw a line along the scale line (see Figure 6.20):

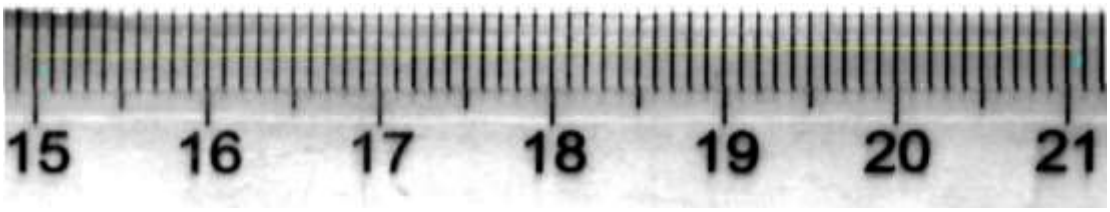


Figure 6.20

As shown in Figure 6.21, Figure 6.20 software automatically identifies the actual length of a straight line drawn in as 59.98mm, while automatically calculating the image magnification (magnification 0.0757094 image at this time). In the "Pulse Delay" column, enter the experimental

amount used with the chosen frame straddle (here, the frame straddle is 826us). Then, save as the ruler (click the button “ ”).

It is worth noting that, if the image quality is poor when shooting the ruler or other non-standard objects (such as experimental model used size) to calibrate, you need to manually use the "Length" column to enter the actual length of a straight line drawn, then click the "Zoom Rate."

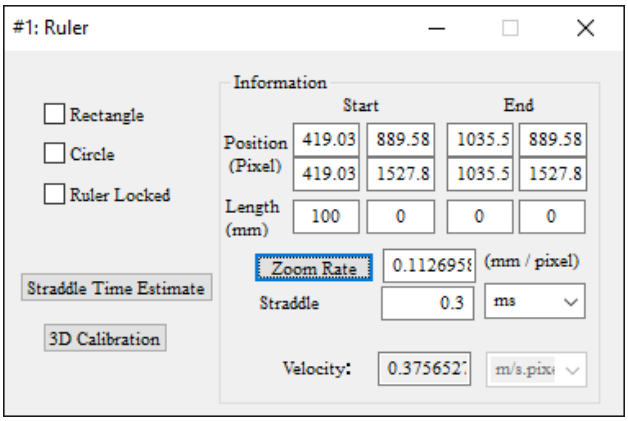


Figure 6.21

Another commonly used ruler image is an on-chip optical ruler (the laser energy transfer is weak, it requires the use of natural light, and a flashlight to illuminate the ruler). As long as the ruler of the captured image is clearly displayed on the scale, this image can be used as the ruler to scale images.

8. Particle Image recording

To make laser energy adjustments to the normal value, in the "Hardware Control" window, select the "Record" button, then select the "Start " and "End" in the “Frame grabber.” For example, "Start "Input 1," End " enter 100, which means that the recorded images are stored in image buffers 1-100, for a total collection of 100 charts. First click on the "Image" menu "Live show image" command or 

until the system is stable, then click on the "record" button. The image will be sequentially stored in the image buffer **(Note: If the sync is in working condition, using the BNC signal line connected to the camera, disconnect the computer synchronizer USB cable that is connected, or disconnected the synchronizer and the camera BNC signal line connected to prevent signal interference synchronizer as the camera records the image).**

9. Check whether the image is consistent with experimental requirements

View image is divided into two steps. First check whether the distribution of particles in the image is better, the main indicator being that the number of particles is more and more evenly distributed.

After the first step of screening images preliminary calculations: bring up the "Ruler" window ("View" menu "Ruler" command or ). Images to be analyzed should be selected according to the appropriate computational domain and using the "PIV vector computing" window ("View" menu "PIV

compute" command or ). Set up the appropriate calculation parameters for the PIV calculation. If the calculated flow vector distribution obvious error vector is small, or the amended result is quite satisfactory, then it can be said that t the images acquired will meet the test requirements.

If you are not satisfied with the acquired images, repeat steps 8 and 9 to capture two particle images that are satisfactory.

10. Save the recorded image

Open the "Save Image Series" window ("File" menu "Save Image Series" command or ). Click on the "Browse" button to set the directory where the image is saved. You need to note that the image sequence is automatically saved as an image label with a default label of 000000001-000999999. The recommended naming of the first image is shown in Figure 6.22. It shows "4.76ms-" as the form of one the first part of the file name is set as pulse delay time, the middle of a "-" in order to allow subsequent image number and separate the front part of the file name.

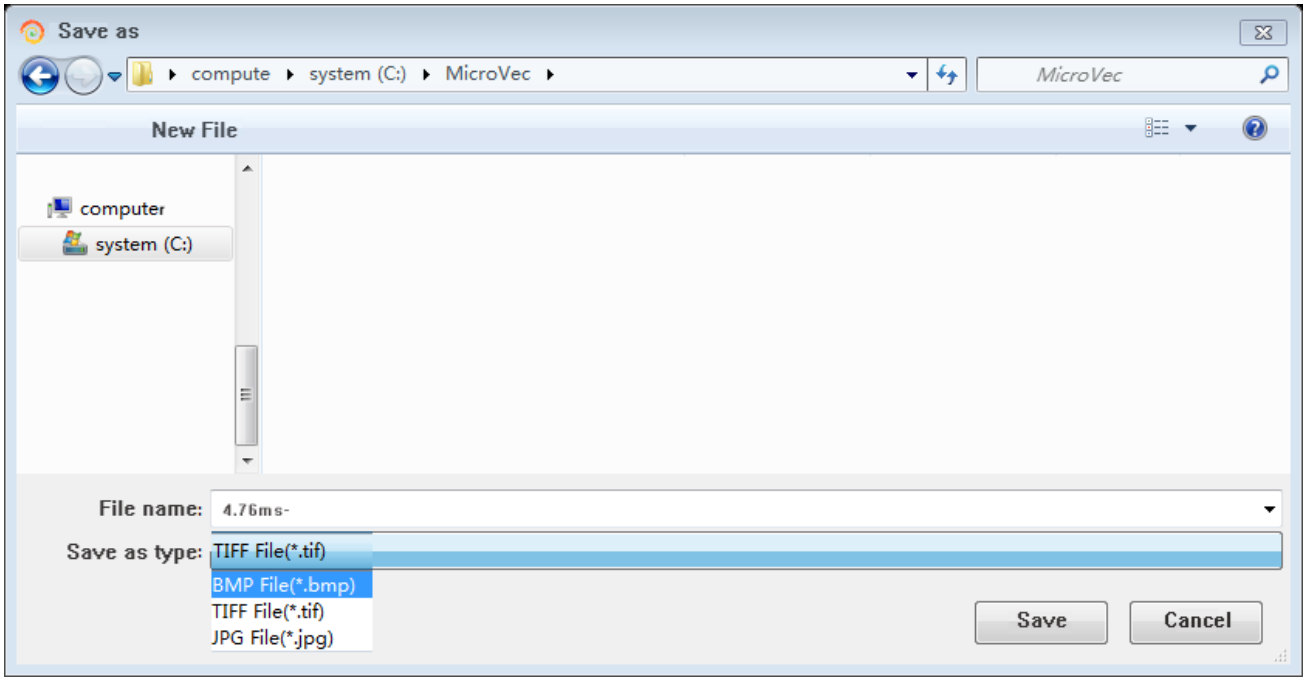


Figure 6.22 Save image sequences naming

ii. Analysis of the test images

1. Open the particle images

Open the "Open Image series " window ("File" menu "Open Image series" command or ), and select a series of experimental images to read into the set image buffer.

2. A pair of images analysis

If you need to select the computational domain, simply open the "Ruler" window ("View" menu "Ruler" command or ), choose “rectangular region show”, and hold down the left mouse button and drag to select the computational domain.

Open the "PIV vector computing" window ("View" menu "PIV compute" command or ), select the appropriate parameters for PIV calculation (you can also use the default value), until the calculated results are satisfactory.

3. PIV Batch process

Open the "PIV Batch process " window ("Analysis" menu "PIV Batch process tool" and "PIV batch process" command), and set the need for batch processing images (see Figure 6.23). Window "Start" indicates the image buffer to start the batch process number, "End" indicates the batch process number of the last image buffer. Select the appropriate method of calculation (default parameters can also be used), and select GPU computing acceleration or multi-threaded acceleration (total number of images involved in the calculation must be an even multiple of the number of threads). Click on the "OK" button and the software will follow the various parameters involved in the calculation of the image batch processing.

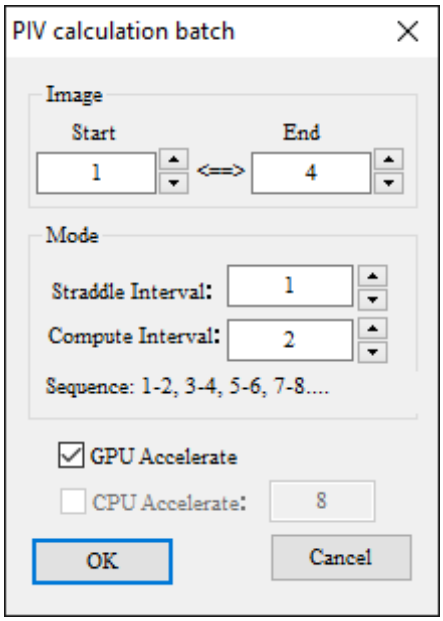


Figure 6.23 PIV calculation batch process

4. Save the result

Before you save the results, you should review first the results of the batch process. Some of the vector fields may not be satisfactory or even correct. You can try to recalculate them with different parameters or different interrogation window size before saving them to hard disk.

After completion of the above work, bring up the "Save Batch process Results" window ("Analysis" menu "PIV Batch process" and "save batch process result" command), set the file name to save the calculated results and save the range. If you need to save the average results of the batch process, you need an image in the final buffer location (the batch process is completed automatically and results in an average of the last image buffer). Open the "Save Vector File" window ("File" menu "Save Vector Files" or ), choose a storage location and click "Save."

5. Further processing of the data

The data processing is now completed. The user can use Tecplot, Origin and other software for the data file for further analysis.

6.2.2 PIV mode with DPSS laser (requires use of MicroPulse synchronizer)

TR-PIV PIV system model for measuring the flow rate at 2 m/s within the flow field is shown in Figure 6.24:

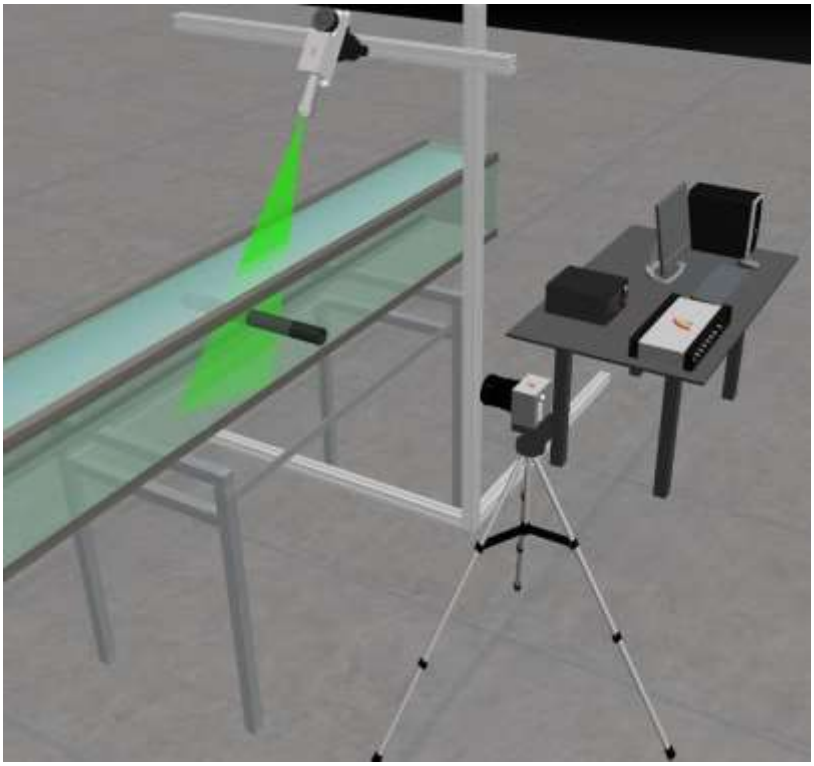


Figure 6.24 schematic of TR-PIV system PIV mode

TR-PIV system PIV mode timing is shown in Figure 6.25:

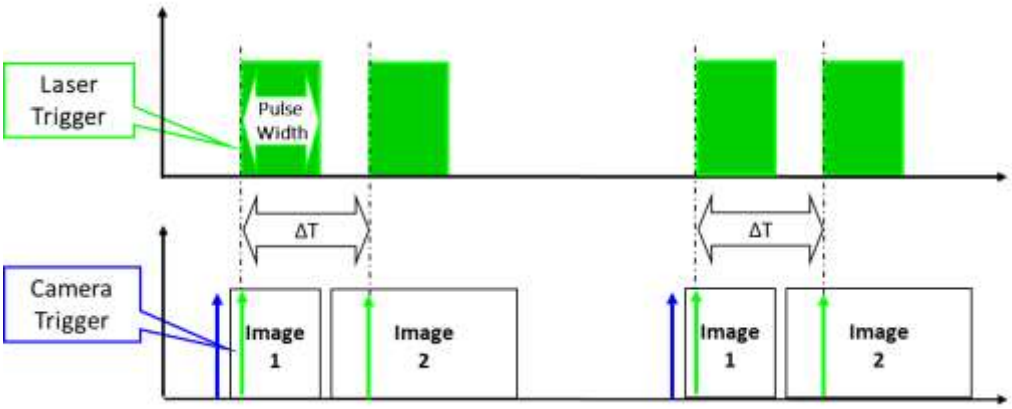


Figure 6.25 Timing diagram for PIV system with DPSS laser

The following describes the TR-PIV system PIV mode specific steps:

i. Test data collection

1. Will be adjusted to the light sheet measuring position

The laser light sheet should be adjusted to a light sheet thickness of about or below 1 mm and should cover the entire intended AOI while the laser modulation mode is switched to "TTL +". Then switch the laser to external modulation mode: "TTL-" to start capturing the frames in double exposure (PIV) mode as image pairs **(for more details see the laser manual).**

2. Adjust the camera frame to the appropriate position

The camera stand (tripod or coordinate frame) should be placed in the proper position and adjusted to a suitable height to place the camera.

3. CCD camera and lens mounting

Attach the lens to the CCD camera fixed on the rack and connect the power cord, the CCD and image space between the data lines.

Note: During the installation turn off the camera's power, don't remove the lens cap and keep the lens aperture to the minimum (largest f-number).

5. Using the synchronizer to control the laser and camera

Connect a BNC cable to the camera's power "TRIGGER" line. The synchronizer "T5" channel should be connected with another BNC TTL trigger line to the laser signal interface "TTL IN" and the synchronizer T7 channel.

6. Running the software

Running the software, bring up the "hardware control" window ("Image" menu, "hardware control" command or ). Then select the "Camera Control" button in the Camera Control window.

select the communication port "CamLink", after the test is passed, the "Camera Control" window camera "mode" should be set to "PIV mode." If the test is not passed, the user can plug the camera's power on reset, but not with a hot-swappable camera data cable, and then re-work the detection. If it is still is not working, then shut down the computer, turn off the power, and remove the CCD re-data cable and power cable.

6. System parameter settings and focus

After adding tracer particles (it's recommended you use a ton of water particles in the proportion of 10 g), run the experiment test section.

In the "Hardware Control" window, select the "Laser" button in the "Pulse Delay" to enter an appropriate value (refer to section 5.4.5 "pulse delay settings" listed experience). Select the appropriate "frequency," click "Advance " in the "Channel 7" "pulse width" column and enter the appropriate value (less than or equal to the cross-frame delay, it is recommended you choose a value preferably below 2000 μs, in order to avoid damage to the camera). Then in the "Hardware Control" window, select "Camera Control" settings in the "electronic shutter" column value, so that the "laser", "Advance" in the "Channel 7" and "pulse width" value is consistent (Note that the unit used in the "Electronic Shutter" column is milliseconds, while the "pulse width" used in microseconds).

In the "laser" window, click "Run" to adjust the laser energy to the proper value. Open the camera lens cover and adjust the lens aperture to fit small to large sizes. Then the photo irradiation zone particles will display real-time image adjustment clearly. Thus, the measurement system focusing is completed. In the "laser" window, click the "Stop" button to stop the system operation.

7. Capture the ruler image

Roughly scaled images can be obtained in two ways, one is by using some experiments in the captured image feature size segment, such as the known pipe diameter or diameter size, or experimental section of the actual length of an object. The feature size image of the object can be saved as a yardstick image.

Another commonly used scale image is placed at an on-chip optical ruler (the laser energy transfer is weak, so the use of natural light is necessary with a flashlight to illuminate the ruler). As long as the ruler of the captured image so clearly displayed on the scale, the image can be used as the ruler scale image.

8. Image calibration

Select the buffer location of an image and open the scale image ("File" menu "Open" command or ). The ruler of the image in Figure 6.26 shows the interception:

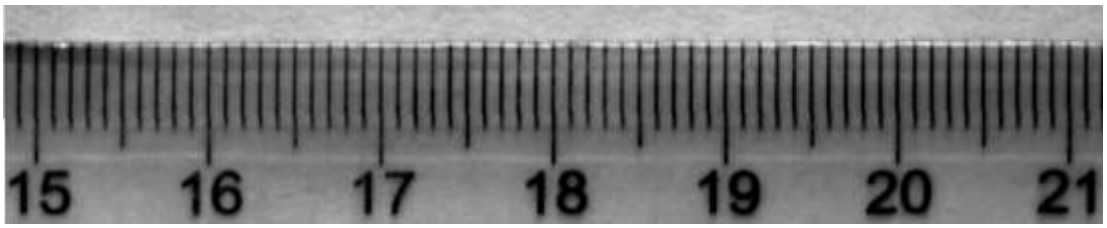


Figure 6.26 scale image

The scale image in the acquisition, without enough light when the scale image is obtained may look dim. Bring up the "Histogram" window ("View" menu "Histogram" command or ) (See Figure 6.27). As can be seen from the figure, the overall image dark/gray distribution is concentrated in a relatively small part. Use the left mouse button to click on the small triangle on the right and drag it to the left to adjust the gray distribution as shown in Figure 6.28:

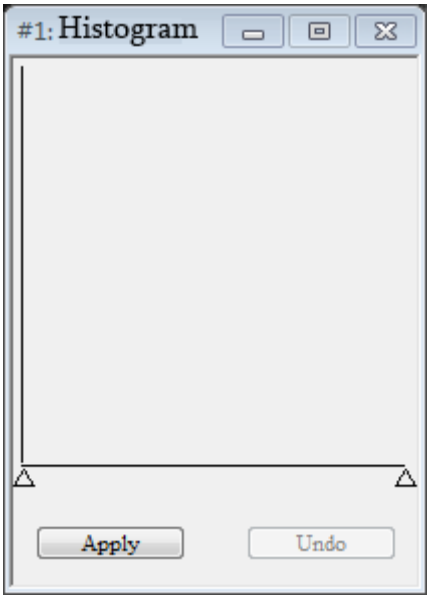


Figure 6.27 grayscale histogram

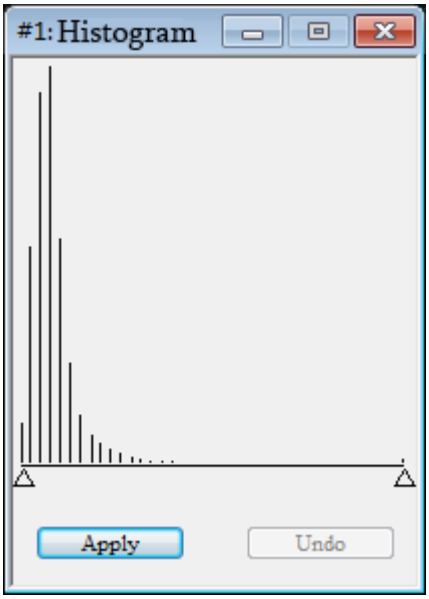


Figure 6.28 grayscale distribution adjustment

Figure 6.27 shows the scale image in a very clear picture:

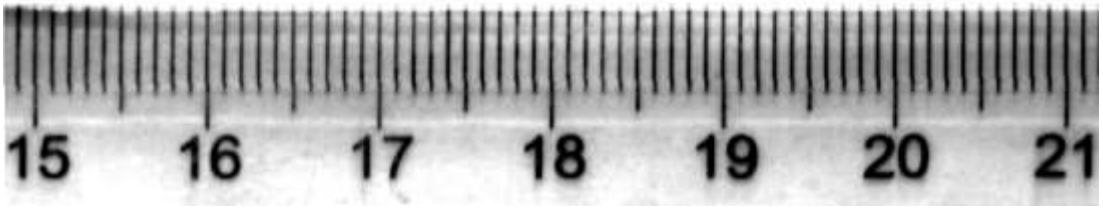


Figure 6.29 Scale image after grayscale distribution adjustment

Bring up the "Ruler" window ("View" menu, "Ruler" command or ), uncheck the "rectangular region show" option, and while pressing the left mouse button on the image, draw a line along the scale line (see Figure 6.30):

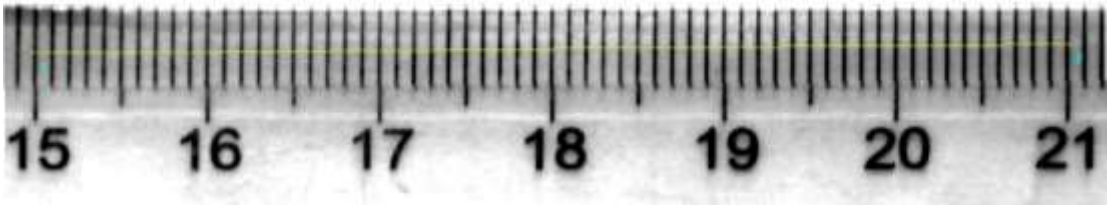


Figure 6.30

As shown in Figure 6.31, the software automatically identifies the actual length of a straight line drawn in to 59.98mm, while automatically calculating the image magnification (magnification 0.0757094 image at this time). In the "Pulse Delay" column, enter the experimental used when the inter-frame time (here, the inter-frame time is 826us). Then, save as the ruler (click the button ).

It is worth noting that if the image quality is poor when shooting the ruler, or other non-standard objects (such as experimental models) to calibrate, you need to manually enter the actual length of a straight line drawn in the “Length” column. Then click the "Zoom Rate."

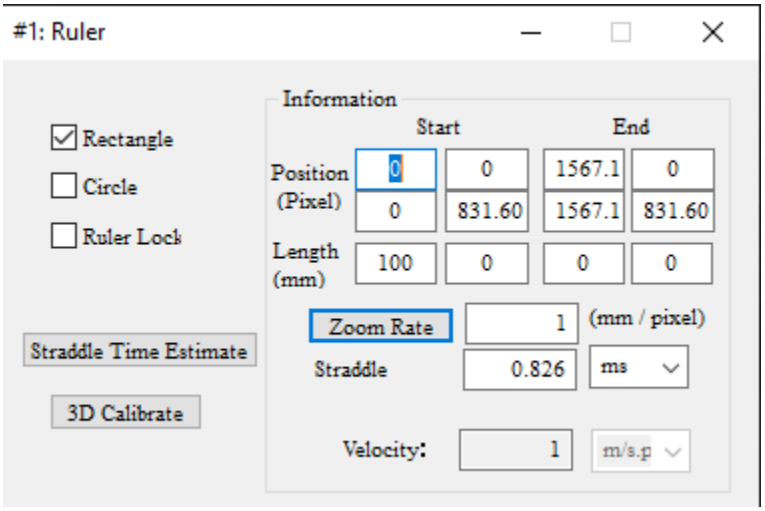


Figure 6.31

9. Particle Image recording

To adjust the laser energy to the normal value, in the "Hardware Control" window, select the "Record" button, and select "starting position" and "end position." For example, for "Start" enter 1 and for “End" enter 100, which means that the recorded images will be stored in the image buffers from 1 to 100, a total collection of 100 charts. Click on the "laser" in the "Run", make sure the system is stabilized and then click the "Record" button, the images will be sequentially stored in the image buffer **(Note: At this point the image is stored in the memory and is not saved yet on the hard disk).**

10. Check images

View image is divided into two steps, first check whether the distribution of particles in the image is better, the main indicator is that the number of particles is more and more evenly distributed.

Secondly, after the first step of screening images, you have to perform preliminary calculations. Bring up the "digital ruler" window ("View" menu "Ruler" command or), and choose “rectangular region show”. Select the appropriate computational domain for the images to be analyzed, and open the "PIV compute" window ("View" menu, "PIV compute" command or). Set up the appropriate calculation parameters for PIV calculation. If the calculated vector field looks right, and there are no obvious erroneous vectors or outliers we can assume that the result is satisfactory.

If you are not satisfied with the acquired images, repeat steps 8 and 9 to the satisfaction of the acquired particle image (if the calculated value is too large or too small, change the "lasers" window "cross-frame delay").

11. Save the recorded image

Open the "Save Image Series" window ("File" menu, "Save Image series" command or). Click on the "Browse" button to set the directory where the image is saved, you need to note that the image sequence is automatically saved as an image label, with the default label being 000000001-000999999, so naming the first image is recommended as shown in Figure 6.32, "1500us-." In one of the more common naming forms, the first part of the file name is set as pulse delay time, followed by a "-" in order to allow the subsequent image number to be separate from the front part of the file name.

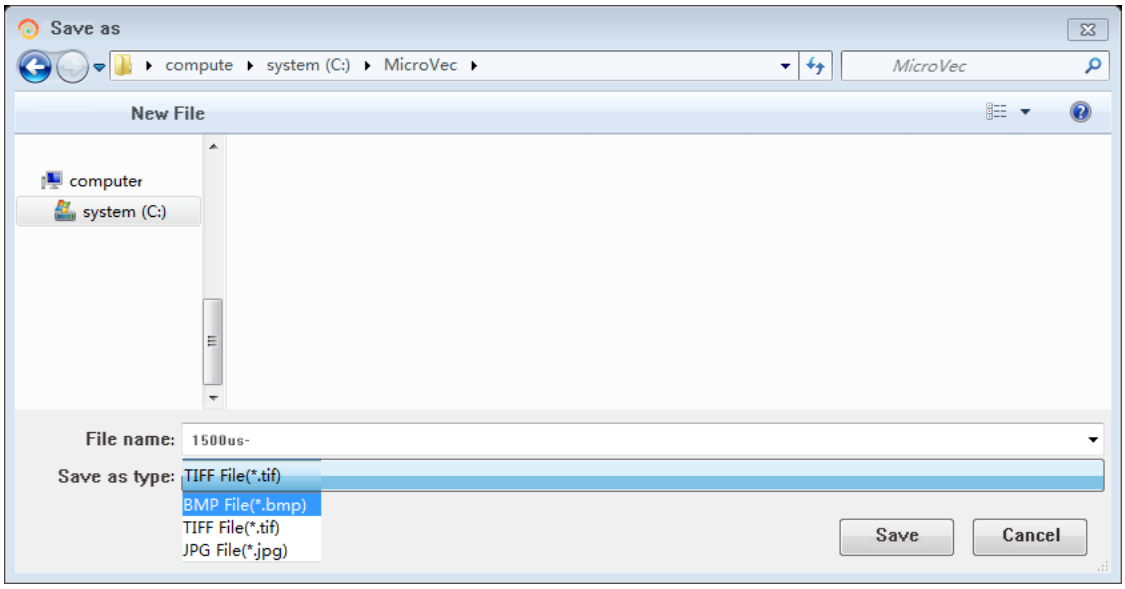


Figure 6.32 save image sequences naming

ii. Analysis of the test image

1. Import particle images

Open the "Open Image series" window ("File" menu, "Open Image series" command or ). A series of experimental images will be read into the set image buffer.

3. Calculate images

If you need to select the computational domain, simply open the "Ruler" window ("View" menu, "Ruler" command or ), choose the “rectangular region show”, and hold down the left mouse button and drag to select the computational domain.

Open the "PIV compute" window ("View" menu, "PIV compute" command or ), and select the appropriate parameters for PIV calculation (you can also use the default value) until the calculated results so far are satisfactory.

3. PIV batch process

Open the "PIV Batch process" window ("Analysis" menu, "PIV Batch process tool" and "PIV batch process" command), and set the need for batch processing images (see Figure 6.33). Window "Start" indicates the image buffer number to start the batch process, "End" is the batch process number of the last image buffer. Select the calculation method (in PIV mode, parameters can generally use the default) and choose GPU computing acceleration or multi-threaded acceleration (total number of images involved in the calculation must be an even multiple of the number of threads), click on the "OK" button. The software will follow before setting the various parameters involved in calculating a good image of the batch process.

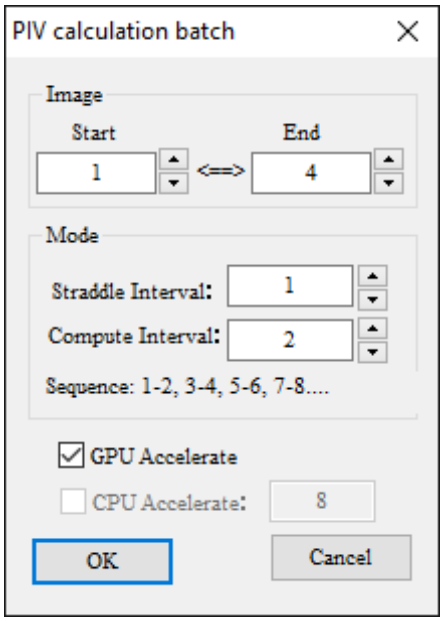


Figure 6.33 PIV calculation batch process

4. Save the result

Before you save the results, you should review first the results of the batch process. Some of the vector fields may not be satisfactory or even correct. You can try to recalculate them with different parameters or different interrogation window size before saving them to hard disk.

After completion of the above work, bring up the "Save Batch process Results" window ("Analysis" menu, "PIV Batch process tool" and "save the batch process results" command). Set the file name to save the calculated results and the need to save the range. If you need to save the average results of the batch process, you need an image in the final buffer location (the batch process is completed automatically and results in an average of the last image buffer). Open the "Save Vector File" window ("File" menu, "Save Vector Files" or ), choose a storage location and click "Save."

3. Further processing of the data

Thus, the data processing is completed; the user can use Tecplot, Origin and other software for the data file for further analysis.

6.3 3D Particle Image Velocimetry system application examples

The process used by the PIV system to measure the three-dimensional velocity of a flow field is divided into two phases: experimental data acquisition and experimental image analysis. This section will be introduced in turn.

6.3.1 System Introduction

3D-PIV system is shown in Figure 6.34:

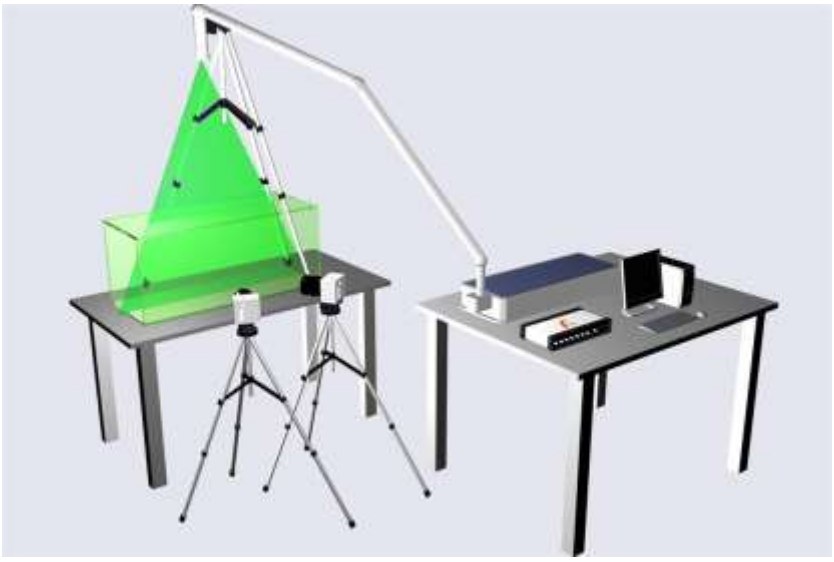


Figure 6.34 Schematic 3D digtal image correlation system

6.3.2 Experimental Data Acquisition

This section describes the specific steps for 3D PIV system calibration, image acquisition, etc.

1. Place the Scheimpflug mechanism

Fix the two assembled Scheimpflug mechanisms (see Chapter 2, “Hardware System Usage” for detailed assembly procedures) on the guide rails so that the camera can capture the same flow field area (the calibration plate is placed in the shooting area).

2. Adjust to the laser light sheet measuring position

Make sure that you make a three-dimensional measurement position. Turn on the laser and fix the position of the light sheet according to the measurement position (note the laser related operating rules). The thickness of the laser sheet is about 2-8mm. Place the calibration plate at the measurement position.

3. Connect the camera

Connect the power cable of the CCD and the data cable between the CCD and the image board. The following description is based on the left CCD connected to the first image board, and the right CCD connected to the second image board as an example. **Note: when installing the CCD, you need to cut off the power supply of the power socket, cover the lens cover, and adjust the lens aperture to the minimum.**

4.Running software

Run the software, click on the “Open New Image Window” command to call up the #2 image window, use the mouse to select the #1 image window, and then call up the hardware control window (“Image” menu, “Hardware Control” Command or ). Detect the left camera under the "Camera Control" column. Select “CamLink” for the communication port, and the next step can be carried out after the test is passed. If the detection fails, the user can reset it by plugging and unplugging the camera, but the camera data cable cannot be hot-swapped, and then the above detection work is resumed. If the detection still fails, turn off the computer, turn off the power, and restart the CCD data cable and power cable connection. After the left camera is detected, select “Head2” in the “CCD Select,” then the right camera detects and sets the parameters according to the parameters in the current camera control window.

5. Coarsely measure system

Call up the real time show on the basis of the selection #1 and #2 windows (“Image” menu, ”Real time show” command or ) and the "Camera control" mode should be changed to "Continuous mode." The lens aperture should be adjusted to the maximum. If you need to further adjust the display image brightness, you can adjust the “Exposure Time” option in the “Camera Control” window (the exposure time of different cameras can be set by switching to Head1, Head2 in “CCD Selection”).

Adjust the coarse adjustment mechanism (the camera and the lens rotate together) connecting the aluminum alloy fixing plate under the camera, and make sure the center image area captured by the two cameras is coincident with the center of the calibration plate, and that the shooting areas are coincident (for detailed operation requirements, please refer to Chapter 5 "Analysis Menu / 3D Velocity Field Measurement").

Adjust the front and rear direction of the screw on the three-dimensional stereoscopic mechanism to a certain point (note the elimination of the freewheel of the lead screw). Adjust the focal length of the lens to make the center of the image clear.

6. First shot of the calibration plate image

Adjust the two 3D Scheimpflug mechanisms (lens statics, camera rotates) for the camera and lens, so that the camera chip plane, lens plane and captured image plane meet the Scheimpflug optical conditions (the image plane, lens plane and object plane for each of the cameras intersect in a common line), and the tilt images captured by the camera are all clear. You can see that if the value displayed in the "Grayscale Analysis" window ("View" menu, "Line Gray" command or ) (+/-) is larger, the quality of the image is better.

At this time, on the basis of selecting windows #1 and #2 respectively, the two images of each camera are saved to #1 and #2 respectively in the first buffer location for the image board by the "Capture an image" or "  " command in the "Image" menu. Then use the “Image” menu “Show Next Image” or “  ” function to adjust the image display of the #1 and #2 windows to the second buffer position, respectively, in order to continue shooting.

7. The second shot calibration plate image

Adjust the adjusting screw on the two Scheimpflug mechanisms separately, turn clockwise twice (0.5 mm in one turn), and move the two cameras 1 mm in the direction of the calibration plate. Save the images captured by the two cameras to the second frame in the corresponding buffer of the #1 and #2 image boards. At this time, on the basis of selecting the #1 and #2 windows respectively, the two images of each camera are saved to #1 and #2 respectively by the "Capture an image" or "  " command in the "Image" menu. The second buffer location corresponds to the image board.

8. Calibration settings and automatic calibration

On the basis of the selected #1 image window. Open the #1 image plate corresponding to the Image Correction window ("Analyze" menu, "Image Correction" command or ) as shown in Figure 6.35:

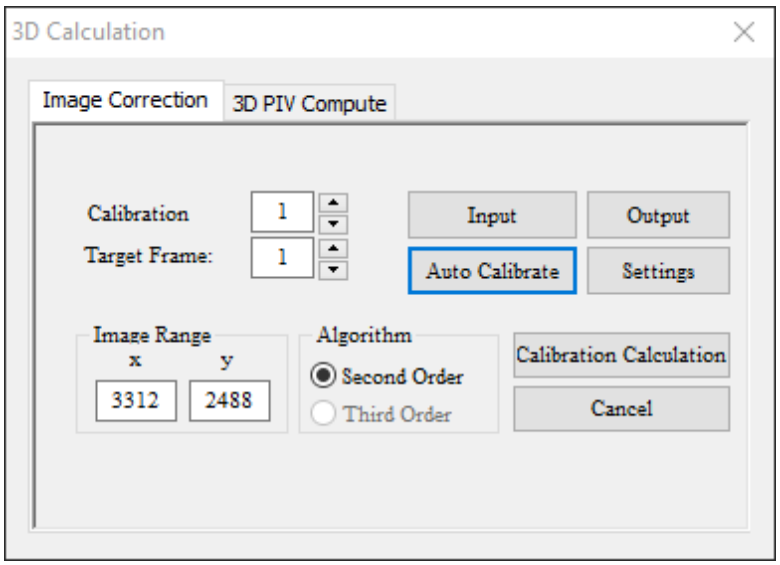


Figure 6.35 Image Correction window

First of all, you need to pay attention to setting the corresponding content of the " setting" button. The corresponding window is shown in Figure 6.36:

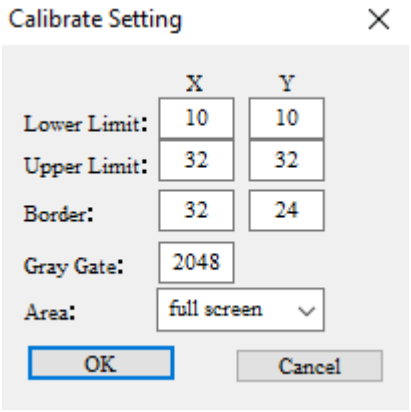


Figure 6.36 Calibration parameter setting window

The "Lower limit" and "Upper limit" in this window correspond to the parameters of the midpoint image of the calibration plate. To do this, you need to determine the calibration point parameters. The specific steps are as follows:

Click on the "Ruler" window ("View" menu, "Ruler" command or ).

Select the "Rectangular Region Show" option to draw a rectangular area around a point image. At this time, the "Ruler" column in the "Coordinate" will display the pixel coordinates of the "Start " and "End." As shown in 6.37, the diameter of the point of interest is roughly: 906-868=38 (pixels). At this point, the calibration point size parameter can be used. Note that the lower limit of the size should be slightly smaller than the minimum diameter of the nine points used for calibration in the image. The upper limit is larger than the maximum diameter of the nine points used for calibration

(preferably 20 pixels or more, because at the end of the image stretching process, the diameter will be slightly larger than the actual shot). At the same time, set the “Gray Threshold”, that is to say, set the value for calibrating the point gray and background gray respectively (you can use the “View” menu, “Image Information” or the function of the “  ” command to assist the judgment).

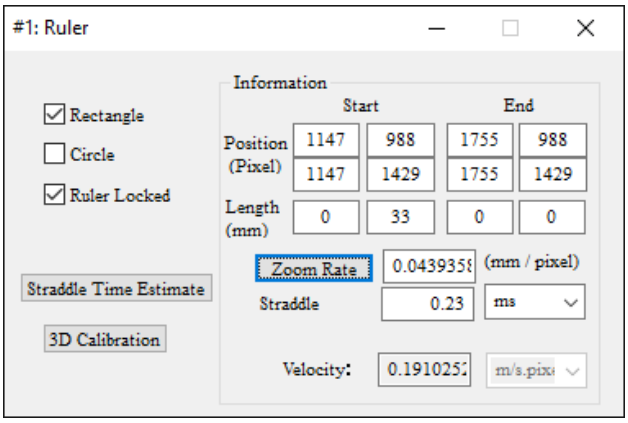


Figure 6.37 Correction point setting appropriate parameters

Next, you can perform “Automatic Calibration.” If the prompt display calibration is unsuccessful, there are two reasons: One is that the parameters in the “calibration setting” are not suitable, and the calibration point parameters are reset according to the above steps; the other case is the first, and second of the two calibration plate images do not meet the calibration requirements, and the left CCD camera needs to restart the sixth, seventh, and eighth steps.

If the display calibration is successful, the CCD image can be used for correct calibration.

9. Save the calibration plate image

Save the calibration plate image in the image buffer corresponding to the #1 and #2 image boards to the hard disk respectively ("File" menu, "Save Image Sequence" command or ), or use the "Analyze" menu "3D PIV" command or  (such as in Figure 6.38). Then select “Save 3D Image,” and mosaic the images of #1 and #2 corresponding to the buffer position into one image for saving.

10. Establish the calibration grid

Click on the "3D PIV Calculation" window ("Analyze" menu, "3D PIV Calculation" command or ) as shown in Figure 6.38:

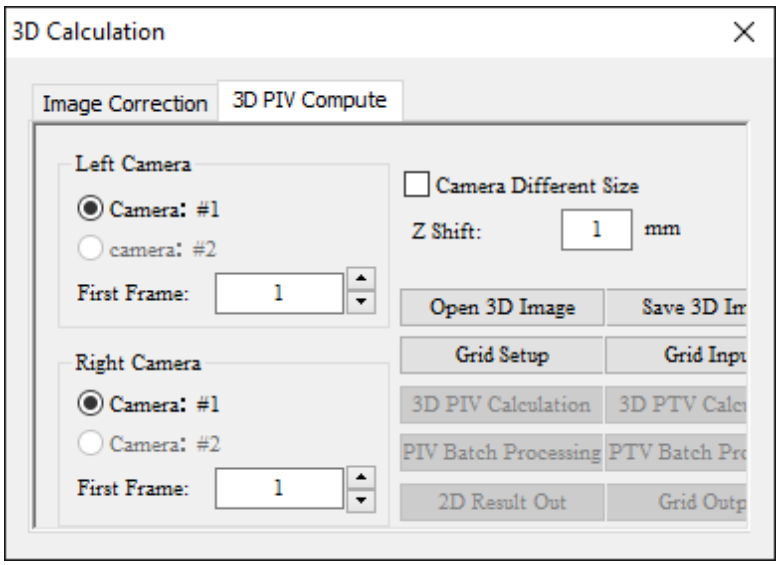


Figure 6.38 3D calculation measurement window

Confirm the following settings in the window:

"Left Camera " selects "Camera: # 1", “First Image:” selects 1.

"Right Camera" selects "Camera: # 2", “First Image:” selects 1.

Z direction: 1mm (If you use the opposite side shooting, that is, the camera is on both sides of the laser light, you need to select the "Camera Difference Configure" setting).

Click on the "Grid Setup" button, and the correction grid will automatically be generated by the program.

Thus, the measurement system has been debugged, and the following can be carried out for specific experimental work.

If you use the camera's different layout, after the calibration is completed, you need to shift the right camera towards the left camera to the distance of the thickness of the target.

11. Recording image

Change the "Operating Mode" of the Head1 and Head2 cameras to "PIV Mode" in the "Camera Control" window.

Click on the "Hardware Control" window ("Image" menu, "Hardware Control" command or ), select the "Record" column and confirm that both image boards are selected in "Record", and set the appropriate "Start " and "End" in the settings.

Click on the "Hardware Control" window ("Image" menu, "Hardware Control" command or ), select the "Laser" column, and preset the "Pulse Delay" to experiment. Click “Run” and adjust the camera aperture and laser energy according to the brightness of the image.

Click the "Record" button in the "Record" window at the appropriate time and the program will collect the corresponding number of images according to the recording settings and save the image in the memory.

12. Check images

Check whether the acquired image meets the experimental requirements, and roughly judge from two points: One point is to see if the particles in the captured image are clear and the particle image density is suitable. Another point is to simply calculate particle images to see if the calculated result meets the experimental requirements.

About the second point, for the selected experimental image, use the “3D PIV Calculation” button in the “3D PIV” window to perform 3D PIV calculations. If the #1 and #2 image boards correspond to the display, the vector distribution result can be corrected. If the corrected result is acceptable, it means that the image in question meets the experimental requirements, and some images can be calculated to see the vector distribution in the result.

If you feel that the captured image cannot meet the experimental requirements, repeat steps 11 and 12 to collect a satisfactory image. If you are satisfied with the captured image, you can proceed to the next step.

13. Save images

For the #1 and #2 image boards, respectively save the recorded experiment images (“File” menu "Save Image Sequence" command or ). You can also use the “Analyze” menu “3D velocity measurement” command or  (as shown in Figure 6.38), and then select “Save 3D Images.” Then mosaic the images of #1 and #2 corresponding to the buffer position into one image for saving.

At this point, the acquisition work of the three-dimensional experimental is completed, and the flow parameters and corresponding acquisition parameters (exposure interval time or total number of images collected in the buffer) can be adjusted in the case where the position of the slice light source, and other flow parameters are not changed. If you need to change the position of the laser sheet, you need to re-calibrate, record, and so on.

The flow diagram of 3D-PIV is shown as Figure 6.39:

Flow diagram of 3D-PIV

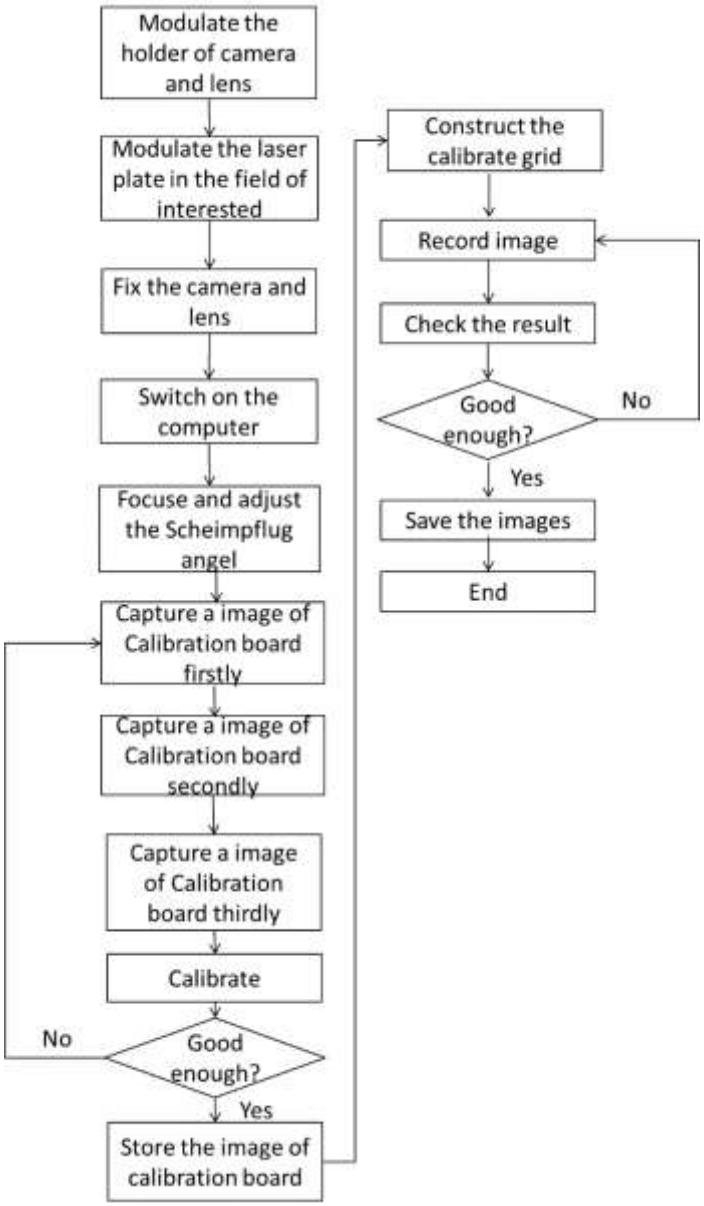


Figure 6.39 Flow diagram of 3D-PIV

6.3.3 3D PIV calibration and measurement

Stereo PIV calibration methods are divided into ipsilateral calibration and heterolateral calibration. Using the calibration board as the reference, two cameras are placed on the same side of the calibration board for ipsilateral calibration; two cameras are placed on the opposite side of the calibration board for heterolateral calibration.

Selection of calibration methods: if the main flow is in the laser plane, same side calibration is used in the experiment; if the main flow flows through the laser plane, different side calibration is used in the experiment.

6.3.3.1 Ipsilateral calibration

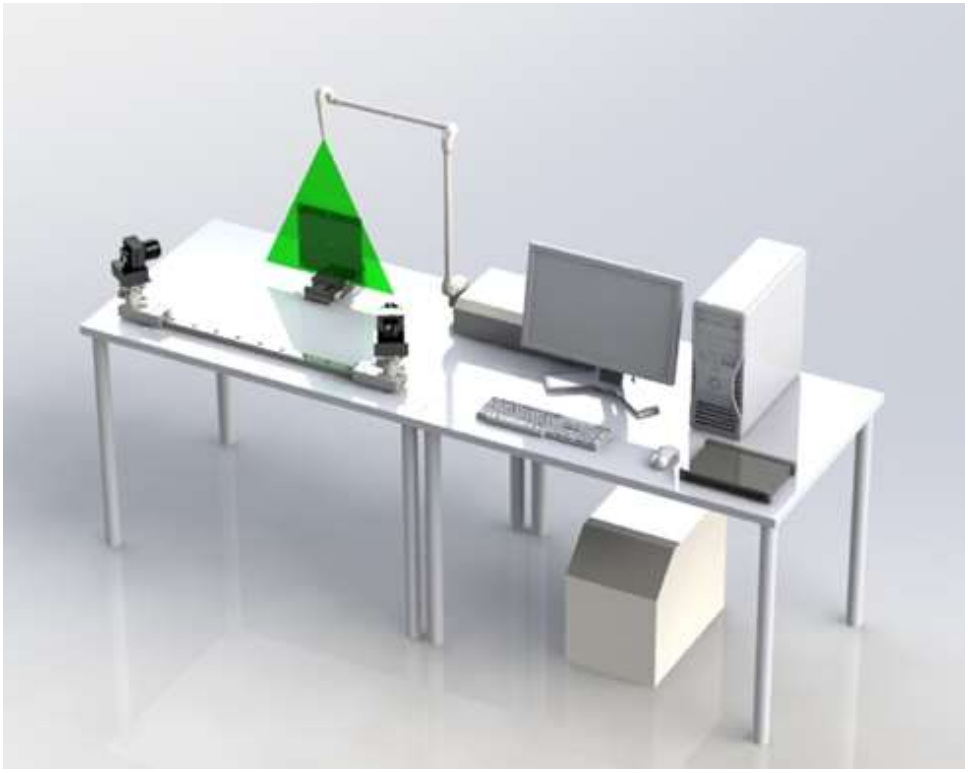


Figure 6.39 Schematic diagram of a 3D particle image velocimetry system

Layout on the same side

Figure 6.40 Schematic diagram of ipslateral calibration

To determine the location of the left and right cameras in a Microvec system, we use two camera viewing angles, the left camera is camera #1, and the right camera is camera #2.

Camera layout precautions：

- Two cameras should be equally spaced on the central axis of the calibration plate;
- The distance between the two cameras from the calibration plate is adjusted according to the actual imaging area of the camera;
- The angle range between the cameras is between 60° to 120°. Microvec recommends the angle range between the cameras in a Stereo PIV experiment be between 60° to 90°

Ipsilateral laser arrangement (DIC system ignores the laser layout)

- The thickness of the laser sheet light in the calibration plate area is 2mm
- Ensure that the laser light evenly illuminates the front surface of the calibration plate

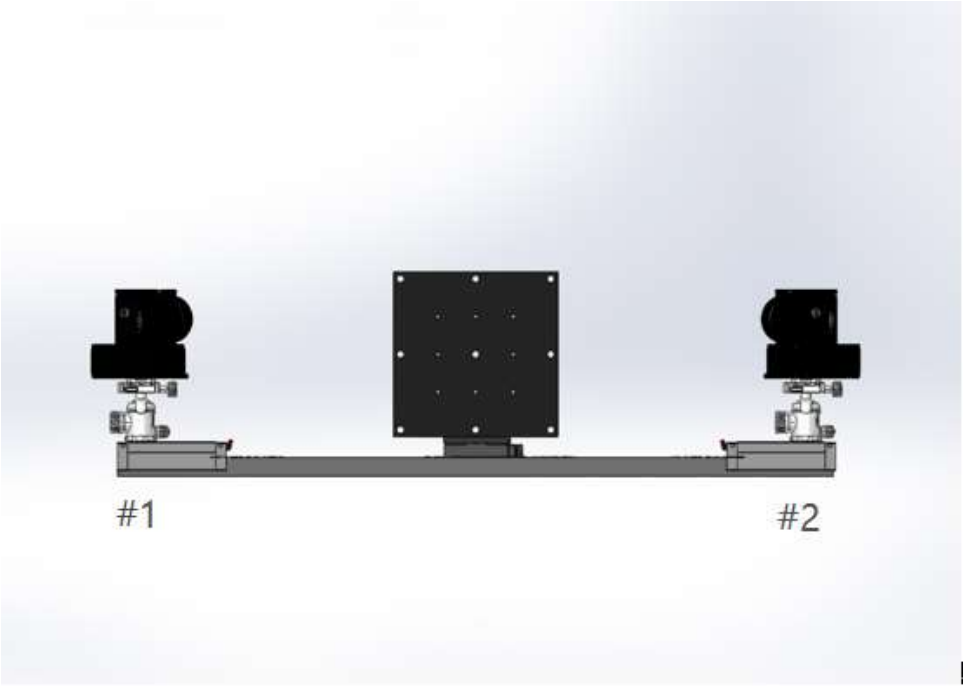


Figure 6.41 Front view of ipsilateral calibration

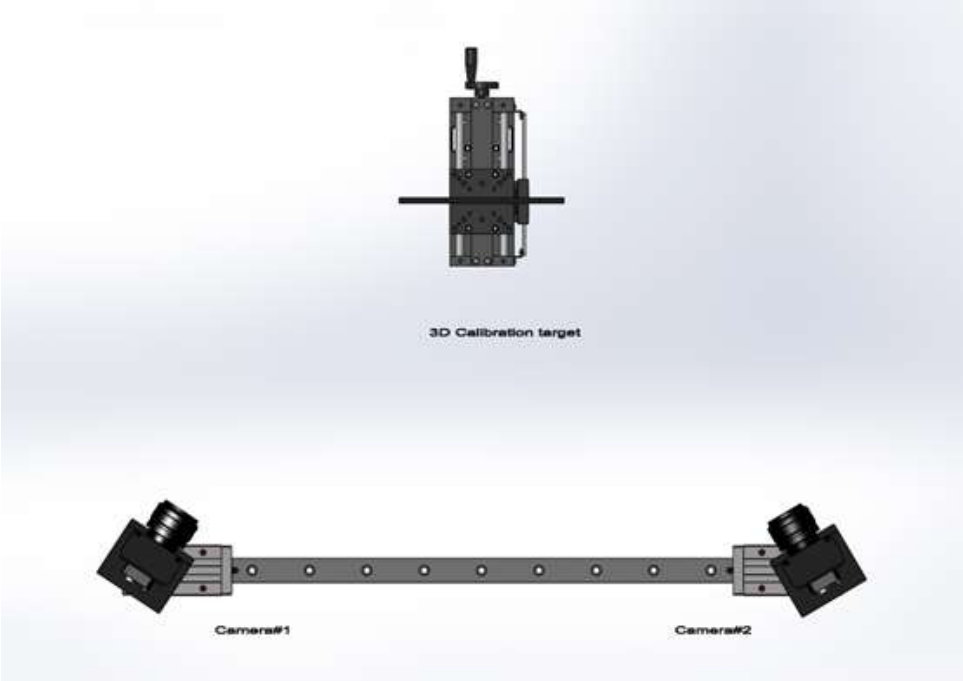


Figure 6.42 Top view of calibration on the same side

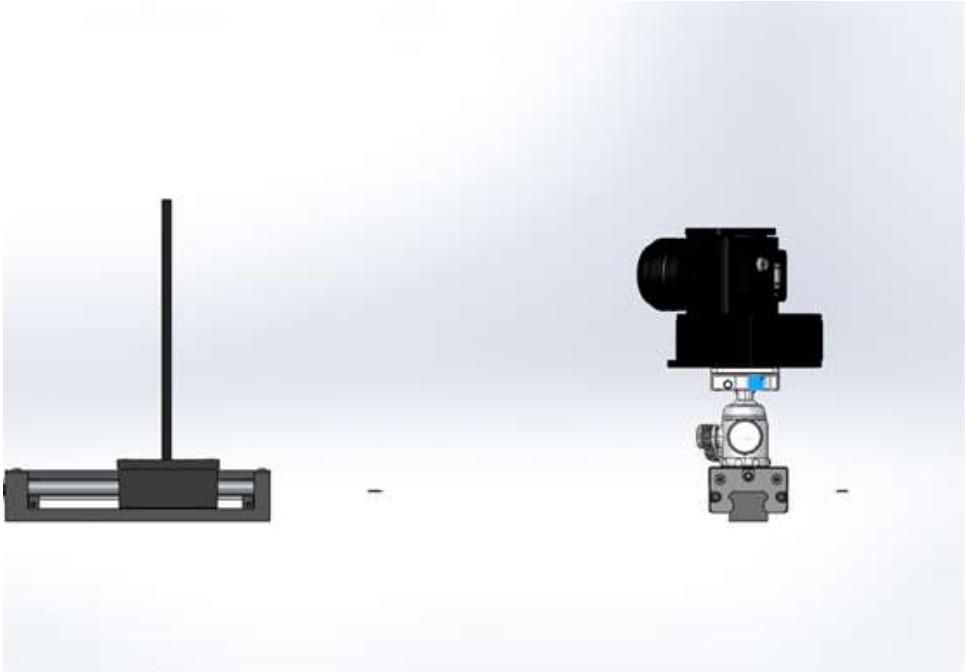


Figure 6.43 Side view of calibration on the same side

6.3.3.2 Taking calibration images

a. Open Microvec 3
b. Go to Analysis -> System Settings -> System Settings -> Software Type: 64bit Stereo PIV (DIC) -> Camera Type (select the current camera model) -> OK -> Restart Microvec 3.

c. Add a new window using the button on the toolbar  .

d. Select window #1 -> open the hardware control window using the toolbar button  -> under the camera tab: change Port to Camlink and Mode to Continuous mode -> click the  button on the toolbar to display the camera in real time.

e. Adjust the left camera (#1) and its lens so that the center point of the calibration plate is at the center of the camera's image. Adjust appropriately to make the calibration plate show clearly, and adjust the Scheimpflug angle and lens focus to make all points on the calibration plate show clearly. The left camera is adjusted. (If the camera's image is still dark after the lens aperture is adjusted to the maximum, you can increase the exposure time or fill light appropriately) Note that the exposure time can only be adjusted in continuous mode, and 0.2ms in PIV mode is not adjustable.

f. Switch the CCD selection from Head 1 to Head 2, select window #2, and perform the same operations on the right camera as the left camera.

g. After adjusting the left and right cameras. Select the #1 and #2 windows respectively and click  to capture one image in Buffer 1  , then click the green arrow  to switch to Buffer 2. (The brightness of the images captured by the two cameras should be kept the same, so that the images captured by the two cameras can be set with the same calibration parameters).

h. Move the calibration board 1mm towards the camera.

i. Select window #1 and #2 respectively and click the camera button  in Buffer2 to capture an image for each window. The calibration image is taken.

j. Go to Analysis -> 3D PIV Calculate -> 3D Vector Save.

6.3.3.3 Ipsilateral image calibration

Select window #1, go to Analysis -> Particle Analysis -> Particle Diameter

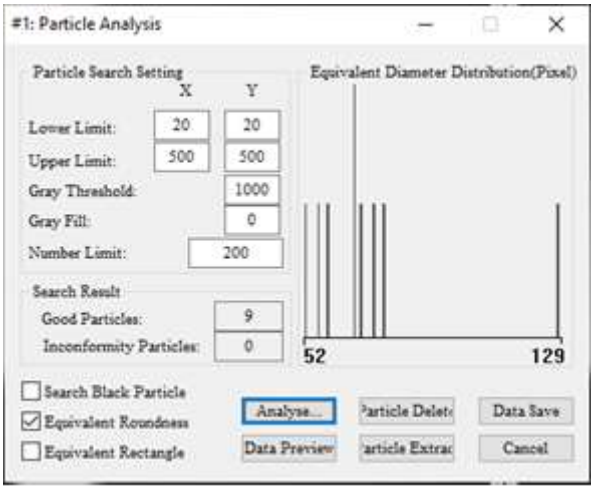


Figure 6.44 Particle analysis window

Lower limit	Set the horizontal and vertical lower limit (minimum) of the particle size to be searched.
Upper limit	Set the horizontal and vertical upper limit (maximum) of the particle size to be searched. The upper limit is set to the pixels actually occupied by the particles multiplied by 5.
Gray threshold	Set the threshold of the grayscale brightness of the eligible particles (the grayscale value that can distinguish the particles from the background). The reference gray value is half of the actual captured particle gray value
Good particles	The number of eligible particles found (9).
Inconformity particles	The number of unqualified particles found.

The upper and lower limits of particle size can be determined by opening the digital ruler and using the frame selection on the particles on the calibration plate image to read the number of pixels occupied by the particles. Generally, the lower limit of particle size is set to be smaller than the number of pixels occupied by the smallest particle, and the upper limit of particle size is a reference value. It is 5 times the number of pixels occupied by the largest particles.

Click the image information button  to read the particle gray value.

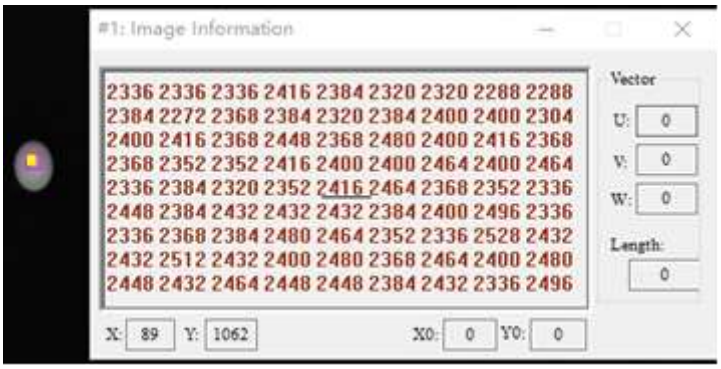


Figure 6.44 Image information window

1. After the particle analysis parameters are set, click Analyse to check whether the number of eligible particles is 9. The software uses 9 points for calibration. If it does not find exactly 9 points, the parameters need to be adjusted until the number of particles that meet the conditions is 9. Extract particles to Buffer 3 using the Particle Extract button.

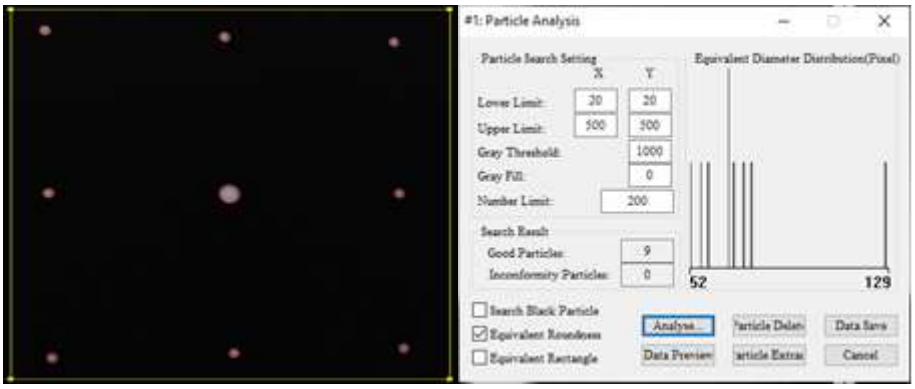


Figure 6.45 Particle analysis

2. Display the previous image, click  to analyze Buffer 2, and then extract the particles to Buffer 4. Window #1 particle extraction is complete.
3. Select Window #2 perform the same operation on the image taken by the right camera.
4. Close all the windows related to Window #2, all subsequent operations are based on left camera #1.
5. Select the Window #1 image interface in Buffer 3
6. Go to Image -> Image Correction -> Correction Settings (size lower limit, size upper limit, gray threshold value using particle extraction parameters) -> OK

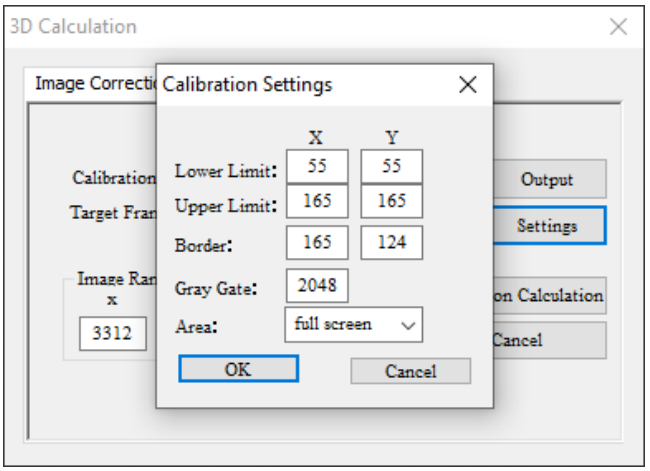


Figure 6.45 Image calibration

7. Click automatic calibration.

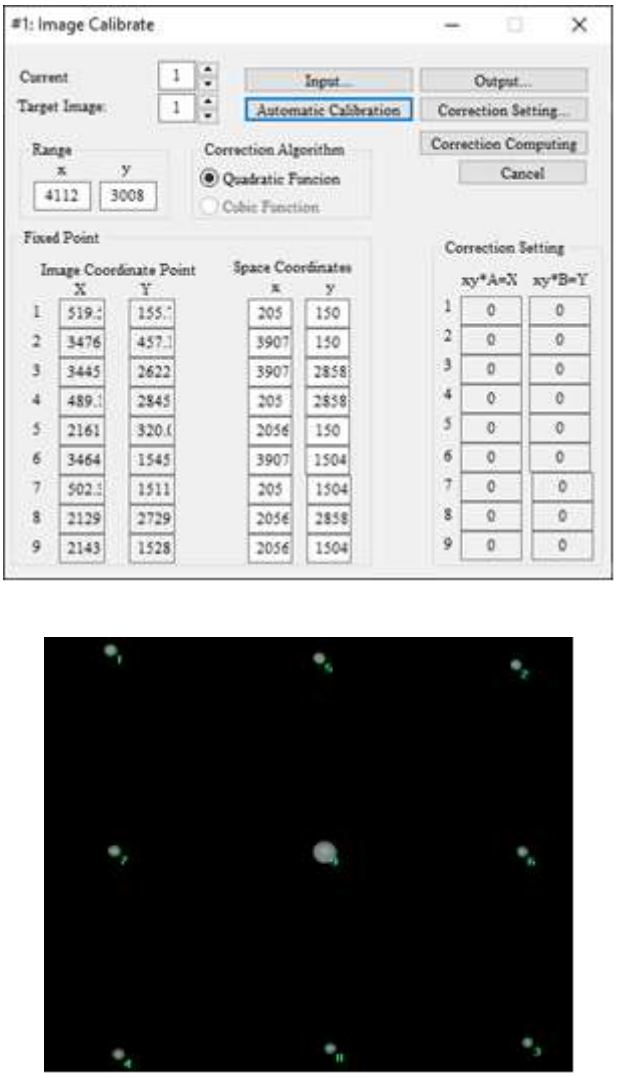


Figure 6.46 Image calibration

8. Go to Analysis -> 3D PIV Calculation -> Move 1mm in the Z direction, use the calibration image of Buffer 3 -> click Grid Setup. Please make sure that you enter the value of the calibration plate displacement. We recommend to use **1 to 2 mm** for Stereo PIV measurements.

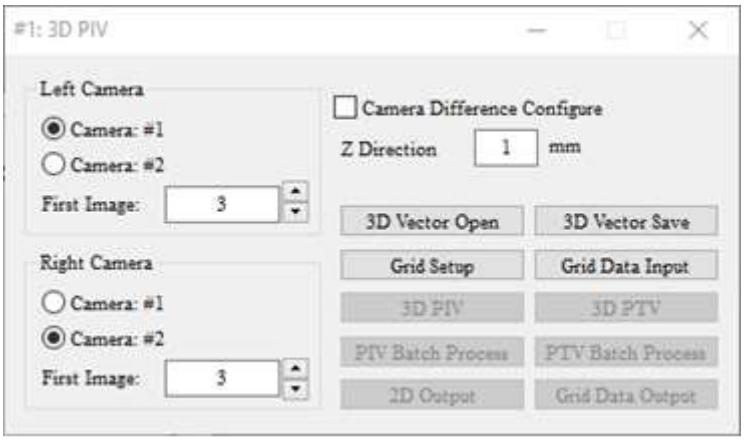


Figure 6.47 3D PIV calculation

9. The grid is successfully established

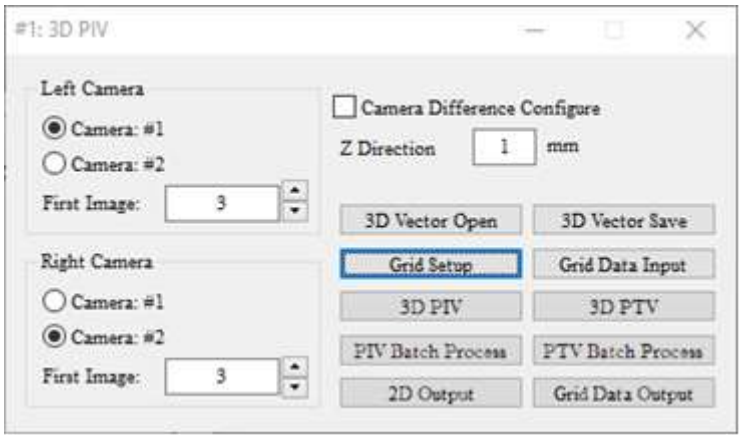


Figure 6.48 3D PIV calculation

10. Open the digital ruler  for Window #1 -> click on 3D Demarcate -> enter the horizontal point distance and vertical point distance in the length row (the point distance is the point distance of the outermost two points) -> click on Image Zoom.

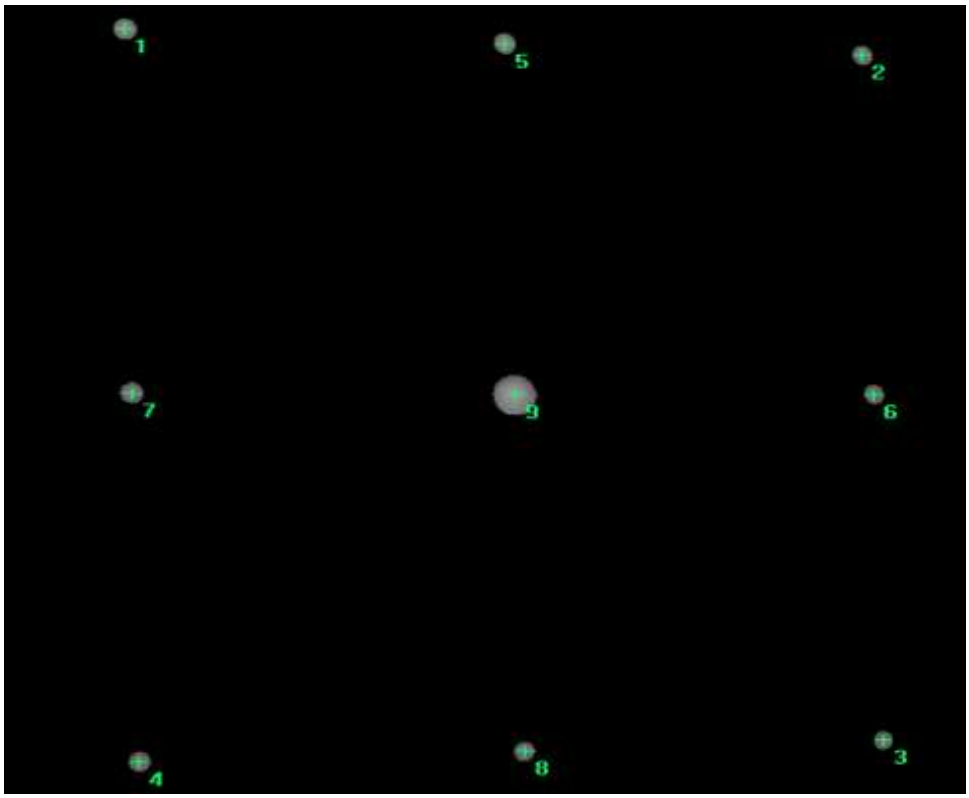


Figure 6.49 Calibration points

11. The dot distance (in small calibration plate) between calibration points 1 and 2 is 100mm, and the dot distance between 2 and 3 is 83.49mm. In the experiment, the actual calibration board

size shall prevail.

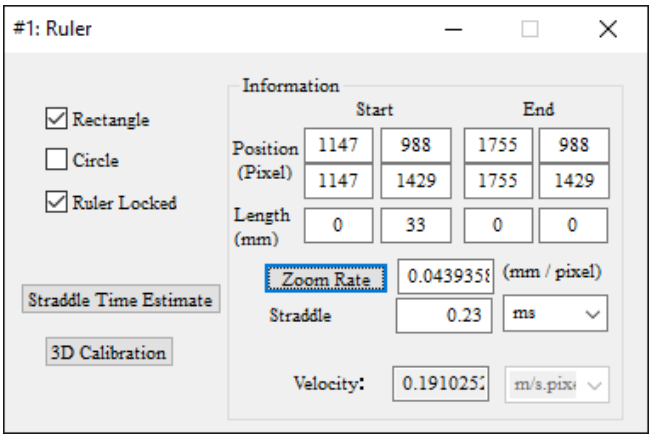


Figure 6.50 Ruler

12. After the calibration is complete, remove the calibration board.

6.3.3.4 Heterolateral calibration

Different side arrangement: Different side calibration refers to the two cameras arranged on both sides of the calibration board.

Figure 6.51 Layout drawing of a different side calibration system

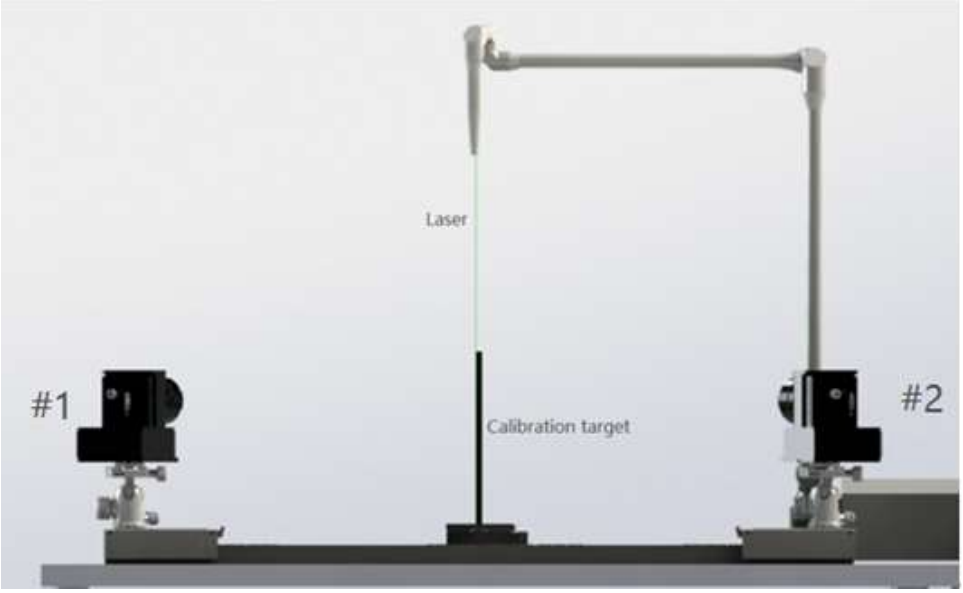


Figure 6.52 Layout drawing of a laser calibration board for different side calibration

Camera layout precautions：

- Two cameras are equally spaced on both sides of the calibration plate；
- The distance between the two cameras and the calibration board is adjusted according to the actual imaging area of the camera；
- The angle range between the cameras is between 60° to 120°, Microvec recommends the angle range between the cameras in the Stereo PIV experiment be between 60° to 90°；

Ipsilateral laser arrangement (The DIC system ignores the arrangement of the laser)

- The thickness of the laser polarized light on the calibration plate area is 2mm
- The laser light evenly illuminates the surface of the calibration plate near the left camera #1

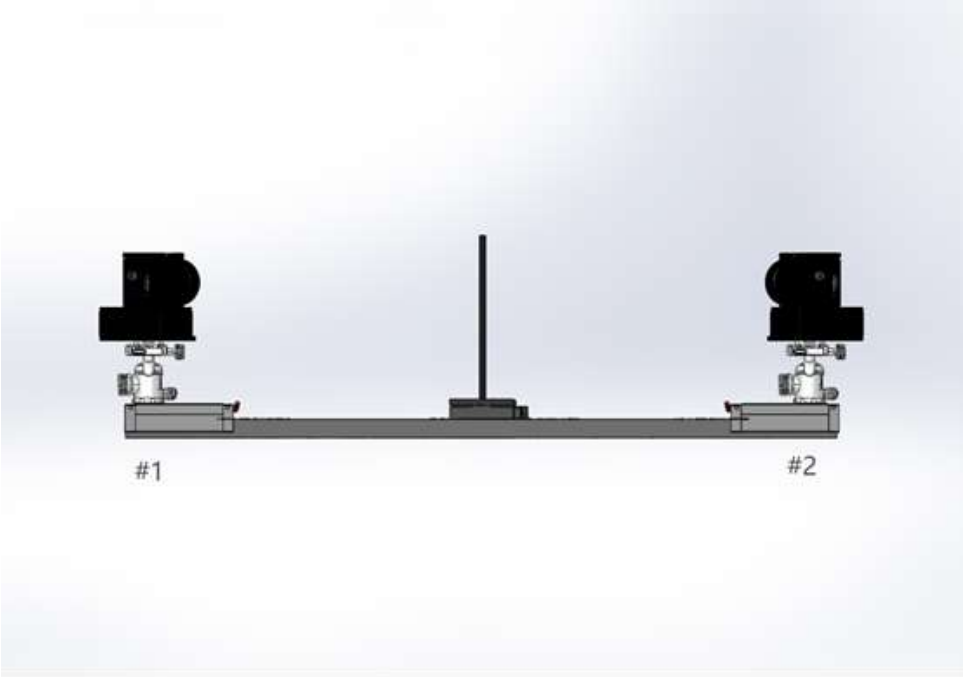


Figure 6.53 Different side calibration front view

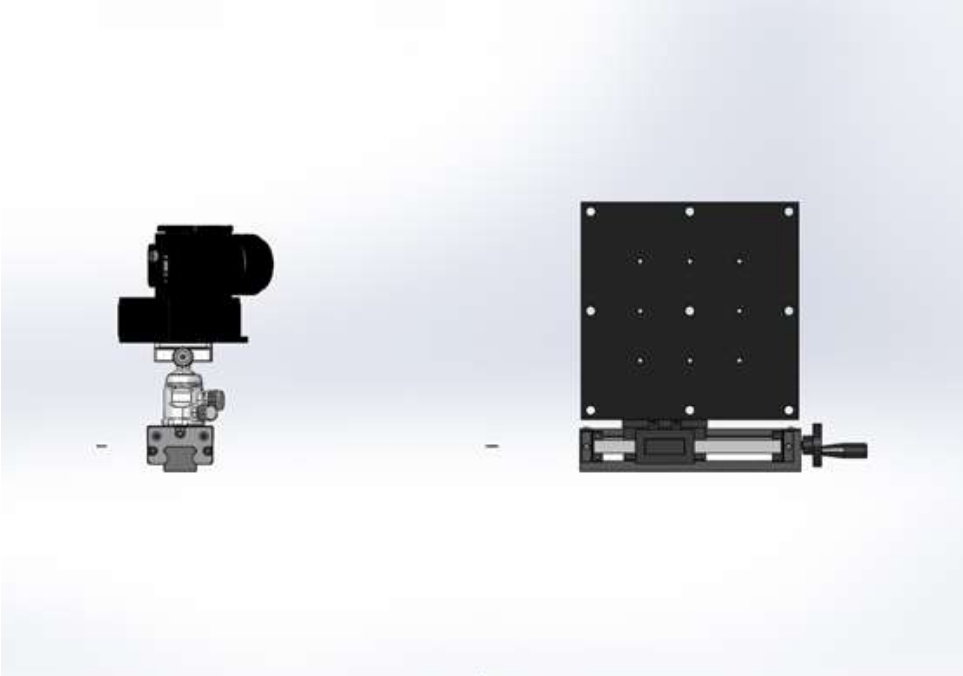


Figure 6.54 Side view of different side calibration

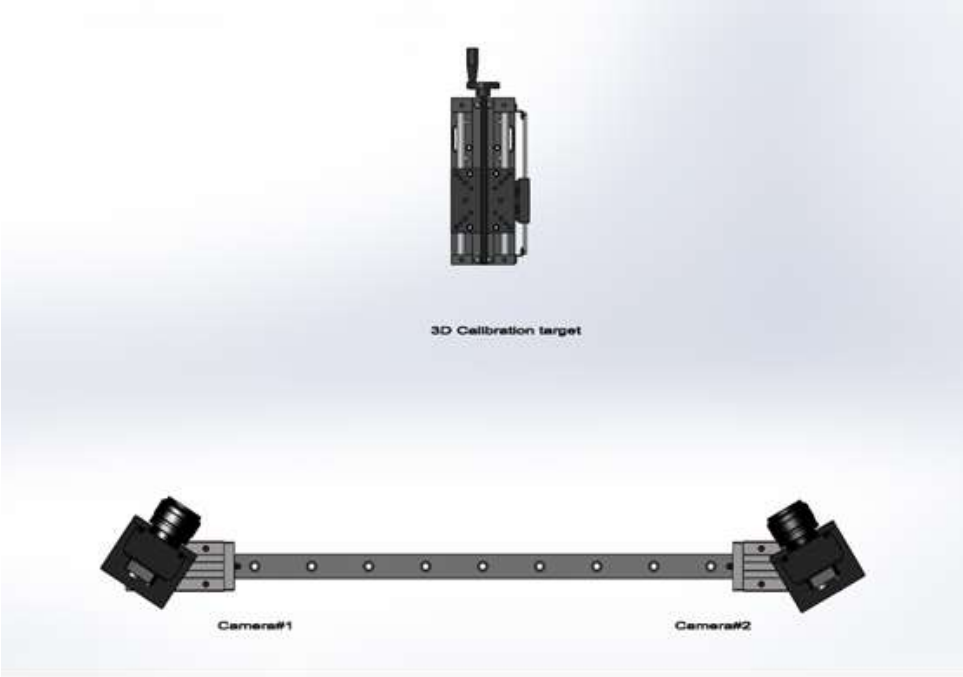


Figure 6.55 Top view of the opposite side calibration

6.3.3.5 Heterolateral calibration steps

The different side calibration operation is the same as steps a - g in section 6.3.3.3 of the same side calibration

h. Move the calibration board 1mm in the direction of left camera #1

i. Select Window #1 and #2 respectively and click on Buffer 2 to capture an image for each window

j. Move the right camera #2 along the guide rail to the direction of the left camera #1. The thickness of the calibration plate is 8mm (in the experiment, the thickness of the actual calibration plate shall prevail)

k. Go to Analysis -> 3D PIV Calculation -> 3D Vector Save

Image calibration on the opposite side

The only difference between image calibration on the opposite side and image calibration on the same side is that the camera which is placed on the opposite side is checked on the software, and the other operations are the same.

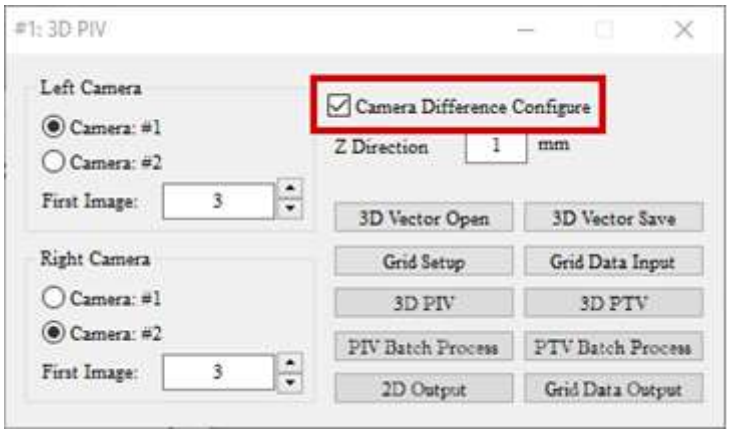


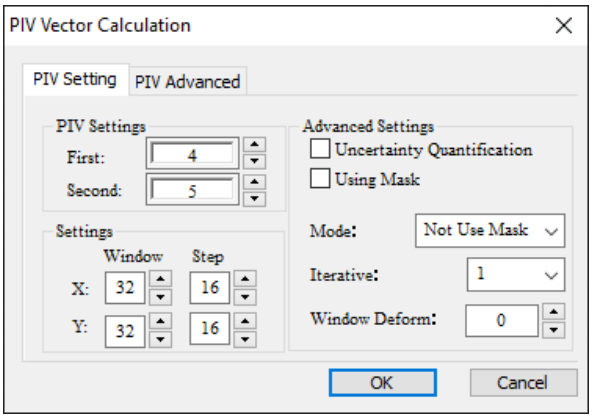
Figure 6.56 3D PIV Calculation

6.3.3.6 Particle image acquisition (PIV experiment)

1. Go to Image -> Hardware Control -> Camera tab -> Mode -> PIV mode;
2. Adjust the lens aperture to the minimum and close the lens cap;
3. Go to the Hardware Control window -> Laser tab -> Run -> adjust the laser to the appropriate energy (you can see the particles being brightened by the laser);
4. Open the lens cover and slowly adjust the aperture (watch the screen in real time when adjusting the aperture, if there are over-saturated bright spots, immediately stop the laser operation and proceed);
5. After the camera captures the particles in real time, compare the particle brightness in the odd and even frames. If there is a difference, adjust the corresponding laser energy respectively;
6. How to set cross-frame time
7. The cross-frame time is based on the particle map captured by the left camera. The calculated maximum speed vector is 5 pixels. (Right-click on the top of the 3D PIV Calculation button  to get the largest vector result, and you can read the pixel length of U/V in the system information. You can also change settings under the Advanced tab.）
8. Record the image after the cross-frame time is set appropriately.

Figure 6.57 Hardware window

9. 3D PIV calculation: Perform 3D PIV calculation  , and then 3D PIV batch calculation by going to Analysis -> PIV Batch Process Tool -> PIV Batch Process.



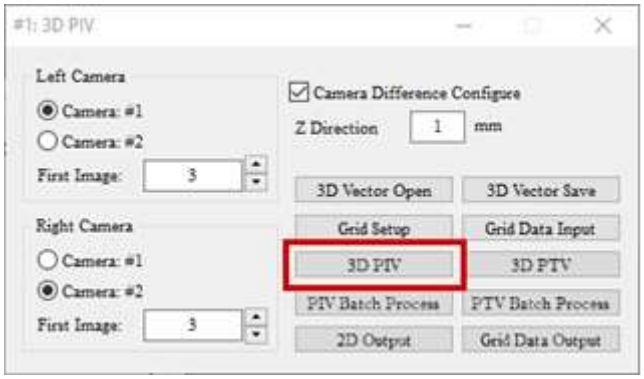


Figure 6.58 3D PIV calculation

10. To save batch results go to Analysis -> PIV Batch Process Tool -> Save Batch Process Result
11. This way you can get 3D calculation results.

6.3.3.7 Image acquisition with 3D DIC

The DIC system has no laser and synchronization controller, and the calibration method and calculation method are the same as the PIV system.

1. Go to Image -> Hardware control -> Camera tab: set port to CamLink and mode to frequency control-input 1fps -> CCD Head: select Head 2 (the same acquisition rate is set for the left and right cameras)
2. Hardware control -> Record tab (input the number of images to be collected by using the Start and End options)
3. When the acquisition rate is 1fps, the time interval between two adjacent frames of images is 1s, so in the DIC calculation, enter 1000ms in the digital ruler and the inter-frame time.

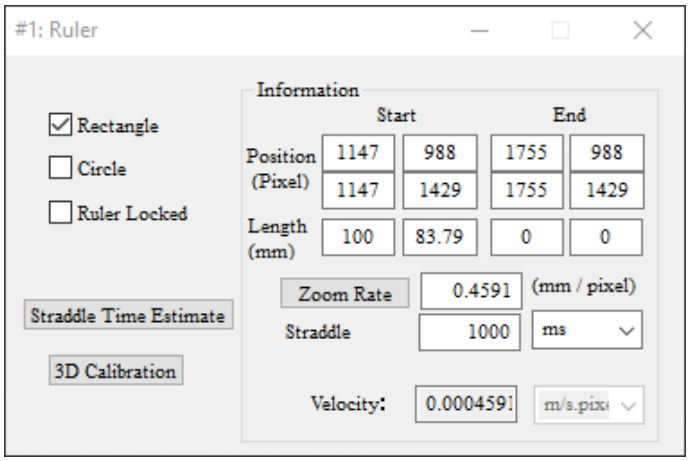


Figure 6.59 Ruler

4. The 3D DIC calculation method is the same as 3D PIV

6.3.4 Analysis of experimental images

The experimental image is analyzed when the image is acquired, but it is a preliminary step to check whether the captured image is experimentally required. This section will introduce the experimental image analysis steps.

1. Import calibration plate image

Import the three or two calibration plate images saved in the hard disk in the corresponding image buffer of the #1 image plate ("File" menu, "Open Image Sequence" command or ), and save the calibration plate image in buffer 1, 2, and 3. Take the same steps to open three calibration plate images in the #2 image plate corresponding image buffer. You can also use the "Open 3D Image" function in "3D velocity measurement" to open a saved 3D image.

2. Calibration settings, and automatic calibration

The calibration process here is similar to the “calibration setting and automatic calibration” process in the process of acquiring images. the calibration plate image meets the calibration requirements; therefore, you only need to pay attention to the setting of "calibration parameter" in "Correction setting."

3. Establish the calibration grid

Same as the “Establish Calibration Grid” process during image acquisition.

4. Calibrate images

Calibration image is done to set the actual length of each pixel.

Set Ruler information

Click on the "Ruler" command ("Ruler" command or ) and click "3D Calibrate." In the "Ruler" column in the starting point or end point, enter calibration for the horizontal and vertical center distances of the nine points used for calibration in the target disk.

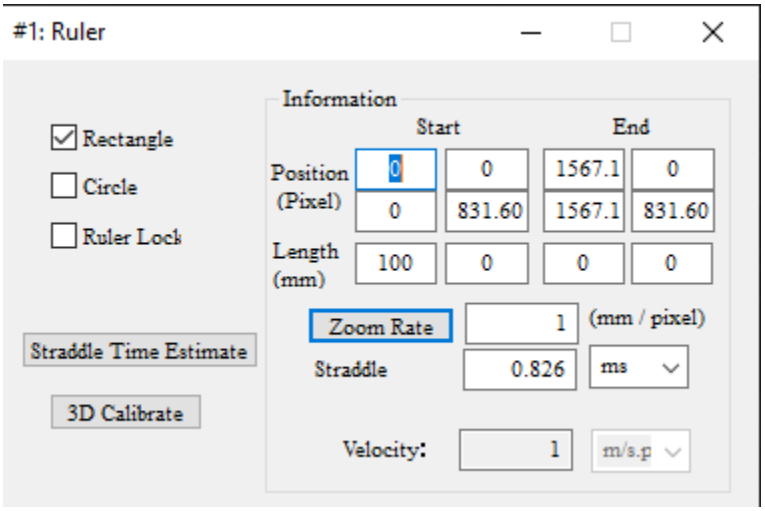


Figure 6.60 Input calibration data

Click on the “Image Zoom” button and set the “Frame Straddle”. At this point, the system automatically calculates the image magnification.

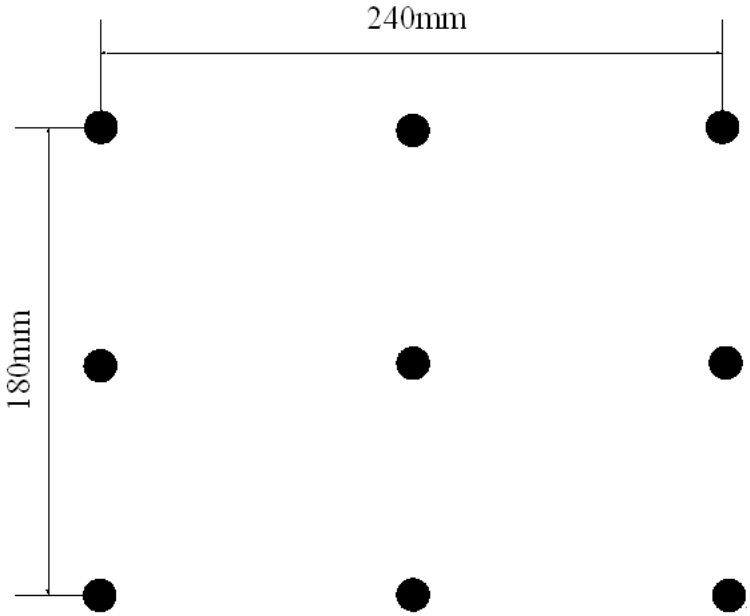


Figure 6.61 3D correction plate

5. Analyze particle images

First, on the basis of the #1 window being selected, perform a 2D-PIV calculation, select the appropriate calculation area, select the calculation parameters, and then perform the 3-dimensional PIV calculation. There are two commands for the 3D PIV calculation: “3D PIV calculation” (calculating data of 3D PIV and “PIV batch processing” (for 3D PIV batch calculation). These two commands can be selected for calculations as needed.

6. Save the calculation results

Select the "File" menu "Save Vector File" command or click  to save the 3D calculation results accordingly. For large amounts of data processed using the “PIV Batch processing” command, save a large amount of data using the “Save Batch Results” command in the PIV Batch in the Analysis menu.

7. Further analysis

The calculated data can be further analyzed in software such as Tecplot or Origin.

The experimental image analysis can be completed through the above 8 steps, as shown in Figure 6.62.

Image analysis：

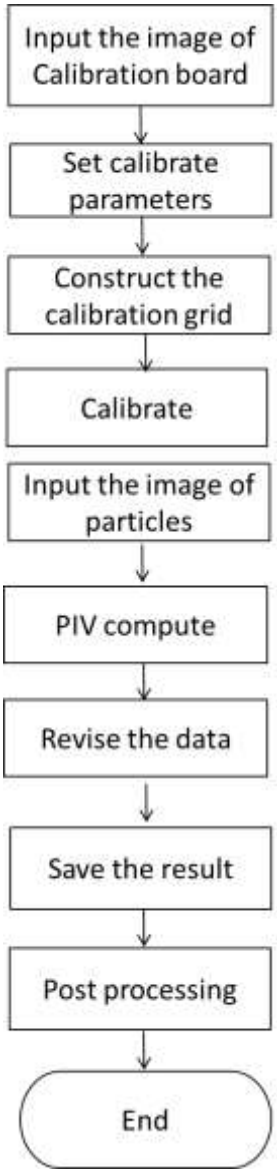


Figure 6.62 3D PIV image analysis process

6.4 Micro PIV

6.4.1 Overview

Microvec's Micro PIV system is designed to measure velocity fields of particle seeded flows with micron scale spatial resolution using the PIV technique. Micro PIV can use a MACRO lens, long distance microscope or epifluorescent microscope.

Micro PIV systems can provide high image magnification with a small focal depth over the flow illumination. Out of focus particles also contribute to the measured displacement. During Micro PIV experiments, small fluorescent particles are used with a combination of proper optics and filters and then only fluorescent light emitting from the tracer particles is captured and used for calculations.

Micro PIV can be used for many applications such as accurate measurements in microchannels, microfluidics, MEMS applications, drug delivery, hemodynamics and others.

Figure 6.63 Sample Micro PIV system from Microvec

6.4.2 Principles of Micro PIV

Because the entire microscopic area under observation is illuminated with light, the image sensors can easily get overexposed. In order to avoid it, the use of fluorescent particles is commonly applied to micro PIV and a technique called Planar Laser-Induced Fluorescence (PLIF) is applied to micro PIV measurements. PLIF is a spectroscopic method in which an atom or molecule is excited to a higher energy level by the absorption of laser light followed by spontaneous emission of light for a certain period of time. When the fluorescent particle is illuminated by 532 nm laser light, the light emitted by the particle is above 550 nm. This process can be repeated if the particle is undamaged. The amount of light emitted by the particle also depends on the size of the particle, the laser pulses, filters, and environment. A high-pass lens filter can be used to separate the particles.

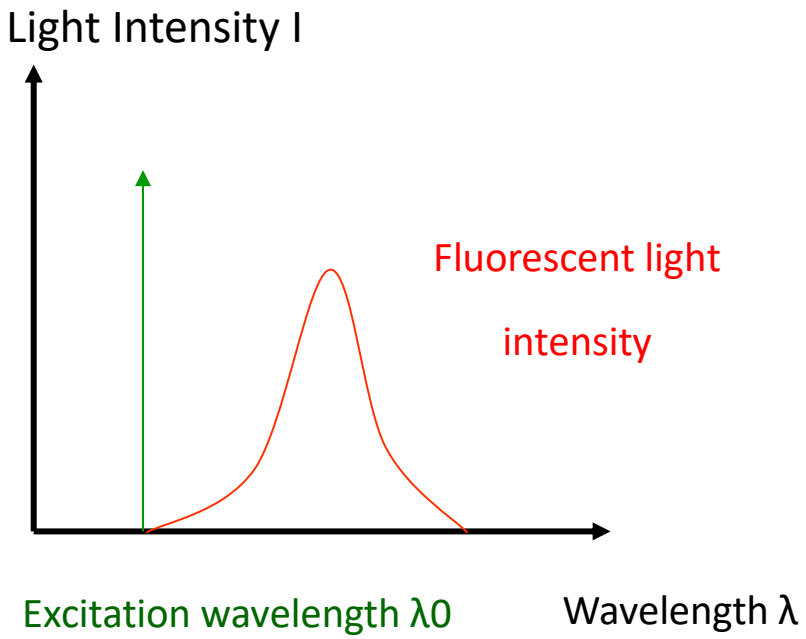


Figure 6.64 Fluorescent imaging principle

Microvec's Micro PIV system uses inverted epifluorescent microscopes which means that all the optics for Illumination and Imaging are on one side and the light travels the same optical path as it does through the microscope's objective. Green light is reflected back into objective and removed by the dichroic mirror, while most fluorescent light passes through. Filters can be used to make sure light can be blocked so you get the images you want. The dye used for the fluorescent particles is used to absorb and emit light for the camera. See figures 6.65 and 6.66.

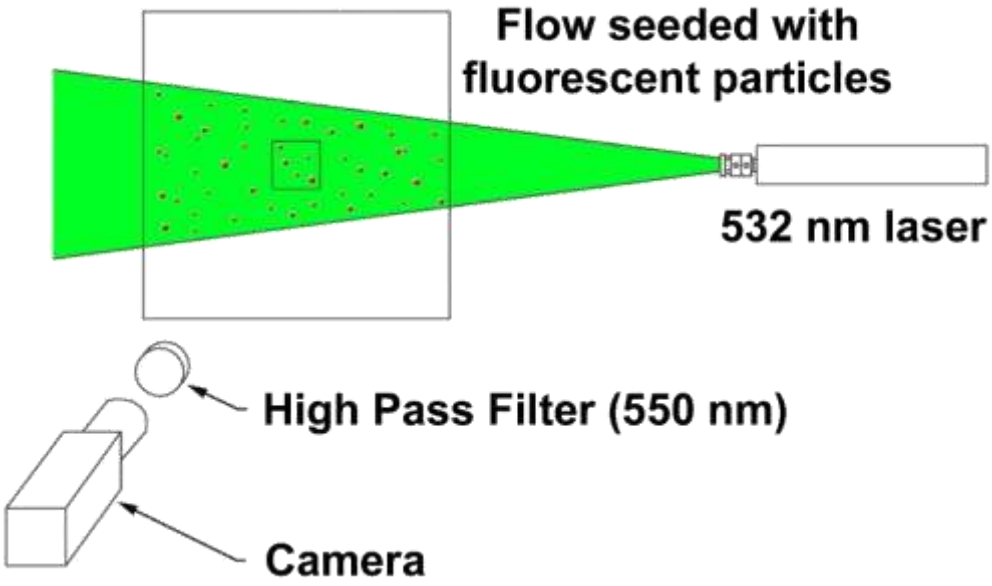


Figure 6.65 Micro PIV system based on Epifluorescent imaging

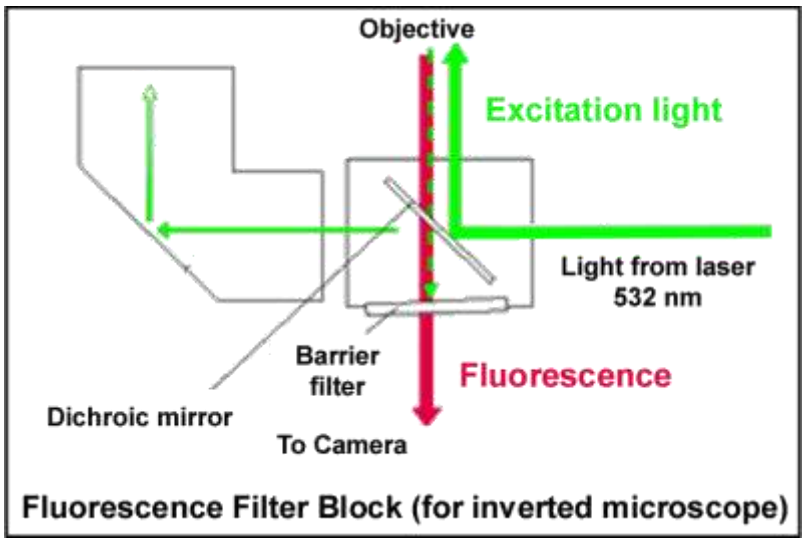


Figure 6.66 Block diagram of Epifluorescent microscope

6.4.3 Setup of Micro PIV

Microvec's Micro PIV system includes a PIV laser, a PIV camera, a microscope, and a Synchronizer.

1. Before beginning the experiment, ensure the fluorescent particles are well mixed. If necessary, dilute the solution to reduce the amount of extraneous particles in the background.

2. Use the microscope included with the system to focus on the area you would like to include and to illuminate the area using white light.

3. Syringes can be used to control the flow of the fluorescent particles.

4. When you're satisfied, capture the images and analyze the correlations in the software.

6.5 Digital Image Correlation

6.5.1 Overview

Digital Image Correlation (DIC) is an optical method that employs image processing techniques for accurate 2D and 3D measurements of changes in images. This is often used to measure deformation, displacement, strain, and optical flow, and it is widely applied in many areas of science and engineering (more details in Microvec DIC user's manual).

Microvec PIV software can be used to calculate simple DIC measurements using PIV software based on cross correlation. For more complex DIC measurements we recommend Microvec DIC software based on Microvec DIC systems.

6.5.2 Application of 2D-DIC system in strain measurement

The time series of a 2D-DIC system is shown in Figure 6.67:

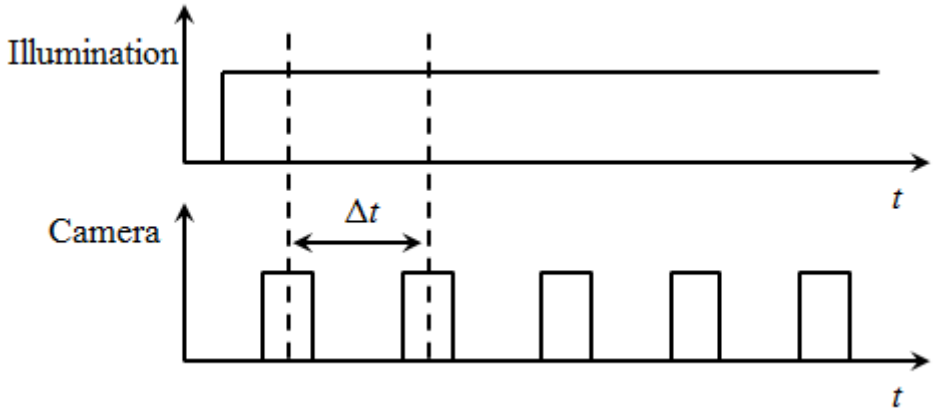


Figure 6.67 Time series of the system

In DIC the illumination can be chosen between a Laser, LED or even natural light, depending on the brightness of the captured images. A LED with high power was employed in this case.

The following describes detailed steps of the PIV system to get good results:

i. Test data acquisition

1. Adjust the light illuminating the measuring position

2. Adjust the camera to the appropriate position

Adjust the camera to a proper altitude till that the camera lens is placed perpendicular to the specimen plane. Careful alignment is useful for accurate results.

Note: During installation, the lens should be covered by the cap and the lens aperture to the minimum (largest f-number).

3. Running the software

Start the software by double clicking the shortcut of “Microvec 3” on the computer desk. Then open the "hardware control" window ("Image" menu "hardware control" command or ). After that, select the "Camera Control" button from the dialogue, set the connecting port as "CamLink." If connected successfully, the camera mode is selected as "continuous." If not, you may check if the camera power is turned on. If it is still not, then restart the computer and the camera.

4. Focus

Use “live show image” function ("Image" menu "Live show image" command or ). Open the lens cover and increase the aperture (decrease the F-number) until the brightness of the images shown on screen is adequate. Use the focus control on your lenses to achieve a sharp focus on the entire specimen. Sometimes, it may be necessary to zoom in on the image to check fine focus. Please remember that accurate 2D image correlation depends on the specimen being planar and parallel to the camera sensor. Therefore, careful alignment is key to obtaining highly accurate results.

After finishing the above steps, the preparation procedure is over. You can then halt the system by clicking the "stop all" command in "Image" menu or  .

5. Capture ruler image

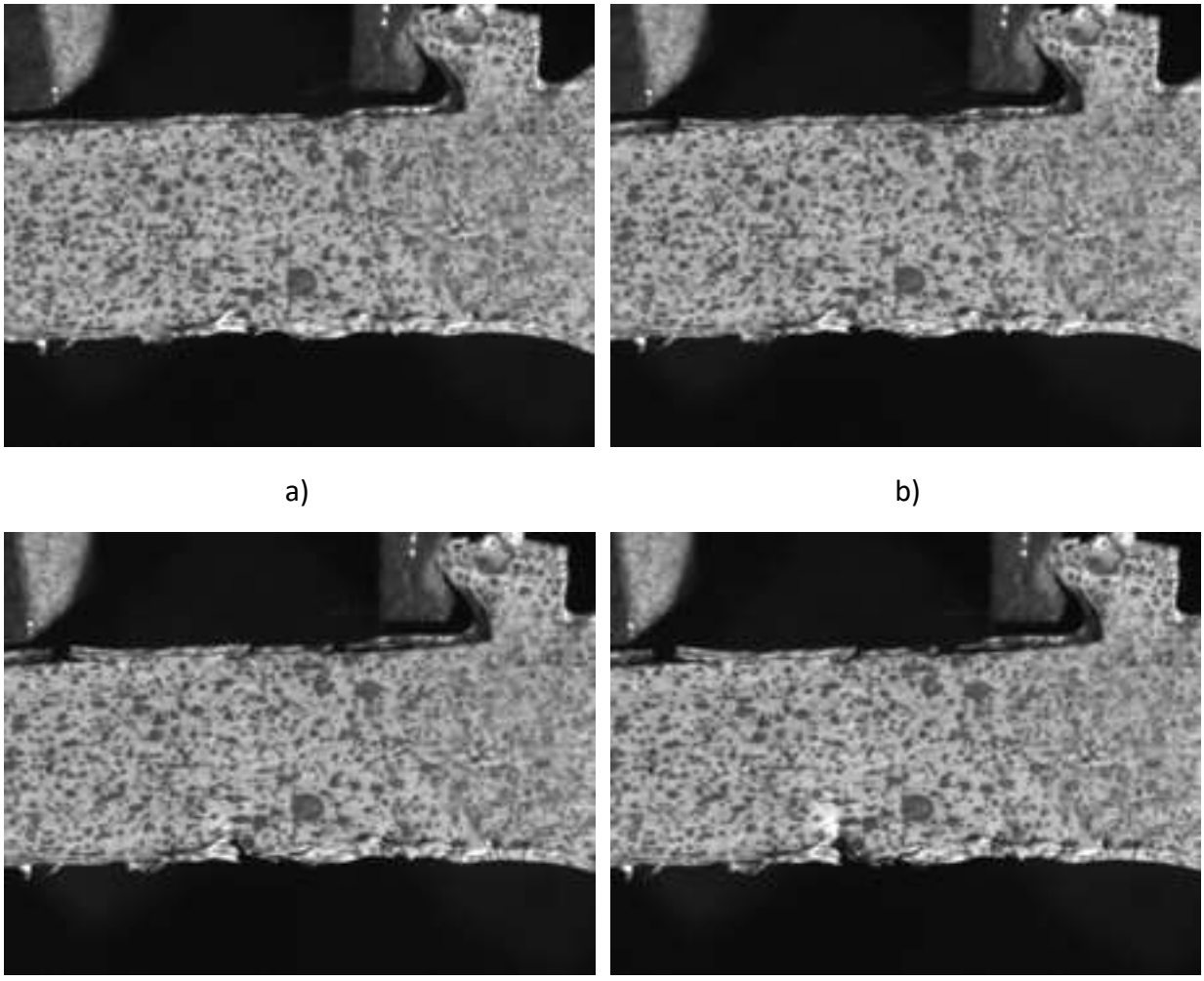
Place a ruler onto the plane where the specimen is positioned. Take a snapshot of the ruler by clicking  , then save this ruler image to the hard disk by clicking  .

6. Specimen images recording

At first, set the "Start " and "End" in the “Frame grabber”. For example, when "Start" is set to 1 and " End" is 100, the recorded images stored in the image buffer is from 1 to 100, a total collection of 100 images.

Secondly, begin the image acquisition by clicking the “Record” button on “Hardware Control” as soon as a pull test to the specimen gets prepared. Save recorded images to the hard disk by clicking  .

Subsequently, the stretch process of the specimen is recorded and excess images at the beginning can always be discarded.



a) b)

c) d)

Figure 6.68 Four consecutive images of the specimen during stretch

ii. Analysis of the test images

1. Open the ruler image.

Open the ruler image on the first buffer ("File" menu "Open" command or ), shown in Figure 6.69.

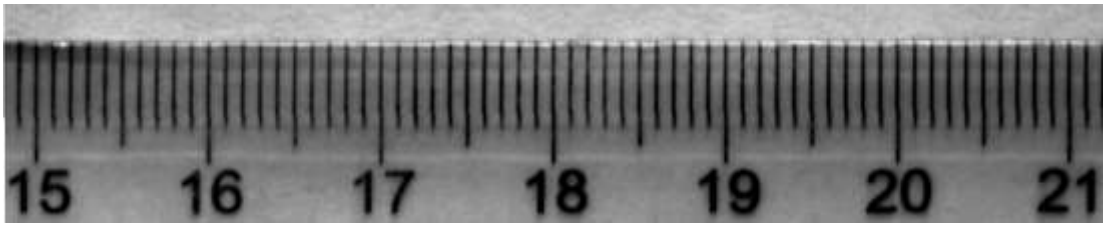
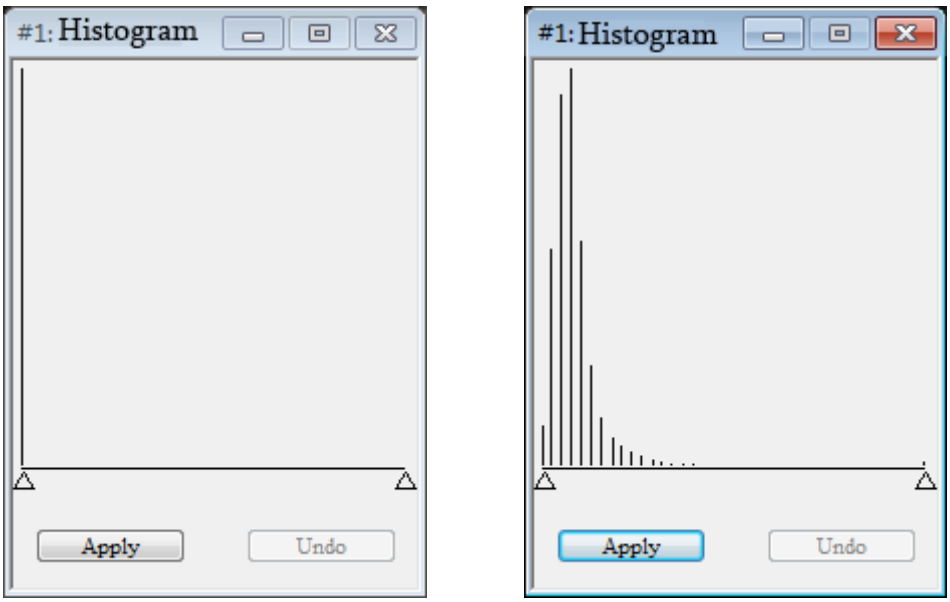


Figure 6.69 Ruler image

If the gray value of the ruler image is too low to distinguish the scale on the ruler, you need to bring up the "Histogram" window ("View" menu "Histogram" command or ) (See Figure 6.70a) and drag the small triangle on the right side to the left. The rescaled gray distribution is shown in Figure 6.70b.



a) before rescale b) after rescale

Figure 6.70 Gray level histogram

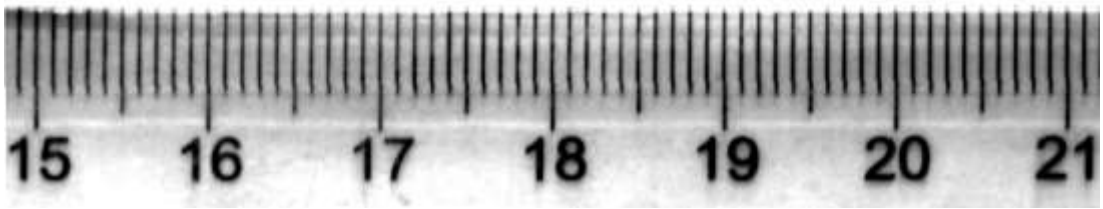


Figure 6.71 Ruler image after gray value rescaled

2. Image calibration

Bring up the "Ruler" window ("View" menu "Ruler" command or ), uncheck the "rectangular region show" option, clicking the left mouse button in the image, and drag the cursor to draw a line along the ruler (see Figure 6.72):

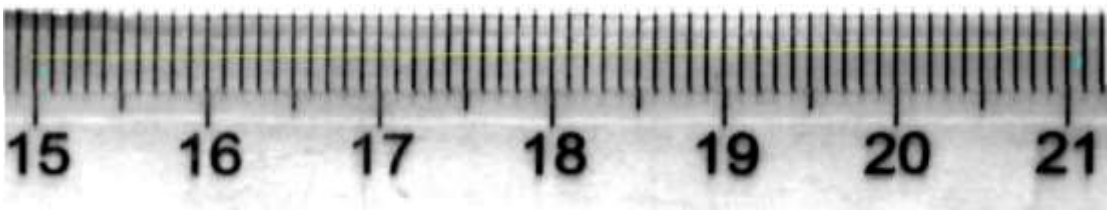


Figure 6.72 Draw a line for calibration

The Software will automatically identify the actual length of the line and calculate the image magnification factor after clicking “Zoom Rate”.

Please note that, if the image quality is poor, shooting a ruler or other non-standard objects (such as experimental model-used size) to calibrate, automatic calibration may not work. You will need to manually set the "Length" column by entering the actual length of a straight line drawn, then click the "Zoom Rate" button. After that, remember to tick the “Rectangular” before closing the Ruler window.

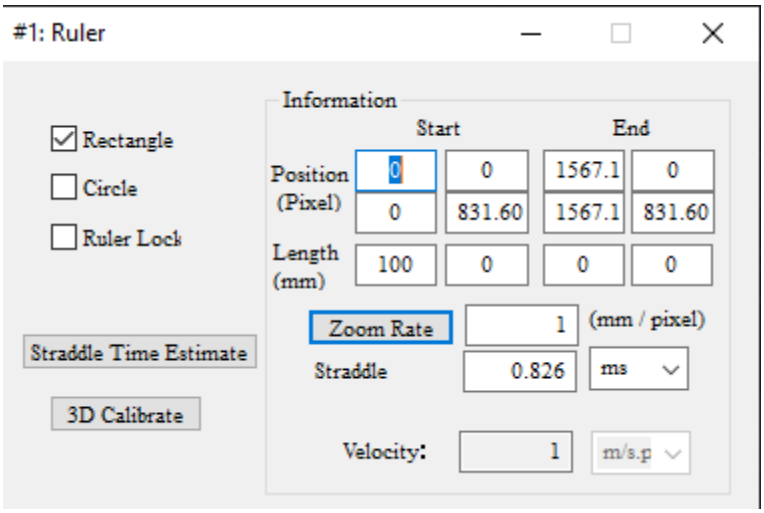


Figure 6.73 Calibration settings

3. Open specimen images

Click the "Open Image series" button ("File" menu "Open Image series" command or ) to read the specimen images into the image buffer.

4. Image cross correlation analysis

Open the "PIV Computer" window ("View" menu "PIV Compute" command or ) and set appropriate parameters for PIV calculation (you may also use the default value).

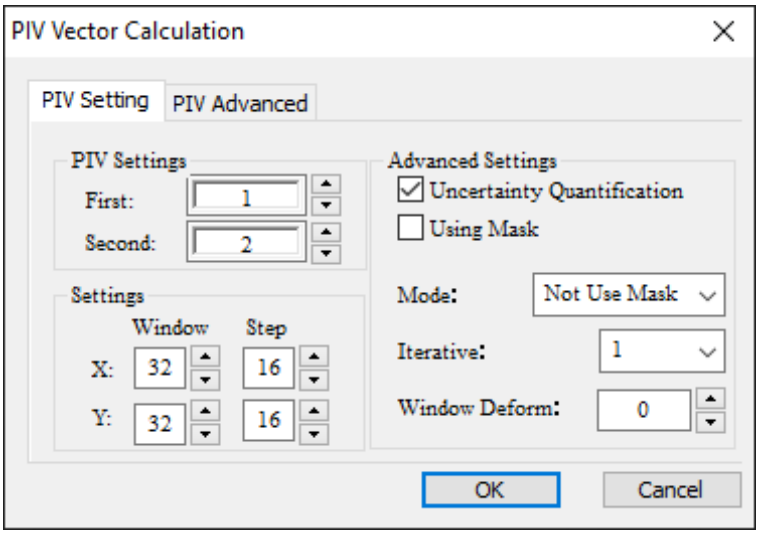


Figure 6.74 Calibration settings

5. PIV Batch processing

Open the "PIV Batch process" window ("Analysis" menu "PIV Batch process tool" and "PIV batch process" command), and select GPU computing acceleration. Click on the "OK" button to start batch processing.

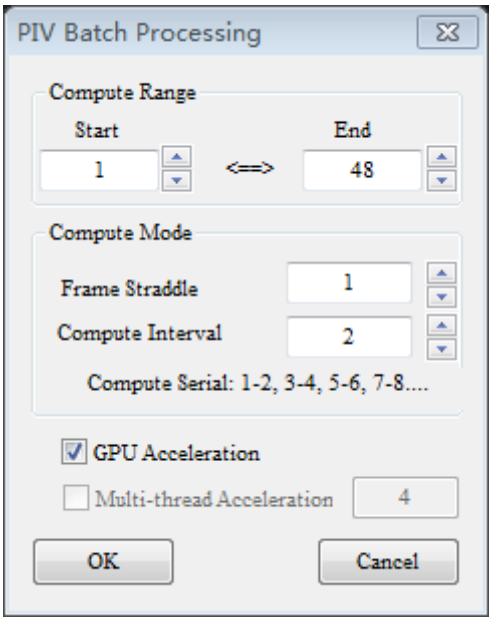


Figure 6.75 PIV calculation batch process

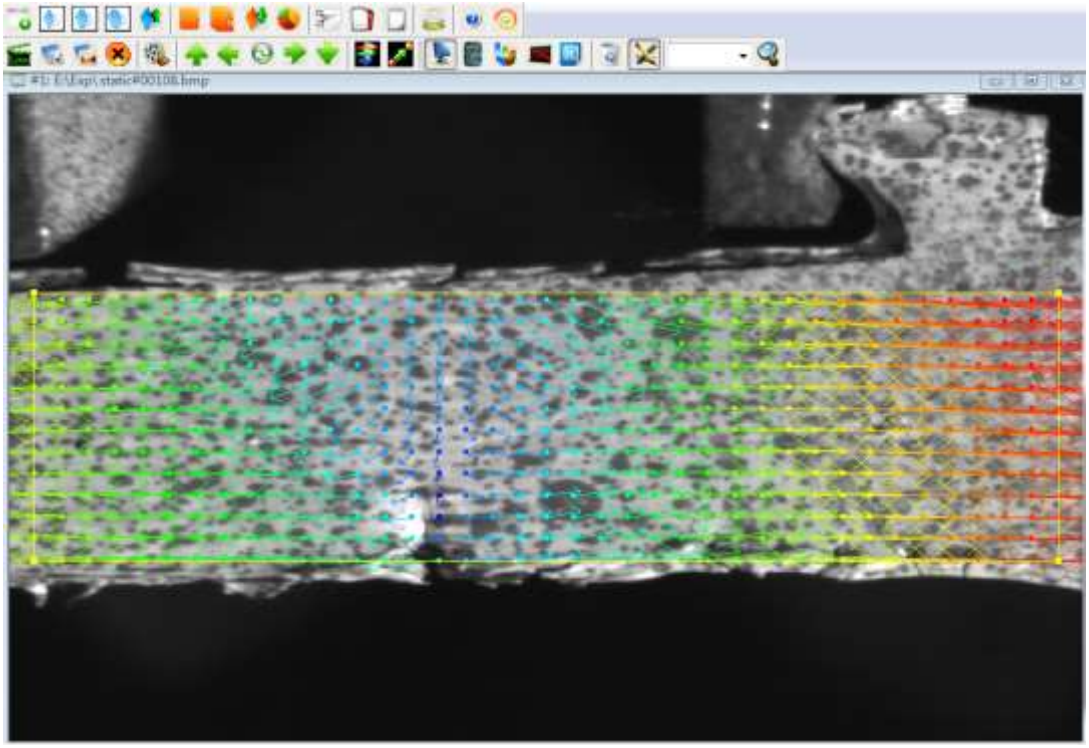


Figure 6.76 PIV calculation result

6. Save the result

Open the "Save Batch Process Result" window ("Analysis" menu "PIV Batch process tool" and "Save Batch Process Result" command). The mesh grid of the result is distributed regularly, shown in Figure 6.77.

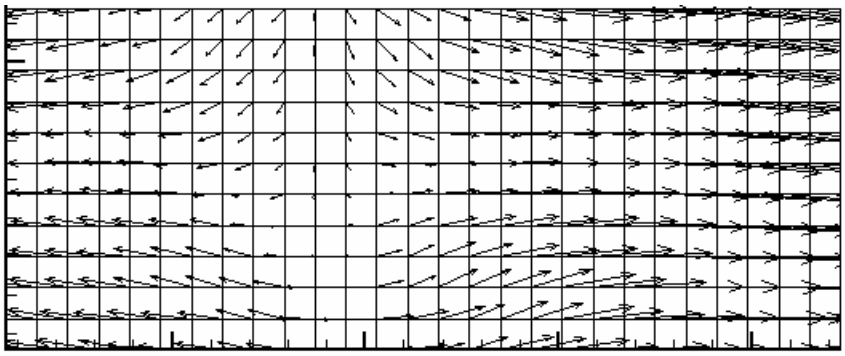


Figure 6.77 Velocity field distributions with uniform grid

When saving the results by clicking the "Save Grid Result" command, the mesh grid is deformed, indicating how the specimen twisted, shown in Figure 6.78.

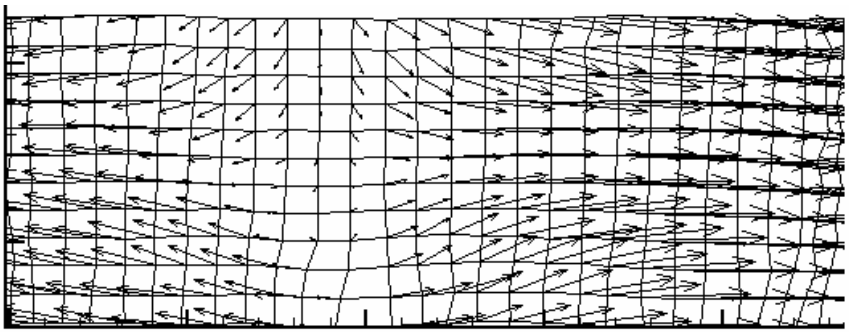
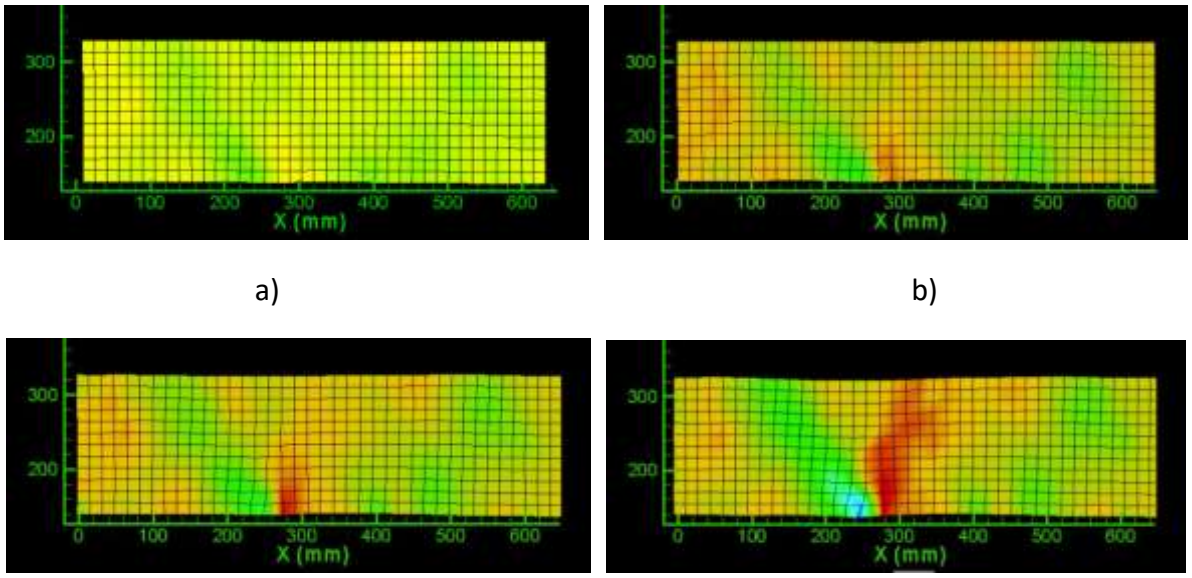


Figure 6.78 Velocity field distributions with deformed grid

The DIC results of Figure 6.79 are presented below:



a) b)

c) d)

Figure 6.79 Strain distribution of DIC results

6.6 PIV Uncertainty

The uncertainty in a PIV calculation refers to the amount of doubt you would allow in a measurement. A range of numerical values are defined and the true value is expected to fall in between.

Moment of Correlation (MC) plane uncertainty method

Microvec software is using moment of correlation (MC) plane proposed by Bhattacharya and Vlachos*. This method is a new uncertainty estimation that uses the correlation plane as a model for the probability density function (PDF) of displacements and calculates the second order moment of the correlation (MC). The cross-correlation between particle image patterns is the summation of all particle matches convolved with the apparent particle image diameter. MC uses this property to estimate the PIV uncertainty from the shape of the cross-correlation plane.

The MC method was tested with simulated image sets and the predicted uncertainties show good sensitivity to the error sources and agreement with the expected RMS error. Results show that the MC method has a better response to spatial variation in RMS error and the predicted uncertainty is in good agreement with the expected standard uncertainty. Overall, the MC method performance establishes itself as a valid uncertainty estimation tool for planar PIV.

With the Microvec software, the Uncertainty Quantification can be enabled in the PIV Vector Compute window.

To export uncertainties in Microvec software, take the following steps:

1. On the open window, select the third tab, PIV Advanced Settings, as seen on the image to the right.
2. Under this tab you will see multiple options for your experiment. For exporting PIV uncertainties, navigate to the subcategory at the very bottom, *PIV Uncertainty*.
3. You will be provided with the two options, standard uncertainty and expanded uncertainty. You can check either option or both.
4. Click the *OK* button.

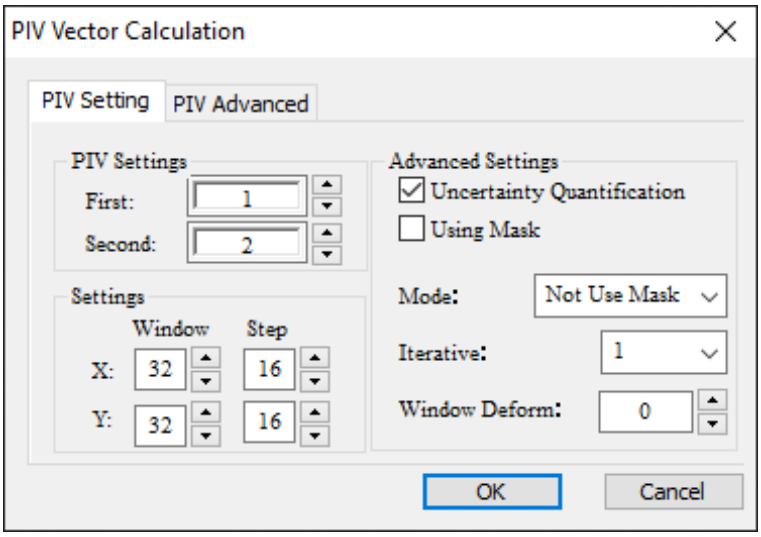


Figure 6.80 PIV Uncertainty

Component-Wise Uncertainties

Each velocity component in a 2D PIV experiment has its own uncertainty, $\triangle V_x$ and $\triangle V_y$, at a certain confidence level. The magnitude of uncertainty is the scalar value which is exported. You can assume $\triangle V_x = \triangle V_y$, so divide the uncertainty magnitude by √2 to find the uncertainty for a specific velocity component.

* Sayantan Bhattacharya *et al* 2018 *Meas. Sci. Technol.* 29 115301

Chapter VII Appendix

This chapter describes the use of digital image correlation software terminology: Digital cameras, lasers, frame grabbers, interrogation window, step size, the image buffer, Tecplot, Origin, standardized dimensions, data file format, TTL and so on.

7.1 Digital Cameras

Nowadays digital cameras use mainly two types of photoelectric sensor chips: CCD and CMOS. CCD is the abbreviation of Charge-Coupled Device, CMOS is the abbreviation of Complementary Metal-Oxide-Semiconductor. CCD or CMOS converts optical signals into electrical signals. Most standard PIV systems use CCD cameras (Figure 7.1).

Figure 7.1 Digital Camera

From generation to now, Digital cameras have two ways of transmitting signals which are in analog and digital formats. Analog signal format uses the ordinary video transmission protocol (PAL/NTSL) and captures images at 25 or 30fps. This format of digital camera is suitable for continuous acquisition images. it cannot trigger the acquisition of images in a single shot, so it can't work with pulsed lasers for accurate velocity field measurement.

Digital formats use common standard digital signal transmission protocol-RS422, and the newer RS644. The biggest feature is that it can cooperate with the external trigger signal to achieve an image, so that we can implement multiple cameras to work in sync with the laser.

There are three types of CCD sensors (see Figure 7.2): A) Full-Frame CCD, B) frame transfer CCD and C) Frame Straddle or Inter-line Transfer CCD.

The Fill Factor of each pixel of a Full Frame CCD sensor (Fill Factor) is close to 100% and the image quality is good, but the drawback is that the exposure control of this sensor only uses a

traditional mechanical shutter so the delay of two consecutive frames is long (If the transfer of the first images is unfinished, the second image can`t be captured), which limits the CCD sensor to using PIV measurements.

Frame transfer CCD has the same size of Non-photosensitive storage areas in the parallel position of the sensor photosensitive array, so the first image signal can be instantly transferred to the Non-photosensitive storage area, followed by the second frame. The second frame is exposed and the first frame signal in the storage area is transported at the same time. In this way, the Fill Factor of each pixel of Frame transfer CCD sensor (Fill Factor) is also close to 100%, and it can change the exposure time of the first frame, which implements the function of the electronic shutter (No need for a mechanical shutter to control the exposure). This approach is close to the basic requirement of PIV measurement. However, due to the limitations of the fabrication process of the sensor, the transfer time is milliseconds and cannot be used in high-speed flow field measurement.

Frame Straddle or an Inter-line Transfer CCD camera is improved on the basis of Frame transfer CCD where each pixel is divided into two parts: one as a photosensitive element, another as a storage unit. So, after shooting the first frame image, the signal can be instantly transferred to the storage unit and the second frame image is captured. Transmission speed can be nearly 1,000 times faster than frame transfer (microsecond dimension, or hundred nanoseconds). This will make up for the lack of frame transfer speed and can reach the requirements of hypersonic flow field measurements. But this structure also has the disadvantage of being photosensitive (about 60%). There are certain requirements for the exposure of the image.

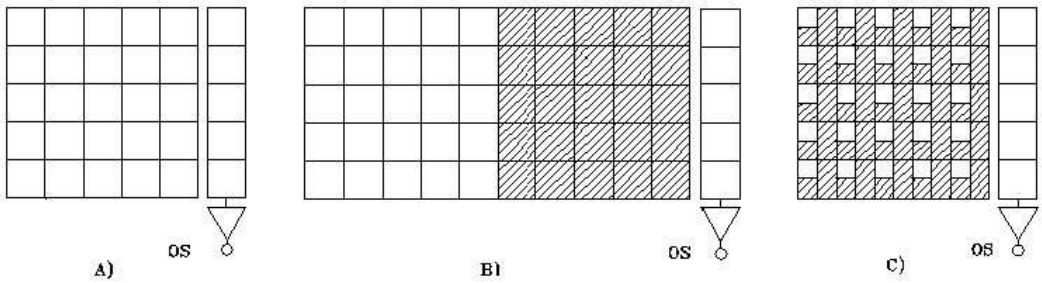


Figure 7.2 The structure of CCD sensor

7.2 Laser

Laser types are solid-state lasers, semiconductor lasers, liquid lasers, gas lasers and chemical lasers. Generally, PIV systems use solid-state lasers and semiconductor lasers.

The laser material of semiconductor lasers is semiconductor materials (see Figure 7.3). The working principle of semiconductor lasers is that the laser material emits photons by energy inter-band optical transitions, using the cleavage plane of the semiconductor crystal to form two parallel mirrors as a reflector and composing a resonant cavity and outputting a laser after oscillating feedback and amplification. The advantages of Semiconductor lasers are their small size, light weight, reliable operation, low power consumption and high efficiency.

Semiconductor lasers are generally composed of a laser working substance, a pumping system (excitation source), a concentrating system, an optical cavity, and a power supply (high power Semiconductor lasers are also equipped with a cooling system). The working principle of Semiconductor lasers is that the light energy radiated by the pumping system passes through the focusing cavity, and the laser gain medium absorbs radiation from an optical pumping source to create a population inversion of excited species, from which the excited species make a laser transition to produce a laser output (Figure 7.4). The energy conversion efficiency of Semiconductor lasers is not high, because only a part of the emission spectrum of the semiconductor laser source is absorbed by the working substance and other losses, the energy conversion efficiency is not high, due to it using Q-switching technology to output lasers which are large energy, high power, short pulses on the order of nanoseconds, so they can be widely used in PIV system.

Figure 7.3 Semiconductor laser

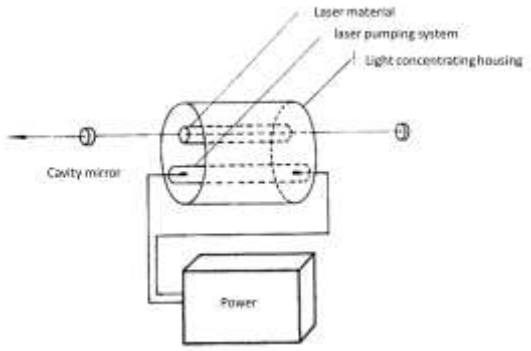


Figure 7.4 Schematic of semiconductor pulse laser

7.3 Frame grabber

CCD cameras complete information transmission between computers through the frame grabber: computers control CCD cameras through the frame grabber, while analog signals are collected by the CCD camera and transmitted to the computer in real time.

When the image is sampled, quantized, converted to a digital image input and stored in the frame memory, the analog signal transmission needs a high transmission speed. Since a common transmission interface cannot meet requirements, it needs a frame grabber (Figure 7.3). A frame grabber is a hardware device which can obtain digitized video image information, capture the image signal to the computer, and store it on the hard drive.

In PIV applications, usually using black and white images, the images can be divided into 256, 1024, 4096 gray scale, namely, 8, 10, 12 bits. In frame grabber supporting software, we can set the gray scale of the captured images.

When the input speed of the frame grabber signal is too high, we need to consider the bandwidth of the frame grabber and image processing systems. In actual use, it is possible that the bandwidth can't meet the requirements of the high speed transmission. In order to avoid losing data when encountering transferring data conflicts with other devices, there should be a data buffer on the frame grabber. In order to solve the transmission problem, a PCI-E computer is used. By utilizing

the transmission characteristics of PCI, you can capture images continuously to RAM and analyze. As the speed of the CPU increases, you can quickly analyze the images in real time.

Further, the frame grabber uses a CamLink interface, which provides a bi-directional communication link, and the frame grabber and camera can communicate through it. The user can complete the camera's hardware parameter setting and change it by sending corresponding control commands to the image board, which is convenient for the user to control the camera in direct programming mode.

Microvec uses the PCI-E (bandwidth of 2GB/ s) of the computer interface + CamLink (bandwidth of 700MB / s) camera interface, ensuring high-speed, real-time PIV image acquisition and storage.

Figure 7.5 frame grabber

7.4 Interrogation window and step size

Before performing PIV calculations, you need to set two parameters: interrogation window and step size (Figure 7.3).

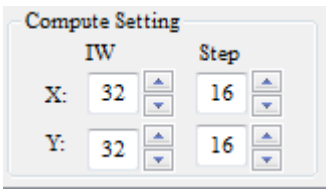


Figure 7.6 interrogation window and step size

The meaning of the interpretation window can be understood by reading Section 4.2.

The step size refers to the change of the position of the interpretation window IW2 relative to IW1 in the whole picture when the next analysis is performed after using the interpretation window IW1 to analyze a part of the image, as shown in Figure 7.4:

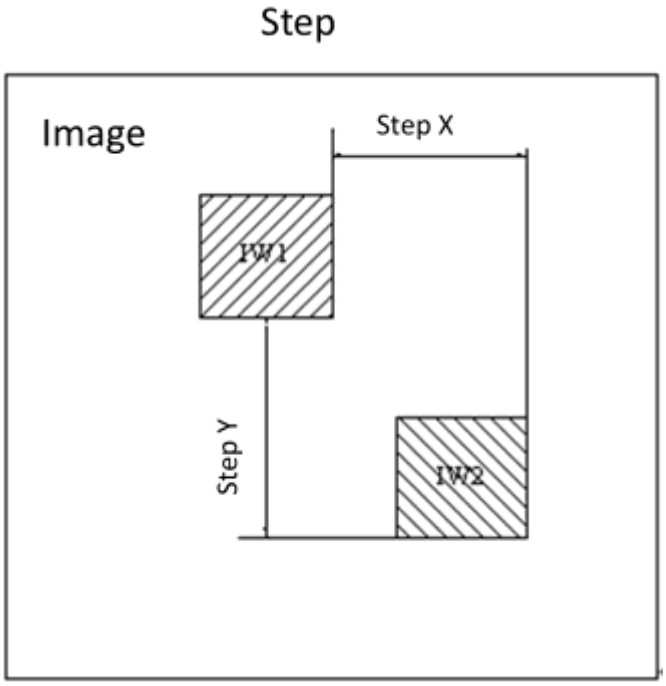


Figure 7.7 step size description

Taking the interpretation window 32 pixel × 32 pixel, step size 16 pixel × 8 pixel as an example, The grid distribution and calculation results are shown in Figure 7.8. The distance between the two data points in the horizontal direction (16 pixels) is the step size in the X direction. The distance between two data points in the vertical direction (8pixel) is the step size in the Y direction. The interpretation window is the surrounding 32 pixel × 32 pixel area centered on the data point.

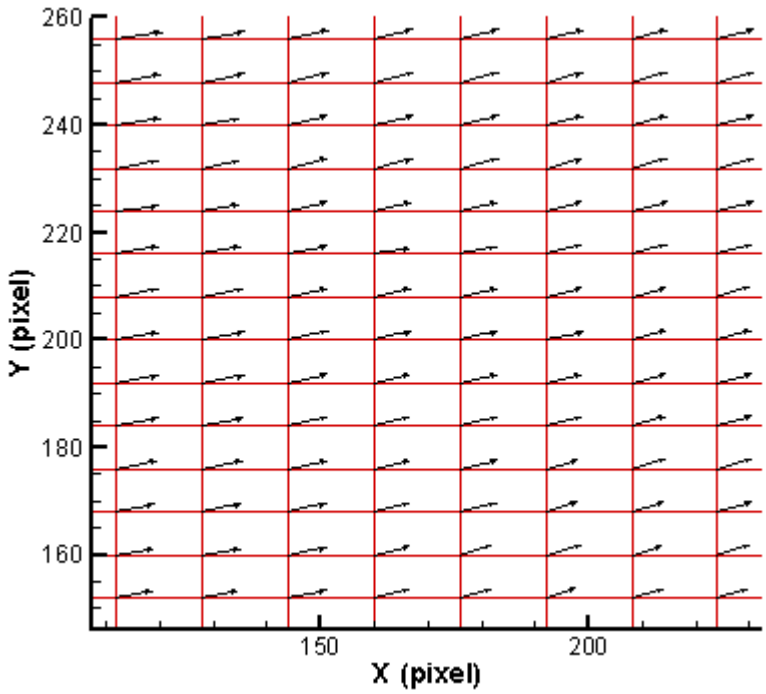


Figure 7.8 PIV results grid distribution

7.5 Image Buffer

The storage area of the computer stores image data. In the PIV image acquisition and processing software, a separate storage area is created in the RAM of computer for storing digital images processed by the PIV software. In addition, all the digital images stored here are numbered (starting with 1, 2, 3, 4 ...), the total number of stored images depends on the size of the RAM. In the PIV image acquisition and processing software, the number of each image is displayed in the  frame grabber window, and the total number of buffered images which can be stored is also displayed here.

7.6 Tecplot

Tecplot is a powerful data analysis and visualization software, widely used in a variety of computational fluid dynamics and experimental results. It provides rich graphics formats, including xy graphs, 2-D and 3-D surface graphs, and 3D volume drawing. The velocity vector calculated by PIV software can be displayed by Tecplot, including u, v, speed, equivalent cloud, vorticity, streamline, and the animation of the results PIV calculation along time.

It can be read directly into a common grid, CAD graphics and the files of the CFD software generated (PHOENICS, FLUENT, STAR-CD). It can directly import CGNS, DXF, EXCEL, GRIDGEN, PLOT3D files. It can export the files into multiple formats, including BMP, AVI, FLASH, JPEG, WINDOWS and other formats. Use the mouse to click directly to know if, at any point in the flow

field, values can be freely added and deleted to the specified contours (surfaces). In engineering and scientific research, the users of Tecplot are from aerospace, defense, automotive, petroleum and other industries as well as fluid mechanics, heat transfer, earth science and other scientific research institutions.

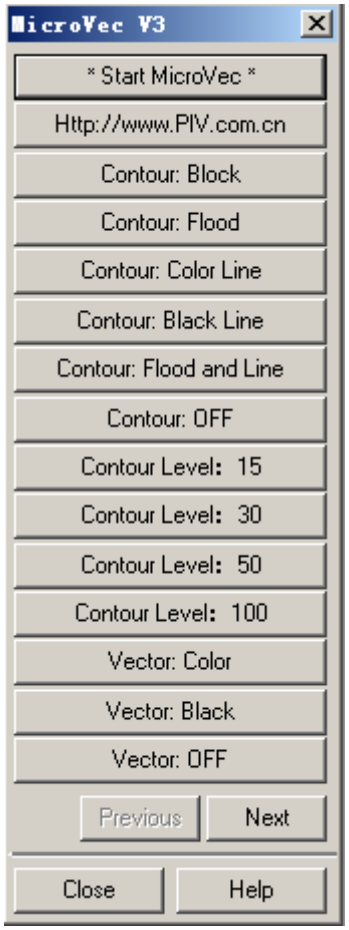


Figure 7.9 Tecplot macro-command

Figure 7.9 is a macro-command which is created by Microvec, Inc. according to the knowledge of Tecplot, PIV and fluid mechanics to click on a button and complete a series of commands. Simply copy the Tecplot.mcr file from our software installation directory (C:\Microvec) to the Tecplot installation directory (eg C:\Program Files\TEC100). Each button has the following meaning:

Macro command button	The significance of Macro command button
Start Microvec	Starts running macros
Http :/ / www.PIV.com.sg	Website of Macro developer (Microvec)
Contour: Block	Display contour in block
Contour: Flood	Display contour in a sequential color
Contour: Color Line	Display contour in equivalent color
Contour: Black Line	Display contour in black equivalent
Contour Flood and Line	Display contour in a sequential color and black equivalent
Contour: OFF	Turn off contour

Contour Level: 15	The gradation of contour is 15
Contour Level: 30	The gradation of contour is 30
Contour Level: 100	The gradation of contour is 100
Vector: Color	Display vector in color gradual
Vector: Black	Display vector in black
Vector: OFF	Close vector display
Next	Next
U	Display the distribution of U
V	Display the distribution of V
W	Display the distribution of W
Speed	Display the distribution of Speed
du / dy	Display the distribution of du/dy
dv / dx	Display the distribution of dv/dx
du / dx	Display the distribution of du/dx
dv / dy	Display the distribution of dv/dy
dw / dz	Display the distribution of dw/dz
Vorticity	Display the distribution of Vorticity
U Standard Deviation	Display the distribution of U standard deviation
V Standard Deviation	Display the distribution of V standard deviation
W Standard Deviation	Display the distribution of W standard deviation
Speed Standard Deviation	Display the distribution of Speed standard deviation
Vorticity Standard Deviation	Display the distribution of Vorticity standard deviation
Dynamic display all layers	This shows all the layers that are open in turn
Overlay all layers	Overlay display all open data layers
Display: first layer	Display the first layer
Display: last layer	Display the last layer
Display: next layer	Display the next layers
Display: final layer	Displays the last data layers
adjust the length of the vector	Vector length automatically adjusts according to the proportion of the velocity vector
Vector length slightly increases	Slightly increase the display length of vector
Vector length slightly reduces	Slightly reduce the display length of vector
Vector length increases	Drastically increase the display length of vector
Vector length reduces	Significantly reduce the vector display length
Vector length is automatically	Vector length automatically adjusts according to the size of velocity
Vector length locks	Constant vector length
Interval Display: NON	Close interval display grid
Interval Display: I = I +1	Data grid is sparsely doubled in horizontal direction

Interval Display: J = J +1	Data grid is sparsely doubled in vertical direction
Interval Display: [I, J] = [I, J] +1	Data are sparsely doubled in horizontal and vertical direction
Flow line center: (Vertical)	Streamlines are equally spaced along the vertical direction
Flow line center: (horizontal)	Streamlines are equally spaced along the longitudinal direction
Streamline Left	Streamlines are drawn at equal intervals from the left
Streamline right	Streamlines are drawn at equal intervals from the right
Streamline upper	Streamlines are drawn at equal intervals from the upper
Streamline under	Streamlines are drawn at equal intervals from the under
Streamline Clear	Clear the streamline
Streamline number: 20	Automatically draw 20 streamlines at a time
Streamline number: 50	Automatically draw 50 streamlines at a time
Streamline number: 100	Automatically draw 100 streamlines at a time
Streamline number: 200	Automatically draw 200 streamlines at a time

7.7 Origin

Origin is a more popular professional graphics software for a variety of data displaying, calculation, analysis and mathematical statistics. It can meet the general needs of cartography, and also accomplish the advanced data analysis, and function fitting. It`s easy to learn, operate, and it's powerful, you just click the mouse and select the menu command to get satisfactory results.

Origin has two main functions: data analysis and graphing. Origin includes statistical data analysis, signal processing, image processing, peak analysis and curve fitting, and other perfect mathematical analysis. Origin's graph is based on a template, Origin provides dozens of 2-D and 3-D templates and allows users to customize their own templates. If you want to draw a graph, just select the required template. Users can customize the mathematical functions, graphic styles and drawing templates; and link office software, image processing software and other convenient connections.

Origin supports multiple date formats, including ASCII, Excel, pClamp and so on. In addition, it can export Origin graphics to multiple formats, such as JPEG, GIF, EPS, TIFF and others.

7.8 Standardized dimensions

The image in the image buffer is saved and showed according to the camera resolution and the standardized dimensions correspond to the  Image board window. More commonly used CCD dimensions:

image Size (million pixels)	H (pixels)	V (pixels)	Acquisition rate (frames / sec.)	PIV velocity field results (counts / s)
100	1004	1004	48	24

200	1600	1200	30	15
	1920	1080	30	15
400	2048	2048	15	7.5
11000	4000	2672	5	2.5
16000	4872	3248	3	1.5

7.9 Data File Format

Hard disk storage supports four image file formats: BMP, JPG, AVI and TIFF.

BMP is the WINDOWS general image file storage format, 8 bits per pixel (10-bit data system will automatically adjust for the eight data storage, there is some data distortion). The file will be in gray scale storage format. JPG is a compressed format, AVI is a video file created by combining the compressed image, TIFF file is a dedicated format for image analysis systems (some image processing software are not compatible) and it retains the original image for each pixel better than 8-bit data, gray scale storage format.

Various data file formats of the image analysis system stored are in ACSII format. The common text editing software can open and browse the data.

7.9.1 PIV calculation result data file

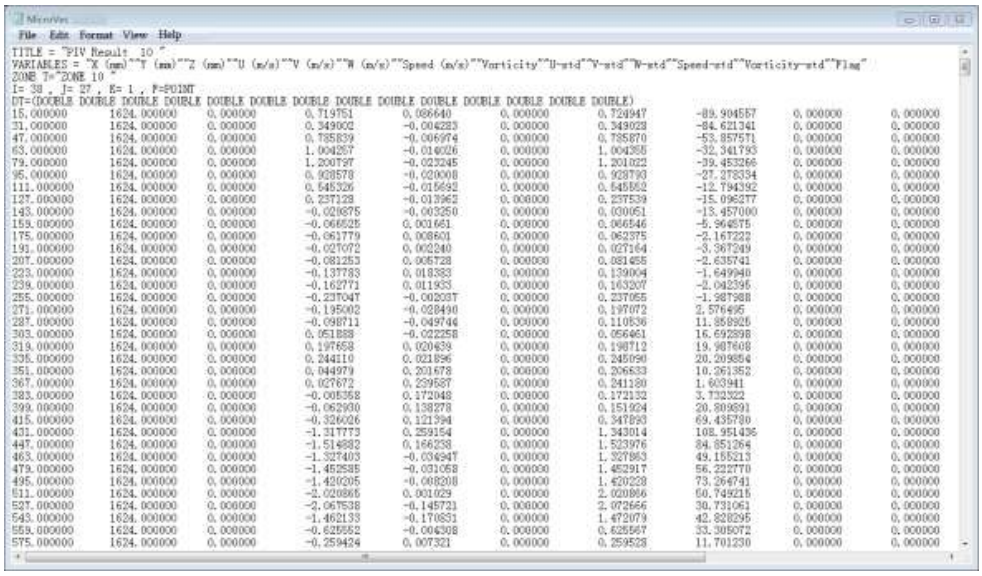


Figure 7.10 the header of PIV calculation result data file

The data file obtained by PIV calculation mainly consists of three parts. (Figure 7.5, Figure 7.6):

A. File header: Including the file characteristic information, data formats, data volume label, the data type, data size and the coordinate information.

B. Data Area: According to the data three-dimensional coordinates, each component is arrayed in order.

If a data file is batched into a data result file, the last five columns contain the different value between each time and the average result. If it is an average result saved separately after batch processing, the last five columns contain the difference of the value of the root mean square results (pulsation) at each moment.

C. Parameter Area: Includes various parameters which are used in the calculation, source image file name, the information of the related calculation parameter setting, etc.

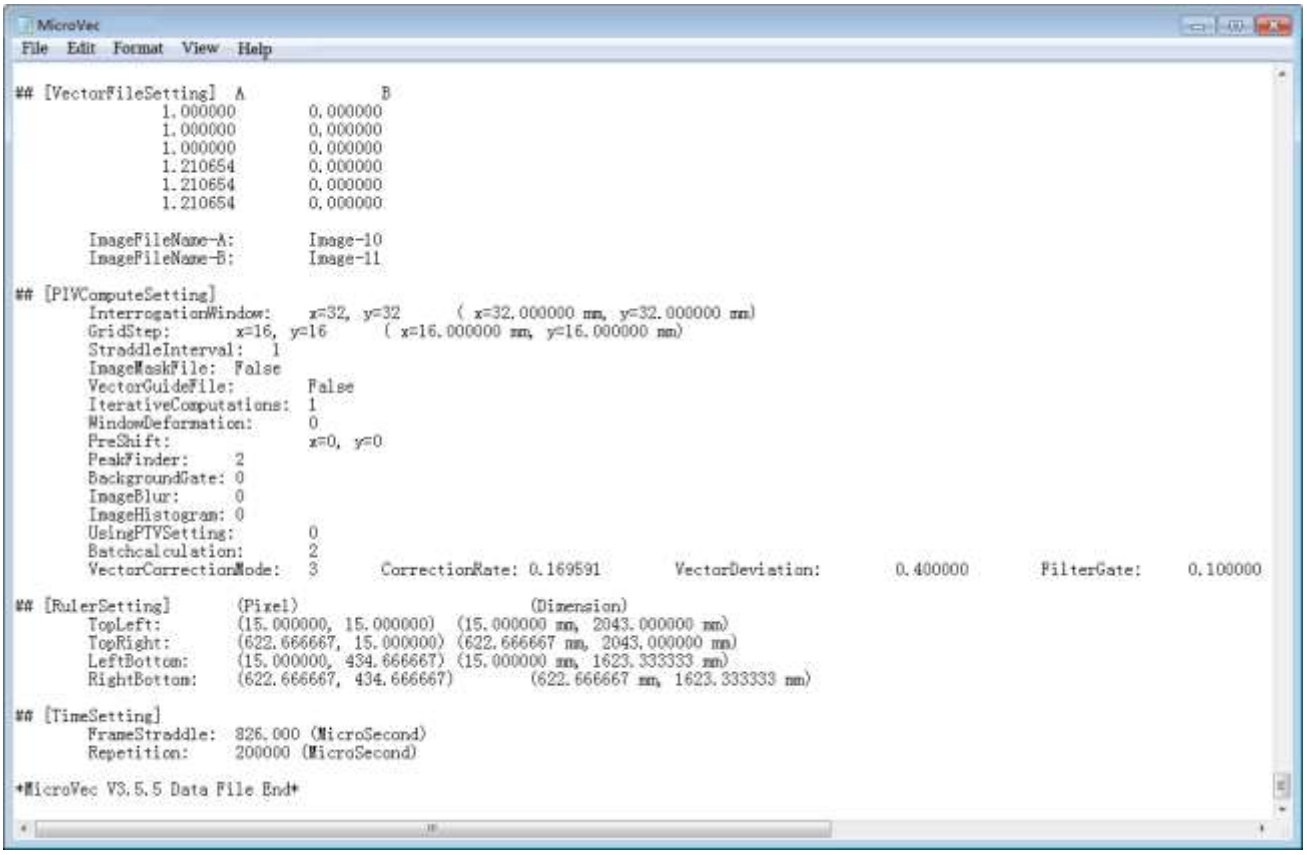


Figure 7.11 PIV calculation result data file trailer

PIV calculation result data file contains various calculation parameters and algorithm information.

7.9.2 Description of the physical realization of the code

1.Vorticity

(1) First: calculate shear strain rate $\frac{du}{dy}$ and $\frac{dv}{dx}$

$$\frac{du}{dy}=\frac{U(i,j+1)-U(i,j-1)}{Y(i,j+1)-Y(i,j-1)},\quad \frac{dv}{dx}=\frac{V(i+1,j)-V(i-1,j)}{X(i+1,j)-X(i-1,j)}$$

(2) Finally: calculate vorticity

$$\Omega=\frac{dv}{dx}-\frac{du}{dy}$$

2. Pulsation

(1) First: calculate the time-average

$$\overline{\xi}=\frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}}\xi dt$$

(2) Finally: calculate pulsation

$$\xi'=\xi-\overline{\xi}$$

3. Shear strain rate

du / dy = [U (i, j +1)-U (i, j-1)] / [Y (i, j +1)-Y (i, j-1)]

dv / dx = [V (i +1, j)-V (i-1, j)] / [X (i +1, j)-X (i-1, j)]

du / dx = [U (i +1, j)-U (i-1, j)] / [X (i +1, j)-X (i-1, j)]

dv / dy = [V (i, j +1)-V (i, j-1)] / [Y (i, j +1)-Y (i, j-1)]

dw / dz = [V (i +1, j)-V (i-1, j)] / [X (i +1, j)-X (i-1, j)] + [U (i, j +1)-U (i, j-1)] / [Y (i, j +1)-Y (i, j-1)]

4. Turbulence

$$u'(i,j)=U(i,j)-\overline{U(i,j)}$$

5. Turbulent kinetic energy

$$k=\frac{1}{2}\rho\overline{U'_iU'_i}=\frac{1}{2}\rho\overline{(U'^2_1+U'^2_2+U'^2_3)}$$

6. Reynolds stress

a. First: calculate the average speed

$\overline{u(i,j)} = \frac{\sum_{n=o}^{N} U(i,j)}{N}$, $\overline{v[i][j]} = \frac{\sum_{n=0}^{N} V(i,j)}{N}$. (N is the total number of velocity vectors)

b. Second: calculate the pulsation of velocity $u'(i,j) = U(i,j) - \overline{U(i,j)}$, $v'(i,j) = V(i,j) - \overline{V(i,j)}$

c. Finally: calculate Reynolds stress

$\tau' = -\rho U'(i,j)V'(i,j) \rightarrow \overline{\tau}' = -\rho\overline{U'(i,j)V'(i,j)}$

7.9.3 PTV calculation result data file

The data file that uses PTV does not contain the file header and directly lists the data. The data is from left to right.

Serial number coordinates X coordinate Y velocity component U V W Speed pixel values of the particle.

7.9.4 The results of the batch process data file

Data file that used batch calculations can be exported in two ways: exporting single-point data results and exporting data results.

The data files that are separately exported are averaged by the data in the same frame, and the data in each frame is averaged, and all the results of each frame are sequentially stored in one data file. The data format is from left to right.

Serial Number velocity component velocity component U V W Speed

This data file is suitable for analyzing time changes in local areas.

The Export Data Result command stores all the data in a data file, retains all data information, and exports the data format according to the PIV/PTV result format (no file header information). It is suitable for statistical and analytical data over the entire space and time.

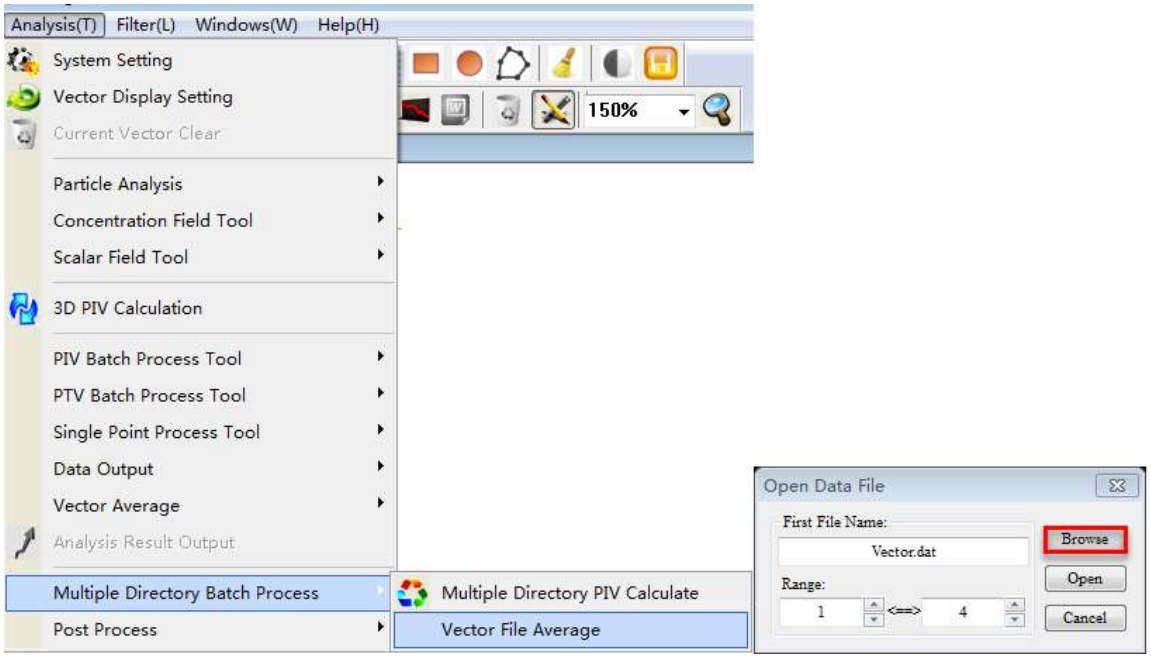
7.9.5 Output analysis results

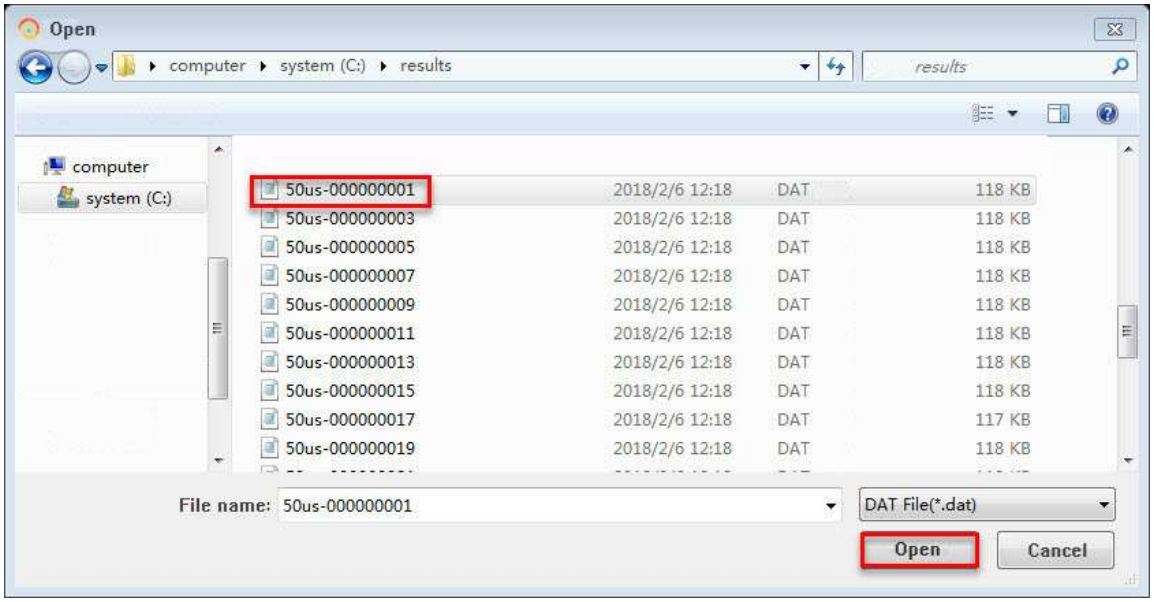
Using the Tools menu in the "Output analysis results" command, you can extract equal interval data on the digital ruler to analyze the data changes of the single image in the space.

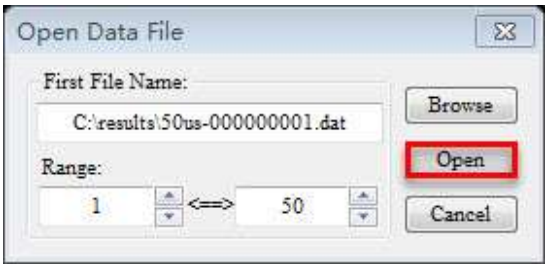
Data format: Serial number and speed value corresponding component.

7.9.6 Data obtained by averaging the results file data files

Use the “Analysis” menu "Data Averaging the results file" command (see Figure7.12) to calculate the results of the batch process calculation process again after storing the corresponding data file.







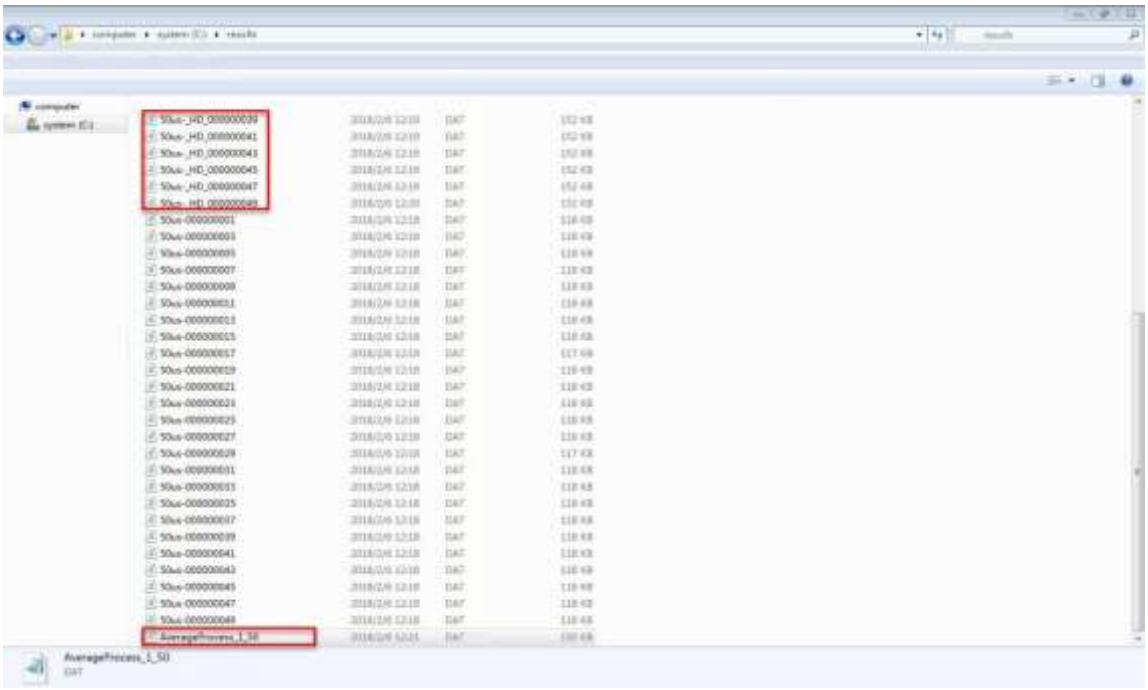


Figure7.12 Vector File Average window

Data file format(see Figure7.13) is:

File Header

Coordinates X Y Z X Y Z direction velocity Speed Vorticity X Y Z -direction velocity standard deviation Speed standard deviation vorticity standard deviation Reynolds stress values in the XY coordinate plane Reynolds stress values in the YZ coordinate plane Reynolds stress values in the XZ coordinate plane Turbulent energy value

Calculation parameters

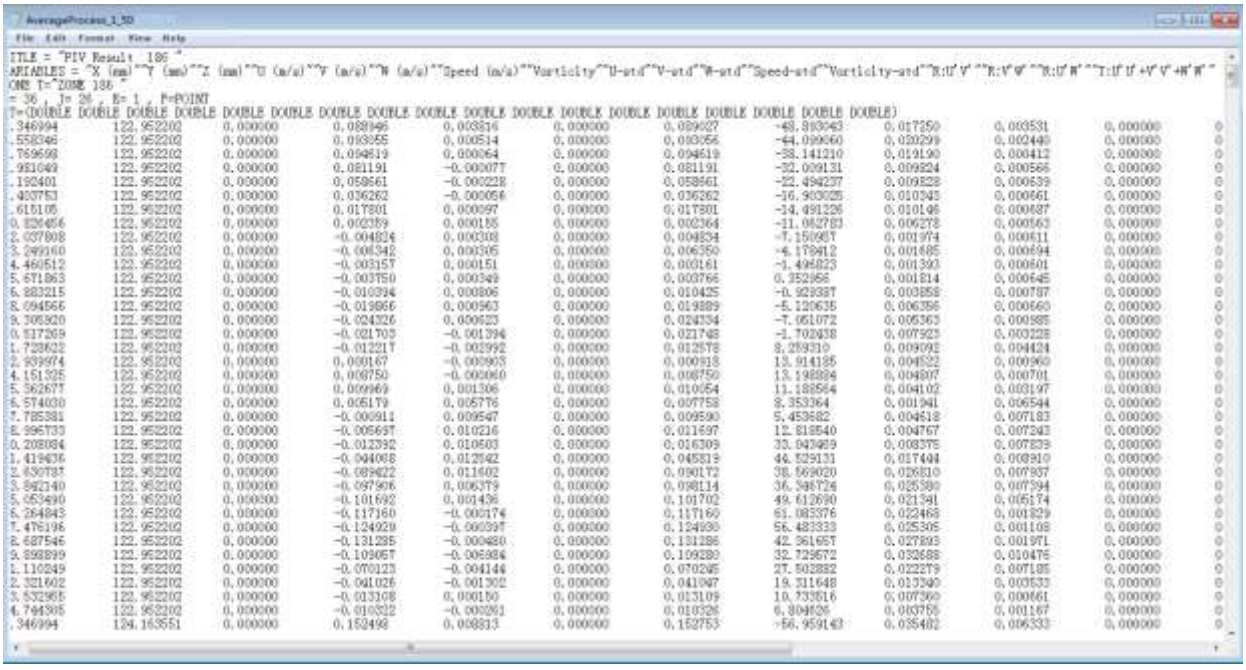


Figure 7.13

7.9.7 Concentration analysis result

Using the "Concentration Analysis" command, the concentration analysis result of a single image can be stored as a corresponding data file. File format:

File Header

Coordinate X, Coordinate Y, concentration values

Using the "particle size analysis" command, the result of a particle search for a single image can be stored as a corresponding data file. File format:

File Header

Serial Number, Coordinate X, Coordinate Y, width of equivalent rectangle, height of equivalent rectangle, pixel values of the particle

7.10 TTL

TTL (Transistor-Transistor Logic) is a BJT-BJT logic gate, it is a kind of logic gate circuit commonly used in digital electronic technology, applied earlier and the technology is relatively mature. TTL mainly includes BJT (Bipolar Junction Transistor) and resistor, it has a fast speed.

TTL level signal: TTL signal is a binary signal, +5 V is equivalent to a logical "1", 0V is equivalent to a logical "0." It is called TTL (Transistor - Transistor logic level) signaling system, which is the standard technique for communication between various parts of a device controlled by a computer processor.

TTL outputs high level voltage >2.4V and outputs low level voltage <0.4V. Generally, output high level voltage is 3.5V and output low level voltage is 0.2V at room temperature. Input high level voltage is ≥2.0V and input low level voltage ≤0.8V. Noise margin is 0.4V.

The TTL circuit is a current control device. The TTL circuit has a fast speed and a short transmission delay time (5-10 ns), but the power consumption is large.

Chapter VIII Synchronization Timing

There are two main types of synchronization trigger modes: internal trigger and external trigger.

8.1 Internal Synchronization

Microvec controls the timing through the synchronization output TTL signal to the laser and CCD camera. It triggers the camera and laser to work synchronously at a specific timing.

8.1.1 Traditional PIV (double pulse laser)

This chapter describes the general working principle of a PIV double pulse laser, how to provide the trigger signals to the laser from the MicroPulse synchronizer through your system computer and how to control the laser with the Microvec software. This chapter can be used for any brand of PIV laser supported by Microvec such as Litron, Quantel, Beamtech or Photonics Industries lasers.

Nd:YAG or Nd:YLF Q-switched lasers produce two exceptionally brief, powerful pulses of energy that last a few nanoseconds. These two laser pulses are produced in rapid succession, as close as 200 ns apart. The laser flash lamps, Q-switches, and camera must be synchronized for the experiment by using the correct settings which are then passed to the MicroPulse synchronizer and sent to the laser and camera. The use of two independent laser oscillators in PIV lasers allows for double pulse outputs with an inter-pulse separation time of less than 1 ns (nanosecond).

Each PIV laser has specific internal adjustment parameters for the flashlamp discharge and Q-Switch delay from the trigger signal. Normally the laser manual has detailed information about the PIV laser.

See examples taken from the PIV laser user manual for optimal Q-Switch delay times between the flashlamp and Q-Switch to achieve the maximum power for the corresponding laser in Figure 8.1.

Note the difference between the timing in the example from Figure 8.1 and how it corresponds to 2 μs.

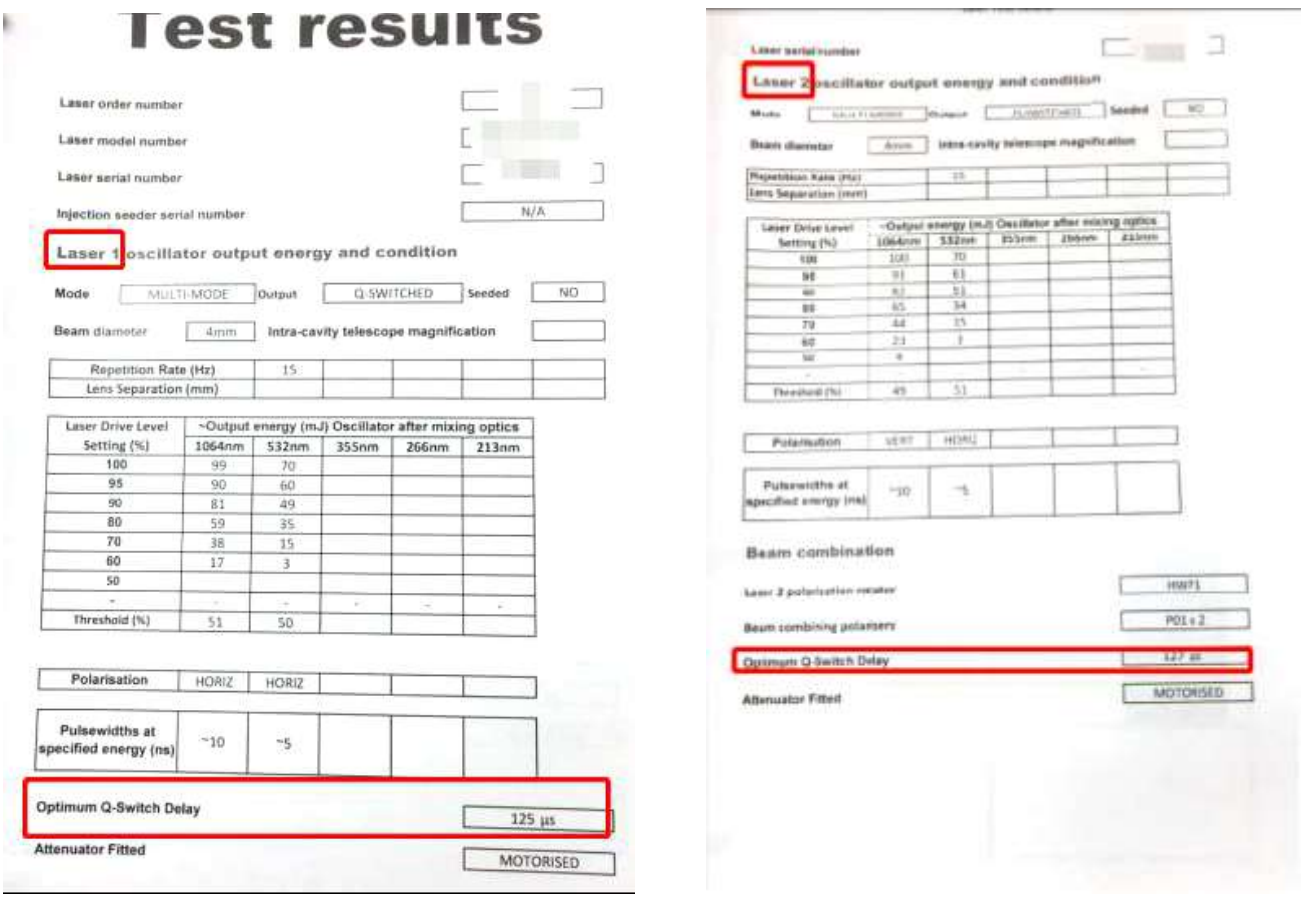


Figure 8.1 Recommended optimal Q-Switch delay values.

We need to start the configuration by setting the laser mode to internal mode. As already explained in Chapter 5, internal mode sets the internal synchronization of the entire system based on the PIV set frequency, as seen in Figure 8.2. This mode is used for starting up the laser system and setting it up.

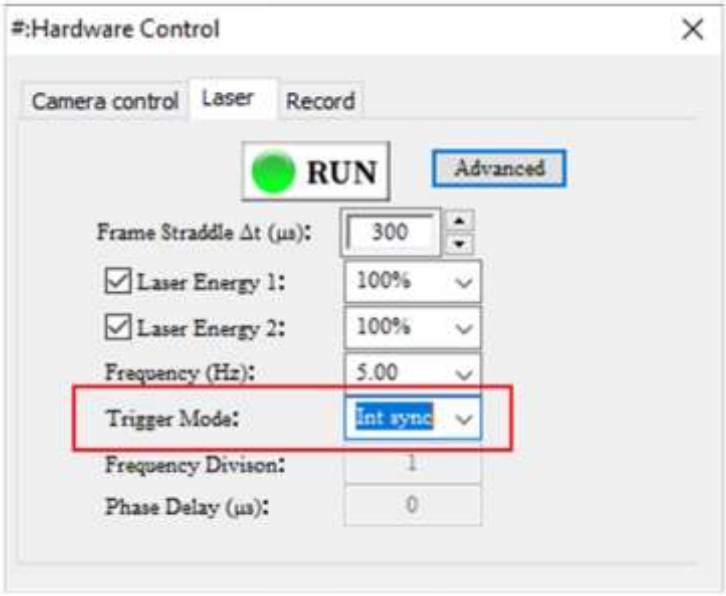


Figure 8.2 Internal mode

When we start the PIV experiment, we need to switch the Mode to External to allow for Microvec to control the timings of the laser.

As explained briefly in Chapter 2.2 and as shown in Figure 8.3, trigger outputs T1, T2, T3, T4 on the MicroPulse 725 synchronizer are connected to four channels of the laser's flashlamp 1 (F1), Q-Switch 1, flashlamp 2 (F2) and Q-Switch 2. Trigger output T5 is connected to the trigger input connector of CCD camera 1 and T6 is connected to the trigger input connector of the CCD camera (for 3D PIV setup with 2 cameras). Trigger output channel T7 is reserved for future use

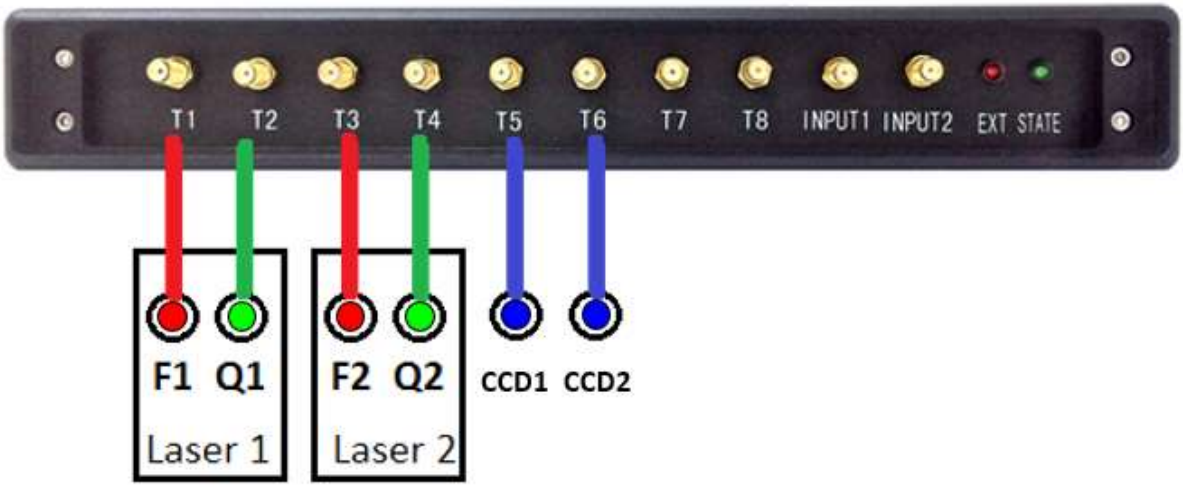


Figure 8.3 Synchronizer wiring diagram

The timing relationship is shown in Figure 8.4. The Synchronizer provides external trigger signals (TTL). The flashlamp of each laser cavity is turned on by the trigger signal from the synchronizer and starts the pumping process (i.e. the start of one flashlamp pulse). The Q-Switch is closed, so no laser oscillation and amplification is possible. After the stored energy in the resonator has reached its maximum peak, the Q-Switch is triggered by the Q-Switch delay signal and opened to immediately start the laser oscillation. The stored energy is extracted in a pulse of a few nanoseconds' duration as shown in figure 8.4. This process is duplicated for the second laser cavity.

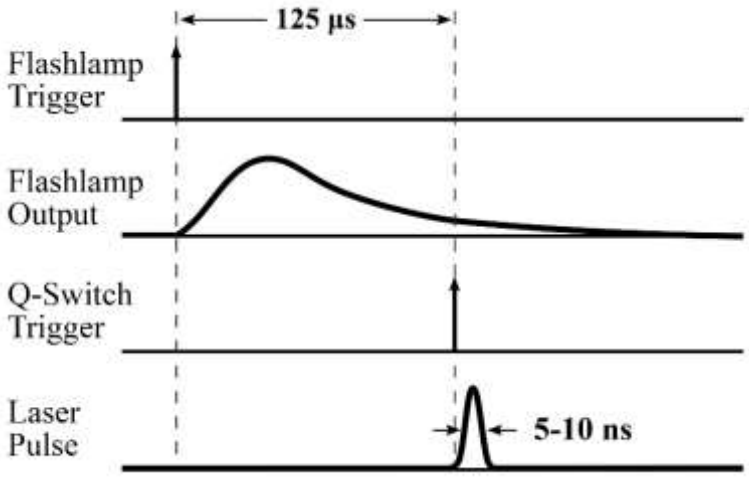


Figure 8.4 Timing diagram for Q-Switched pulsed laser

As a result, the laser emits double pulse lights within a certain time interval (**Δt**), set in the Advanced dialog box of Microvec software.

At the same time, the MicroPulse synchronizer sends a trigger to the camera, which is put in PIV mode (double-frame mode) - see Chapter 5.4.5 for more details. The trigger to the camera (T5) needs to set the exposure time of the first image pair to coincide with the first laser pulse. Then the camera starts the exposure for the second image pair and the second pulse will illuminate the camera after the time set in (Δt), as shown in Figure 8.5.

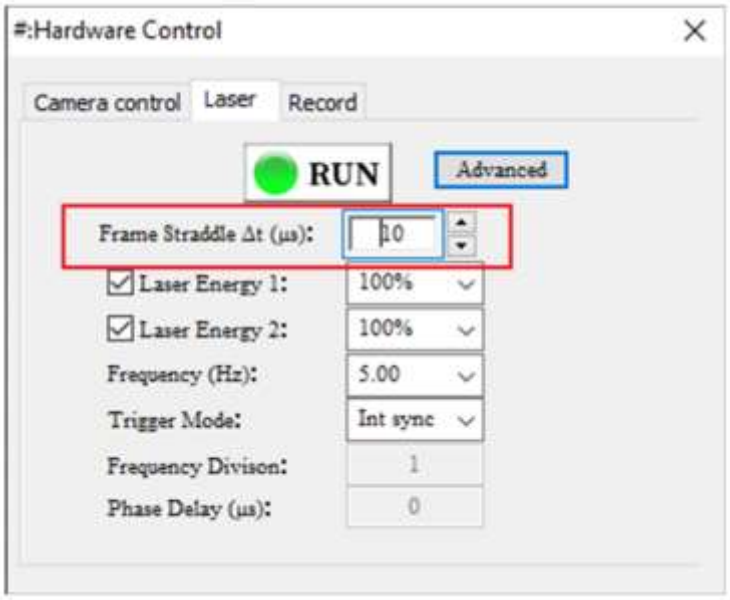


Figure 8.5 Setting the time between the two laser pulses (Δt)

As a result, we get two frames (also called image pairs), captured with only one external trigger but with two laser pulses. The time interval between the laser's dual pulses (**Δt**) cannot be lower than the inter-frame time of the camera used (each camera has a minimum inter-frame time between

70ns to 600 ns depending on camera model). This time interval (**Δt**) allows the capturing of an image pair with a very low amount of time between them. By using this image pair, we can calculate the corresponding velocity field for a very high flow velocity.

During the setup, we need to ensure that the two laser pulses happen during the exposure period of the first or the second image. It is easy to recognize the first and the second image within the image pair and ensure that the timing of the laser pulses is correctly set. The first frame has a short exposure time of about 200 ns, the background light is negligible and the image looks dark. The exposure time of the second frame is longer. Therefore, the captured image will be brighter and usually will have a brighter background.

If both pulses happen simultaneously in the first image, we need to appropriately increase the delay parameter of the synchronizer's T5 output channel (connected with the camera) until both laser pulses happen in the acquisition of both images. If both laser pulses fall within the second frame image, we need to reduce the delay parameters of the T5 channel.

The settings of the synchronization timings for the flashlamp discharge, Q-Switch delay and the camera can be done by clicking on the advanced button in the Laser dialog box, leading to the opening of the Advanced dialog box, as seen in Figure 8.5.

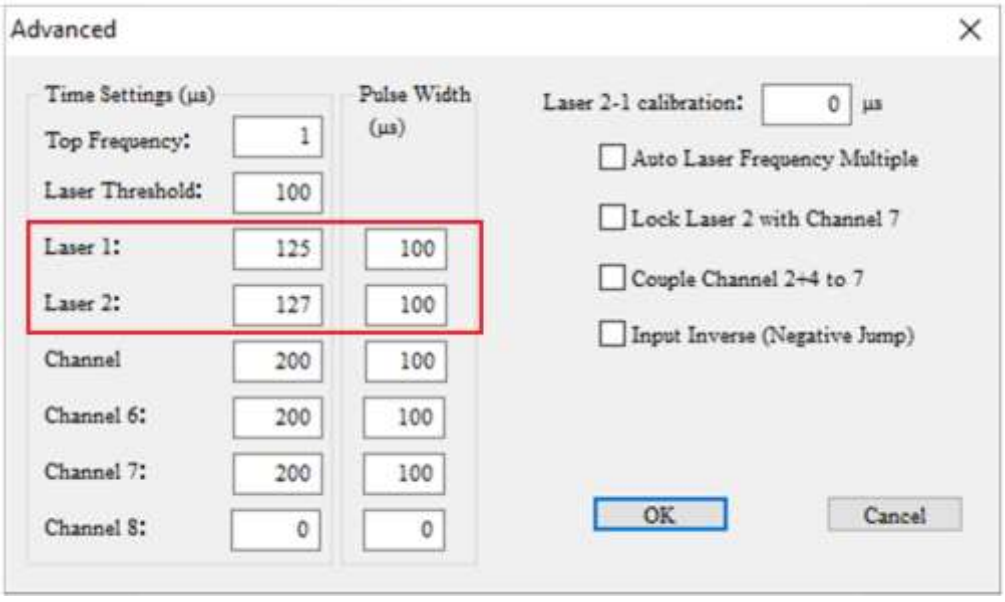


Figure 8.5 Advanced dialog box for PIV synchronization setup

Detailed descriptions of all the settings can be found in Chapter 5, specifically in Figure 5.25. In this chapter we describe the relationship of these settings relative to the timing needed to capture the image pair accurately.

Laser 1 and **Laser 2** settings in the Advanced dialog box are used to define the Q-Switch delay for the respective laser cavities and the trigger width as shown in Figure 8.5 above.

The Q-Switch delay for the laser 1 cavity (connected from T1 output of the synchronizer to flashlamp 1 input on the laser and from T2 output of the synchronizer to the Q-Switch delay 1 on the laser) is set to 125 µs in this example. Q-Switch delay for the laser 2 cavity is set to 127 µs. Physically, the T3 output of the synchronizer connects to the flashlamp 2 input on the laser and the T4 output of the synchronizer is connected to the Q-Switch delay 2 on the laser. We recommend using the optimal Q-Switch delay time values as shown in the manual of the laser - Figure 8.1 – to take advantage of the maximum energy of the laser.

For **Channel 5** settings (corresponding to the T5 output of the synchronizer and connected to the camera with an appropriate trigger cable), the first value is the amount of time needed to trigger the camera before the Q-Switch for laser cavity 1. The CCD camera trigger signal should be connected to the T5 output channel of the synchronizer. In the example shown in Figure 8.5, the setting is 200 µs. The camera will be triggered 200 µs before the Q-Switch of laser cavity 1. The timing diagram for these sample values is shown in Figure 8.6 below.

Settings for **Channels 6** and **Channel 7** are the same as for Channel 5 if we have additional cameras connected to the synchronizer outputs T6 and T7.

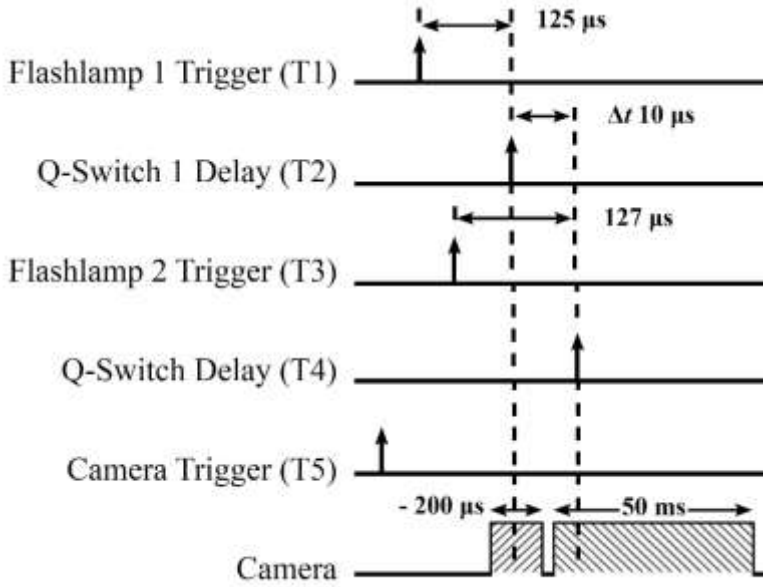


Figure 8.6 Timing diagram for two laser cavities and a camera in a Microvec PIV system with the sample values shown in previous figures (note that the timings are shown not to scale)

As seen in Figure 8.6, the MicroPulse synchronizer sends external trigger signals. Both flashlamps of the laser are turned on, and the Q-Switch interval is set to the optimum peak values. The timing of T3 is calculated by Microvec software using the equations: T1 + Q-Switch delay 1 + Δt - Q-Switch delay 2. In our sample, assuming T1 as a ZERO point, the T3 is 0 + 125 µs + 10 µs - 127 µs = 8 µs.

8.1.2 Traditional PIV with DPSS laser

Microvec PIV system can also be used with a Microvec Continuous Wave DPSS laser. In this case, the MicroPulse synchronizer starts modulating the laser output with the trigger signal coming from Channel 7, when it is coupled to Channels 2 and 4.

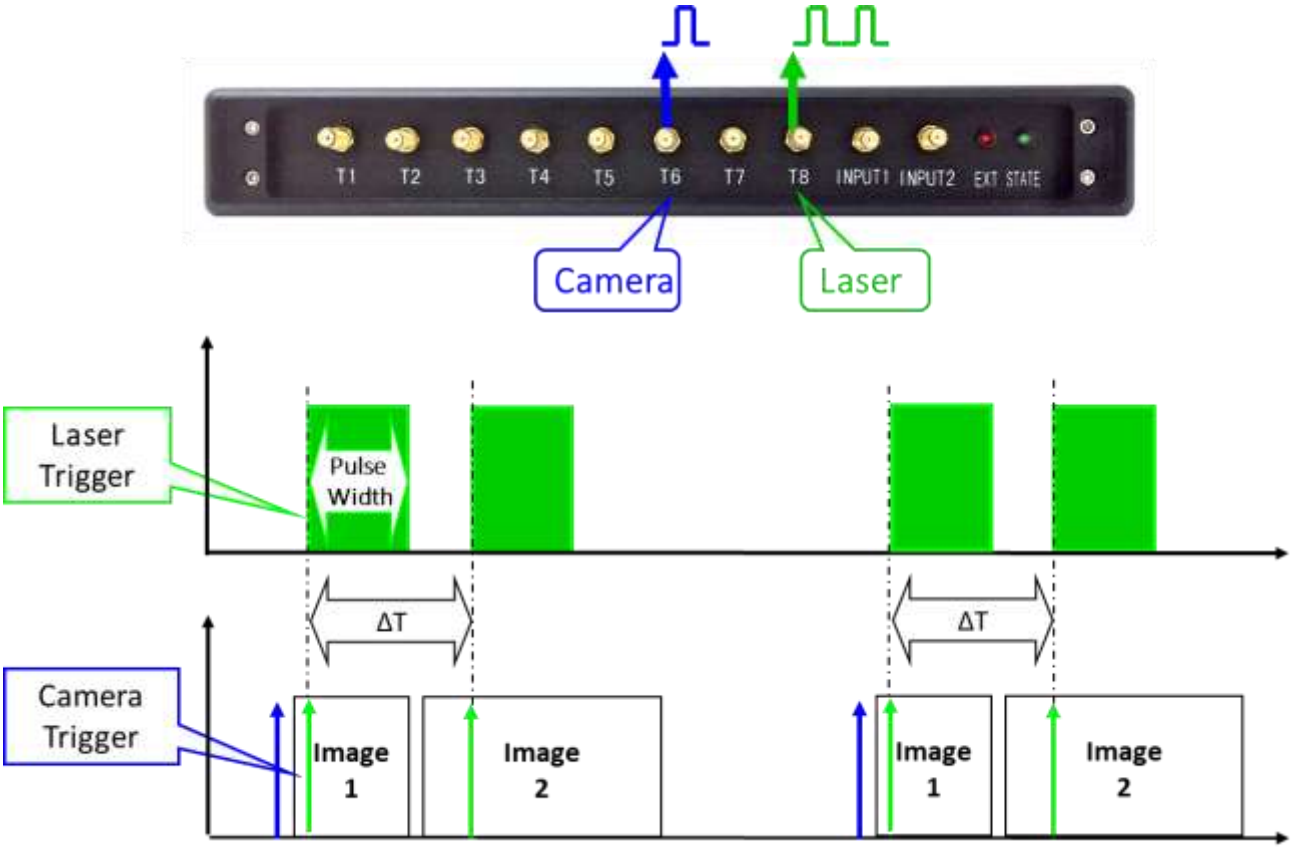


Figure 8.7 Timing diagram of PIV system with CCD camera and DPSS laser

The MicroPulse synchronizer generates two high-level trigger signals to the laser within a certain time interval equal to Δt. These trigger signals modulate the laser and the laser outputs with two square “pulses” with a certain pulse width. The continuous laser acts here in a very similar way to a PIV laser with real pulses.

The CCD camera is set to PIV mode and it is triggered by a trigger signal coming from the Channel 5 output of the synchronizer. The camera captures frame 1 and frame 2 in an image pair, with the laser illuminating the camera during the exposure time of frame 1 and 2 as seen in Figure 8.7.

To get this operating mode, we need to select “Couple channel 2+4 to channel 7” in the Advanced dialog box as shown in Figure 8.8.

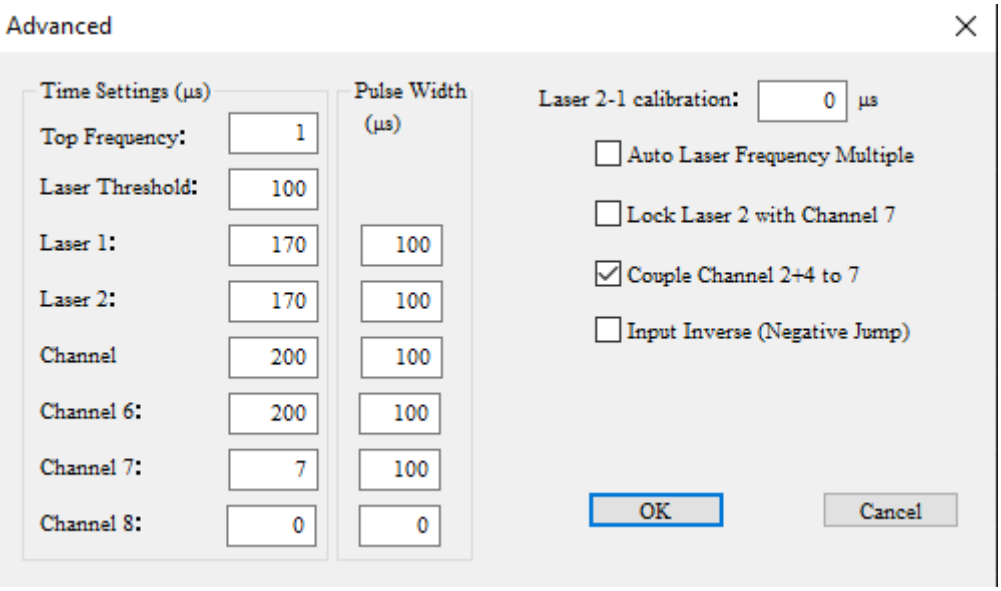


Figure 8.8 Advanced Settings for PIV system with DPSS laser

When the pulse width of the laser generated by the trigger signal from channel 7 is lower than or equal to the intra-frame time, we recommend reducing it to 2000 microseconds

8.1.3 Time resolved (TR) PIV with DPSS laser

The Time Resolved PIV (TR PIV) technique is an extension of PIV and includes the capturing frames at a high speed of hundreds or thousands of frames per second usually with the use of high-speed cameras. Images are recorded at a series of time intervals and are subsequently processed to extract velocity information based on the time between the frames.

Microvec offers two types of TR PIV systems:

- TR PIV system including high-speed camera and continuous (DPSS laser) for flows below 1 m/s
- TR PIV system including high-speed camera and high frequency PIV laser for flows above 1 m/s

In a TR PIV system with a DPSS laser MicroPulse synchronizer, the user starts modulating the laser output with the trigger signal coming from Channel 7. The camera is triggered at the same time by the trigger signal coming from the Channel 5 output of the synchronizer.

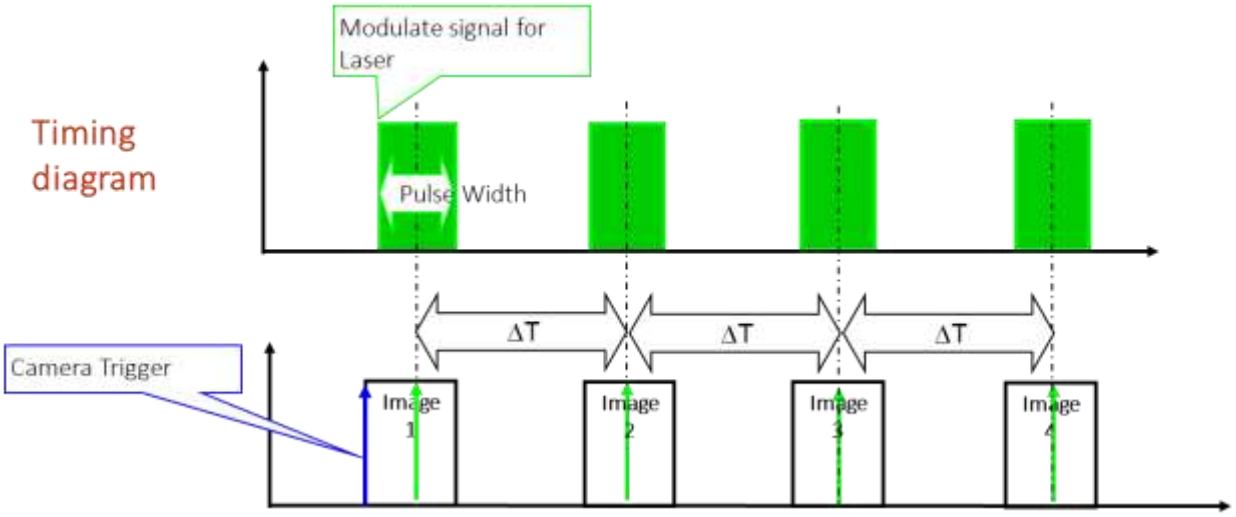


Figure 8.7 TR-PIV system PIV mode timing diagram

The camera captures the images at a time interval (**Δt)** equal to the difference between the frame based on the camera recording speed. For example, if the camera is recording at 1,000 fps, the Δt is 1/1000 equal to 1 ms. If the camera is recording at 20,000 fps the interval (Δt) between the recorded frames is 1/20000 = 50 µs.

In the Advanced dialog box, we need to select "Lock Laser 2 to channel 7" as shown in Figure 8.8. This way, the trigger signals from the Channel 2 signal are coupled to Channel 7. T7 output of the MicroPulse synchronizer, which now uses a two-way channel output, is used to control and modulate the DPSS laser.

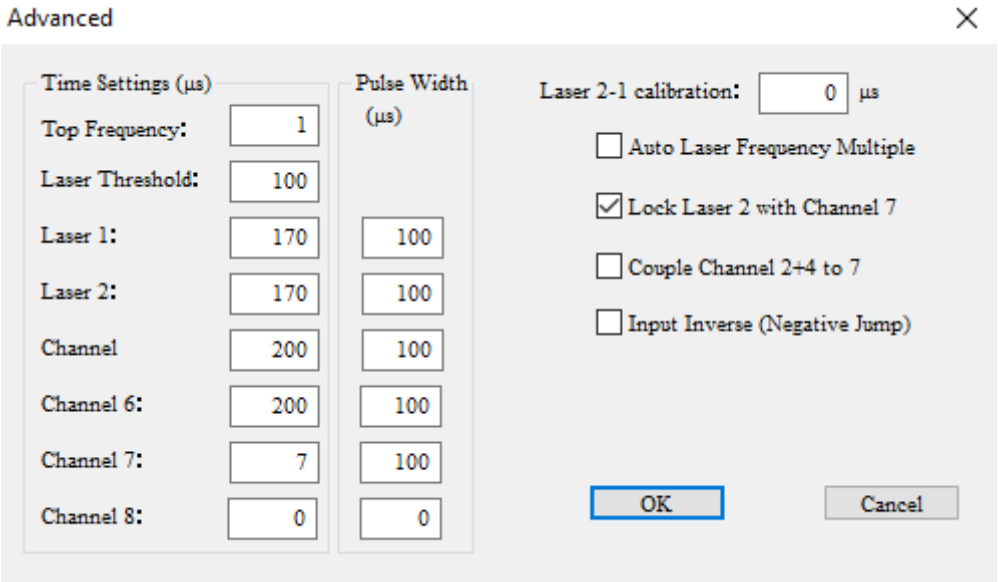


Figure 8.8 TR PIV System Advance Settings

When the pulse width of channel 7 is less than or equal to the cross-frame time, we recommend making it lower than 2000 microseconds, in order to avoid damage to the camera.

8.2 External Synchronization

8.2.1 External Mode

On many occasions, a laser in a PIV system needs to be provided with trigger signals that are synchronized to other devices, e.g. an external trigger from the experiment outside the synchronous operation mode. See the settings, wiring diagram and the timing diagram for Microvec PIV system to be used in external mode in Figures 8.9, 8.10 and 8.11 below:

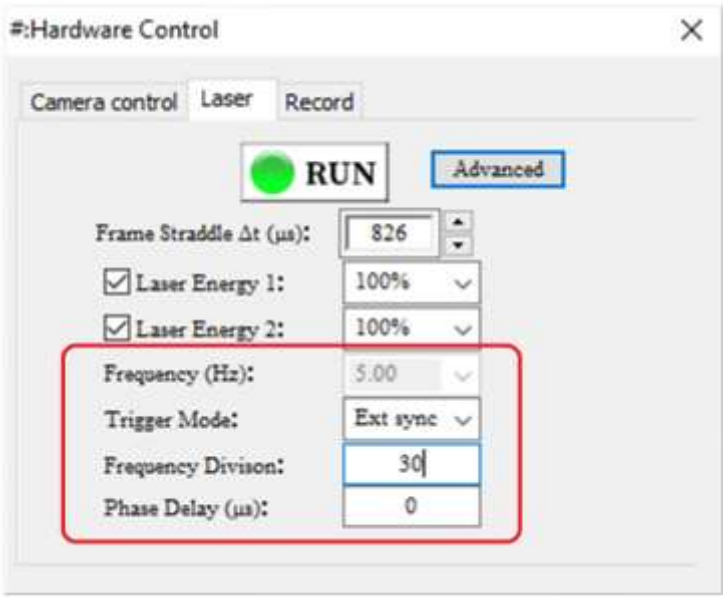


Figure 8.9 Setting the system to external synchronization mode

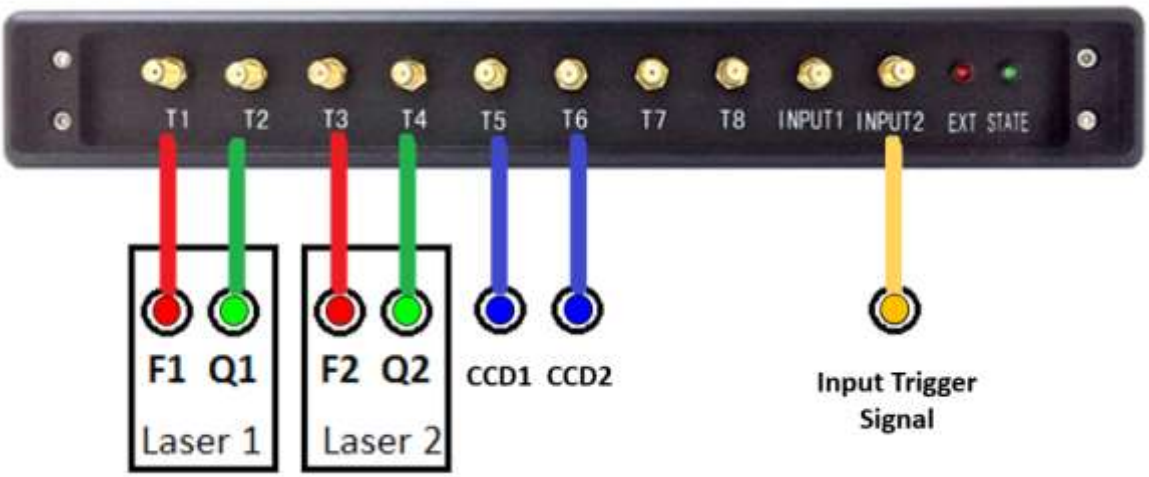


Figure 8.10 Synchronizer wiring diagram for external synchronization mode

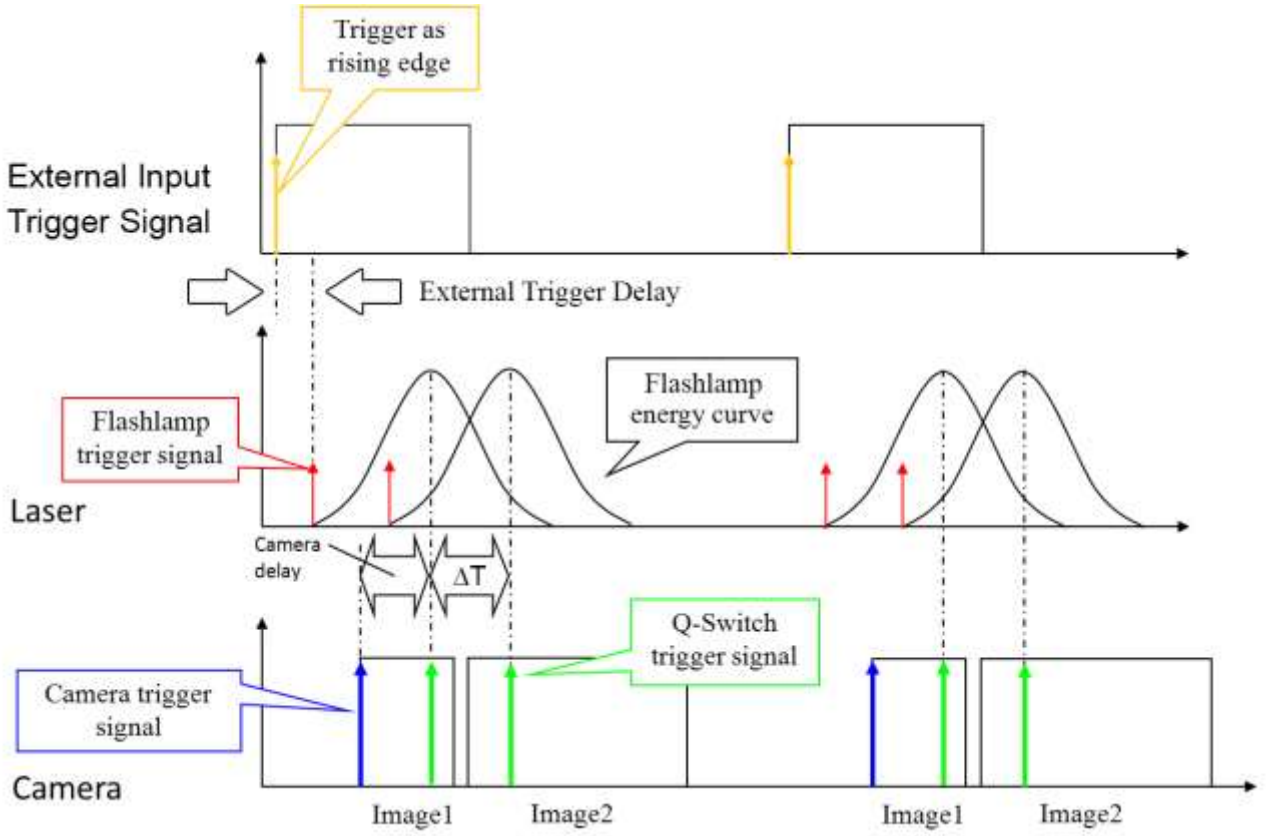


Figure 8.11 Timing diagram for external synchronization mode

When the MicroPulse synchronizer receives an external TTL trigger signal (0 V -> 5 V) please note that there is a response delay of about 200 µs. This external trigger timing between channels is set in advance and compensated by Microvec software. The PIV system operating frequency will be determined by the external signal frequency as long as it does not exceed the maximum frequency of the PIV system, usually limited by the laser frequency (e.g 15 Hz).

The following is an example of a phase-locked measurement for three propeller blades.

The propeller with its three blades moves at a speed of 50 revolutions per second (rps). An encoder disc or induction sensor is installed on the blade shaft to generate trigger signals and, as a result, 3 trigger signals are generated per rotation. The total number of these trigger pulses in this experimental setup is 150 per second.

As shown in Figure 8.10, the T1 and T3 outputs of the synchronizer correspond to the trigger signals of the flashlamp of the laser, T2 and T4 outputs correspond to the timing of the Q-Switch delays. T5 output is sending the trigger signal to the camera.

In the Advanced dialog box, the synchronization of the PIV system is set to the external mode, as shown in Figure 8.9. With 150 external pulses per second coming in, but the laser operating at the maximum of 15 Hz, we need to adjust the numbers to make sure that we can set the PIV system within its performance limits. We can do this by using the Frequency Division function and setting it to 30 (Figure 8.9), which means that the external trigger signal coming to the MicroPulse synchronizer will only generate one output trigger pulse for every 30 external input pulses. This also means that with the 3 pulses per rotation from the 3 propellers, the output trigger from the MicroPulse

synchronizer will generate only one trigger signal to the laser and camera, every 10 rotations of the turbine.

All the values for the 5 output channels, starting with the Laser 1 value for Q-Switch delays are set according to the to the values recommended by the laser manufacturer. The only additional variable in external mode is the External Trigger Delay (see Figure 8.11). It may be necessary to increase or decrease this time by setting the appropriate value in the Phase delay box. This way, the image pairs are captured at the exact moment, when the rotating turbine blades are passing the camera as shown in Figure 8.12 below:

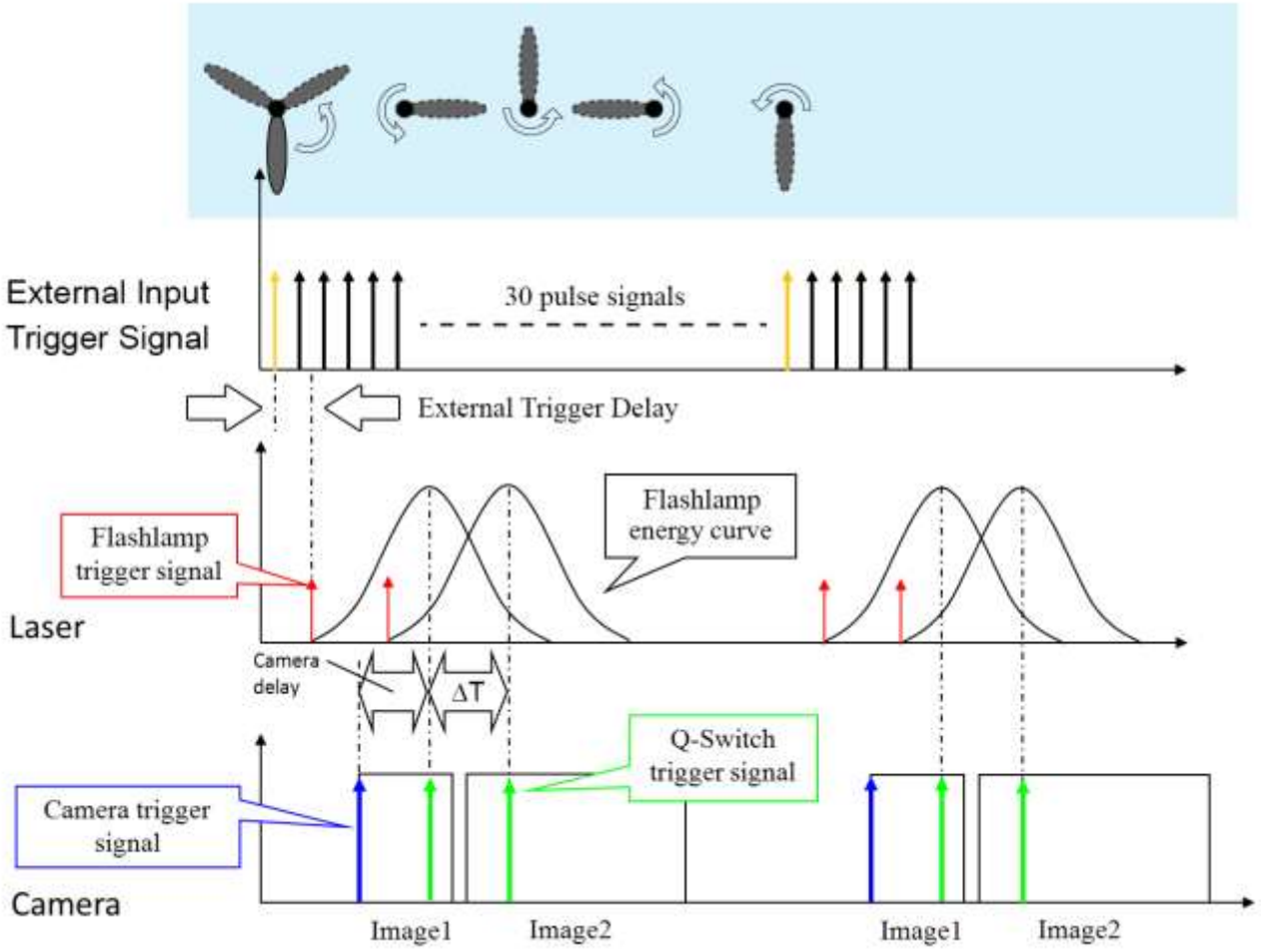


Figure 8.12 Timing diagram for phase locked external synchronization mode

8.2.2 External Gated Mode

Another external way to synchronize the Microvec PIV system is by using External Gated Mode. input trigger signal marks the opening and closing of the gate. The system only works during the entire gate period.

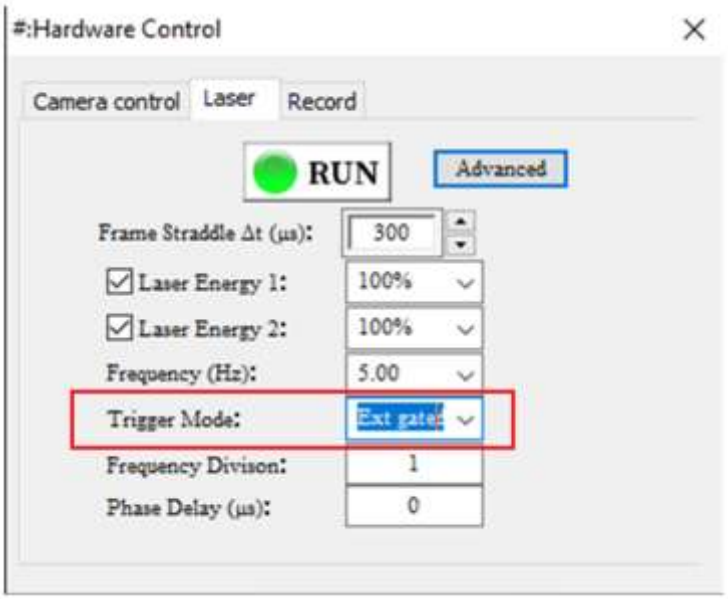


Figure 8.13 Setting the system to external gated mode

The timing diagram is as follows (using the PIV camera mode):

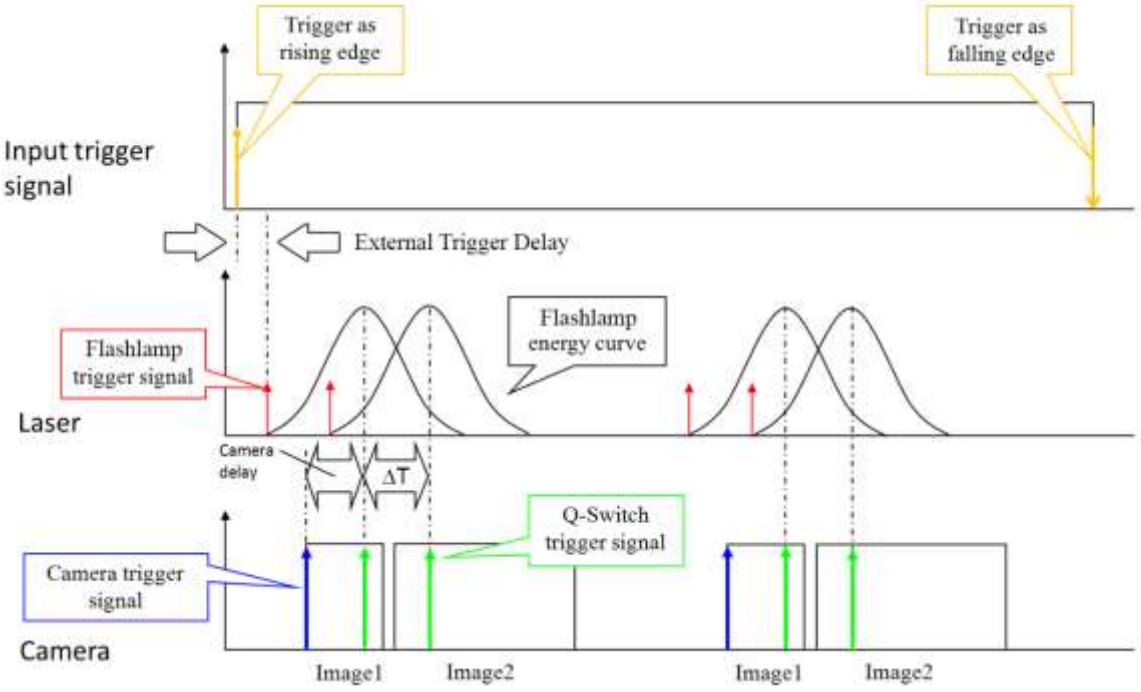


Figure 8.12 Timing diagram for external gated mode

When the MicroPulse synchronizer receives an external TTL trigger signal (rising edge from 0V -> 5V), it sends respective trigger signals to the laser and camera. The PIV system will start the acquisition of image pairs continuously until it gets another trigger signal (falling edge from 0V -> 5V). The operating frequency is determined by values set in the software. In the External Mode, It may be necessary to increase or decrease the external trigger delay time by setting the appropriate value in the Phase Delay box.

8.3 Photoelectric switch

All CCD cameras offered by Microvec in the PIV systems have double exposure mode (PIV mode). As already explained, the exposure time of the second frame in an image pair is much longer than the first one and can take from milliseconds to hundreds of milliseconds. Because of this phenomenon, the second frame of the image pair has often a severe background noise. In order to avoid it, PIV experiments can be conducted in the darkness or the band pass filter used can have a narrower wavelength band to limit the amount of incoming light.

In PIV applications involving flames, the above methods are not very helpful because the amount of light coming from the flame is so high that the second frame image background in an image paid becomes overexposed and this image overexposure can prevent obtaining good PIV results. In order to go around thus problem, Microvec PIV system offers a solution. We add a photoelectric switch (Figure 8.13) in front of the camera. The second laser pulse happens during the second frame and the photoelectric switch immediately begins working. It shuts down and stops the second frame exposure from getting any more incoming light. This action reduces the excessive amount of flame light and makes the second frame useful for PIV analysis.

Figure 8.13 Photoelectric switch

Increase the photoelectric switch and the PIV system timing diagram is as follows:

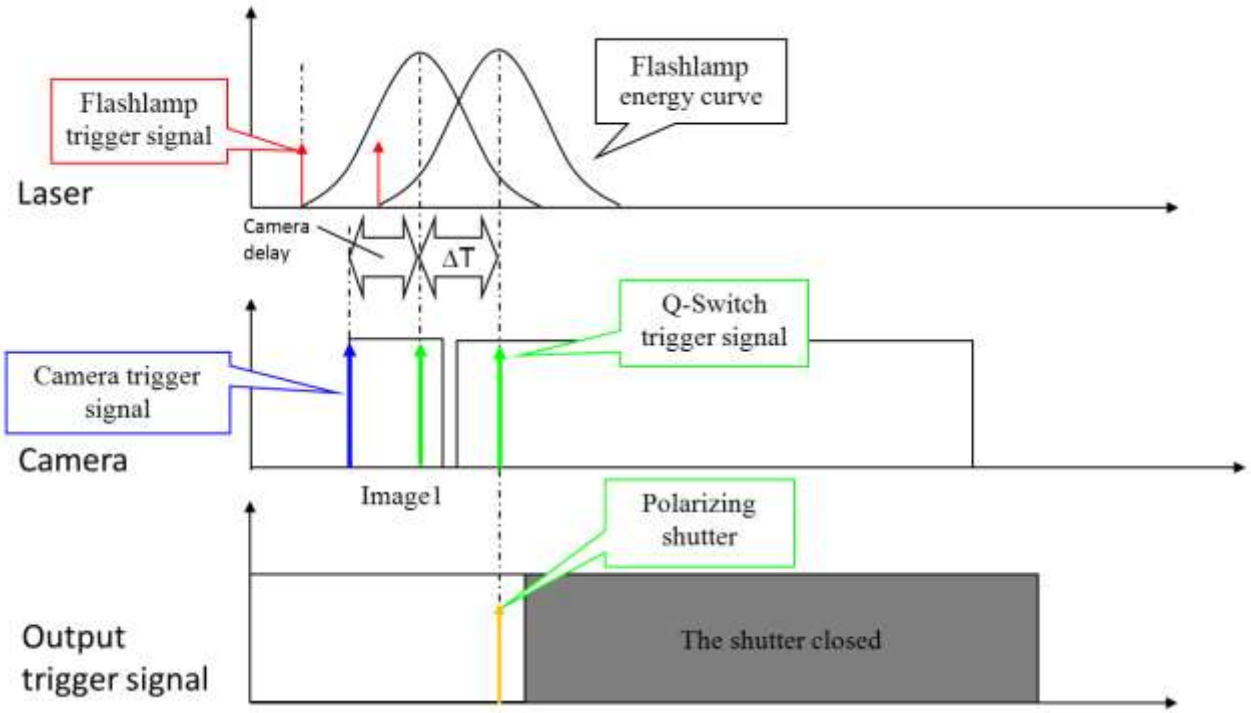


Figure 8.14 increase photoelectric switch PIV System Timing Diagram

Microvec software settings are as follows:

a. Q-Switch laser trigger signal and optoelectronic switch trigger signal is set to 0 (Figure 8.16);

b. Synchronous Channel 7 delay parameter is set to 0, and then the "Intra-frame" time (Δt) is set to 0. Click the "Run" button to save parameters (Figure 8.15);

c. Lock laser 2 with synchronizer 7 Channel: Select the "Lock Laser 2 with Channel 7 Sync" button function (Figure 8.15);

d. Depending on the conditions, set straddle time (Δt) and then run the experiment.

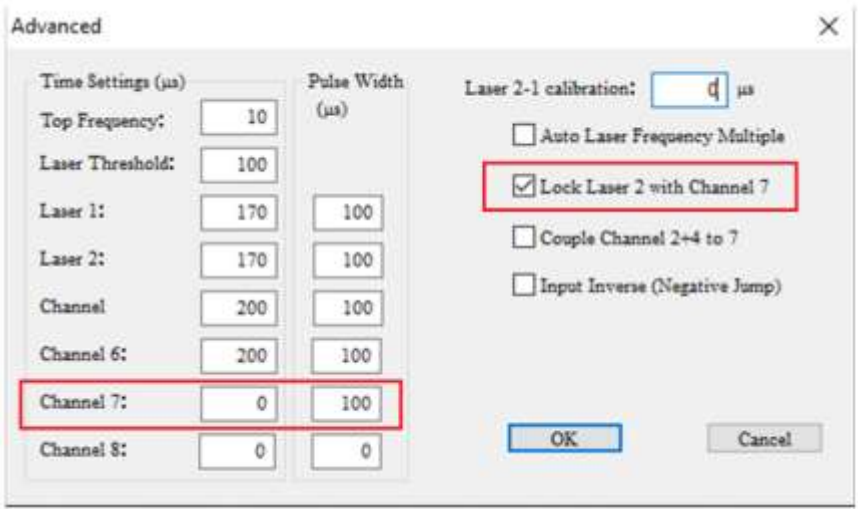


Figure 8.15 Advanced settings with photoelectric switch

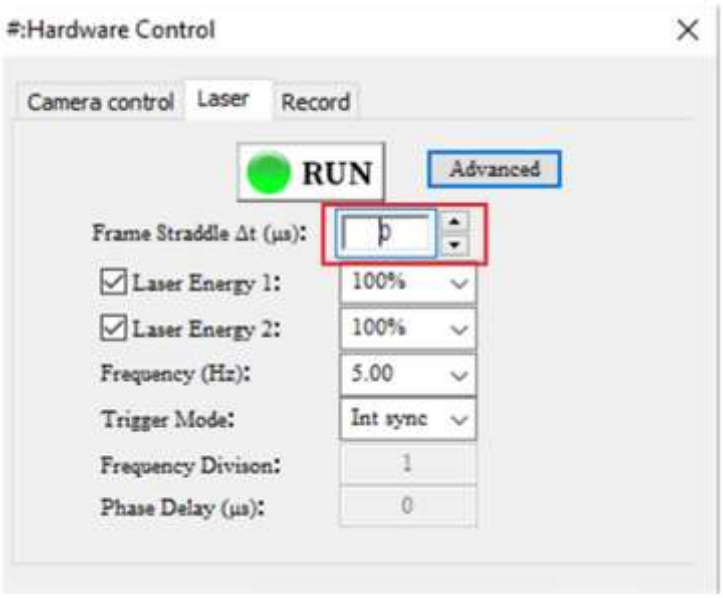


Figure 8.16 Settings the system with photoelectric switch

Figures 8.17 and 8.18 show a comparison of images of particles on flame without and with and using the photoelectric switch.

Figure 8.17 Flame image without the photoelectric switch

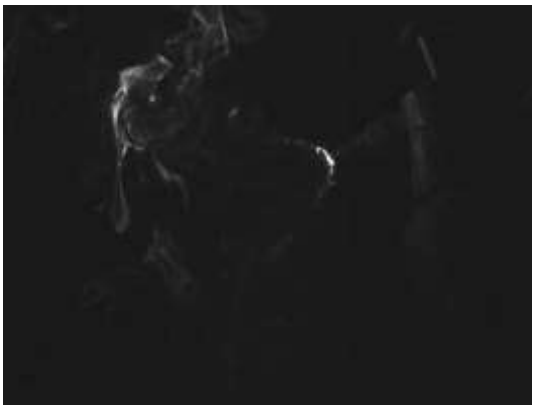


Figure 8.18 Flame image with the photoelectric switch

8.4 Advanced Settings

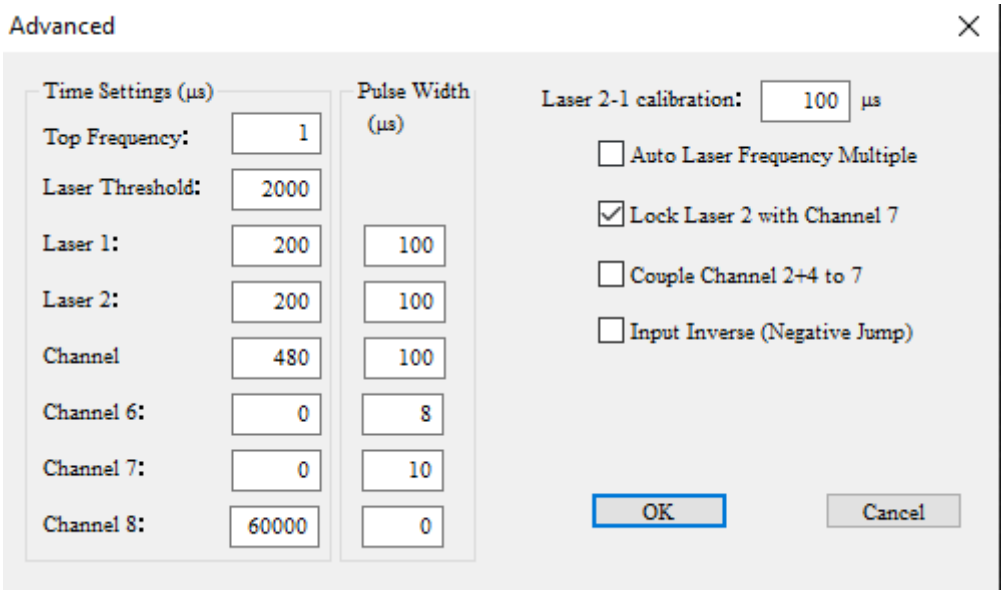


Figure 8.19 Advanced Time Settings dialog box

The parameters have the following meaning:

Top Frequency	Limits the operating frequency of the laser, which is determined by the synchronizer. If the operating frequency is set outside the range of the actual laser frequency, the software will display a warning.
Laser threshold	Sets the internal laser adjustment parameter, which means that the Q-switched laser is higher than this value after at least being open to the laser. This parameter is only valid for the software to adjust the laser output energy work and does not affect other functions.
Laser 1 and 2	Sets the internal adjustment parameters for the flashlamp discharge and Q-Switch delay from the trigger signal. The first value is Q-Switch delay time after the trigger and the start of the flashlamp. Normally the laser manual has detailed information about the optimum time for the flashlamp to reach the maximum energy, where we recommend for the Q-Switch to be set. The second input is for the second value if the trigger pulse width.
Channel 5, 6, 7, 8	Each of them sets the timing for the respective camera trigger to start capturing frames. It is relative to Q-Switch 1 delay time, meaning that 200 us will start the camera trigger 200 us before the Q-Switch 1 delay time and the first pulse of the laser. The second input is for the second value of the trigger pulse width.
Lasers 2-1 Calibration	Sets a time offset between the Q-Switch delay 2 and Q-Switch delay 1. This value can be used for calibration or fine-tuning of the synchronization of a PIV laser. Typically, the intrinsic delays of

	the laser systems are constant, but differ from one model to another. This value can be negative if we want the Q-Switch 2 delay to move toward Q-Switch delay 1.
Auto Laser Frequency Multiple	When using this mode, the laser discharge flashlamp will automatically multiply to integer multiples of the operating frequency, then it is less than equal to the Advanced Settings inside the maximum operating frequency.
Lock Laser2 with Channel 7	Channel 2 is redirected and locked with channel 7 to operate and output a trigger signal at the same frequency and phase (mainly used in TR-PIV).
Couple channel 2+4 to channel 7	The output signals from channel 2 and channel 4 are combined and redirected to channel 7. In this way, the combined signal contains two trigger signals and can be used to modulate a continuous laser pulse to generate double pulse signals, acting like a double pulse PIV laser.
Input Inverse (Negative Jump)	Sets the external trigger to reverse, if the laser flashlamp requires a negative falling edge TTL trigger (5 V -> 0 V).
Pulse width	The trigger signal pulse duration, which sets the duration of each trigger signal.

Chapter IX maintenance record sheet

No.	Processing phenomena	Processing results	Date of service	Maintenance personnel (Signature)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Particle Image Velocimetry (PIV) operating procedures

1. **Particle Image Velocimetry (PIV) operators are required to pass the training of Microvec, Ltd. and are familiar with the relevant provisions of the Particle Image Velocimetry (PIV) Operation Manual.**
2. **The particle image velocimetry system (PIV) uses power requirements: 220V 18A (including laser and image acquisition system), and has a reliable and complete ground wire. The laser system and image acquisition system should use separate power sources. If you use the system equipped with double-pulse lasers, the lasers require strict accordance with the user manual to provide power and to operate the experiment. Then turn off the laser light control switch in the back to avoid particle image velocimetry (PIV) software to adjust the laser process error.**
3. **Before all the hardware is powered on, it is necessary to ensure that the power signal is reliably grounded, the camera lens cover is closed, the laser source light exit hole is closed, the laser light guide arm is reliably fixed, and the input and output signal lines are connected correctly. The output port is connected to any high voltage power supply or shorts the output port.**
4. **If you use a double-pulse laser equipped with the system, you need to follow the laser manual to turn on the power and prepare for the experiment. Then turn off the laser light control switch to avoid accidental laser power outage during the subsequent particle image velocimetry (PIV) software adjustment process.**
5. **Connect the relevant hardware of the image system according to the particle image velocimetry system (PIV) manual.**
6. **Start Microvec image acquisition control software. First, adjust the camera aperture to the maximum, detect the camera working state through the software camera control module; set the Microvec software in real-time image display state, open the camera lens cover and watch the camera to capture the image. According to the lighting conditions of the shooting area, further adjust the camera software to control the exposure time to capture the image with the camera aperture (if the image brightness is not enough, you can further increase the software to control the camera gain multiplier).**
7. **According to different experimental requirements, refer to the particle image velocimetry system (PIV) operation manual to further set the software camera control mode, adjust the camera to work in the corresponding state, and capture and save the experimental flow field image.**
8. **After the experiment is completed, first close the camera lens cover and turn off the laser light source exit. Turn off the image acquisition system power, the laser, Q switch and the laser power after stable cooling.**

9. **During the entire experimental operation, if an unidentified fault is found, it must be handled in strict accordance with the particle image velocimetry system (PIV) operation manual. In an emergency, you need to close the camera lens cover, turn off the laser light source exit, turn off the laser light, and turn off the Q switch. For other unclear matters, please contact Microvec, Ltd. in time to provide detailed fault phenomena for elimination.**

10. **Maintenance: The entire PIV system needs to be dust-proof, moisture-proof, and in a 15-25 ˚C environment. It is necessary to prevent vibration from damage to the optical instrument during the moving process; the laser needs to be replaced every 3-6 months (6-8 liters deionized water).**