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TEMA DIC User's Guide

Introduction

The purpose of this document is to describe how to get started with DIC evaluation in TEMA.

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System Requirements

Computer Requirements

Please refer to the table below:

System requirements for TEMA DIC 4.0	
Operating System	<ul style="list-style-type: none"> • 64-bit Microsoft® Windows® 8/8.1 • 64-bit Microsoft® Windows® 8/8.1 Pro • 64-bit Microsoft® Windows® 8/8.1 Enterprise • 64-bit Microsoft® Windows® 7 Enterprise • 64-bit Microsoft® Windows® 7 Ultimate • 64-bit Microsoft® Windows® 7 Professional • 64-bit Microsoft® Windows® 7 Home Premium
CPU Type	<ul style="list-style-type: none"> • x64/x86-64/AMD64 CPU • Support for SSE4 is recommended but not required • 4 cores or more recommended • 3GHz or more recommended
Network Interface	<ul style="list-style-type: none"> • Supports 1 GigE • Support for Jumbo-frames.
Memory	4 GB (8 GB or more recommended)
Display Resolution	1024x768 (1600x1050 or higher recommended) with True Colour
Display Card	Windows display adapter capable of 1024x768 with True Colour capabilities. DirectX® 9 or DirectX 11 compliant card recommended but not required.
Disk Space	Installation 0.5 GB, Storage 100GB (500GB or more recommended)
Input Devices	MS-Mouse compliant pointing device and keyboard
Install Media	DVD Drive or Internet Connection

Camera & Optics General Requirements

The camera(s) that are to be used in a DIC test must have the following characteristics:

- Monochrome sensor.
- Low noise.
- High sensitivity.
- Analogue gain setting.
- All image processing/enhancement features must be turned off.
- Low distortion.

We recommend using cameras supplied and tested by Image Systems Nordic AB.

Lighting Requirements

The light source used for DIC tests should be carefully selected in order not to cause any flickering. We recommend using a LED light source designed for the film industry. In general such light sources will not flicker as long as they are not dimmed. This has to be verified either with the light source manufacturer or tested manually.

If using Halogen lights, make sure to select a DC powered light source. If using AC powered halogen lights, the amount of flicker is related to the type of bulb, wattage and physical size of the filament. In general, lamps of 5000W or larger that use tungsten filaments are so large that they do not have time to cool and dim before the power cycles back-up. Therefore, it is recommended to use 2000W or greater tungsten light bulbs when shooting above 120fps in 60Hz countries and 5000W or greater when shooting above 100fps in 50Hz countries.

We recommend using light sources supplied and tested by Image Systems Nordic AB.



Figure 1: Tripod Case

DIC System Contents

The DIC System is delivered with a tripod case containing the rig and a Pelican™ case containing camera(s), lighting, laptop computer and other components.

Tripod Case Contents

The contents of the tripod case are shown in Figure 1 and listed below:

1. Tripod.
2. Horizontal Rail.
3. LED Mount.
4. Camera Mount.
5. Quick Lock.

In the case of a TEMA DIC STEREO system, two camera mounts is provided.

Pelican™ Case Contents

The contents of the Pelican™ case are shown in Figure 2. The numbers indicate:

1. Laptop
2. Cables
3. Manual
4. Speckle Spray
5. LED Lights
6. Batteries
7. Diffusors
8. Calibration Board
9. Battery Chargers
10. Camera(s)
11. Optics
12. PoE Injector
13. Software Dongle



Figure 2: Pelican™ Case



Figure 3: The assembled DIC 2D System

Work Flow

A brief overview of the TEMA DIC work flow, from setting up the test to exporting the results.



Figure 4: TEMA DIC 2D Work Flow

TEMA DIC Stereo work flow, differs only in the case that Camera Orientation (yellow) is required.

Divided up into Preparation (blue), Post-processing (red).

For a 2D test, the Camera Orientation may be skipped.

Camera and Lighting Setup

Begin by preparing the testing machine and its environment. Remove possible sources of flicker that may influence the test images (for example fluorescent lights). Then assemble the DIC hardware as per section Hardware Setup on page 9. Align the camera so that the image plane is parallel with the specimen surface. The LED-lights are set to full intensity and aimed so that no glare is visible in the camera live image. Turn off the LEDs until you're ready to begin the test.

For a DIC Stereo test, try setting up the cameras so that both cameras have as much of a perpendicular view as possible, while keeping approximately a 20° angle between the cameras from the object. Having an angle lower than 15° or larger than 25° is NOT recommended and may compromise the accuracy of the results.

A faulty Camera orientation will have its largest impact on the depth-data. A way to quantify this is to film a sequence of a rigid object moved a set distance, and measuring both the overall displacement, as well as the smoothness of the surface.

As a rule of thumb, if the cameras are at a distance D from the target object, the distance between the cameras L should be approximately:

$$L = 2 * \tan(10) * D \rightarrow L \approx \frac{1}{3}D$$

Prepare the Test Specimen

The test specimen is then prepared with a high contrast speckle pattern. The speckle size and density should be carefully chosen to match the requirements of what is going to be analysed (see section Specimen Preparation on page 16).

Record Images

When the test is ready to be performed, the cameras are configured with an appropriate exposure time and frame rate. The recording is started before the test object deformation process in order to obtain at least two static images in the sequence which will be used to estimate the tracking quality, and for the Stereo case, Camera Orientation.

For a Stereo DIC setup, using the same frame rate is required. While using the same camera type and lens type is HIGHLY recommended, it is not a strict requirement technically. However practically, if the difference between the output images of the cameras is significant, it might affect the accuracy severely.

See section Camera Setup on page 18.

Camera Orientation

For a Stereo DIC analysis, a Camera Orientation has to be performed. The Camera Orientation has a large impact on TEMA DIC's ability to automatically match the subsets in the two different views, and is a crucial factor for the accuracy of the 3D-results.

The easiest way to do a Camera Orientation in TEMA is to find 7 points that are easily defined in both camera views, and perform a Relative Camera Orientation. This requires one distance among the points, as well as the camera & lens properties, such as focal length and pixel size, to be defined.

To setup the Relative Camera Orientation, please see the TEMA help section on "Relative Camera Orientation".

Tracking

After recording the images, optionally one may configure Motion Planes to correct for camera attitude errors (section Correcting for camera attitude errors on page 22); or just proceed with adding a DIC tracker to the test and setup according sections Correcting for camera attitude errors

2D DIC measurements are sensitive to errors in the camera attitude. Specifically if the camera's optical axis is not perpendicular to the test specimen's plane of motion then systematic errors will appear in the calculated strain.

TEMA DIC has a feature called Motion Planes which allows to compensate for and remove this erroneous strain. To use motion planes the test specimen must have been prepared with 4 identifiable features with 6 known distances between them (all edges and opposite corners).


To setup for Motion Planes, please see the TEMA help and manual. Once setup, the motion plane is automatically used to correct the analysis. This may be done before or after the tracking but we recommend doing it before.

Tracker Setup and Tracking on pages 22 and 26 respectively. The tracking process is started and TEMA will automatically track the image sequence.

Analysis

Carry out the required analysis steps such as adding inspection lines, extensometers or POI's (Points of Interest) to the test. More information in section Analysis on page 28.

Presentation and Data Export

Add diagrams to present the required data for the current test (see section An "Inspection Line" can be placed anywhere in the tracking view. To add an Inspection Line, use the tool button  or the menu entry Camera/Add Inspection Line.

When an Inspection Line is selected in the Test Contents, it is possible to move the endpoints of current line by click-and-drag in the image. If the cursor does not hit an existing endpoint, click-and-drag will add a new Inspection Line.

A right click on the Inspection Line in the Test Contents will open a dialog (Figure 34) where the start and end points can be modified. If the test is scaled (e.g. by using Motion Planes) the unit is meters and the positions are in the coordinate system defined by the Motion Plane. If no scale is used the unit is pixels.

This line will appear as a sequence in the Advanced Diagram which can be plotted, and can also be exported from the "Export DIC Data" function. This allows inspection of strain values along any line to get a cross-section of sorts. Inspection lines work by simply picking samples from the (previously calculated) continuous strain field along the line definition. This guarantees that the results shown in the inspection line will always agree with other results in TEMA DIC.

Presentation on page 30. Export individual diagrams/tables, export combined image sequences containing both images and diagrams or chose to export the complete results to a TEMA Viewer CD (optional).

Hardware Setup

The intent of this section is to familiarize you with how to assemble and connect the hardware included with the DIC system and to provide some important information that you should know before using the system.

Precautions

Notice

Avoid dust on the camera sensor.

The ISAB B-AC series cameras are shipped with a protective plastic seal on the lens mount. To avoid collecting dust on the camera's sensor, make sure that you always put the protective seal in place immediately when there is no lens mounted on the camera.

Notice

Lens thread length is limited.

The ISAB B-AC series cameras are equipped with a plastic filter holder located in the lens mount. The location of this filter holder limits the length of the threads on any lens you use with these cameras. If a lens with a very long thread length is used, the filter holder will be damaged or destroyed and the camera will no longer operate. We recommend using lenses supplied by Image Systems Nordic AB.



Figure 5: Charging the batteries for the LED lights.



Figure 6: Case with tripod and mount bar.

Charge the batteries for the LED-lights

Insert the batteries in their respective charger as shown in Figure 5. The LED-light on the charger turns green when the charging process is completed.

Assemble Tripod

The tripod and the aluminium bar for mounting the lights and the camera are stored in a case for protection and ease of travel. See Figure 6.

Take the tripod out of the case and fold out the legs. Place it on a stable surface like in Figure 7.

Distribute the mounts evenly on the mount bar to make it balanced, like in Figure 8. To release the stainless steel adapters, turn them counter-clockwise.



Figure 7: Unfolded tripod.

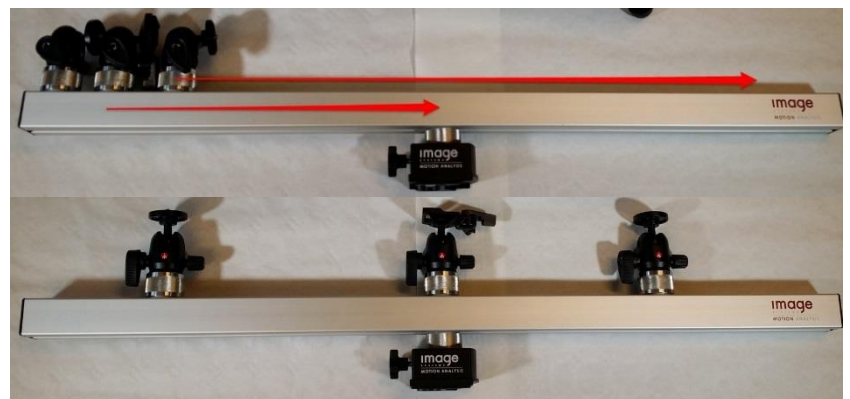


Figure 8: Balanced mount bar.

Snap the mount bar into position on the tripod (Figure 9).

Tighten the black fastening lever firmly by pulling it all the way back as the arrow in Figure 10 (right). To release the mount bar from the tripod, pull the fastening lever towards your (opposite direction of arrow in Figure 10, right), then push the metallic safe release lock down and pull the black lever all the way towards you. Then simply lift *the mount bar off*.

Please note that the mount bar will not separate from the tripod until the safe release lock has been pushed and the black lever released all the way. CAUTION do not attempt to remove the mount bar by force.

Make sure that the assembly is well balanced and that there is no risk that the tripod will fall over. Then tighten the lock screw on the adapter block and tripod as in Figure 11.



Figure 9: Snap the mount bar onto the tripod.

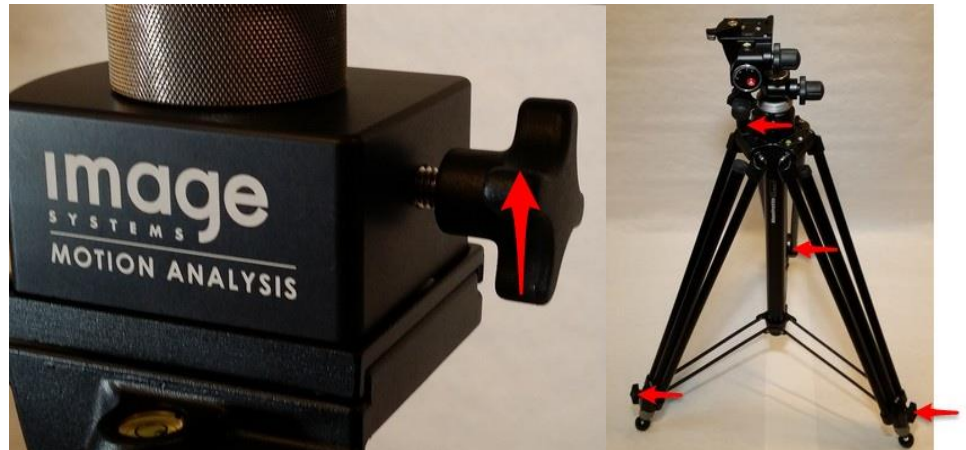


Figure 11: Tighten the lock screws on the adapter block and tripod.



Figure 10: Tighten the lever holding the mount bar in place (left). The fastening and safe release lock on the lever (right).



Figure 12: Camera and lens covers.

Camera Mounting

CAUTION: At all times, avoid getting dust or dirt on the camera sensors. Always attach the dust and lens covers to the cameras and lenses when the cameras are not being used. Cameras should always be assembled in a dust-free environment.

CAUTION: When screwing the optic make sure you always grip on the inner metallic ring, otherwise you may damage the focus and aperture settings.

Begin by removing the dust cover from the lens (keep the lens cover on, see Figure 12) and place it standing on a clean surface with the thread down, so that no dust will collect on the inside. Then hold the camera with the dust cover pointing down, remove the dust cover and grip the optic on the metallic ring and carefully screw it onto the camera's mount while holding the camera with the sensor pointing down.

To disassemble a camera, simply follow the above procedure in reverse. Always attach the dust and lens covers when disassembling a camera.

With the lens cover still attached place the camera on the camera mount, make sure the camera sits flush on the mount and then tighten the lever to lock the camera in place as in Figure 13.



Figure 13: Mount the camera on the camera mount.



Figure 14: Mounting the LED lights.

Mounting the Lights

Release the lock- and friction knobs on the ball-joint light mounts in order to be able to rotate the mounting plate. Fasten the LED-light on the mount, adjust the friction knob and then tighten the lock lever. Snap the diffuser into place if needed. See Figure 14.

When the LED-lights are mounted on the mount bar, we can attach the batteries. Place the battery on mount on the back of the LED-light and slide it to the left as in Figure 15 until the lock lever snaps into position.

Turn the LED-light on and make sure that the dim-level is set to the highest position (numerical display on the back shows "30") in order to avoid any flickering.



Figure 15: Attaching the battery to the LED unit.



Figure 16: Camera Connectors.



Figure 18: PoE Injector Connectors

Connecting the Cables

CAUTION: Category 6 (Cat 6) Ethernet-cable is a cable standard with stringent specifications to guarantee gigabit data throughput. Using Category 5 or lower cables will result in loss of frame rate and possibly lost frames from the cameras. Always make sure to use the correct type of Ethernet-cable. The type of an Ethernet-cable can be distinguished by the markings along the cable which should clearly say "CAT.6" for Category 6 cables.

Connect a Category 6 Ethernet-cable between the camera (Figure 16) and the OUT (Power + Data) port on the PoE-Injector (Figure 18). Connect another Category 6 Ethernet-cable between the IN (Data) port on the PoE-Injector and the laptop (arrow 1 in Figure 17). Finally connect the power adapter to the laptop (arrow 2 in Figure 17).

For the Stereo case connect the cameras to a switch instead of the laptop, which is then connected to the laptop.



Figure 17: Laptop connectors. Ethernet connector (1) and power cord (2).

Test Preparation

Performing a DIC test requires some preparation of the test object/test specimen. This chapter is an attempt at helping the the user understand what it means to prepare an object, how it should be done and how to identify a well prepared test specimen.

Specimen Preparation

CAUTION: A poorly prepared specimen will reduce the accuracy of the strain analysis! Take time to carefully prepare the specimen and to verify that the thumb rules below are fulfilled before performing the test.

Speckle Pattern

The Area of Interest (AOI) on the test specimen to be analysed needs to be covered by a speckle pattern. The pattern can be either black on white or white on black. An example of a test specimen that has been prepared with a black on white speckle pattern is shown in Figure 19, this example has many speckles that are either too big or too small and is thus not a very good pattern.

A good speckle pattern must have the following properties:

- Non-periodic
- High Contrast
- Isotropic
- Correct speckle size for the camera FOV/resolution.
 - The smallest usable speckles should be at least 3-4 pixels in diameter.
 - There should be at least 3-4 speckles per subset.

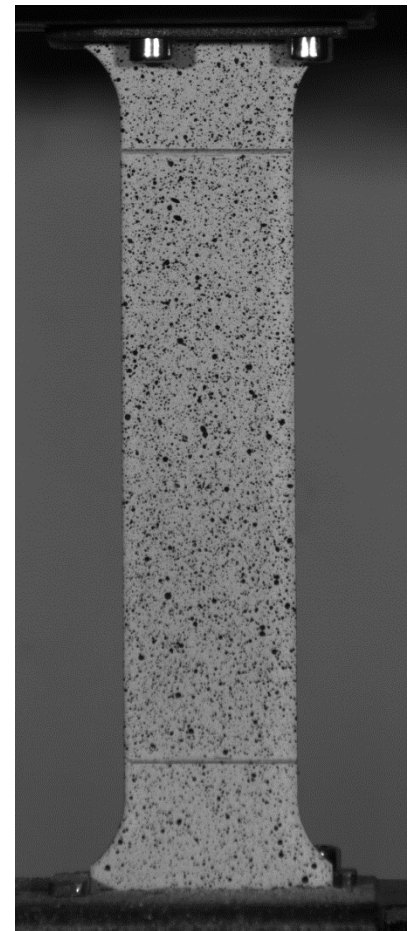


Figure 19: Example of a test specimen prepared with a speckle pattern.

Too large speckles, while usable, are not ideal. They will force the use of larger subsets to comply with the number of speckles per subset rule of thumb above. Large subsets will degrade the spatial resolution, i.e. the smallest local phenomena that can be measured.

Too small speckles will result in aliasing which will manifest itself as band- or moiré- like patterns of erroneous strain. See section Pit-falls on page 38 for more information.

Depending on how large the deformation will be, you might need a base coating and speckle paint with elastomeric properties to prevent the paint from falling off. If the base colour of the test specimen is white (or black) - a base coating is not needed to achieve good contrast against a black/white speckle pattern. There are several different methods to apply a good speckle pattern on the test specimen; either you could spray paint the specimen directly from a distance of approximately 60 cm, this will produce very small speckles, suitable for very small field of views (<25 cm²). Another way is to hold a spray can next to the object and try to "lob" paint while depressing the spray can trigger just slightly, this can work for slightly larger field of views. If this method does not work out for you, try using a toothbrush to "flick-on" paint on the specimen.

Another way is to use a stamp to stamp on a homogenic random dot pattern. These are easily reproducible and suitable if tests at the same distances and field of views are often performed.

For very large applications using a sponge or similar to dot on a black pattern over a white coating can be used.

Motion Planes Markers

If you wish to use Motion Planes to compensate for camera attitude errors (see section Correcting for camera attitude errors on page 22) which we recommend that you do; then the specimen needs to be prepared with 4 clearly and accurately identifiable markers with 6 known distances between them (all edges and the two distances between the opposite corners).

These distances and the 4 point positions in the images must be measured with high accuracy.

For a Stereo DIC, similar points can also be used to perform a Relative Camera Orientation with high accuracy.

Adjusting Camera and DIC Rig

This chapter contains tips for aligning cameras and setting up the test rig for test

TEMA DIC 2D

After the test specimen has been prepared and mounted, and there is no risk of damaging the camera or rig, move and adjust the rig so that the camera's optical axis is as close as possible to being perpendicular to the test specimen's surface. Try to place the camera so that as much as possible of the camera's field of view is covered by the test specimen. But make sure that any movement of the testing machine or other personnel will not damage the camera and that the interesting region of the test specimen will stay in the camera's field of view during the test.

Prefer to use the 25mm optic included, but if it is not safely possible to get close enough to the test specimen to get a good view with the camera, then try the 50mm optic.

Make sure that any cables running to the camera and rig are firmly fastened to the rig as to avoid vibrations in the camera housing.

In conventional DIC systems, any misalignment of the camera would cause the test specimen to ever so slightly move in or out of the camera's image plane during extension. This out of plane motion appears as an enlargement of the specimen in the camera view which will be seen as an erroneous strain. However TEMA 2D DIC offers a unique feature, called Motion Planes, where if there are four (4) identifiable points on the test specimen with known distances between them, small misalignments can be compensated for. It is still advised to try to align the camera as carefully as possible. See the section "Correcting for camera attitude errors" on page 22 for more details.

Turn on and adjust the lighting so that the specimen is evenly and brightly lit but free from any glare.

Open TEMA and add the camera to the test. Enable the live view and open a zoom window to look closely at the speckle pattern. Verify that the pattern fulfils the criteria on speckle size and density given in the Specimen Preparation section earlier. If the pattern is not acceptable, remove the test specimen and if possible try to amend the pattern or clean it off and try again. Take caution to not damage the DIC system while moving about.

TEMA DIC Stereo

Having the cameras perfectly perpendicular is not as important for the Stereo version of TEMA. However, with Stereo DIC one has to have Camera Orientation in mind. If the orientation is performed before the test sequence, the user has to be absolutely sure that the cameras have not moved since the orientation. Keep in mind that even non-visible movement can affect the accuracy of the 3D-analysis significantly.

Software Guide

This chapter deals with getting started with the TEMA software to do DIC analysis. For general TEMA topics, please refer to the TEMA Help Manual.

Camera Setup

Camera Finding in TEMA

The on-line help has a chapter called "Camera Control" where you can read more about how it works.

1. Start TEMA.
2. Add a camera view (the green 'Add Camera to test' icon), Figure 20.



Figure 20: Add Camera

3. The 'Add Camera Views' dialog will open. If this is the first time you add a camera, the Cameras list will be empty. Press the 'Scan' button at the bottom of the window. Scanning will take 10-20 seconds.
4. If the camera is connected a row with a green icon will show up. If several cameras are connected they should all show up separately in the list.
5. TEMA will remember previously used cameras so the next time you start TEMA and go into the Add Camera Views dialog, the cameras will already be there.

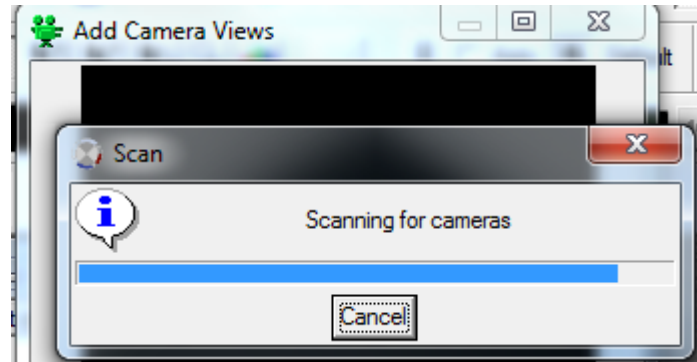


Figure 21: Add camera views dialog scanning for cameras.

6. A live image is shown in the pre-view pane. Click OK at the bottom of the dialog. The Test Contents will have a new entry for the camera. If several cameras are connected, repeat this action for both of the cameras, or select them both holding CTRL and click OK.

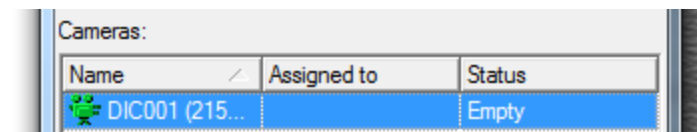


Figure 22: Found a camera.

7. The Image Window shows a live feed from the camera. The live updating can be turned on and off with the 'Enable Continuous Live Image' button in the 'Camera Control' tool bar marked with RED in Figure 24. In the case of two cameras, two live feeds will be available.

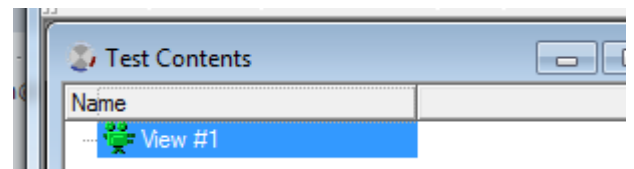


Figure 23: New camera added to test contents.



Figure 24: Enable live view (red) and open camera setup (blue).

Configuring the Camera

For the best possible accuracy, as much information as possible should be contained in the images. This means that the histogram over the gray values from the camera should ideally be wide and centered in the middle. No part of the histogram should clip on the edges of the spectrum, i.e. the image should not be over or underexposed (clipped or crushed).

1. Open the Camera Setup Window (button marked with BLUE in Figure 24) shown in Figure 25.
2. Enter wanted Image Size and Frame Frequency. If the values you need are not in the list, go to the Preference Archive (*Tools/Preferences/Camera Control*) and add the requested values to the lists.
3. Adjust the aperture and focus on the camera so that it's as open (image is bright) as possible while keeping the entire test specimen in focus.
4. Adjust Exposure to make the image be properly exposed, no part of the test specimen should be clipped or crushed. Aim to have the test specimen be a mid gray tone on average in the camera view. Exposure should be short enough to not cause motion blur during the test.
5. Repeat from step 3 until a good image that is in focus, evenly lit, not clipped or crushed and not motion blurred is obtained. In the case of several cameras, repeat for all connected cameras.

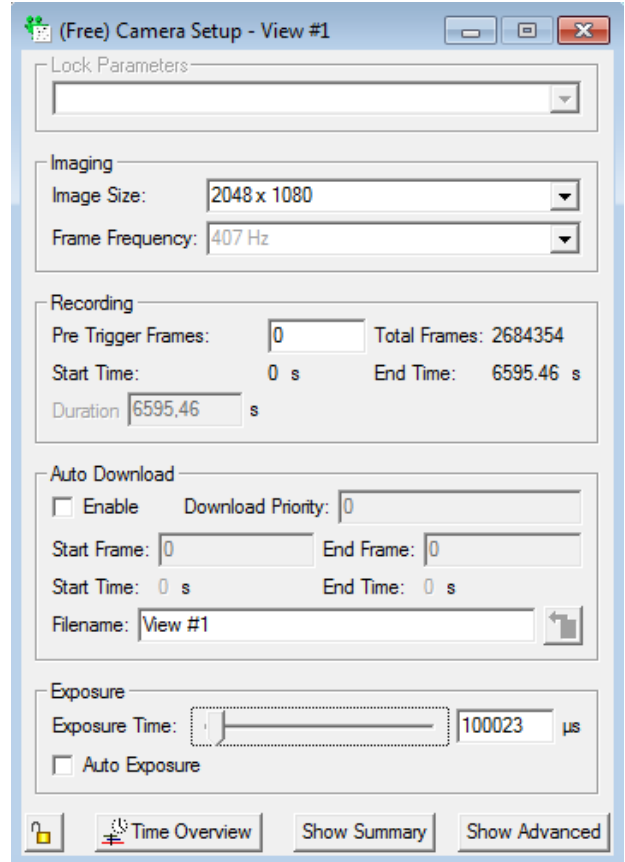


Figure 25: Camera setup window.

Remember:

1. Smaller aperture gives a larger depth of field but a darker image (higher number means smaller aperture, typically 11 or 12 is good). For a Stereo DIC application, more out-of-plane movement is usually expected, and a smaller aperture could be required. Make sure that the image is focused throughout the expected measurement volume.
2. Shorter exposure time gives less motion blur but a longer exposure time gives a brighter image with less noise.
3. A high exposure time will prevent high frame frequency.

Now you are ready to set up for the test.

Recording and Download

When you are satisfied with the camera settings it is time to perform the test and record images from the camera.

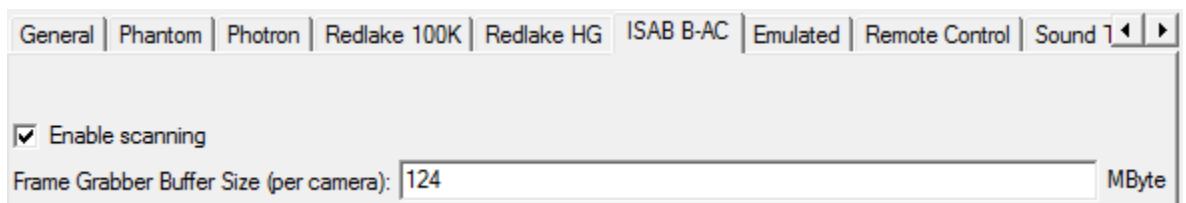


Figure 26: Adjusting frame grabber buffer size.

First check that the camera can record the number of images that you desire. The information is found in the Camera Setup, Recording (Figure 4).

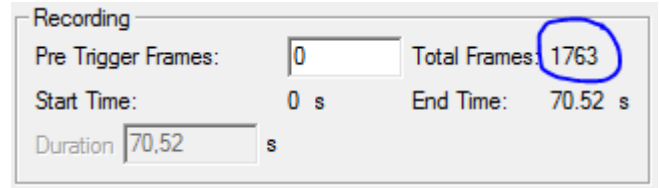


Figure 27: See how many frames the camera can record.

To change it, go to the Preference Archive (*Tools/Preferences/Camera Control*). At the bottom you find settings for different camera types. Choose the ISAB camera and change the Buffer Size (Figure 26) to see the resulting number of images in the Camera Setup Window.

1. To record images, you first ARM the connected cameras. This means that the cameras are actively grabbing images. Use the yellow button in the toolbar or Camera/Arm from the menu.



Figure 28: Arm the camera.

2. The Arm dialog is opened
3. Press the Arm button. The Trigger button will be active.
4. When you want to start recording, press the Trigger button and wait until the images are recorded. The Close button will be active. Press Close.
5. Use the Download button in the toolbar.

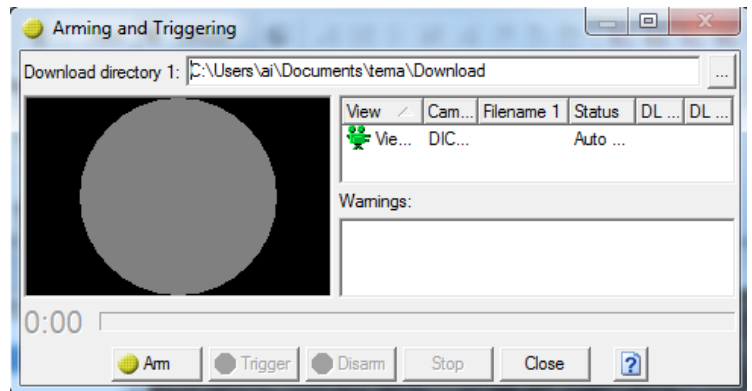


Figure 29: Camera arm dialog.

6. The Download dialog is opened
7. The default directory for download can be changed in the Preference Archive (*Tools/Preferences/Directories/Download*). In this dialog you can inspect the recorded images using the navigation buttons to the left. You can also change the range of the download (Start/End fields). When you are satisfied with the settings, press OK and the download will start.



Figure 30: Download button.

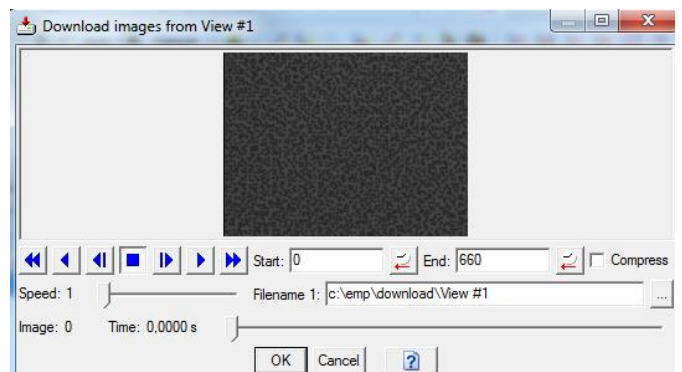


Figure 31: Download dialog.

Now the recorded images from the test are stored on your computer and it is time to do the tracking.

Correcting for camera attitude errors

2D DIC measurements are sensitive to errors in the camera attitude. Specifically if the camera's optical axis is not perpendicular to the test specimen's plane of motion then systematic errors will appear in the calculated strain.

TEMA DIC has a feature called Motion Planes which allows to compensate for and remove this erroneous strain. To use motion planes the test specimen must have been prepared with 4 identifiable features with 6 known distances between them (all edges and opposite corners).

To setup for Motion Planes, please see the TEMA help and manual. Once setup, the motion plane is automatically used to correct the analysis. This may be done before or after the tracking but we recommend doing it before.

Tracker Setup

In this chapter we will learn what the different parameters of the DIC tracker are and how they are used.

Search Area

The search area is specified in pixels and dictates how large an area should be searched for the initial guess of the frame by frame deformation. A large search area guarantees that even large frame to frame deformations can be found, but increases computational time. On the other hand a small search area means a faster computation but if the frame to frame motion exceeds the search area, then subsets may be lost. Apart from the very binary lost/not lost result, the search area does not affect the tracking quality. For tests with small deformation per frame, 3-4 pixels in the load axis, and 2 pixels in the secondary axis is recommended (slightly more if a large deformation perpendicular to the load axis is expected). Do not set this parameter below 2 in either direction.

Subset/Template setup

What is typically called a template in TEMA's vocabulary is known as a "subset" in DIC literature. We will use the terms interchangeably.

In order to be able to track the displacement field (and determine the strain) for the test specimen we need to define a grid of points that will approximate the displacement field. To be able to track each of the points, we need an area of neighbouring pixels with sufficient information content (speckle pattern). The point and the surrounding area defined by size parameters constitute the subset.

Steps

The steps parameter is the distance between points in the grid approximating the displacement field. If the step between points is too large, strain concentrations with small spatial extension may be missed completely and sharp peaks of high strain may be lower than the true value. See Figure 32 for two illustrative examples.

On the other hand, if the step size is too small the computation time will increase rapidly as:

$$O\left(\frac{1}{steps\ x * steps\ y}\right).$$

For draft/test tracking, we recommend values of around 20 for largely homogeneous strain and 10 for smaller strains that have very local behaviours. For an actual analysis we recommend steps of 5-10 pixels, again depending on the expected strain behaviour and size of the area of interested. Values below 7 may take significant time to track.

Size

The size of the subset must always be odd as it has to be symmetric around the centre point. Choosing a good subset size depends on the image noise, speckle pattern and expected strain behaviour. The subset must be large enough to contain enough information to make it uniquely identifiable in the deformed image, but a large subset introduces a bias error when matched against deformations with a high spatial frequent (non-homogeneous). I.e. the deformation is not approximately constant in the subset. A large subset can also help alleviate accuracy problems caused by acquisition noise due to the law of large numbers, but high noise levels are better addressed by applying a Gaussian blur (later). Avoid using a subset size 10 times larger than the biggest feature in each subset, this may affect tracking accuracy.

As a rule of thumb the subset needs to be large enough to contain at least three discernible features, i.e. speckles. Typically this should be set between 15x15 and 31x31, if in doubt, the default size of 21x21 is suitable for most cases. The subset size affects the computation time as $O(width * height)$.

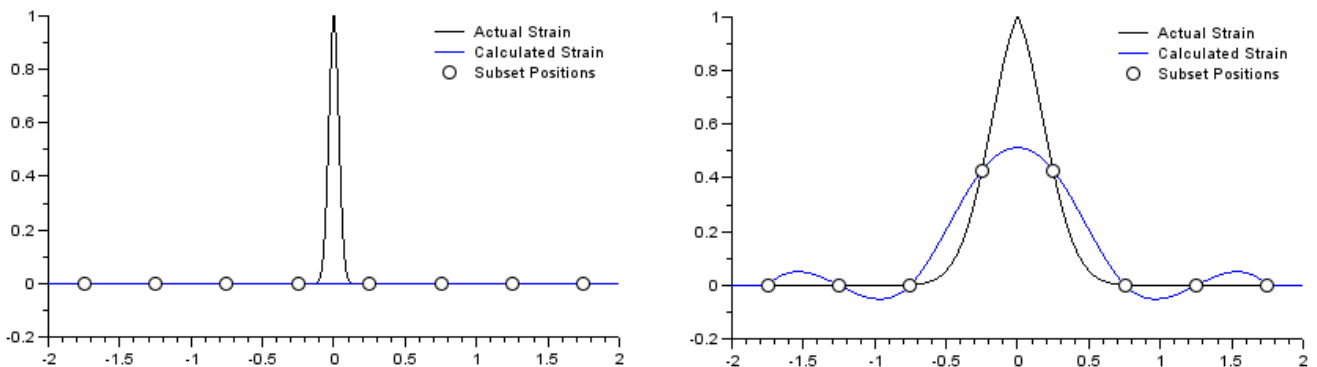


Figure 32: Strain transient that is completely missed (left) and strain peak that is lower than the true value (right) due to too sparse sampling.

Strain Type

In TEMA DIC there is a strain type selector, here you can switch between “Homogenous” and “Non-Homogenous” strain.

This switches between different “shape functions” for matching the deformed subset. The Non-Homogenous setting will handle peaks and nonlinear effects better than the Homogenous counterpart, but may result in slightly higher noise in the results. For 2D-DIC Homogenous is more commonly used, while in Stereo DIC the Non-Homogenous setting is often the best alternative unless very linear deformation is expected.

Correlation Function

Subset based DIC function by taking a reference subset and matching it in deformed images. The quality of the matching is measured by a correlation function. The most simple correlation function is the Sum of Squared Differences (SSD) which simply takes the difference between the original subset and the deformed subset, squares them and sums them up. SSD has good numerical properties and is computationally faster than ZNCC (later). However if there are variations in lighting conditions during the test, for example clouds when outside or flicker from lamps, SSD may not perform well. The alternative is Zero Normalized Cross Correlation (ZNCC) which normalizes the subsets on mean light intensity and intensity variation before calculating a correlation. The result is that ZNCC is a bit slower than SSD, has a bit worse numerical properties but is more robust against changes in lighting conditions during the test.

If you're unsure what this means, choose ZNCC (default). It's the safe bet.

Reference time

The time that shall be taken as the definition of the subsets. This shall be a time that is before the load is applied to the test specimen. The analysis tools, such as Inspection Line, Virtual Extensometer and Point of Interest have to be defined at the reference time.

Gaussian Blur

Sometimes it's useful to apply a low-pass filter to the image data prior to processing. This can help with aliasing issues (see pitfalls) and images where significant noise is present. It shall be noted that Gaussian Blur will reduce the information in the image, it can result in worse tracking accuracy and will definitely worsen the spatial resolution on strain. But it may also be the difference between getting significant artefacts in the strain results due to aliasing and simply not being able to track accurately at all due to significant acquisition noise. Consider adjusting test conditions and subset size/step prior to trying to use Gaussian Blur.

The blur is applied as follows: The radius value is taken as the sigma parameter (in pixels) to a 2D Gaussian function centred on the current pixel. The pixel values that lie within $\text{ceil}(3\sigma)$ of the Gaussian's centre are multiplied by the weight of the Gaussian function at each pixel position and then summed to create the new value for the pixel at that location.

Noise Analysis

TEMA DIC offers the ability to evaluate the tracking error in the test prior to an actual tracking. When using TEMA Camera Control, the user may also perform a real-time analysis in order to adjust lighting conditions, tracking and camera parameters while monitoring their effect in real-time in the tracking accuracy report; Before even performing the test.

The analysis is performed by taking two images of a fixed, static test specimen without any external load applied. A tracking is performed on these two images, as the target has not moved the expected result is zero for all displacement values. However, due to camera noise the displacements will not be exactly zero, we calculate the mean and standard deviation (sigma) of these errors. The mean is expected to be very close to zero. Two sigma of the error means that "for 95% of all tracked samples, we expect that the tracked error is less than this". The max, mean and 2-sigma values are presented for both the X and Y axis. Typical values for 2-sigma on a well prepared test is < 0.03 .

The noise analysis section has two tabs: Online and Offline. Online is only available when a camera is attached and controlled by TEMA in "live mode". Offline works by taking two images from the image sequence and using them as input to perform an accuracy analysis post-test. Typically the first two images of the image sequence, before the load is applied, are used.

To be able to perform a noise analysis and get an accuracy report, it must be possible to fit enough non-overlapping subsets inside of the AOI. If you are unable to obtain an accuracy report, try making the Area of Interest bigger, or the subset size smaller.

Tracking

DIC is implemented as a new tracker type in TEMA. As such it will behave in ways that TEMA users are accustomed to. We recommend that new TEMA users read the section about Tracking in the online help.

However as the output from DIC is a field, the presentation of the results will be new. This chapter will outline how to setup and record a test using TEMA Camera Control and also how one should proceed to track a test that has been recorded.

Using TEMA Camera Control to record the test:

1. Add a new live camera view. This is described in more detail in the chapter Camera Setup earlier in this document.
2. Right click on the camera view and open the "Camera Setup" dialog. Perform initial adjustments of camera parameters with the camera setup dialog. Leave the camera setup dialog open.
3. Right click on the camera view and open the "Image Enhancement" dialog. Hide all graphs except the Histogram, leave the image enhancement window open.
4. Add a new tracker to the camera view. Open the tracker setup and change to DIC tracker, perform initial, rough adjustment of ROI and tracker settings. Switch the Noise Analysis tab to "Online".
5. In the tracker setup, zoom on the subset and check the speckle size.
 - a. If the speckle size is too small (less than 3-4 pixels) try to move the camera closer to the specimen or use a different optic.
6. Align the camera so that the image plane is as perpendicular as possible to the test specimen's surface.
7. Adjust focus and aperture so that the whole of the test specimen is in focus. Keep aperture as open as possible while maintaining focus.
8. Set the target FPS and Region of Interest in the camera setup dialog and an initial guess at the exposure setting. Leave some margin on the ROI, at least one "subset size".
9. Add any exclude areas to exclude irrelevant or interfering parts from the test specimen from the tracking. Such as notches and holes. See the page "Exclude Area (Rectangle or Polygon)" in the TEMA Help Manual.
10. By looking at the histogram and the tracker setup preview image adjust the light position and angles so that no highlights appear on the test specimen. If possible always use both lights! Never dim the lights!
11. Try to eliminate sources of flicker (fluorescent lamps for example).
12. Next adjust the camera settings so that as much as possible of the camera's input range is used without clipping either the dark or bright end.
 - a. If the image is too dark:
 - i. Try to increase the exposure time within what is reasonable for the wanted FPS and test's temporal behaviour.
 - ii. If the exposure can't be increased further, see if the aperture can be opened further without defocusing the test specimen.

- iii. If neither the exposure, aperture or light positions and angles can be adjusted to give enough light to use the full range of the camera's sensor, then adjust the raw gain value of the camera so that the full range is used without clipping. Leave some headroom for changes in light conditions during the test.
 - b. If the image is too bright:
 - i. Lower any gain settings on the camera first.
 - ii. Then try to reduce the exposure time (shorter exposure time reduces effects of motion blur)
 - iii. Finally, reduce the aperture size.
13. Adjust the ROI in the tracker setup to the wanted position and size.
14. Adjust subset step and size parameters.
15. Adjust tracker parameters and camera focus in order to minimize the 2-sigma error in the online noise analysis. Remember to keep tracker parameters as the values you want to use in the analysis (see tracker setup).
16. Close the dialog windows and save the settings.
17. Prepare to start the test.
18. Arm the camera and start downloading images. This is described in more detail in the Camera Setup chapter earlier in this document.
19. After at least two images have been downloaded, apply the load and start the test.

Tracking a 2D DIC-test after the test has been recorded:

1. If using image data from outside of TEMA:
 - a. Load the recorded sequence.
 - b. Add a new tracker to the camera view.
 - c. Place exclude areas to exclude any non-interesting parts from the tracking. Typically notches or holes in the test specimen. See the page "Exclude Area (Rectangle or Polygon)" in the TEMA Help Manual.
2. Open the tracker setup for the tracker.
3. Set the reference time for the subsets as the first image after any headers in the sequence.
4. Open the "Offline" tab under "Noise Analysis"
5. Set the noise reference time as any other point in the image sequence after the subset reference time but before the actual load is applied.
6. Adjust the tracker settings, click "Calculate" on the "Noise Analysis" section to get an estimate of the accuracy.
 - a. If the accuracy is poor, try increasing the subset size slightly or using ZNCC correlation function and press "Calculate" again.
 - b. If neither of these have the desired effect, restore the subset size to its original value and enable the Gaussian Blur and try different values of the blur radius to see what works best, pressing "Calculate" each time you want to see the updated report.
7. Apply, save and close the tracker setup.
8. Press "Track automatically"

9. If the tracked result looks weird or unexpected, consult the pit-falls section of this manual.

Tracking a Stereo DIC-test after the test has been recorded:

1. If using image data from outside of TEMA:
 - a. Load the recorded sequences.
 - b. Add a new tracker to the main camera view.
 - c. Place exclude areas to exclude any non-interesting parts from the tracking, typically if the analyzed object is not rectangular in the main camera view. See the page "Exclude Area (Rectangle or Polygon)" in the TEMA Help Manual.
2. Perform a Relative Camera Orientation. See the page "Relative Camera Orientation" in the TEMA Help Manual.
3. Open the tracker setup for the tracker.
4. Set the reference time for the subsets as the first image after any headers in the sequence.
5. Apply, save and close the tracker setup.
6. Add a point to the second view
7. Open the tracker setup for the tracker and change it to a "DIC Slave"-tracker
8. Select the main tracker and press OK.
9. The field should automatically match the AOI from the main tracker to the second, if not:
 - a. Make sure the Camera Orientation is correct
 - b. Set Tracker tolerance to 25% in the first view and try again
 - c. Add some Gaussian blur with a radius of 0.6.
10. Press "Track automatically"
11. If the tracked result looks weird or unexpected, consult the pit-falls section of this manual.

Analysis

Strain Types

TEMA DIC can calculate the Infinitesimal, Green-Lagrange and the Euler-Almansi strain descriptions. The upper half of the strain tensor ($E_{xx}, E_{xy}, E_{xz}, E_{yy}, E_{yz}, E_{zz}$) is calculated along with the principal strains (E_1, E_2, E_3) for each description.

By definition the Green-Lagrange & Euler-Almansi strain has a quadratic error term which means that it is only usable for quite small strains; However the Green- Lagrange & Euler Almansi description is not affected by rigid-body rotation which makes it suitable for tests where the test specimen may undergo rotation and strains are small so that the quadratic error can be neglected. Infinitesimal strain does not have the error term that Green-Lagrange & Euler Almansi does so it is usable for larger strains. On the other hand the infinitesimal strain description wrongly recognizes a rigid-body rotation as a strain when it in fact is not, so it is not usable for test specimens that undergo rotation during the test.


Strain Window

Strain is calculated once for every point (subset) in the discrete approximation to the displacement field (described in Tracking). For every such point, we centre a window on the point, called the "strain window". Typically it is a window of 3x3 subsets. We fit a bi-quadratic surface over the window over these displacement points to obtain a smooth, once continuously differentiable displacement field. This continuous displacement field is differentiated to obtain the displacement gradient which gives the strain values through application of their respective definitions.

For Stereo DIC there is a separate drop-down menu for the 3D-Strain window, this has a minimum size of 5x5.

The strain window size can be changed from the DIC menu under Settings, see Figure 33.

Inspection Lines

An "Inspection Line" can be placed anywhere in the tracking view. To add an Inspection Line, use the tool button  or the menu entry Camera/Add Inspection Line.

When an Inspection Line is selected in the Test Contents, it is possible to move the endpoints of current line by click-and-drag in the image. If the cursor does not hit an existing endpoint, click-and-drag will add a new Inspection Line.

A right click on the Inspection Line in the Test Contents will open a dialog (Figure 34) where the start and end points can be modified. If the test is scaled (e.g. by using Motion Planes) the unit is meters and the positions are in the coordinate system defined by the Motion Plane. If no scale is used the unit is pixels.

This line will appear as a sequence in the Advanced Diagram which can be plotted, and can also be exported from the "Export DIC Data" function. This allows inspection of strain values along any line to get a cross-section of sorts. Inspection lines work by simply picking samples from the (previously calculated) continuous strain field along the line definition. This guarantees that the results shown in the inspection line will always agree with other results in TEMA DIC.

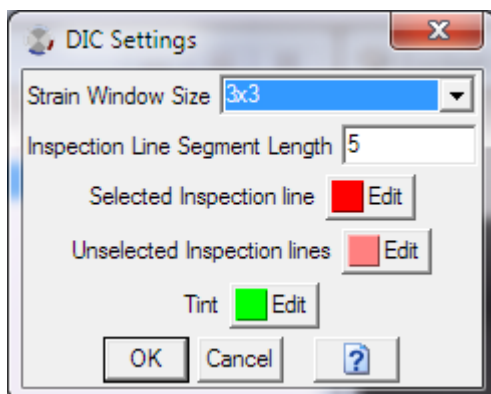


Figure 33: Settings for DIC

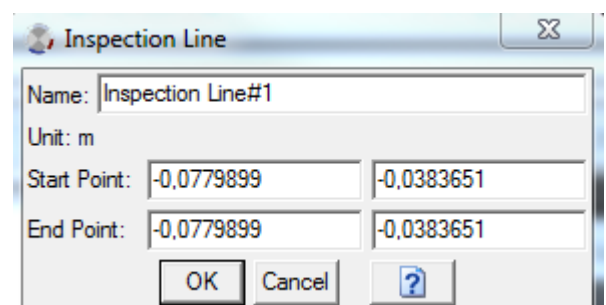


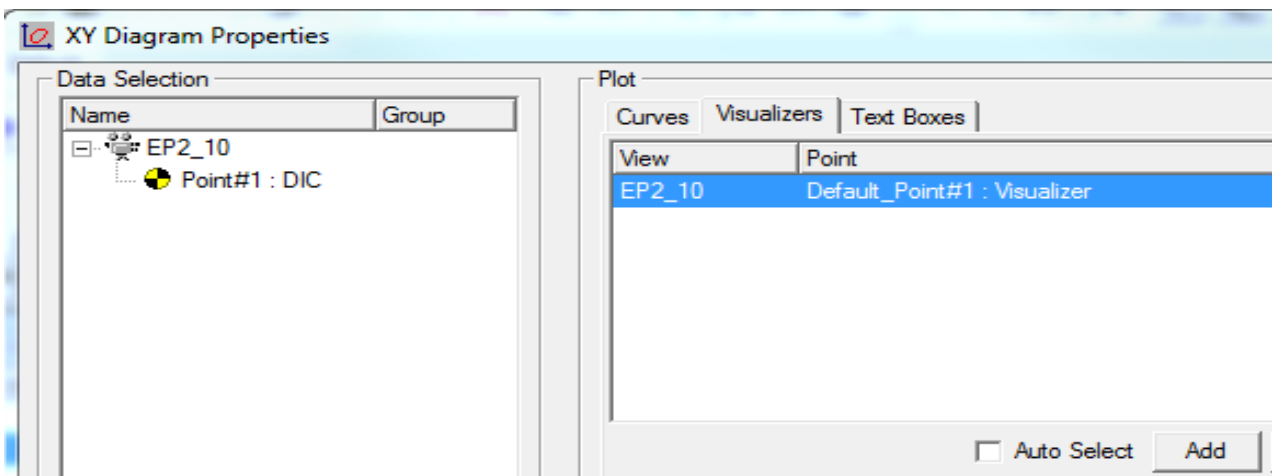
Figure 34: Inspection line dialog

Presentation 2D analysis

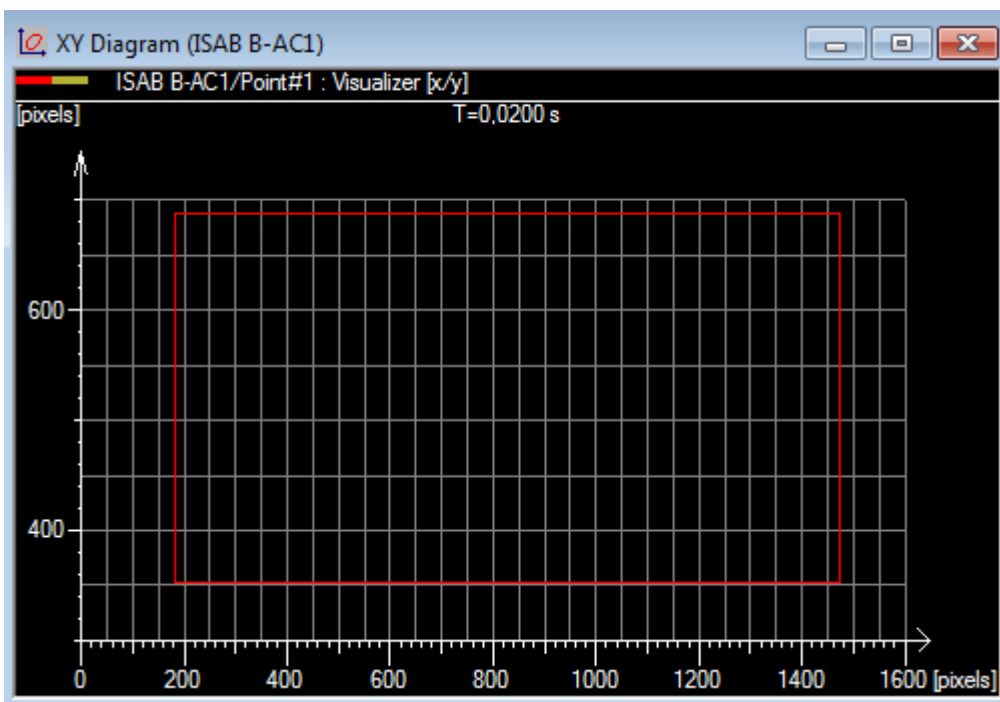
The data from a DIC tracking can be displayed in various ways. The on-line help section **“Working with TEMA / Presentation”** gives the basics for the different diagram types available.

The tracker visualizer

The DIC field shown in the Camera View window can also be used in an X/Y Diagram and in an Image Diagram. The Visualizer sequence represents this view. Create a new Image Diagram and select Properties on the right-click menu. Select the Visualizer for the DIC point.



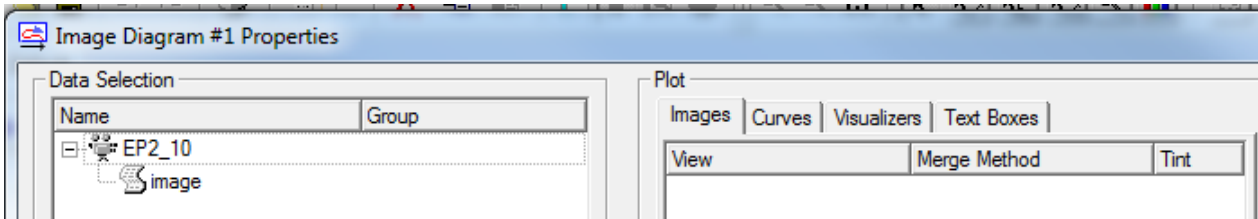
The resulting diagram may look like:



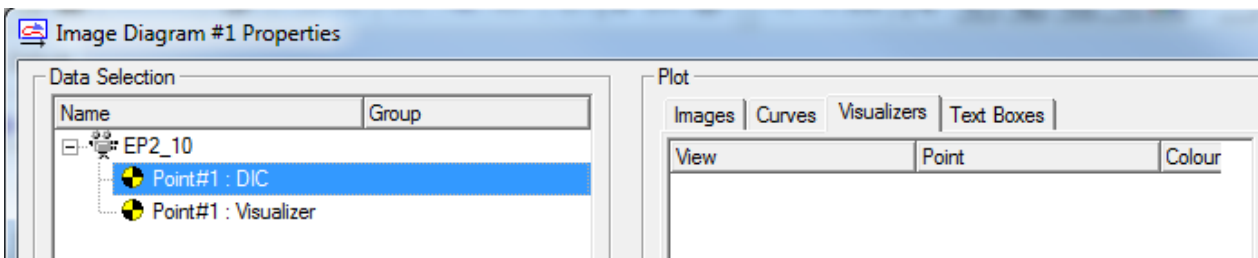
The DIC visualizer

The DIC Field Sequence can be shown as vectors in an X/Y- or an Image Diagram. The visualizer also has the option to overlay one component of other field data as colour coded. For example the shear strain can be shown in a colour scale from purple to red, where purple is low strain and red is high strain.

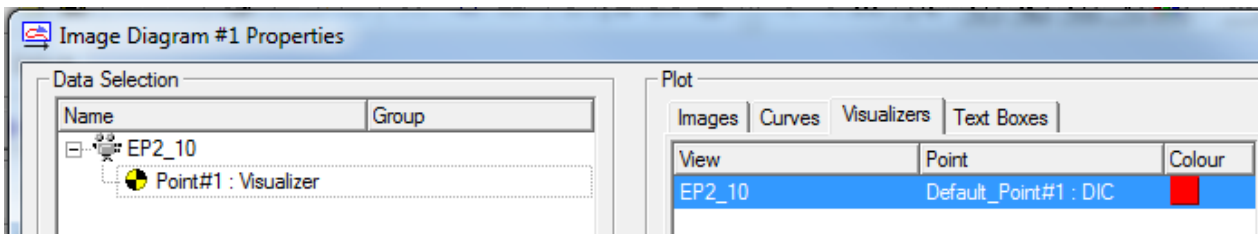
Create a new Image diagram, from right-click menu, select Properties



From the Plot/Images tab: Add the image.

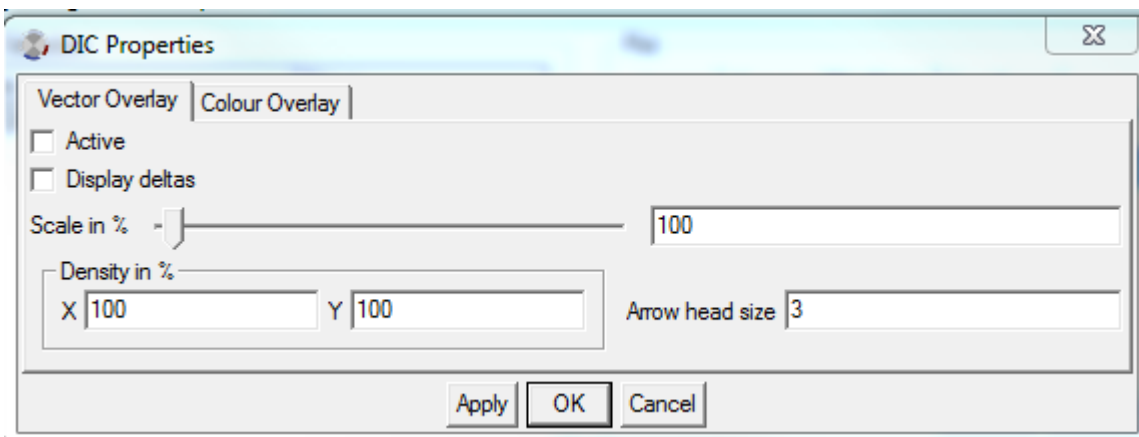


From the Plot/Visualizers tab, Select the DIC sequence and add it.



Now right-click the DIC sequence (the blue marked line in the image above) and select Properties.

The Property dialog for the DIC sequence visualizer will show:



This dialog has two notebook tabs, one for the Vector overlay and one for the Colour overlay. One or both can be overlaid on the image.

Vector

The Vector overlay can also be used from an X/Y Diagram.

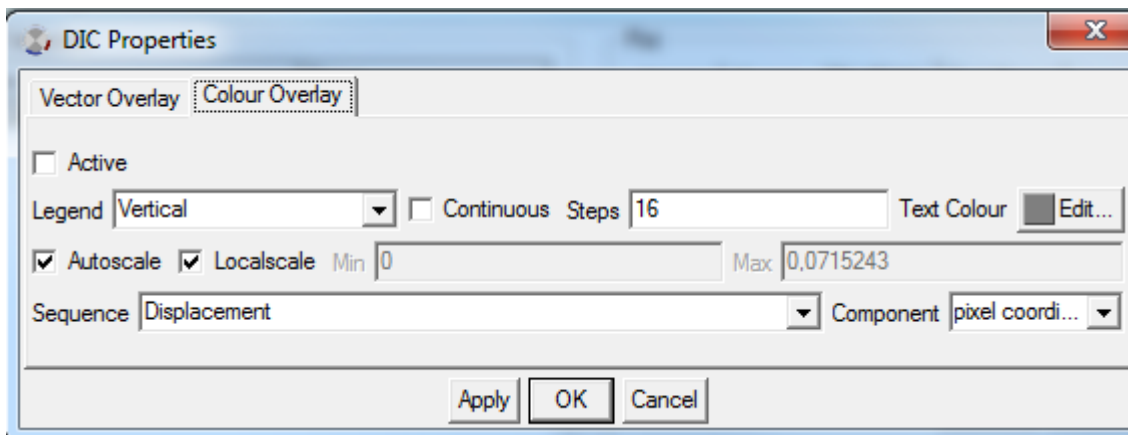
The settings are:

- **Active:** a toggle to activate/deactivate the overlay
- **Display deltas:** the vectors can show the displacement from the reference image or (if the toggle is checked) the displacement from the previous image
- **Scale in %:** Scale factor. 100 % means that the vector has its real length. To make the diagram more readable you can use the slider. If the maximum of the slider is not enough, a new maximum can be entered in the field to the right.
- **Density in %:** 100% means that the grid has the same density as it had in the Tracking setup. Choose a larger value to fit more vectors (e.g. 150). You can use different values in the horizontal and vertical directions (X/Y).
- **Arrow head size:** It is possible to control the size of the arrow heads in order to make the diagram more readable. The size is given in 'pixels on screen'.

Colour

The Colour overlay can only be used in Image Diagrams. It makes it possible to colour code one component from one of the DIC output sequences. For example the U_x component from the DIC field or the E_{xx} component from Strain – Green-Lagrange.

To set up the overlay, select the Colour Overlay tab in DIC Properties



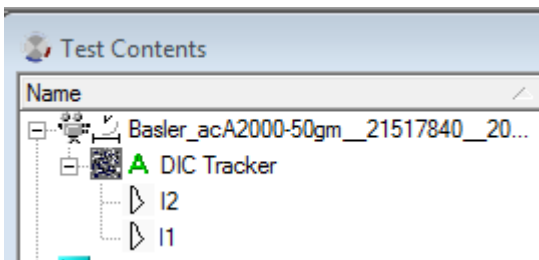
The settings are:

- **Active:** a toggle to activate/deactivate the overlay
- **Legend:** the colour legend can be positioned to the right or under the diagram. It can also be hidden
- **Continuous:** The colour scale can be continuous or have discrete steps.
- **Steps:** Number of steps in the colour scale

- **Text Colour:** To make the colour legend more readable, it is possible to change the colour use for scale numbering.
- **Autoscale:** The colours are distributed over the whole range of values.
- **Localscale:** Works only if Autoscale is on. If localscale is checked, only the values in the current image are used to distribute colours. If it is not checked, the range of the whole sequence is used.
- **Min/Max:** If Autoscale is off, you can type your preferred limits in the Min and Max field.
- **Sequence/Component:** Choose between
 - **DIC:** The result of the tracking; components are x0/y0 (starting point) u/v (horizontal/vertical displacement) and sigma (correlation)
 - **Displacement:** length of the displacement vector
 - **Strain - Green-Lagrange:** components are Exx, Eyy, Exy and more
 - **Strain - Infinitesimal:** components are Exx, Eyy, Exy and more

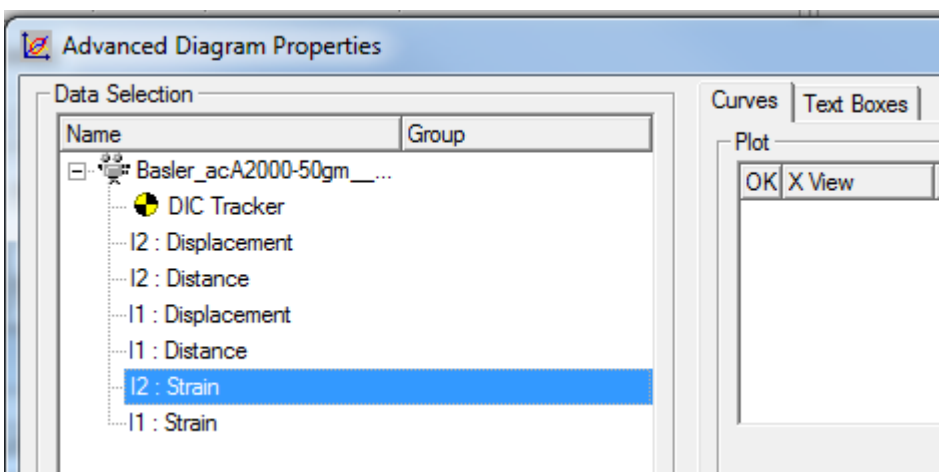
Inspection lines

In the Test Contents, it is possible to add one or more **Inspection Lines** for a DIC tracker: See Tracking above.



Use the Advanced Diagram to display field data along Inspection Lines. As for the Colour Visualizer, one component of field data can be selected for the y-axis. The x-axis represents the Inspection Line itself and the curve will show the selected component along the line, e.g. shear strain.

This is how the Advanced Diagram Properties looks when two Inspection Lines are added.



If we add two of the Strain sequences, the Plot area may look like

OK	X View	X Point	X Plot	X Comp	Y View	Y Point	Y ...	Y ...	Col...	Alt Colour	Filter
<input checked="" type="checkbox"/>	ISAB B-AC1	Inspection Line#1 : Length	pixel coordi...	pixel coord...	ISAB B-AC1	Inspection Line#1 : Strain - Green-Lagrange	Str...	eyy	■	■	<input type="checkbox"/> CFC
<input checked="" type="checkbox"/>	ISAB B-AC1	Inspection Line#1 : Length	pixel coordi...	pixel coord...	ISAB B-AC1	Inspection Line#1 : Strain - Infinitesimal	Str...	eyy	■	■	<input checked="" type="checkbox"/> CFC


Notice that 'Length' is automatically selected for the X Point. Length represents the actual Inspection Line and will be used as the X-axis in the diagram. For Y Point we find e.g. Strain – Green Lagrange, the sequence we selected. Right-click on the value in the column Y Comp (eyy in the picture above) to choose another component of Strain.

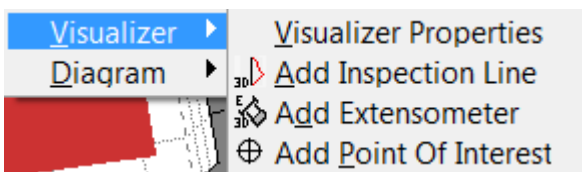
Presentation Stereo DIC

For Stereo DIC, there are several other options available for displaying the 3D-data. A bit different from the 2D analysis, the Inspection Line, Extensometer and Point of Interest tools are placeable in the 3D-diagram, directly on the surface.

3D-Diagram

After performing a Stereo DIC tracking, it is possible to show the DIC surface in a 3D diagram.

To do this, open a 3D Diagram, which can be added through the 3D Diagram button , as well as in the menu entry Diagram/New/3D Diagram. Right click the 3D diagram – Properties, and double click the "Point#X – 3D Displacement Field". At reference time this should add a red surface corresponding to the tracked DIC area in the 3D-diagram. Right clicking the 3D-surface in the diagram brings up the diagram and visualizer menu. Under the visualizer menu some new features can be found



The "Visualizer Properties" brings up the "DIC Properties" window as explained under the section "The DIC Visualizer".

Add Inspection Line, Add Extensometer and Add Point Of Interest allows 3D analysis tools to be placed directly in the 3D-diagram.

3D Inspection lines

The inspection lines are placeable by right-clicking the DIC surface in the 3D diagram, and placing them on the surface at reference time. Right clicking the 3D inspection line in the Test Contents points menu allows the angle of the plane intersection with the 3D surface, since the 3D inspection line is a curve following the surface, with an infinite amount of paths between the two selected points.

To view the results along a 3D Inspection Line, use the Advanced Diagram, exactly like a 2D inspection line. For more information see the “Inspection lines” section.

3D Extensometer

The 3D Extensometer is placeable by right-clicking the DIC surface in the 3D diagram, and placing them on the surface at reference time. This measures the Euclidean distance between two points, and is possible to show as both engineering strain and extension. To view the results from the 3D Extensometer, use the XT-diagram just like the 2D Extensometer. For more information see the “Virtual Extensometer” section.

Point of Interest

A point of interest can be added through right-clicking the DIC surface in the 3D diagram, and placing them on the surface at reference time. A point of interest samples the surface in a specific point, and similarly to the Inspection line allows data to be displayed.

A point of interest has one point of data per mechanical property, and can thus be displayed in the XT-diagram as a function of time.

In addition to this, the Point of Interest allows for FFT, velocity and acceleration to be calculated over the entire DIC surface.

Export Test Results

2D Diagram

This includes Image-, XY-, XT- and Advanced Diagrams. They all can be exported as e.g. an AVI Sequence. Other formats, as jpeg or tiff are available. **Export images** is on the right-click menu in the diagram and the export window is described in the on-line help (Working with TEMA / Data output / Combined Image Export).

Export DIC data

Field data (displacement, strain etc.) and Inspection Line Data are exported using the **Export Data** function available in the **DIC** menu.

Each available field sequence is exported to a separate data file, one section for each tracked sample. All data for an Inspection Line is exported as one file with Distance along the line as the first column.

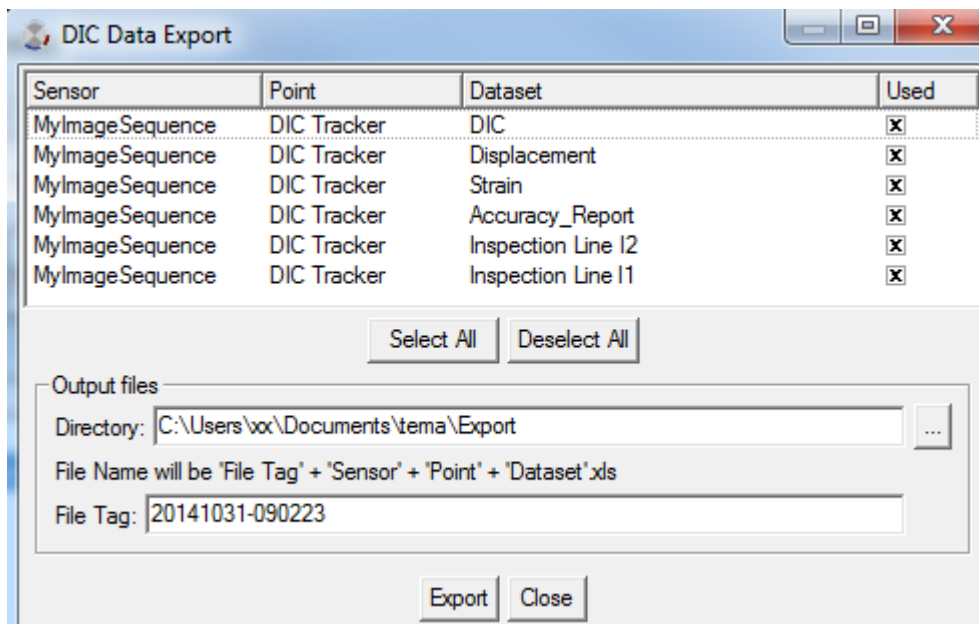
The data in the file is tab separated to make it easy to import in Excel or Matlab. The Export dialog has one line for each available data set. The columns are:

Sensor: The name of the image view as seen in the Test Contents.

Point: The name of the DIC tracker as seen in the Test Contents.

Dataset: Name of the dataset. It is either one of the field sequences or one Inspection Line.

Used: Uncheck the toggle to skip the sequence for export



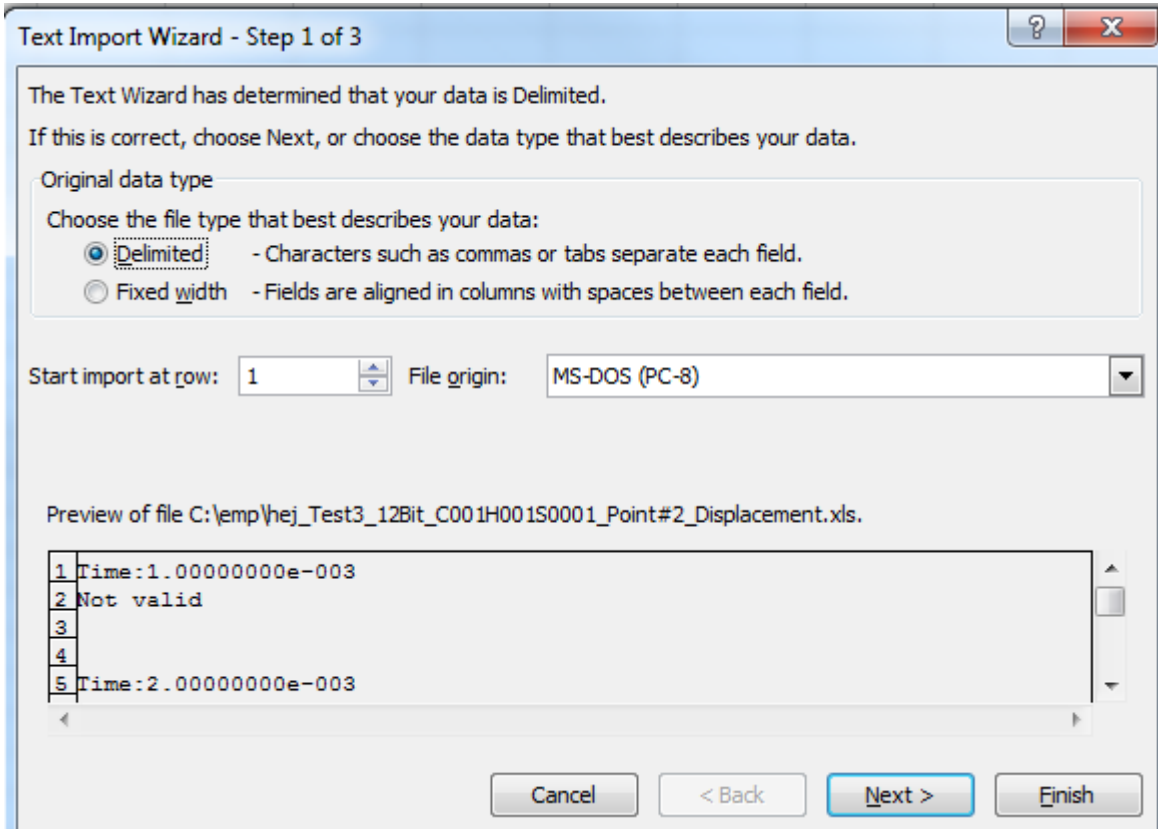
Select All/Deselect All: Affects the Used column

Directory: Default directory is taken from the Preferences / Directories / Data Export

File Tag: Default is the current time/date. The filename is composed of File Tag, Sensor, Point and Dataset name.

Use DIC data in Excel

If you open a DIC Export file in Excel you might get a warning about the format and a question if you want to open the file anyway. Answer Yes. The Text Import Wizard is shown. Select Finish.



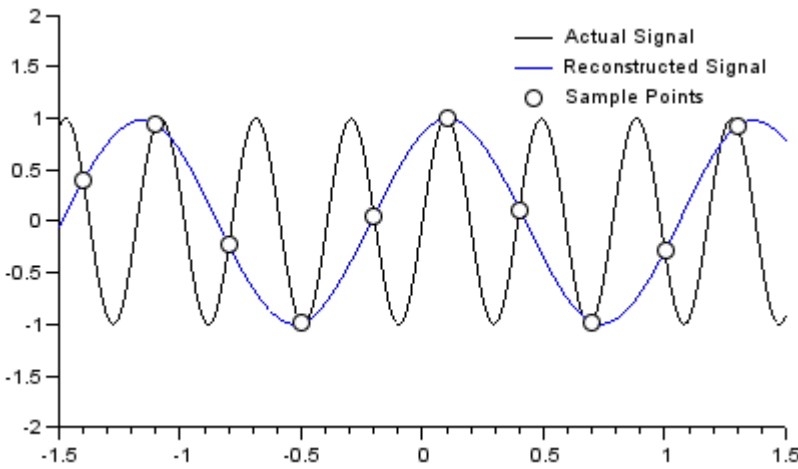


Figure 35: Aliasing in a 1D signal due to too low sampling frequency.

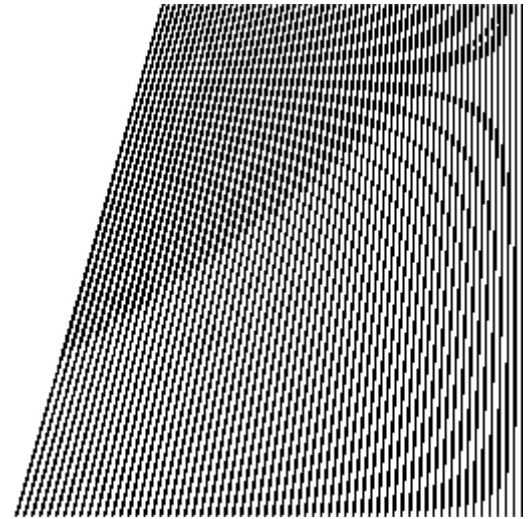


Figure 36: Aliasing in a 2D signal, appearing as a moiré pattern.

Pit-falls

Banding/Aliasing

Aliasing occurs when the bandwidth of a sampled signal exceeds half the sampling frequency, also known as the Nyquist sampling theorem. The result of aliasing is that the original signal cannot be correctly reconstructed. See Figure 35.

In a 2D signal, aliasing is often seen as banding or moiré type patterns, see Figure 36 for an example. In Figure 36 the bandwidth of the signal in the horizontal direction is too high resulting in a visible pattern that is not part of the original signal due to aliasing.

If aliasing occurs in the input data for DIC a moiré or banding type artefact will become visible in the calculated displacement and strain values as well. Most obviously seen in the sigma (correlation) component of the tracker. But it can also be seen as an erroneous strain in the results.

The criteria for aliasing to not occur is that the speckles are at least 3 pixels in each direction!

Aliasing is best avoided by making sure that the speckles or other features that are used for DIC are large enough in the resulting image sequence. However if the test is already performed and aliasing is an issue, one can apply an appropriate low-pass filter to the data prior to processing. In DIC we do this by applying a Gaussian blur (see tracker setup). However it shall be noted that applying a Gaussian blur will degrade the spatial resolution and possibly also the tracking accuracy.

Measuring very local strain

When one is interested in local behaviour of a strain the step size of the grid and the subset size becomes very important.

It's helpful to think of the grid as the sampling period for the strain in the spatial domain. If the sampling rate is too low (period too long) you cannot capture strain with a high spatial bandwidth. This can result in the peak value of the strain being too low and small ringing artefacts, see Figure 37 for an example where the step size is too large to capture the strain peak. If the strain happens to be periodic, you can also get aliasing of the strain in the same way as you get with images.

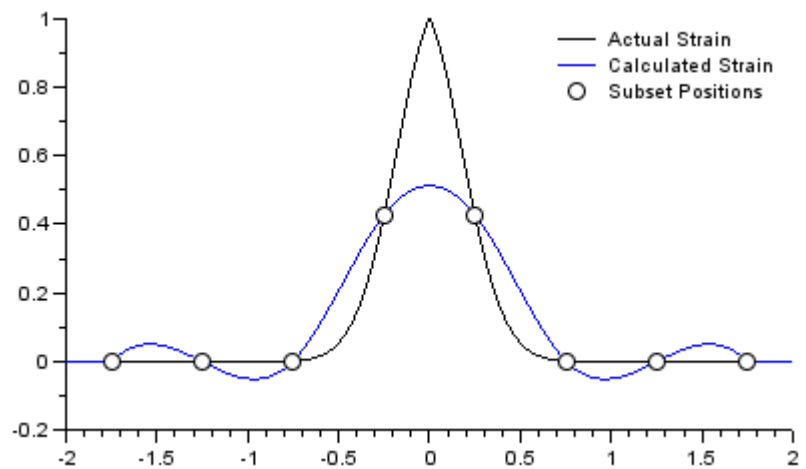


Figure 37: Too large step size

Subset size also has a significant impact on the measurable spatial bandwidth of the strain, also known as the spatial resolution. Essentially a subset captures the mean strain under its area. So if the subset area is too large, the strain under it is averaged and the high frequent strain events are averaged out.

Important:

Hence for highly localized strain it is important to have the step size be small enough to capture good data while balancing the trade-off in accuracy vs computational time. Furthermore the speckle pattern has to be good; in the sense that the speckles are big enough to not cause aliasing, but small and frequent enough to allow small subset sizes to be used. For largely homogeneous strain one can get away with larger steps and larger subsets.

Dealing with Acquisition Noise

All cameras have an error in the acquisition of the light intensity from its surroundings. We call this error the *Acquisition Noise (or just noise)*. The noise is the single largest contribution to the accuracy and spatial resolution obtainable with DIC. We always recommend that you use a camera that has been recommended and tested by Image Systems Nordic AB with TEMA DIC.

Noise is directly related to the quality of the sensor on the camera and the amount of light available, thus we recommend always using both LED lights at their highest intensity. If the image is too bright, reduce gain in the camera first, then reduce the aperture.

If for some reason the captured images still contain non-negligible noise, it is possible to get useful results from the images although the spatial resolution of the strain will be degraded and strain peaks may be lower than their true value. Prefer to use ZNCC correlation method for noisy images. When dealing with homogeneous strain first try increasing the subset size since by the law of large numbers the effects of noise should be reduced. If this is not enough, try enabling the Gaussian Blur and try different strengths of the blur filter. These two settings together may make the test trackable in the presence of significant noise, at the costs mentioned above.