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Experiment 4

Analysis of diffraction images of laser light by ultrasonic waves

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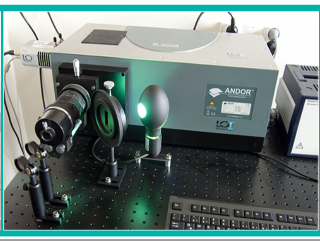
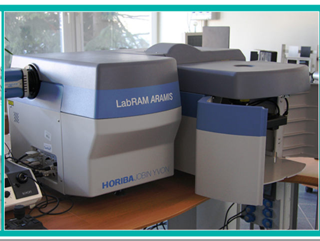
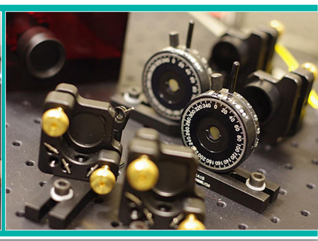




I. Background theory.

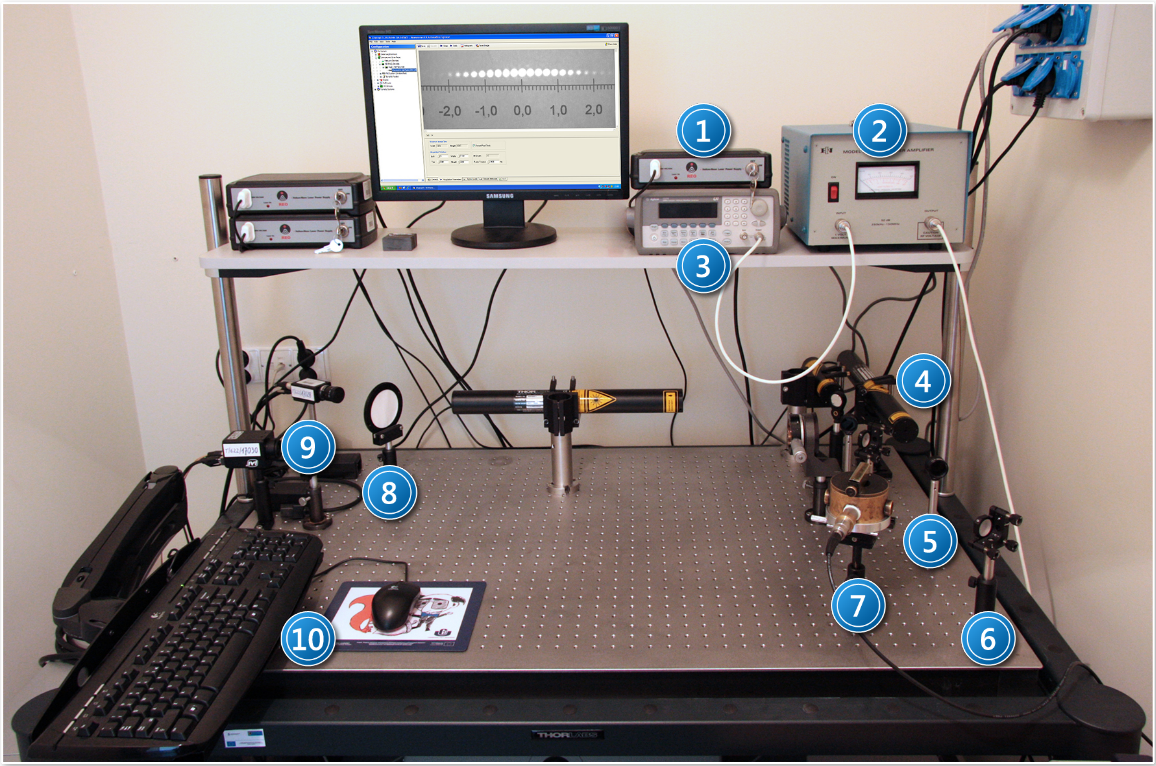
1. Propagation of elastic waves in a continuous medium.
2. Wave equation for sound waves.
3. Production of acoustic waves in liquids.
4. Properties of ferroelectric crystals:
   a) domain structure;
   b) spontaneous polarization;
   c) domains movements in an external electric field.
5. Piezoelectric effect.
6. Piezoelectric transmitters:
   a) design of piezoelectric ultrasonic probes;
   b) longitudinal and transversal resonant vibrations of a piezoelectric transducer.
7. Interaction of light with ultrasonic waves in liquids.
8. Normal deflection of light by ultrasonic waves:
   a) light intensity distribution of the diffraction spectrum;
   b) Raman – Nath theory.
9. Determining the speed of sound based on the diffraction pattern of light diffracted by an ultrasonic grating (primary interference method).
10. Construction and operation of a gas laser (for example, helium-neon laser):
    a) radiant transition: absorption, spontaneous and forced emission;
    b) construction of a laser;
    c) active medium of He – Ne lasers;
    d) population inversion;
    e) optical resonators;
    f) properties of laser light.
11. The principle of image detection using CCD cameras.

II. Experimental tasks.

1. Familiarise yourself with the setup in *Picture 1*.
   Two separate experiments are performed with the setup in *Picture 1*.

   The components used in this experiment are marked with numbers 1 through 10.
2. Pour the methanol into the measuring chamber (7 in *Picture 1*), cover it with lid and set it on the sliding table.
3. Turn on the computer, the He – Ne laser (1, *Picture 1*) and generator (3, *Picture 1*).
4. Start the program *Measurement & Automation Explorer* and enable the CCD camera view (see *Appendix A*).

   Check that the camera lens is not obstructed.
5. The laser beam should fall on the screen just above the centre of the centimetre scale. If necessary, adjust the angle of the beam with the vertical axis knob on the mirror holder (6, *Picture 1*).



Picture 1. Experimental setup for measuring laser light diffraction by ultrasonic waves: 1 – He – Ne laser power supply; 2 – amplifier; 3 – generator; 4 – He – Ne laser; 5 – grey filter; 6 – mirror; 7 – measuring chamber; 8 - screen; 9 – CCD camera; 10 – computer.

6. Using the instructions in *Appendix B*, set a generator voltage of 70 mV and frequency of 5 MHz.
7. Paying attention to the following warning, turn on the amplifier (2, *Picture 1*) (using the main power switch).

ATTENTION!

Before turning on/off the amplifier, **disconnect** the signal cables from the generator and ultrasonic chamber.

Connect both signal wires to the amplifier *INPUT* and *OUTPUT*.

8. Connect the generator to the ultrasound head, indicated by the supervisor, in the chamber. You should see a diffraction pattern in the CCD camera preview window (9, *Picture 1*).
9. Obtain the best possible diffraction pattern, i.e., with the largest number of visible bands.

   To do this, watch the monitor while **gently** making the following adjustments:

a) rotate (slightly) the entire ultrasound chamber to improve the perpendicularity of the chamber window relative to the beam.
After finding the correct chamber position, lock the bolt to secure it;

b) precisely adjust the distance between the reflector and ultrasound head in the chamber using the screw in the chamber lid, thereby creating the conditions needed to produce a standing wave;
c) rotate the lid slightly to ensure that the transmitter and reflector surfaces are parallel.

10. Still observing the resulting diffraction pattern, see if minor adjustments in voltage or frequency on the generator do not provide an increased number of rows in the diffraction image.
11. Record the value finally chosen for the oscillation frequency of the transmitter.
12. Use the CCD camera to record a diffraction pattern (see *Appendix A*).
13. Discard the methanol, dry the measuring chamber and fill it with liquid indicated by the supervisor.
14. Repeat steps II.8. – II.12.
15. Measure the distance between the ultrasound layer and the screen.
16. Determine the distance between the fringes in the diffraction images obtained using the *NI Vision Assistant* program (described in *Appendix C*) or using another graphics program running under *Windows* or *UNIX/Linux*.
17. Calculate the speed of propagation of ultrasonic waves in the chosen liquids.
18. Discuss measurement errors.
19. Compare the calculated values of the speed with the given data.

III. Apparatus.

1. He – Ne laser (λ = *543 nm*).
2. Laser power supply.
3. Measuring chamber with ultrasound heads (with frequencies 5 MHz and 10 MHz).
4. Table for mounting the measuring chamber.
5. High frequency power generator (*Agilent 33220A*).
6. CCD camera (*JAI Pulnix CM – 140MCL*).
7. Power amplifier.
8. Grey filter (*ND = 2.0*).
9. Screen with centimetre scale.
10. Mirror.
11. Ruler.
12. Computer.

IV. Literature.

1. M. Young – "*Optics and Lasers*", Springer 1977.
2. G.F. Knoll – "*Radiation Detection and Measurement*", Wiley 1979.
3. Ch. Kittel – "*Introduction to Solid State Physics*", Wiley 2004.
4. R.P. Feynman, R. Leighton, M. Sands – "*The Feynman Lectures on Physics*", Vol. 1., Part 2., Addison – Wesley, 2005.

Appendix A

Instructions for *NI Measurement & Automation Explorer* and CCD camera *JAI Pulnix CM – 140MCL*

A. Starting the program and CCD camera preview.

1. Start the program *NI Measurement & Automation Explorer* by clicking the desktop icon.

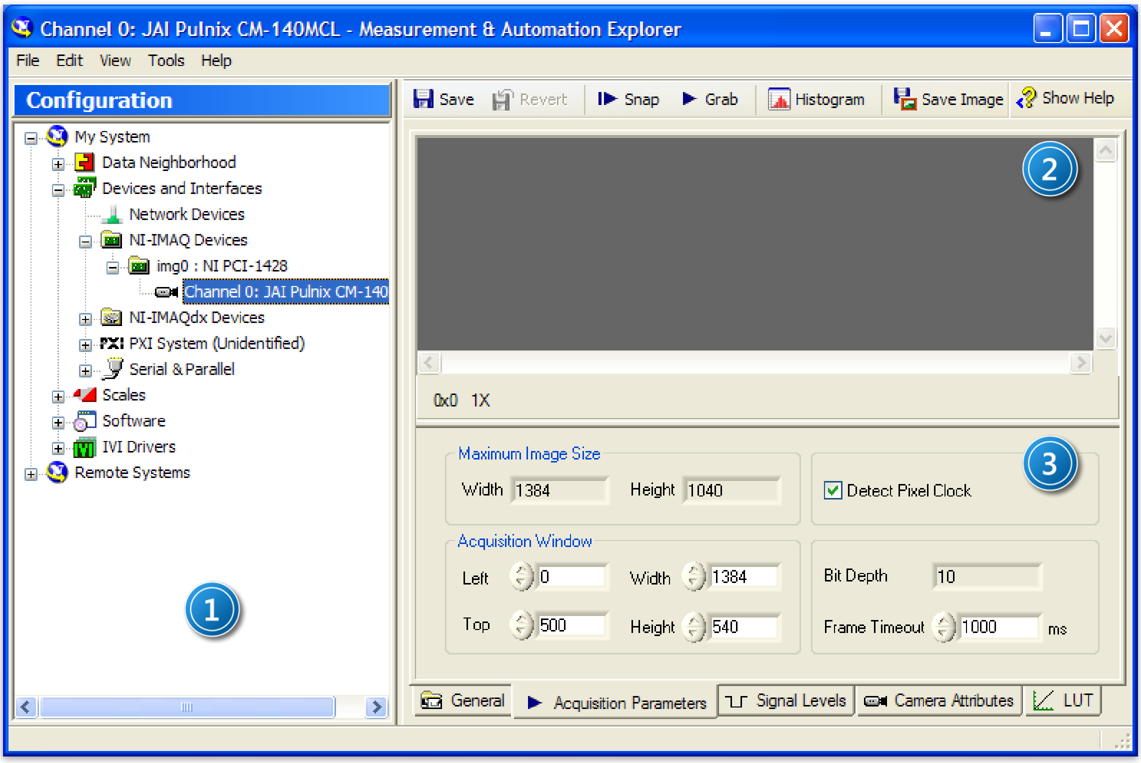


Figure 2. NI Measurement & Automation Explorer program window: 1 – left panel; 2 – preview panel with CCD camera image; 3 – camera settings and image properties panel.

2. Remove the cover from the CCD camera.

ATTENTION!

Before removing the cap from the CCD camera lens, make sure that the grey filter is in the beam of laser light (5, *Picture 1*). Shining an unattenuated laser beam into the camera lens can damage the CCD.

3. Start the camera preview using the left panel (1, *Figure 2*).

   To do this, expand the section Devices and Interfaces by clicking the ⊞ next to NI-IMAQ Devices and img0 : NI PCI-1428 and then clicking the camera interface symbol Channel 0: JAI Pulnix CM-140MCL, and then turn on the preview with the button ▶ Grab in the preview pane (2, *Figure 2*).

4. You should see an image in the preview window after a few moments.

   If this is not the case, ensure that the camera lens is not obstructed.

5. In the event of an error message, ensure that the camera is connected to the power, plugging it in if needed. If you still have a problem, report to the supervisor.

B. Using the program to capture an image from the CCD camera.

1. The ▶ Grab button (2, *Figure 2*) is used to enable or disable continuous view of the CCD camera.

   Turning of continuous preview will display the last recorded frame in the preview pane.

2. By right-clicking in the preview pane, you can customize the display options of the camera image. For example, set the dynamic attributes of an image to adapt to the current window size (using *Zoom to fit* in the *Zoom* menu).

3. You can save the current image in *PNG* or *TIFF* format by clicking Save Image and choosing a location, name and format for the image.

C. Upon completion.

1. In order to close the *Measurement & Automation Explorer* program, simply close the window.
2. Replace the CCD camera lens cap.
3. Report to the laboratory supervisor.

Appendix B

High-frequency generator *Agilent 33220A* instructions

A. Starting the device.

Turn on the generator (with switch 1 in *Picture 3*). The generator settings with display automatically (on display 2 in *Picture 3*) and disappear after a few seconds or after pressing any button.

Picture 3. View of the high-frequency generator Agilent 33220A control panel: 1 – main switch; 2 – display; 3 – parameter adjustment knob; 4 – decimal point selection buttons; 5 – output cable; 6 – mode button and status light; 7 – frequency mode selection; 8 – amplitude mode selection.

B. Selection of the output signal modulation parameters.

> **Hint**
>
> Numbers appearing on the Agilent 33220A are displayed in American notation with a period as the decimal symbol and a comma for digit grouping. For example, **1.234,567 MHz** is equivalent to **1,234567 MHz** in European notation.

1. Ensure that the chosen mode of modulation of the output signal is sinusoidal (*Sine* 7 in *Picture 3*).
2. Choose the frequency or amplitude of the output signal by pressing the frequency mode button (8 in *Picture 3*) or amplitude mode button (9 in *Picture 3*).

   The display will show the corresponding selection.

ATTENTION!

Pay special attention to whether the display shows ***Freq*** (for frequency) or ***Amp*** (for amplitude). If it shows ***Period*** or ***HiLevel,*** press buttons 8 or 9 in *Picture 3* again.

3. After selecting the appropriate mode for adjustment, you can change the frequency or amplitude using knob 3 in *Picture 3*. Using this knob, you can change the currently highlighted digit by turning it clockwise or counter-clockwise.

   Using the decimal place selection button (4 in *Picture 3*), you can highlight a different digit. In the same way, you can change the units: ***M*** for *MHz* can be changed to ***k*** for kilohertz using the knob.

C. Working with the generator.

1. After selecting the type and properties of modulation (see point *B.2.*), accept the generator output mode by pressing *Output* (6 in *Picture 3*). The button will be highlighted.
2. Pressing the *Output* button again disables the output mode and the backlight will turn off.

D. Turning off the generator.

1. Disable output mode (see *C.2.*).
2. Turn off the generator.

Appendix C

Measuring the distance between diffraction fringes using *NI Vision Assistant 2009*

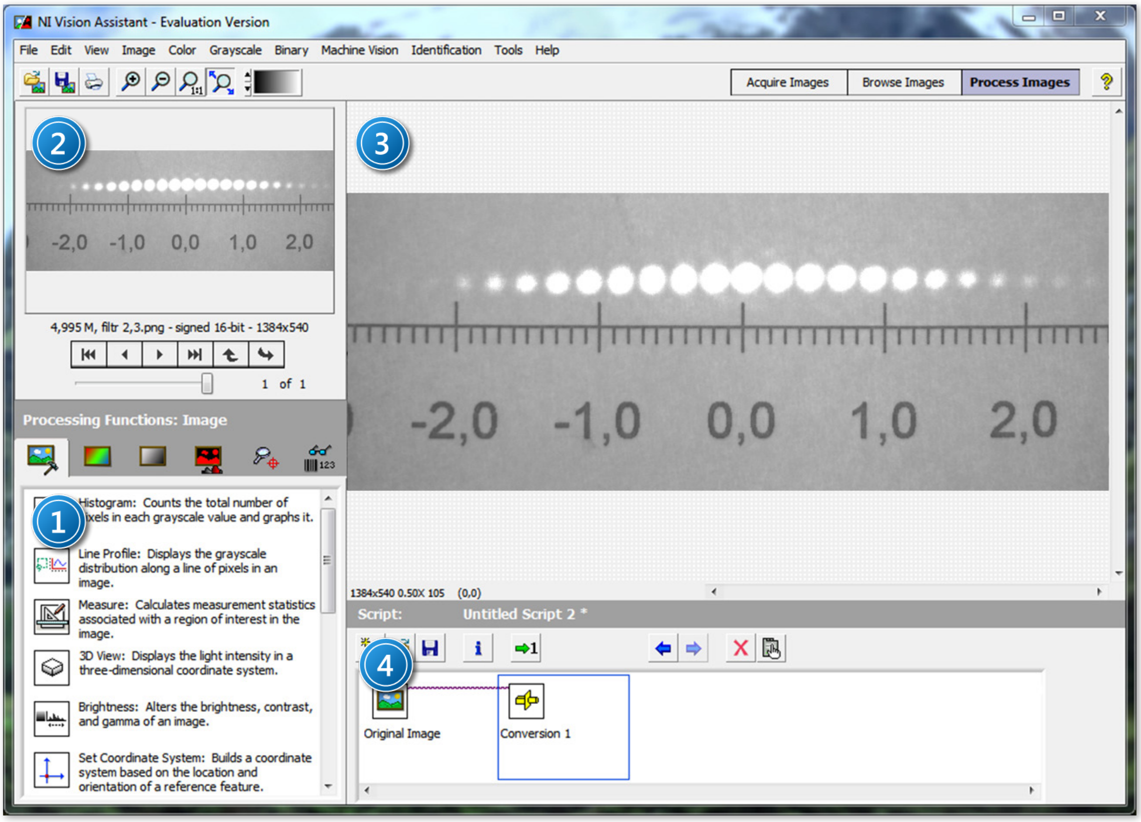


Figure 4. NI Vision Assistant program window: 1 – function selection panel; 2 – image selection panel; 3 – image preview panel; 4 – script editing panel.

A. General information.

National Instruments Vision Assistant offers the ability to make readings of geometric properties of objects shown in raster images, such as distances between points, areas, diameters, etc. The program supports most of today's popular raster graphics formats (including **.bmp*, **.jpg*, **.tif*, **.png*).

A List of operations performed sequentially by *NI Vision Assistant*, such as image transformations, distance measurements and conversions is written in a script that appears in the script editing panel (4, *Figure 4*).

Each step in the current script may be deleted by clicking on the icon, or edited by clicking on or double-clicking on the icon representing a step.

B. Opening and preparing their images for editing.

1. Open a picture (pictures) in *NI Vision Assistant* in one of two ways:

a) click the button on the toolbar of the main window (or select *Open Image…* in the *File* menu), and then select the image (images) and click *Open*;

b) go to the image viewer, click *Browse Images* on the right of the toolbar in the main window, click at the bottom of the screen, select the images and click *Open.*

2. After opening the desired image (images), you can start editing them and making measurements. All operations are found on the image processing tab, accessible by clicking *Process Image*, located on the right of the toolbar in the main window.
3. At any time, you can select which image to edit with the *Process Image* tab by clicking in the image selection panel (2, *Figure 4*), or by going to the browser (click *Browse Images*) and double-clicking the selected thumbnail image (or selecting the thumbnail with a single mouse-click and going to the *Process Image* tab).
4. To add new images to the browser, click at the bottom of the screen, then select the image (images) and click *Open.* Depending on the preferences, a dialogue box will appear asking whether you would like to replace the existing images with the newly selected images.
5. Clicking in the image viewer allows you to switch between a grid view of thumbnails or a single image.

Hint

If after opening, the image (images) appear completely black, you must convert the file by changing its bit-depth. To do this:

1. select the appropriate image and go to the edit tab (*Process Image*);
2. under the *Greyscale* menu, select *Conversion*, and in the function selection panel (1, *Figure 4*), choose *8-bit [0, 255]* and confirm by clicking *OK*.

The converted image can be saved by clicking *Save Image* from the *File* menu.

C. Measuring distances between two points.

The program *NI Vision Assistant* allows you to measure distances between points on images, transforming the distance in pixels into a distance expressed in physical units. To do this, you have to calibrate the image.

Image calibration.

1. Select *Image Calibration* from the *Image* menu. The calibration wizard window will appear.
2. Ensure that the first option is selected - *Simple Calibration*. Click *OK*.
3. In step 1 (*Step 1 of* 3) you will see a preview of the currently open image.
   Ensure that you select square pixels (*Square*), and click *Next*.

4. In step 2 (*Step 2 of* 3), select two points on the image separated by a known actual distance (e.g., two points on the centimetre scale on the image screen), clicking on the appropriate points in the preview.

   In the numeric field in the section *Correspondence Image – Real World*, enter the physical distance between the selected points and select the appropriate unit (see *Figure 5*).

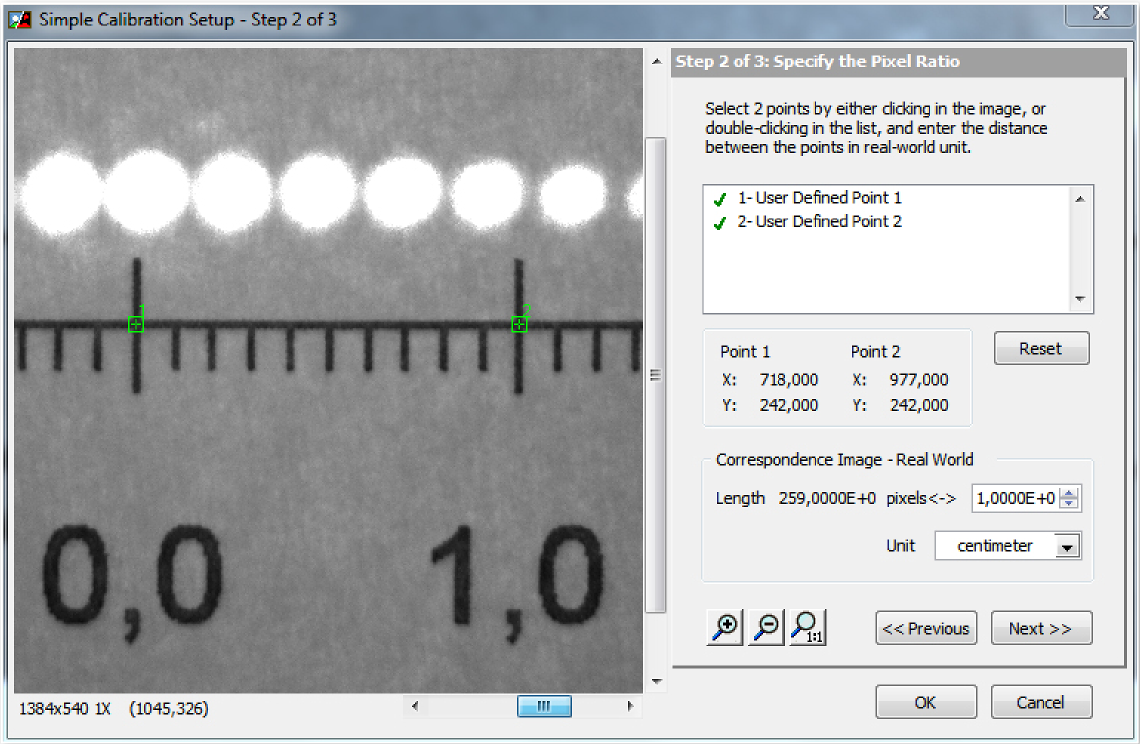
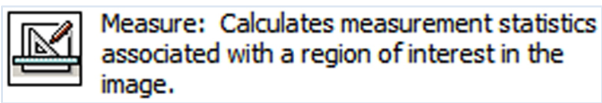


Figure 5. Calibration wizard for the program NI Vision Assistant (image preview with two points separated by a known physical length (1 cm))

5. After setting the reference distance, click *Next* and then *OK*. The calibration wizard will close.
6. Confirm the image calibration data by clicking *OK* in the function selection panel (1, *Figure 4).*

Measuring distances on images

1. After image calibration, you can make distance measurements between any two points. To do this, click *Measure* in the function selection panel (1, *Figure 4*):



2. Select *Length* from the list of possible measurements in the function panel (titled *Measure Setup*).

3. Use the mouse to select the two end points of the segment for the distance you wish to measure.
   The length of the segment in physical units will be displayed in the table of measurements in the script editing window (*Length = …*).
4. A series of distance measurements can be made by drawing new segments. Each new measurement will be stored on a separate line in the table.
5. Collected data can be saved as a text file or put in a spreadsheet in *Microsoft Excel*. To do this, click one of the buttons on the right-hand side of the script editing panel (*Save Results* or *Send Data To Excel*). The resulting file can then be imported into any program used for processing and visualising numeric data (e.g.: *Origin*, *Sigma Plot* amongst others).
6. To exit the *Measure tool*, click *OK* in the *Measure Setup* panel.

   You can always go back to the results of your measurements (or take more), by double-clicking the *Measure* icon in the script editing window.