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DLF
DYDAKTYCZNE LABORATORIUM FIZYCZNE

Experiment 1

Diffraction of laser light through a slit and a circular aperture

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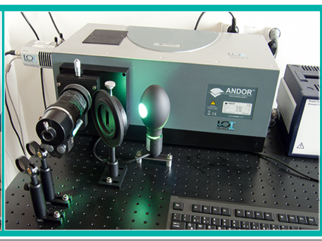
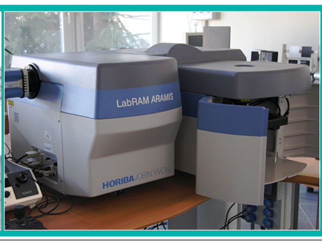
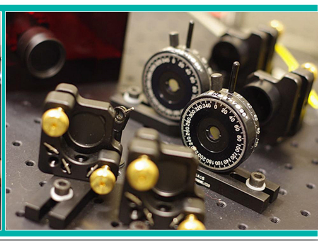




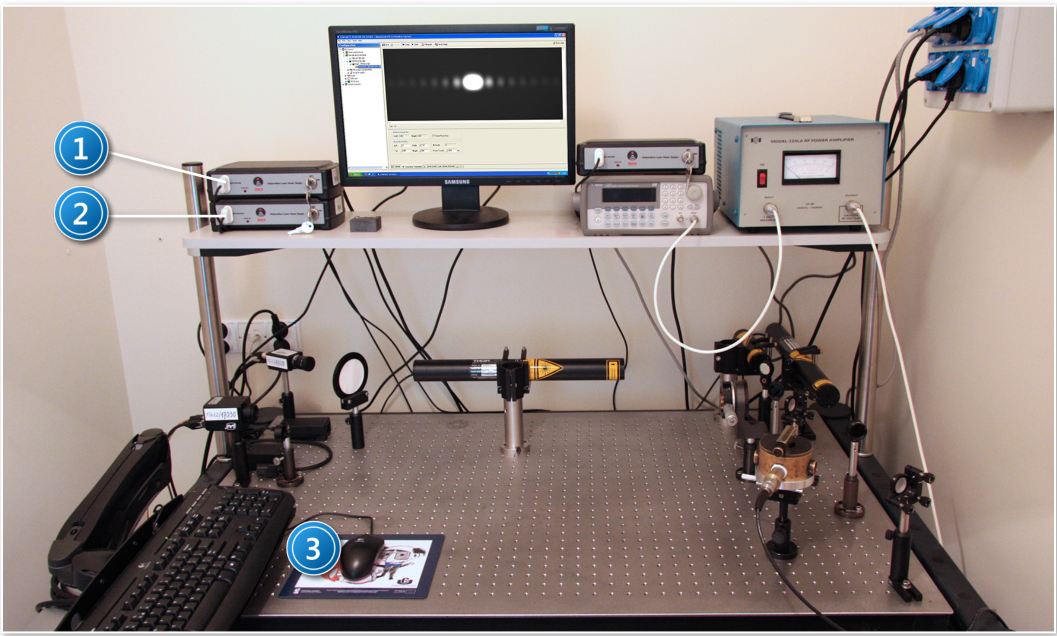


I. Background theory.

1. Periodic wave motion.
2. One-dimensional wave equation for transverse waves.
3. Particle-wave properties of electromagnetic radiation.
4. Interference of light:
   a) notion of coherence;
   b) Young's experiment;
   c) general conditions for interference.
5. Diffraction of light:
   a) Huygens principle;
   b) diffraction of light through a slit;
   c) diffraction of light through a double slit;
   d) diffraction of light through a circular aperture;
   e) light intensity distributions in images of diffraction phenomena I.5.b) – d).
6. Processes: absorption, spontaneous and stimulated emission.
7. Construction and operation of a He – Ne laser :
   a) energy levels of helium and neon atoms;
   b) the principle of pumping;
   c) principles of operation;
   d) optical resonator;
8. Properties of laser light.

II. Experimental tasks.

1. Refer to the experimental set-up shown in *Picture 1* and *Figure 2.*



Picture 1. Experimental set-up for studying laser light diffraction: 1, 2 –He – Ne laser power supply; 3 – computer.

2. Turn on the computer and both He – Ne laser power supplies (1 and 2, *Picture 1*) and the CCD camera power supply (8, *Figure 2*).

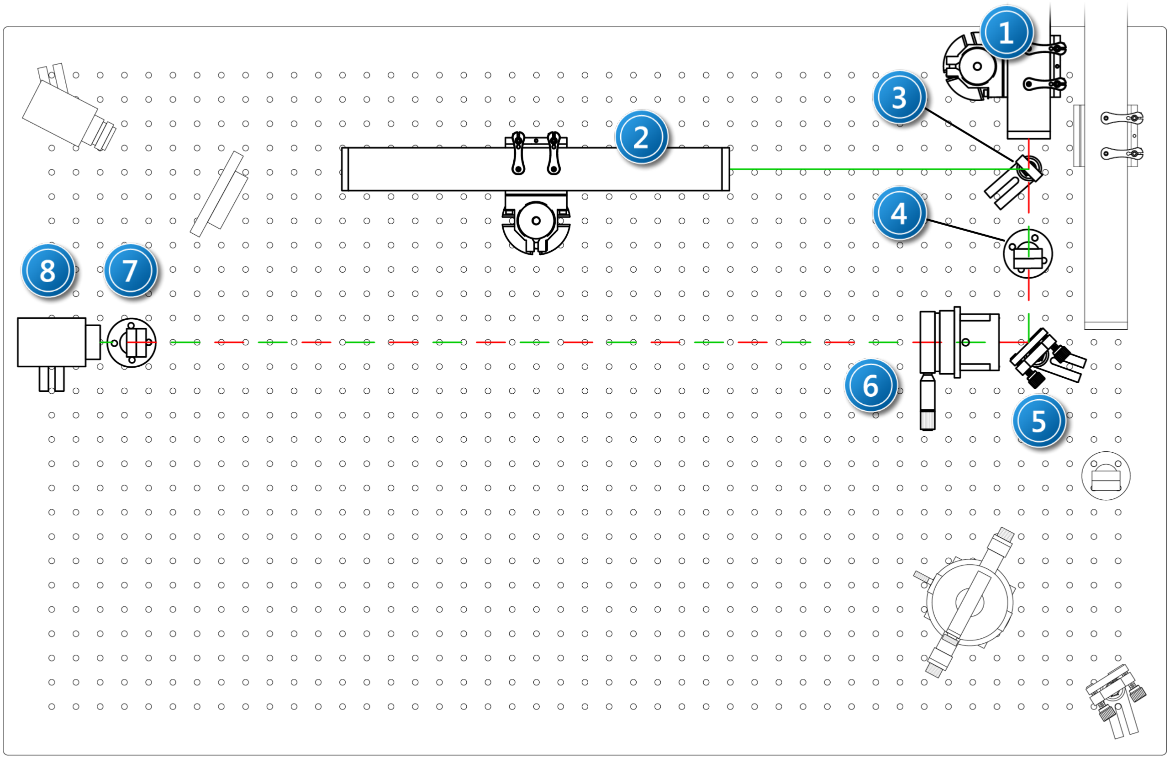


Figure 2. Optical layout: 1 –He-Ne laser (λ = 632,8 nm); 2 –He-Ne laser (λ = 543 nm); 3 – hinged mirror; 4 –gray filter; 5 – mirror; 6 – adjustable slit; 7 – hinged gray filter; 8 –CCD camera.

3. Start the program *Measurement & Automation Explorer* and enable the CCD camera display (see *Appendix A*).

   Ensure that the camera lens is not obstructed.
4. By removing the hinged mirror (3, *Figure 2)* from the optical path and adjusting the angle of the mirror (5 in *Figure 2)*, direct the red laser beam (1, *Figure 2*) precisely to the centre of the CCD camera lens.
5. Insert the single adjustable slit (6, *Figure 2)* in the path of the laser perpendicular to the beam.
6. Adjust the width of the slit (using the adjusting screw) to obtain a clear, balanced diffraction image.
7. Record an image of the resulting diffraction pattern as described in *Appendix A*.
8. Without adjusting the slit width, direct green laser light into the optical axis by inserting a mirror into the beam (3 in *Figure 2)*.

   By adjusting the mirror (5 in *Figure 2),* direct the beam through the centre of the slit.
9. Record the resulting diffraction pattern for the green laser.
10. Remove the single slit from the optical path and replace it by the circular aperture.
    Record the resulting diffraction pattern.
11. Graphically present the light intensity distributions in the obtained diffraction images.
12. Based on the measurement results obtained in section II.7., calculate the half-width of the central maximum.
13. Calculate the width of the slit (in II.8.).

14. Based on the measurements in II.7 – II.9. and the calculations in II.11. - II.13., determine the wavelength of the green laser (using the central band half-width or matching the resulting intensity distribution to the theoretical model).
15. Discuss errors.
16. Compare the result obtained in II.14. with the data printed on the laser.
17. Describe the differences in the observed diffraction images of the slit and circular aperture.

III. Apparatus.

1. Two He – Ne lasers.
2. He – Ne laser power supplies.
3. Two mirrors (one hinged).
4. CCD Camera.
5. Set of slits: single (adjustable), double, circular.
6. Set of gray filters.
7. Computer.

IV. Literature.

1. E.L. Goldwasser – "*Optics, Waves, Atoms and Nuclei*", W.A. Benjamin, Inc., 1965.
2. C.L. Andrews – "*Optics of the Electromagnetic Spectrum*", Prentice – Hall, Inc., N.Y. 1961.
3. M. Born, E. Wolf – "*Principles of Optics*", Pergamon Press Inc., 1970.
4. G.F. Lothian – "*Optics and it's Uses*", Van Nostrand Company, 1975.
5. O. Svelto – "*Principles of Lasers*", Plenum, New York 1998.
6. J. Orear – "*Physics*", Vol. 2. , Macmillan Publishing Co., Inc., 1979.

Appendix A

Support for the program *NI Measurement & Automation Explorer* and the *JAI RM – 4200GE CCD camera*

A. Starting the program and the CCD camera.

1. Start the program *NI Measurement & Automation Explorer* by double-clicking on the shortcut (bearing the same name), found on the desktop.

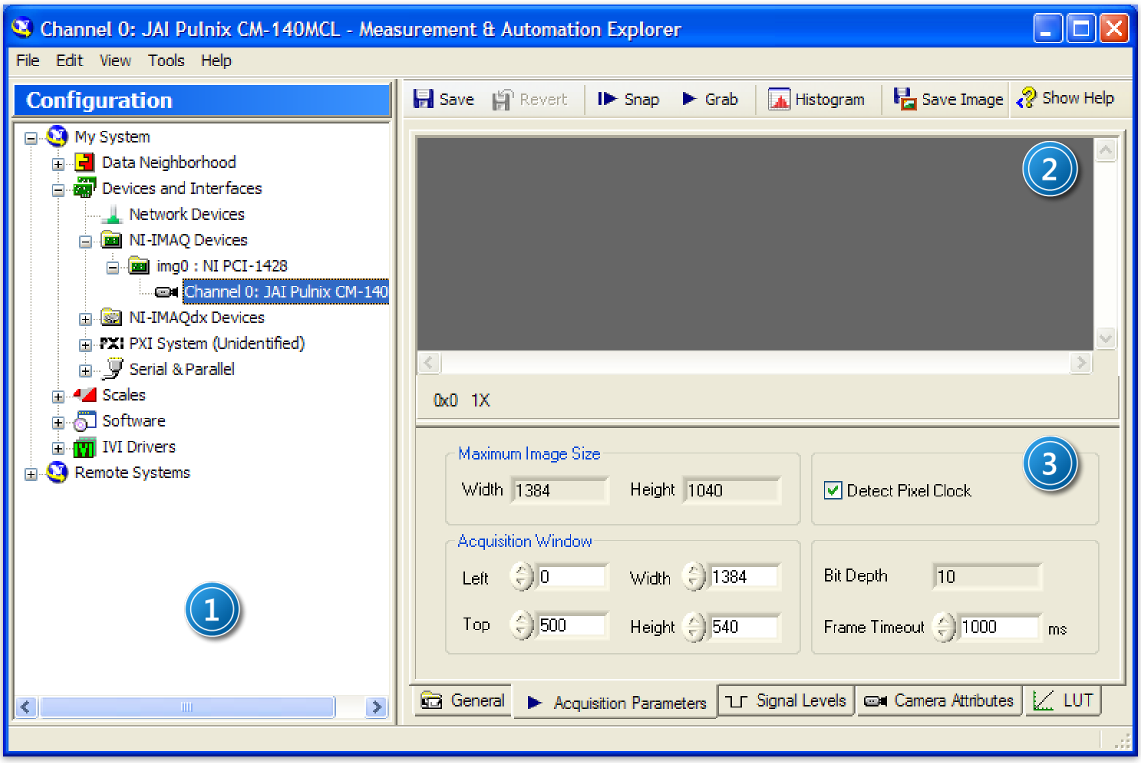


Figure 3. NI Measurement & Automation Explorer program window: 1 – left panel; 2 – CCD camera preview panel; 3 – panel for adjusting the camera parameters.

ATTENTION!

Before removing the CCD camera lens cap, ensure that the laser beam is filtered through the gray filter (4, Figure 2). Unattenuated laser light can damage the CCD.

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

   To do this, expand the section Devices and Interfaces and clicking on the ⊞ next to

NI-IMAQdx Devices, click on the camera interface symbol ***JAI Inc. RM-4200GE***, and then turn on the preview by clicking ▶ Grab in the preview panel (2, *Figure 3*).

4. After a few moments, the preview panel should show the image from the CCD camera.
5. If you receive an error message, ensure that the camera lens is not obstructed and that the camera is connected to the power supply.

B. Recording an image with the CCD camera.

1. The button ▶ Grab on the preview panel (2, *Figure 3*) is used to enable or disable continuous viewing of the CCD camera image.

   The preview can be turned off at any time by clicking this button, after which the last recorded frame will be displayed.
2. You can customise the display options of the camera image, such as fitting or zooming, by right-clicking in the preview panel.
3. At any time, the currently displayed image can be saved as *PNG* or *TIFF* by clicking the button Save Image and selecting a name, location and file format.

C. Upon completion.

1. To close the program *Measurement & Automation Explorer*, simply close the window.
2. Replace the CCD camera lens cap.
3. Announce to the supervisor of the experiment that you have completed your work.

Appendix B

Making distance measurements and obtaining a diffraction profile from CCD camera images using the program *NI Vision Assistant 2009*

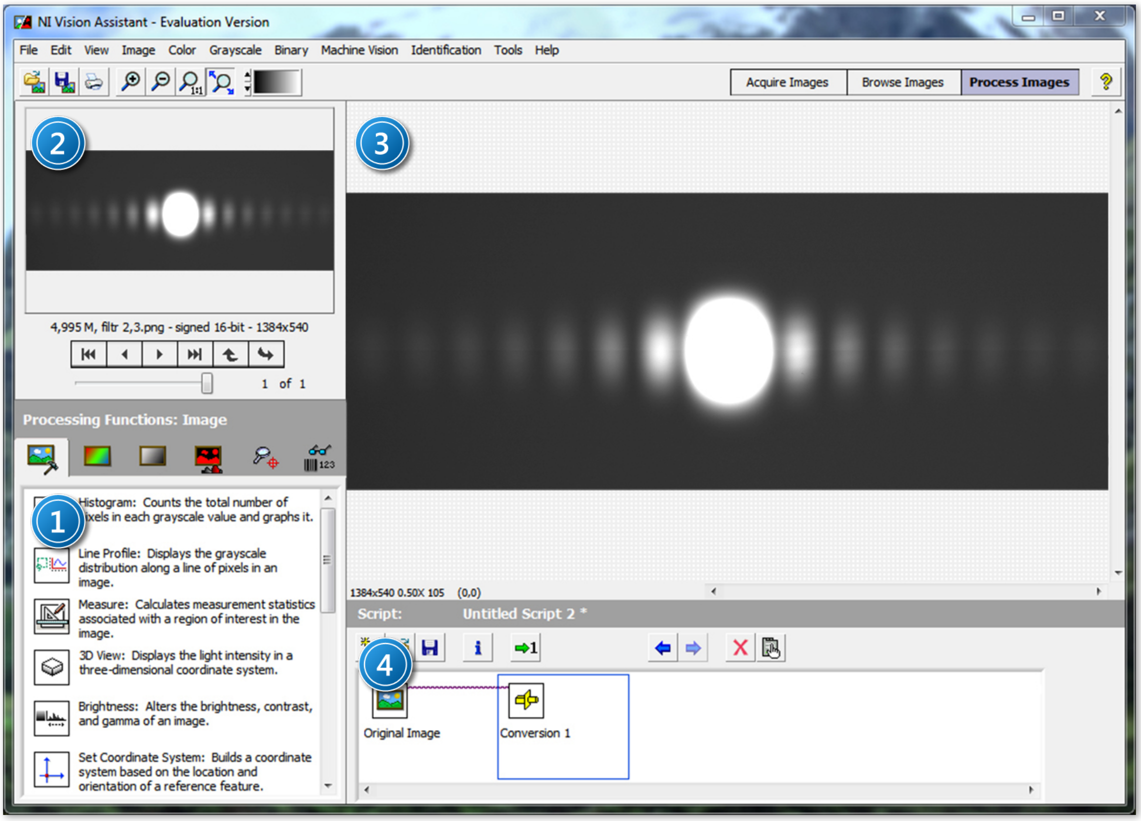


Figure 4. NI Vision Assistant program window: 1 – function selection panel; 2 – image selection panel; 3 – image preview panel; 4 – script editing panel.

A. General information.

The software program *National Instruments Vision Assistant* offers the ability to take measurements of geometrical properties of objects shown in raster images, such as distances between points, areas, diameters, etc. The program supports most of today's popular 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*).

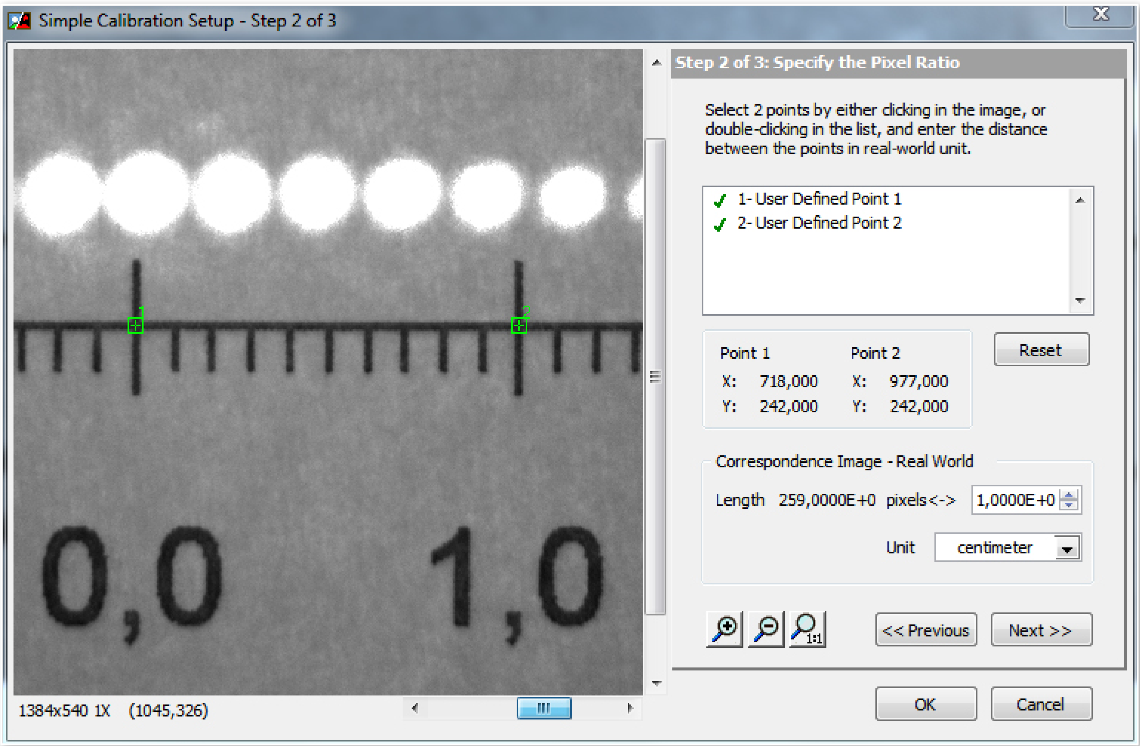
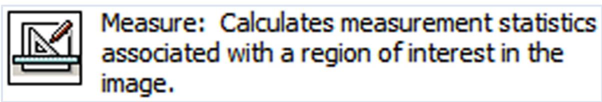


Figure 5. Calibration wizard for the program NI Vision Assistant (image preview with two points separated by a known physical length (1 cm))

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 = …*).

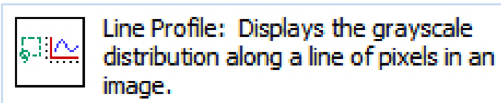
4. A series of distance measurements can be made by drawing new segments. Each new measurement will be stored on a separate line in the table.

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.

D. Obtaining a light intensity profile along a defined segment.

1. Click *Line Profile* in the function selection panel (1, *Figure 4*):



2. Use the mouse to mark a segment in the image preview panel (3, *Figure 4*) along which you wish to measure light intensity. To draw horizontal or vertical segments, hold the *Shift* key.

3. The light intensity profile along the marked segment is shown in the function selection panel marked *Line Profile Setup* (1, *Figure 4*).

ATTENTION!

If the resulting laser light intensity profile along the marked segment has a distinct plateau region in the central part (it is cut off), this means that there was an oversaturation of the image. In this case, re-acquire the image from the CCD camera, choosing the optimal (which guarantees a profile without oversaturation) set of hinged gray filters (7, *Figure 2*).

4. 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).

5. To exit the *Line Profile tool*, click *OK* in the *Line Profile Setup* panel.
   You can always go back to the results of measurements by double-clicking the *Line Profile* icon in the script editing window.