Principles of resolution and detail detectability

(Item No.: P2550400)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
ILIAS	Physik	Hochschule	Moderne Physik	Röntgenphysik

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	1 Hour	2 Hours	2 Students

Additional Requirements:

- PC
- Sample for CT

Experiment Variations:

Keywords:

Resolution, detail detectability, binning, focal spot size, magnification

Overview

Short description

Principle

In X-ray imaging, resolution is an important factor. It determines the sharpness of the images and the de-tails of a sample that can be observed. In this experiment, the different factors that determine the resolu-tion are investigated.

Fig. 1: Experimental set-up

Equipment

Position No.	Material	Order No.	Quantity
1	XRE 4.0 X-ray expert set, with tungsten tube	09110-88	1
2	XRCT 4.0 X-ray Computed Tomography upgrade set	09180-88	1

Tasks

1. Investigate the resolution in function of detector binning.
2. Investigate the detail detectability.
3. Investigate the resolution in function of SOD.

Set-up and procedure

Set-up

Attach the XRIS to its stage.

Place the Digital X-ray detector XRIS on the rail at position 35 cm. The back side of the XRIS stage cor-responds to its position on the rail. This position is called the 'source to detector distance' SDD (mm).

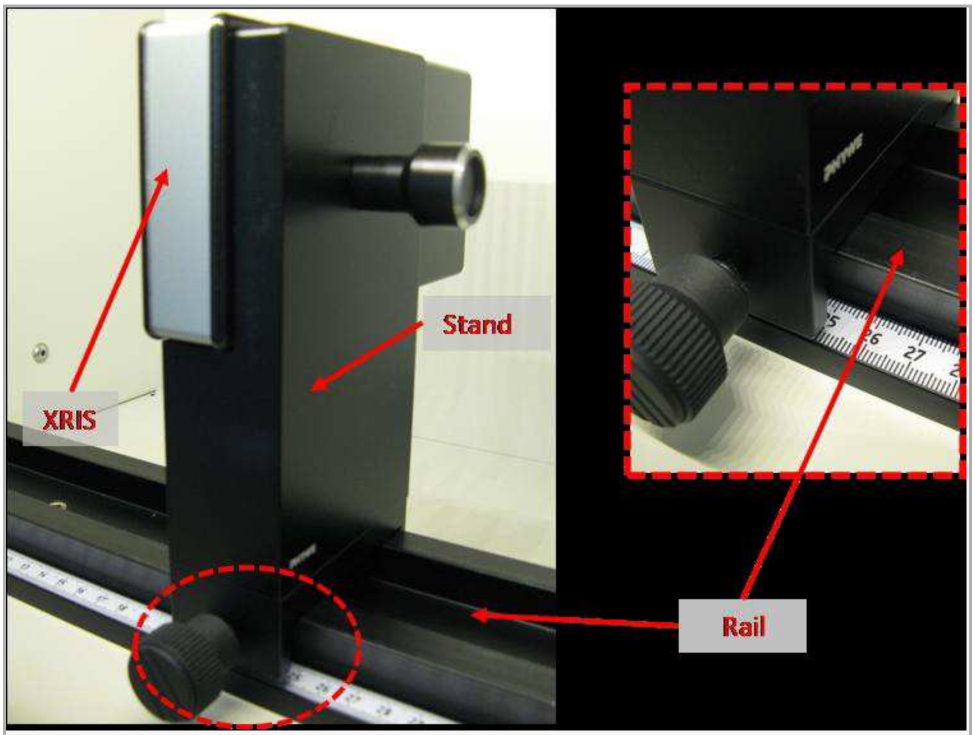


Fig. 2: Set-up of the XRIS

Note

Details concerning the operation of the X-ray unit and Detector as well as information on how to handle the detector can be found in the respective operating instructions.

Procedure

- Connect the X-ray unit via USB cable to the USB port of your computer (the correct port of the X-ray unit is marked in Fig. 3).

Fig. 3: Connection of the computer

- Connect the usb cable of the detector to the computer.
- Start the “measureCT” program. A virtual X-ray unit , rotation stage and Detector will be dis-played on the screen. The green indication LED on the left of each components indicates that its presence has been detected (Fig. 4).
- You can change the High Voltage and current of the X-ray tube in the corresponding input windows or manually on the unit. (Fig. 4).
- When clicking on the unit pictogram additional information concerning the unit can be re-trieved(Fig. 4).
- The status pictogram indicate the status of the unit and can also be used to control the unit such as switching on and off the light or the X-rays (Fig. 4.).

- The position of the digital detector can be ad-justed to its real position either by moving the XRIS pictogram or by filling in the correct value in the input window. (Fig. 4).
- The settings of the XRIS can be adjusted using the input windows. The exposure time controls the time between two frames are retrieved from the detector, the number of frames defines how many frames are averaged and with the binning mode the charge of neighbouring pixels is aver-aged to reduce the total amount of pixels in one frame.

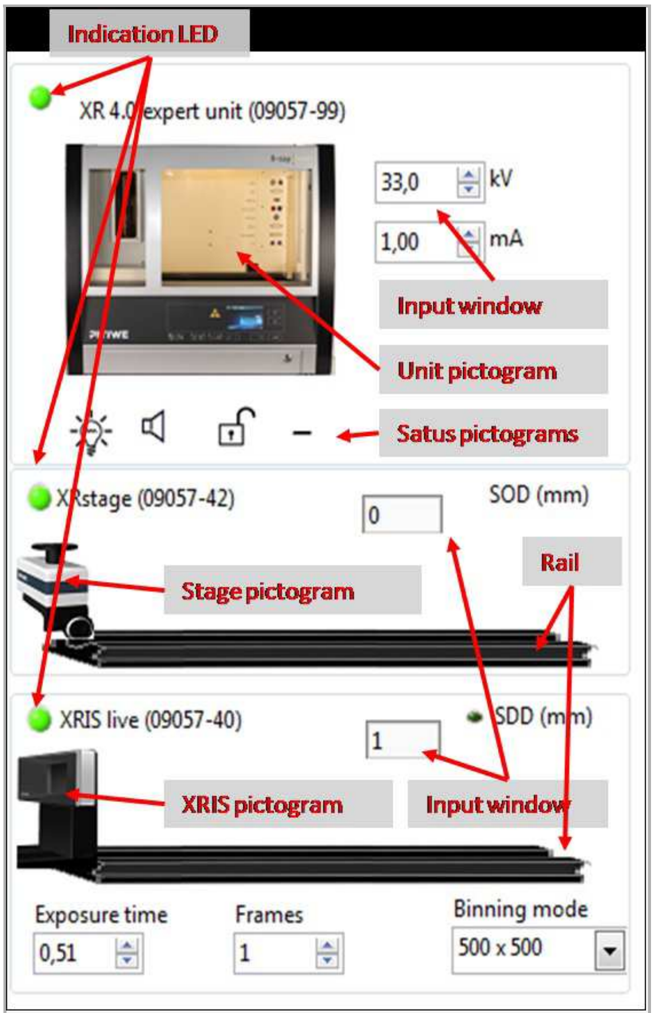


Fig. 4: Part of the user interface of the software

Experiment execution

1. Determine the resolution in function of binning

- Adjust the XRIS settings and X-ray unit settings according to Fig. 5 or load the configuration from the predefined CTO file 'Experiment 4' (see Fig. 6).

Overview of the settings of the XRIS and X-ray unit:

- 35kV, 1.00mA
- exposure time 1 sec
- Number of frames: 1
- Binning mode 250x250
- SDD= 350

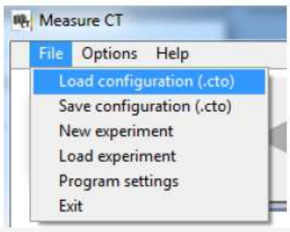


Fig. 5: The settings for this experiment (left panel) and the method load and adjust the settings (right panel)

- Start a new experiment, give it a unique name and fill in your details (Fig. 6). Alternatively it is also possible to load this experiment with pre-recorded images and open this manual. The correct con-figuration will be loaded automatically as well but the functionalities of the software will be limited to avoid overwriting the existing data.

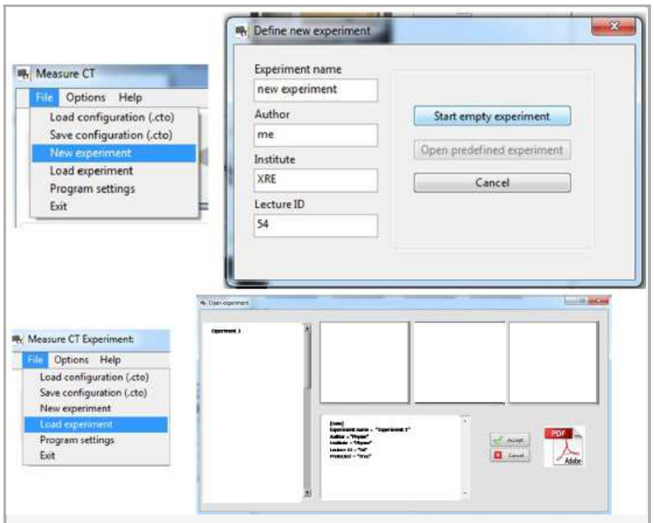


Fig. 6: How to create a new or open an existing experiment

- Check whether the detector is not saturated (see experiment 1)

- Calibrate the detector (see experiment 1)

- Place the object xx in the detector with its coloured side towards the source (see Fig. 7). This object contains a resolution pattern in the centre.

- Take a radiography of the object and save it as 'binning250_350' under the tif format.

- Remove the object

Adjust the detector binning (see Fig. 8) from 250x250 to 500x500 and repeat the previous steps while saving the image as 'binning500_350'.

Adjust the detector binning (see Fig. 8) from 500x500 to 1000x1000 and repeat the previous steps while saving the image as 'binning1000_350'.

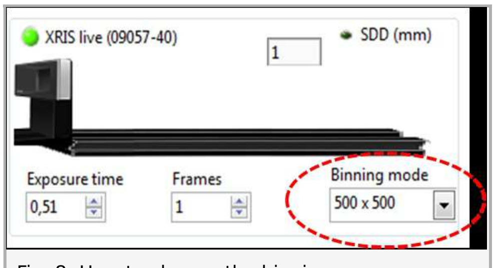


Fig. 8: How to change the binning

- Open the viewer (see experiment 1) and select the directory with the images you just saved.

- Start with the 'binning250_350' image. Play with the upper and lower levels of the histogram to clearly see all markings and change the middle colour to white.

- Start with the 1000 µm region (see Fig. 9), these are holes in the resolution pattern with a diameter of 1000 µm and the same distance between the edges of the holes. Adjust the cursors and look at the line profile (zoom in on the region if necessary). Move the image towards the 500µm region and re-peat this for all the regions. Determine for which region the circular holes are still separately visible, this is the resolution of this configuration.

- Determine what the contrast between the centre of the hole and the metallic plate of the resolution pattern itself is for all the visible hole-series using the line profile.

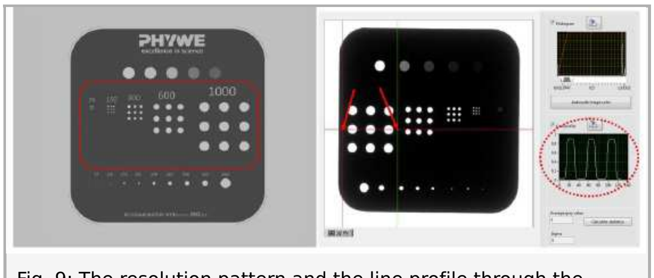
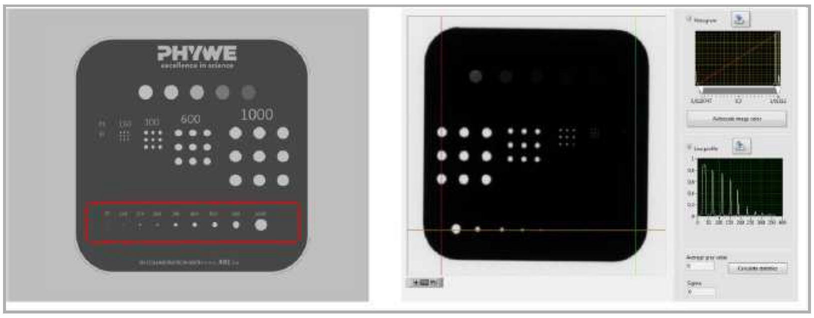


Fig. 9: The resolution pattern and the line profile through the 1000µm holes series

- Repeat this operation for the two other images and compare the results.

2. Investigate detail detectability

- Using the images previously saved images.
- Zoom in on the region with the single holes, start with the $1000\,\mu\mathrm{m}$ hole. Adjust the cur-sors and look at the line profile. Move the image towards the $500\,\mu\mathrm{m}$ hole and repeat this for all the holes. Determine which hole is still visible, this is the detail detectability for this configuration.



- Determine what the contrast between the centre of the hole and the metallic plate of the resolution pattern itself is for each hole.
- Repeat this operation for the two other images

Note: Although in bin 250x250, the smallest holes are not separately detectable anymore, the smallest hole, when it is alone is still detectable. this is the difference between resolution and detail detectability.

3. Investigate resolution in function of the SOD

Keep the detector in binning 1000x1000 and calibrated. Place the object XX on a stand and take some images with the stand on different positions: $250\,\mathrm{mm}$, $200\,\mathrm{mm}$, $100\,\mathrm{mm}$. Save the images as 'bin-ning1000_XXX' with XXX the position of the stand.

Compare the resulting images with 'binning1000_350' recorded before. Determine the resolution and de-tail detectability of these images.

Note: By placing the object closer to the X-ray source, the projection of the object will be magnified upon the detector. At that point the resolution is not only determined by the resolution of the detector alone but also by the resolution of the X-ray source. As the resolution of this source is inferior to the detector reso-lution, the image will be blurred and the resolution will be less good.

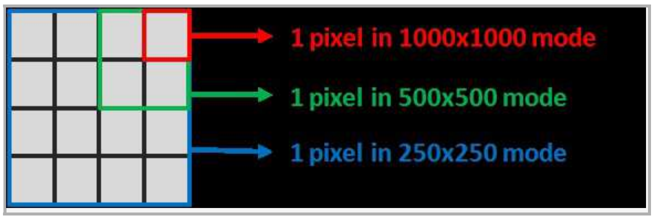
Theory

Detector binning

The Xris is a digital sensor composed of 1000×1000 (1000^2) pixels (picture elements). Each X-ray pho-ton that interacts with the detector generates a signal under the form of a charge that is collected by the pixel corresponding to the location of the interaction. During read-out, the total charge that was collected by each pixel during the exposure time is converted to a digital signal by a digital-to-analogue converter (DAC). This signal is displayed as a grey-value in a 1000×1000 array to form a $1\,\mathrm{Mpix}$ image.

When detector binning is used, the charge corresponding to several pixels is averaged to represent one new pixel. In the 1000×1000 mode, no binning is applied while for the 500x500 mode 4 pixels are grouped together to generate a 500^2 pixels image, and for the 250×250 mode, 16 pixels are grouped to-gether.

Binning has the advantage that the size of the images becomes much smaller, which is very intersting for CT as a large number of images are recorded and reconstructed.



Definition of contrast

Contrast is the difference in luminance that makes an object distinguishable. There are many possible definitions and ways of calculating contrast that are used in different situations. Also in X-ray imaging contrast can have different meanings and be measured in a different ways.

Overall, the most representative way of expressing contrast (C) between two objects in an X-ray radio-graph is as their absolute difference in transmission:

$$C = T_{obj1} - T_{obj2}$$

with T_{obj1} the transmission of object 1 and T_{obj2}, the transmission of object 2.

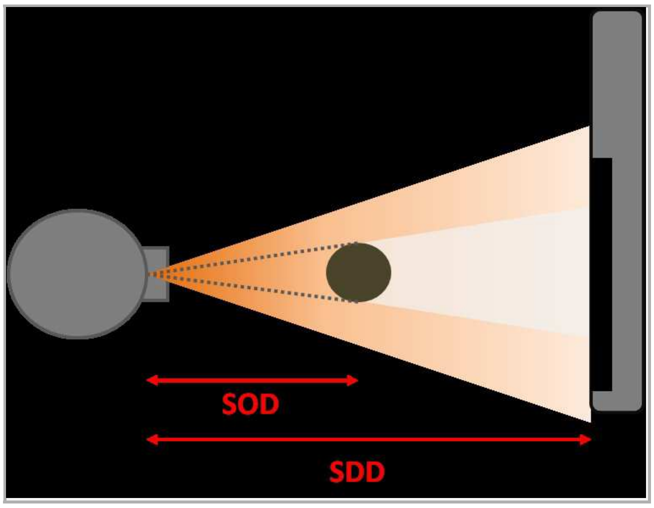
The best possible contra$stexistswhenoneobjectshasnoabsorption$(\($T = 1 - A = 1$) while the other object has no transmission (\)T = 1 - A = 0). The C-value can either be expressed as a value between 0 and 1 or as a percentage ($0 - 100\,\%$).

In these experiments the absorption of air is taken into consideration when calibrating the detector, therefore the air has no absorption ($T_{air} = 1 = 1 - A_{air}$).

Principle of X-ray imaging resolution

In an X-ray source, all the X-ray photons originate from one location on the target of the source, this lo-cation is called the focal spot of the source. The generated X-rays leave the focal spot in all possible di-rections and a part of the beam illuminates the detector, this part of the beam is called the field of view. As the origin of the X-rays is a point and the field of view beam conical, each object placed between the source and detector is magnified upon the detector. The level of magnification (M) is the relation be-tween the distance of the object to the source (SOD) and the detector to the source (SDD).

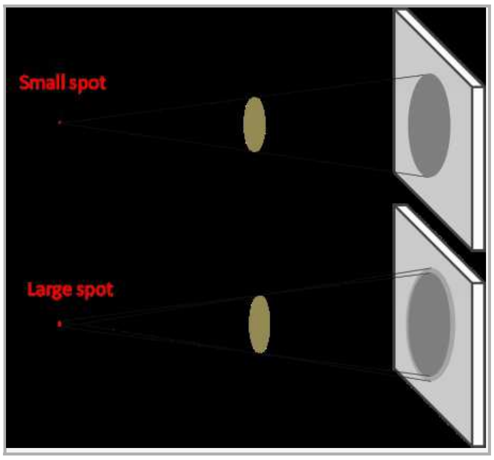
$$M = \frac{SDD}{SOD}$$



The resolution of an X-ray system is mainly determined by the detector resolution and the focal spot size resolution.

- Detector resolution: The maximal obtainable resolution of a detector is its pixel size. The XRIS has a pixels size of $48\,\mu\mathrm{m}$ in the 1000×1000 binning mode. When the detector is used in 500×500 binning mode, four pixels are grouped together as one and the resolution becomes two times lower with $96\,\mu\mathrm{m}$. In reality, the resolution is slightly inferior to this because the interaction of one single X-ray photon can cause a signal in more than one pixel.

- Focal spot size: The smaller the size of the focal spot, the sharper the radiography. When the focal spot has a certain size, the X-ray projection of the object in the field of view is slightly blurred. this blurring is proportional to the size of the spot and the magnification.



The relation between the detector pixels size (d), the focal spot size (s) and the system resolution (R) can be simplified with this formula:

$R = \frac{d}{M} + s(1 - \frac{1}{M})$

If the object is placed very close to the detector ($M = 1$), the resolution equals the pixel size. The closer the object is brought to the source, the more important the spot size becomes. If the spot size is larger than the pixel size, bringing the object closer to the source will magnify it but will worsen the sharpness of the image.

Resolution versus detail detectability

Resolution on itself is a relatively vague term as it can be defined in many ways. But it is important to discriminate resolution from detail detectability. Detail detectability refers to the ability to identify one de-tail. Even if the detail is smaller than one pixel, it can often be identifies if its signal is sufficiently different from the surroundings. resolution on itself is the ability to disciminate two small features that are placed very close to each others.

The easiest way to verify the resolution of a system is by using a resolution pattern.