

08/13-W07-Hund



## Instruction Sheet 554 828

X-ray image sensor (554 828)

Precision slide X-ray image sensor (554 829)

Software Computed Tomography Pro (554 820)

Sensor head on precision slide with USB module

## 1 Safety notes

The X-ray image sensor and the software are designed for education in schools and universities. The values determined and representations do not have any meaningfulness for medicine.

The x-ray apparatus may only be operated in conformity with the operating instructions for the x-ray apparatus.

- Power the USB module using only the power supply unit (6.5 V=) supplied.
- Use only the dual link DVI cable supplied for connecting the USB module to the X-ray image sensor.
- Handle the carbon-fibre surface of the X-ray image sensor carefully.

## 2 Description

The X-ray image sensor (554 828), consisting of a sensor head and a USB module, is used for recording X-ray images in the experimentation chamber of an X-ray apparatus (e.g. 554 800). In order to achieve this, the X-ray radiation is transformed to visible light in the sensor head by means of a scintillator screen. Between this scintillator screen and CMOS image sensor behind it, the remaining X-ray radiation is screened by a fibre optics system in order to ensure a long service life for the image sensor.

The analogue output signal from the sensor head is transmitted to the USB module outside the X-ray apparatus via the DVI cable included. The digital X-ray image is created there for direct transmission to the PC.

The separately available precision slide (554 829) serves to precisely position the X-ray image sensor in the X-ray apparatus. Computed tomograms are recorded at the right-hand end of the rail. The centre of the image sensor can be aligned there precisely on the rotational axis of the goniometer. The left-hand end of the rail is well-suited for the production of digital Laue images.

The software Computed Tomography Pro (554 820) is used for the automatic recording, taking only a few minutes, of projections of the X-rayed object as a function of the angle. During the recording, the back-projection process is visualised in either two or three dimensions. This means that cross-sections and 3D images of the unfinished 3D object are available using all of the 3D viewing tools (rotate, zoom, transparency effects, sections, stereoscopic view, and illumination similar to the Heidelberg ray tracing model). With every further angular step, the back-projection process adds to the 3D object until it is finally complete.

Despite the low X-ray energy of 35 keV of a school X-ray device, highly resolved computed tomograms of various objects can be recorded and evaluated qualitatively and quantitatively. The emphasis is on the didactic processing of the recording process and the evaluation.

In addition to the software, the Package Computed Tomography Pro (554 820P) also includes the X-ray image sensor (554 828) and the precision slide (554 829). An appropriate X-ray apparatus and a high performance computer are required in addition.

### 3 Technical data

#### 3.1 Analogue sensor head

- Sensor: CMOS without pixel line defects (Premium Grade)
- Sensor area: 49.2 mm x 48.0 mm (shielded for increased durability)
- Resolution: 1024 pixel x 1000 pixel
- Pixel size: 48 µm x 48 µm
- Video output: analogue (0.5 µV/electron)
- Connection: Dual-Link DVI socket
- Housing: Special steel
- Dimensions: 75 mm x 88 mm x 34 mm
- Mass: 500 g

#### 3.2 Digitalising USB module

- Resolution AD converter: 12 bit greyscale
- Read-out time: approx. 3.3 s
- Connection: USB 2.0 (full speed)
- Dimensions: 186 mm x 165 mm x 30 mm
- Mass: 700 g

The SYNC IN and the SYNC OUT connections are suitable for the external sensor synchronisation and are currently not used.

#### 3.3 Software

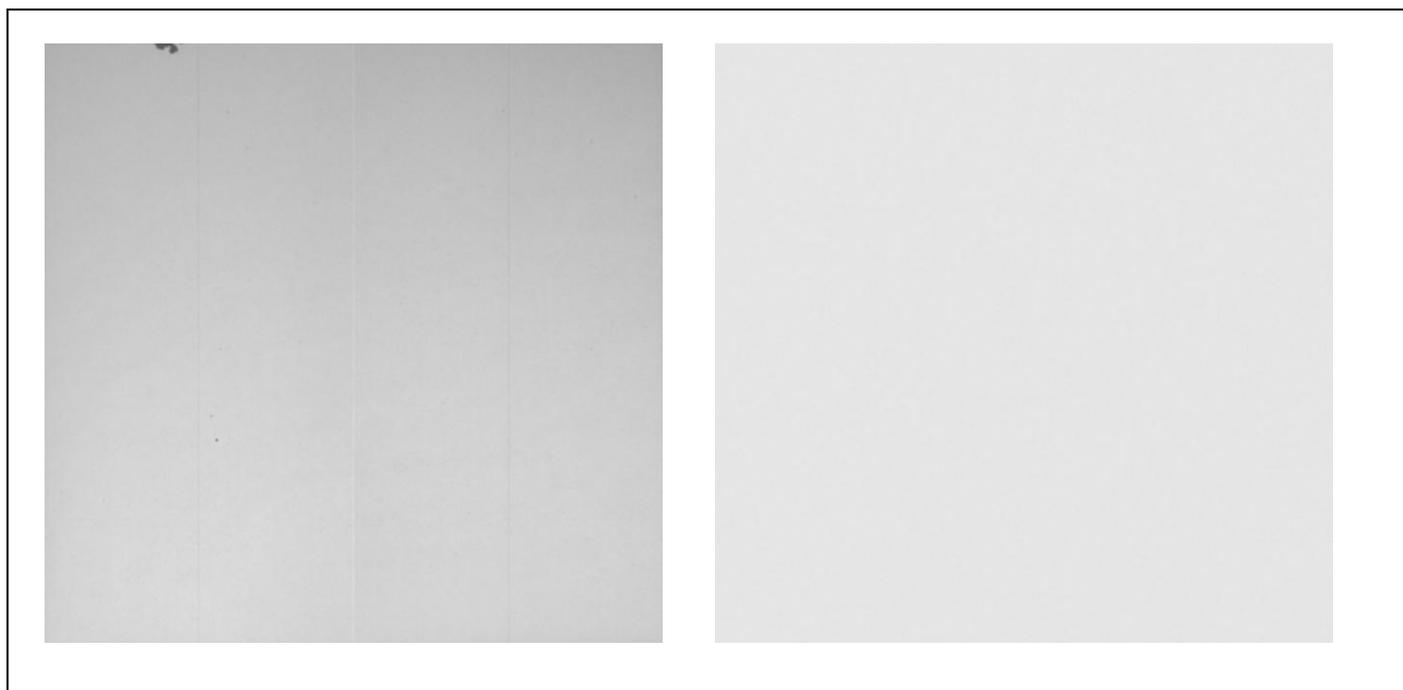
- Control: X-ray apparatus, goniometer, and image sensor over USB
- Number of projections: 1/4/15/45/90/180/360/720 images per computed tomogram
- Angular resolution: up to 0.5°
- Size of the computed tomogram: 200 ... 940 pixels per dimension (8 ... 830 megavoxels)
- Versions: 32 bit and 64 bit (for larger computed tomograms)

#### 3.4 Image faults

Image faults cannot be totally excluded for large area CMOS sensors. The CMOS sensor does not have any defective pixel lines or pixel columns (premium grade). It may, however, have up to 3 cluster faults (2x7 pixels) which can be taken account of by means of a pixel correction (see section 9.2).

Independently of this, individual pixels or pixel areas can have various sensitivities to X-ray radiation and, in addition, the X-ray tube does not uniformly illuminate the image sensor.

In order to correct these effects, a flat-field correction should be executed before recording a computed tomogram based on several white frames (flat-field correction, see section 9.2). For such a correction, the subsequently recorded X-ray images are divided by the determined reference image and in that way have a uniform intensity distribution, which is important for the calculation of high quality computed tomograms.



Typical possible intensity faults of the X-ray image sensor. In the left-hand image three smaller dark areas, three vertical lines of a modified intensity and a slightly irregular illumination of the image are apparent. All these effects are automatically corrected by the flat-field correction as shown in the right-hand figure.

## 4 System requirements

Both for the X-ray apparatus and for the PC, minimum requirements apply.

### 4.1 Minimum requirements for the X-ray apparatus

The X-ray apparatus has to have a channel for the DVI cable to pass through, e.g. basic X-ray apparatus (554 800 or 554 81).

For the recording of computed tomograms, a goniometer and a USB port are also required, e.g. X-ray apparatus Mo (554 801 or 554 811USB). The X-ray apparatus (554 81) with the serial interface cannot be used for computed tomography.

The X-ray tube used is responsible for the intensity of the images. We recommend the use of a W or Au tube.

The firmware for the X-ray apparatus has to be compatible with the computed tomography software:

- for 554 801: version 1.03.A-2.2 or newer
- for 554 811USB: version 3.03 or newer

The version is displayed in the settings of the software.

The up-to-date firmware is contained in the X-ray apparatus program which can be downloaded from <http://www.ld-didactic.com/software/xrsetup.exe>.

### 4.2 Minimum requirements for the computer

- PC with Windows XP SP3 or Vista/7/8 (x86 or x64)
- Dual-core processor 2.4 GHz
- 3 GB RAM
- 3D graphics card (Nvidia GT 630 / AMD HD 6670 or better)
- 2 x USB 2.0-Port
- DVD drive

### 4.3 Recommended requirements for larger computed tomograms

- PC with Windows Vista/7/8 (x64)
- Quad-core processor 3 GHz
- 8 GB RAM
- 3D graphics card with 2 GB RAM (Nvidia GTX 660 Ti / AMD HD 7870 or better)
- 2 x USB 2.0-Port
- DVD drive

## 5 Installation of the X-ray image sensor

- Attach the sensor head by means of the four screws supplied to the precision slide.
- Insert the precision slide with the sensor head into the 4 mm sockets provided for this purpose in the experimentation chamber of the X-ray apparatus.
- Push the DVI cable through the cable channel and fix the sensor head on from above.
- For the adjustment of the height and parallelness to the goniometer axis for the computed tomography, carry out a correction of the rotational axis in the software (see section 9.3).

## 6 Software installation

The software installation is done either

- automatically after the CD-ROM is inserted or
- manually by starting the setup.exe file

and by observing the instructions given on the screen.

If necessary, .NET Framework 3.5 and DirectX Runtimes are installed during the software installation.

Manual driver installation is not required for the X-ray image sensor. It is automatically installed as a mass storage device both by Windows x86 (32 bit) and by Windows x64 (64 bit).

### 6.1 Activation code

An activation code is required for the operation of the software with the X-ray image sensor (554 828) as a computed tomograph. This activation code is found on the delivery note for software 554 820 and consists of a name and a code. Both pieces of information together activate the software at  **Help** → **About** ....

For the evaluation of radiography images, the creation of Laue images (see section 8) or for the creation of computed tomograms with the computed tomography module (554 821) no activation code is required.

## 7 Handbook

After the installation, the handbook for the software is available as a PDF file under Start → Programs → Computed tomography. For reading and printing the handbook, an Adobe Reader must be installed. It is available for free downloading at <http://www.adobe.com>.

The purpose of this handbook is to give an overview of the facilities of the computed tomography software. Its text is identical to the help which can be called at all times from the program by a click of the mouse.

## 8 Laue images

After successful installation, the computed tomography software can be found at Start → Programs → Computed tomography.

A more comprehensive description of the program functions is found in the handbook also found there and in the help contained in the program.

For the creation of Laue images, neither an activation code (see section 0) nor a powerful PC are required.

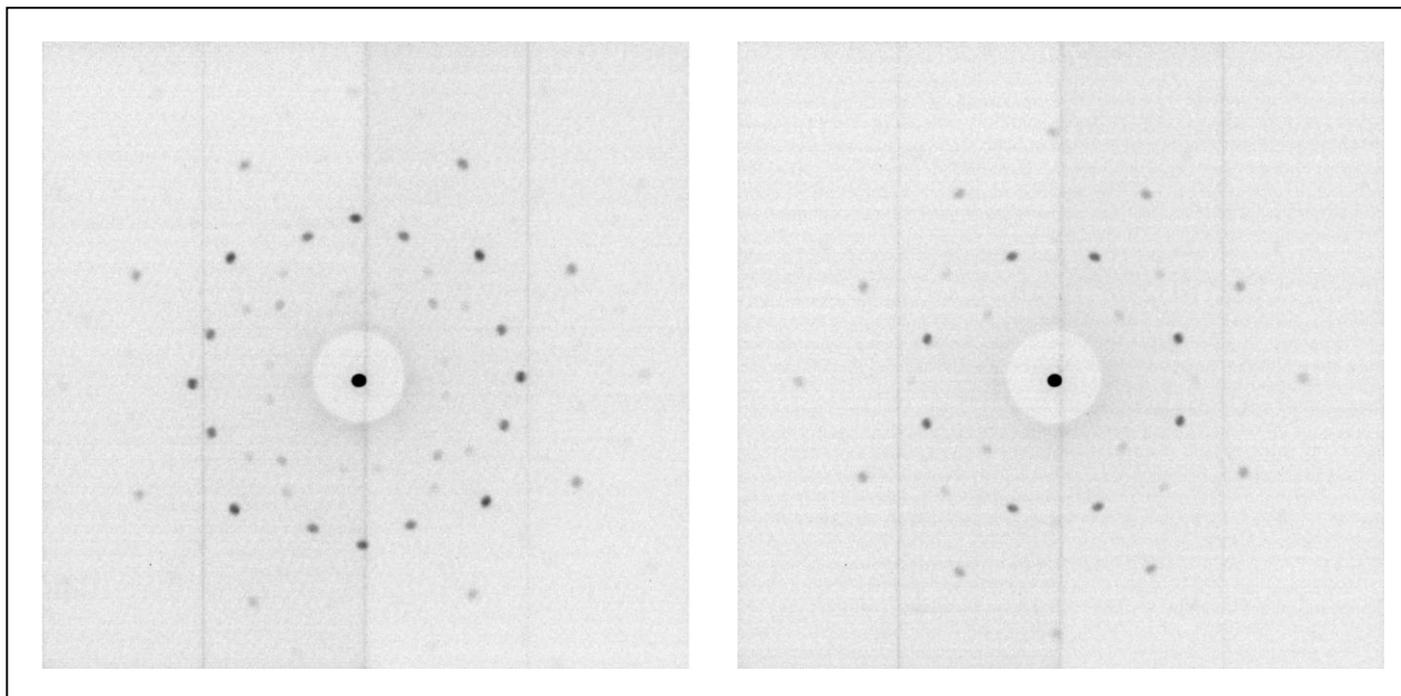
### 8.1 Preparation

- Insert the W, Au, Ag or Mo (tungsten, gold, molybdenum or silver) X-ray tube into the X-ray apparatus. A W tube or Au tube provides a better contrast than the much weaker Mo tube or Ag tube.
- Insert pinhole collimator (in 554 8381) and fit crystal.
- In order to make Laue images less affected by interferences, cover the centre of the X-ray image sensor by means of a beam stop (in 554 8381).
- Place the X-ray image sensor in front of the crystal at a distance of approx. 1.5 cm. The X-ray image is created 2 mm behind the carbon-fibre surface.
- Connect the devices to the PC and switch them on. Allow the X-ray image sensor to warm up for approx. 5 minutes.
- Start the computed tomography software.

### 8.2 Creating Laue images

The settings are located in 6 fields (Camera, X-Rays, Radiography, ...), which can be opened up with .

- The X-ray image sensor has to record dark images. This is apparent by the flashing of the red dot () in the camera settings. If not, check the connections and video device in the **Camera settings**.
- Set the integration time in the **Camera settings** to 3500 ms.
- Record the offset image. For this approx. 10 images have to be averaged before the offset can be completed.
- Switch on the **X-Rays** by clicking .
- Record reference image. While making this recording of the reference image, the intensity and the contrast can be readjusted in the **Radiography** (open with ) and the Laue image can be made visible.
- After approx. 10 images stop the **Camera** by clicking  and thereby stop the averaging of the Laue image.
- As a special evaluation for Laue images, the distances between two peaks can be determined with  **Radiography** → **Create Line Profile** → **Line Between Peaks**.
- If desired, the original image or a contrast-enhanced image can be saved with  for further processing. If the image is saved in the \*.png or \*.tif format, the high greyscale resolution (16 bit) allows saving of the original image. If the intensity or the contrast of the saved image is to be changed, saving as \*.bmp with a normal greyscale resolution (8 bit) is necessary.



Digital Laue images of NaCl and LiF. The 0<sup>th</sup> order reflexion was shielded by a small plate. The three vertical lines indicate increased noise on account of the geometry of the CMOS sensor.

## 9 Computed tomograms

After successful installation, the computed tomography software can be found at Start → Programs → Computed tomography.

A more comprehensive description of the program functions is found in the handbook also found there and in the help contained in the program.

### 9.1 Preparation

- Insert the W, Au, Ag or Mo (tungsten, gold, molybdenum or silver) X-ray tube into the X-ray apparatus.
- Remove the collimator, sensor holder and the target holder from the X-ray apparatus.
- Push the goniometer to the right-hand side and secure it.
- Attach the object under investigation to the goniometer axis and close the doors. Preferably, the small objects are stuck onto Lego plates (e.g. from 554 826) and attached to the Lego adapter (also from 554 826) on the goniometer.
- Connect the devices to the PC and switch them on.
- Start the computed tomography software.

### 9.2 Starting up

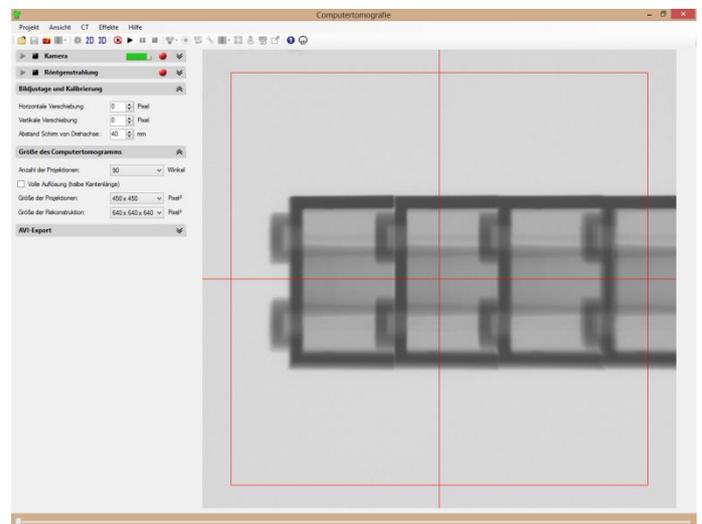
Before it is used as a computer tomography device, the precision slide has to be adjusted. As an object for investigation, a few Lego bricks mounted on the Lego adapter are sufficient (e.g. in 554 826).

The settings are located in 6 fields (Camera, X-Rays, ...), which can be opened up with .

- The X-ray image sensor has to record dark images. This is apparent by the flashing of the red dot (●) in the camera settings. If not, check the connections and video device in the **Camera settings**.
- Set the integration time in the **Camera settings** to 825 ms (for W and Au tubes) or to 1750 ms (for Mo and Ag tubes).
- If the black camera image shows irritating light spots, these can be suppressed by means of a defective pixel list in the **Camera settings**. The same applies to individual, disruptive, dark spots when the X-ray radiation is switched on.
- The offset and flat-field corrections are also possible there in order to improve the quality of the computed tomogram. During the flat-field correction, the object to be investigated has to be removed briefly and the X-ray radiation has to be switched on.
- Switch on the **X-Rays** by clicking .
- If the exposure display next to the upper, flashing, red dot (●) indicates overexposure, either reduce the integration time by one step or reduce the anode current of the X-ray tube.
- Carry out **Image Adjustment and Calibration**. The parameters set there are saved and will be available when the program is started up again. If the adjustment of the image and the calibration have been successfully carried out and the experimental setup has not been changed it does not need to be carried out again.
- The **horizontal shift** of the red wire cross is set in such a way that the wire cross is placed horizontally in front of the tube and should remain at 0.
- The **vertical shift** of the red wire cross from the centre of the rotational axis should also remain at 0. It is recommended to remove the offset with respect to the rotational axis by means of the two adjustment screws on the preci-

sion slide, which are turned following the instructions for the correction of the rotational axis.

- The **distance of the screen from axis of rotation** is required for the length calibration of the tomograph. The recommended distance of 40 mm corresponds to the goniometer shifted to the very right and to the sensor head shifted to the very right. The fluorescent screen on the sensor head is located approx. 2 mm behind the carbon-fibre surface.
- Set the **size of the computed tomogram** to 90 projections with a projection size of 450x450 pixel<sup>2</sup> and the size of the reconstruction to 320x320x320 pixel<sup>3</sup>. If desired, choose **Full resolution (half edge length)** and double the reconstruction size.
- Select  **CT → Start CT scan**, enter the activation code if this has not been done earlier (see section 6.1), enter a project name and wait for the scan to be completed. During the scan it is possible to switch between a 2D and a 3D representation. The correction of the rotational axis is located after the end of the scan in the 2D representation.

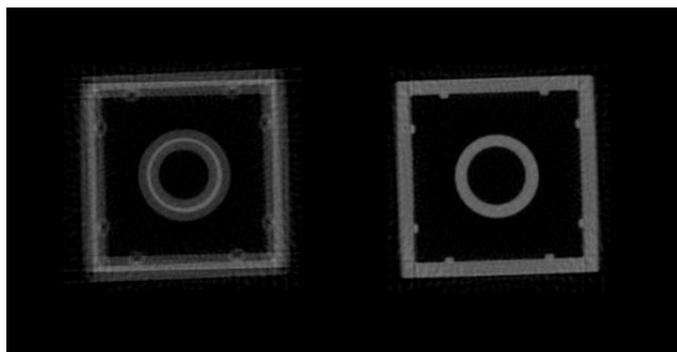


An adjusted X-ray image sensor with Lego bricks.

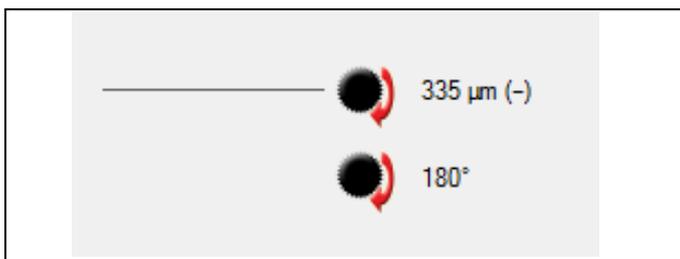
### 9.3 Correction (open with )

After the scan, the rotational axis can be corrected to the set z-position (large slide bar). A false rotational axis leads to double edges in the computed tomogram. These double edges can be prevented by a correction of the rotational axis:

- Carry out the correction of the rotational axis for z = 25% (left edge) and select **1st position**. Afterwards, the software will attempt to automatically optimise the image sharpness in the range  $\pm 3$  pixels. If this is not successful, re-adjust manually and select **1st position** once again.
- Carry out the correction of the rotational axis for z = 75% (right edge) and select **2nd position**. Afterwards, the software will attempt to automatically optimise the image sharpness in the range  $\pm 3$  pixels. If this is not successful, re-adjust manually and select **2nd position** once again.
- Adjust the adjustment screws on the precision slide or the computed tomography module as shown in the illustration.
- Repeat computed tomogram via  **CT → Start CT scan**.
- After the second correction at the latest, no further correction of the rotational axis should be necessary.



A Lego brick with faulty and correct rotational axis.



Adjustment diagram with the information provided for the manual correction of the rotational axis. In this case the thumbscrew has to be turned clockwise by 180° and the fine drive 335 μm downwards (also clockwise).

### 9.4 Scanning

- If this has not already been done, increase the quality of the computed tomogram in the **Camera settings** by applying an offset and flat-field correction.
- Select the number and size of projections as well as the size of the reconstructions (see section 9.5) depending on the desired quality and time to be expended. The projections should always be a little larger than the reconstructions. It is recommended to start with fewer angles and smaller reconstructions. Only when you are sure that the camera alignment is good can the settings be increased. This method saves a lot of measuring time.
-  Start the CT scan. The remaining scanning time is displayed in the upper right corner.

### 9.5 Reconstruction sizes

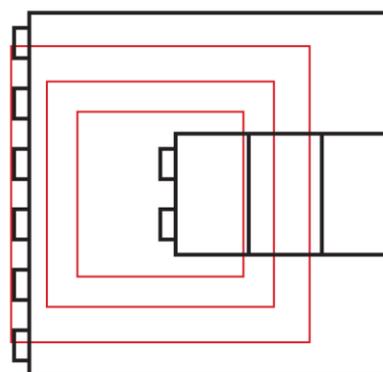
Normally CTs are calculated with half the sensor resolution of 96 μm or **512 x 500 pixel<sup>2</sup> (binning 1:2)**. This means that the projections have a maximum size of 500 x 500 pixel<sup>2</sup> and that the maximum sensible length of the edge of a computed tomogram of 460 pixels is approx. 4 cm in reality. The PC and the graphics card then process up to 100 megavoxels (100 million volumetric pixels).

With particularly powerful computers, the full sensor resolution of 48 μm or **1024 x 1000 pixel<sup>2</sup> (without binning)** can be deployed. In this way the maximum size of the projections is increased to 1000 x 1000 pixel<sup>2</sup>. The edge length of 460 pixels is then only approx. 2 cm, but can be increased to 940 pixels (corresponds to approx. 4 cm). This increases the demands on the PC and the graphics card because then over 830 megavoxels have to be processed, which can only be realised by means of a 64 bit operating system with 8 GB RAM and a high-performance graphics card.

If the performance of the graphics card is not sufficient to render a new 3D image within 2 s, Windows will stop the graphics driver and then re-start it. In this case please select the smaller reconstruction size or a more powerful graphics card.

Reconstruction size	Binning	Cube edge	File size
200 x 200 x 200 pixel <sup>3</sup>	1:4 (170 μm)	3.4 cm	30 MB
240 x 240 x 240 pixel <sup>3</sup>	1:4 (170 μm)	4 cm	54 MB
256 x 256 x 256 pixel <sup>3</sup>	1:2 (85 μm)	2.2 cm	64 MB
340 x 340 x 340 pixel <sup>3</sup>	1:2 (85 μm)	3 cm	150 MB
460 x 460 x 460 pixel <sup>3</sup>	1:2 (85 μm)	4 cm	370 MB
512 x 512 x 512 pixel <sup>3</sup>	off (43 μm)	2.2 cm	512 MB
700 x 700 x 700 pixel <sup>3</sup>	off (43 μm)	3 cm	1.3 GB
940 x 940 x 940 pixel <sup>3</sup>	off (43 μm)	4 cm	3.2 GB

On account of the cone beam back-projection, the voxel resolution of the computed tomogram is somewhat better than the sensor pixel resolution.



The location of the reconstruction volume with the edge lengths 2.2 cm, 3 cm and 4 cm relative to the Lego bricks if the Lego adapter has initially been fitted with the Lego plate 6x6. This template can be printed at the correct size (actual size, do not modify).

### 9.6 Evaluation

In the 3D view there are numerous evaluation options available:

- rotate volume
- zoom volume
- adjust intensity, transparency and colour spectrum
- display of 2D cutting planes
- measuring of distances in a 2D cutting plane
- determination of the attenuation coefficient  $\mu$  and the CT numbers H
- animation around the rotational axis or using the mouse, e.g. for the creation of videos
- display of the edges of the cube
- illumination with setting of the light parameters
- stereoscopic view for red-cyan glasses
- full screen display

Further information about the evaluation options is available in the handbook and the help.

### 3D graphics settings

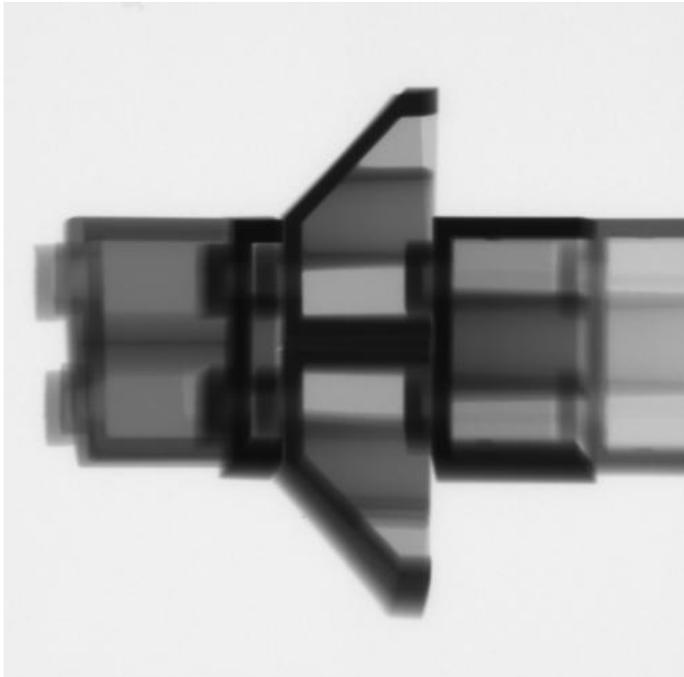
In particular for older graphics cards, it can be sensible to improve the refresh rate by adaptation of the 3D graphics settings. Further information about the 3D graphics settings is available in the handbook and the help.

## 10 Examples

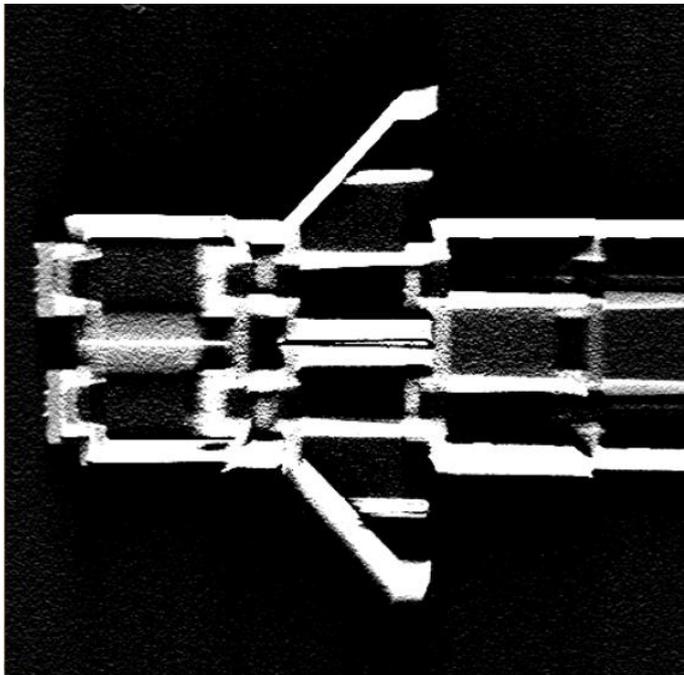
### 10.1 CT scan of Lego bricks

With the Lego adapter (e.g. in 554 826) practically any of the small Lego structures can be investigated by tomography.

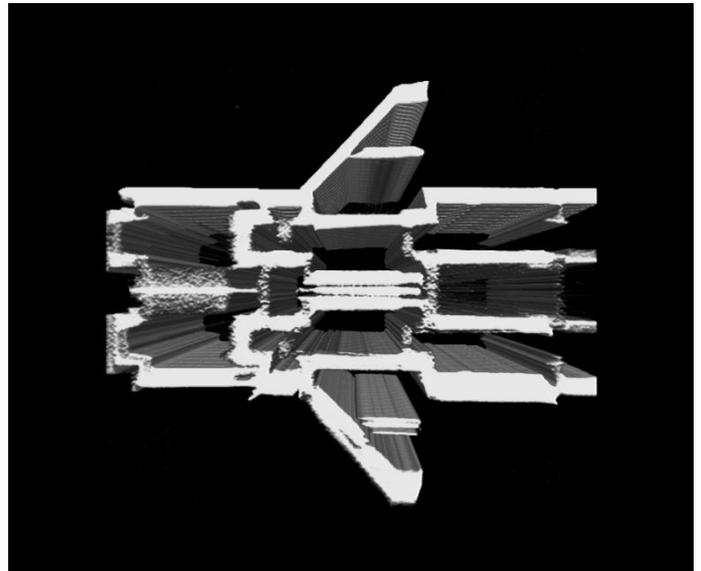
The fluorescence screen shows the projections of the object for the set angle:



The computed tomography uses the "filtered back-projection" for every angle for the reconstruction of the complete volume. After calculation of the logarithms and filtering, the above projection looks like this:

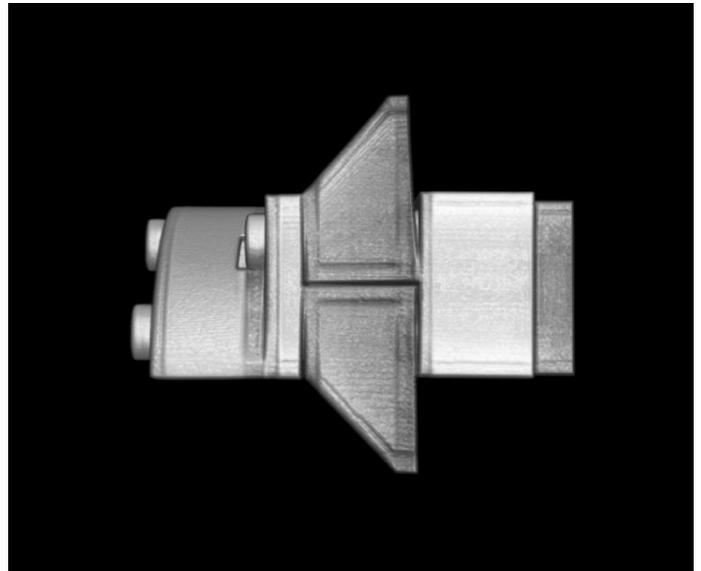


On back-projection of the beam cone towards the X-ray source, after the first back-projection the 3D reconstruction volume shown below is obtained. In order to show the volume from the same direction as the projections, it was rotated by 90° so that the line of sight is in the direction of the X-ray source.



While the projections were being recorded for all angles and back-projected, the reconstruction process can be observed in either 2D or 3D.

In this example, the reconstruction is complete after 360 recorded projections at 360 different angles and 360 totalled back-projections in the reconstruction volume. The reconstruction is again displayed for the same angle as the previous illustrations.



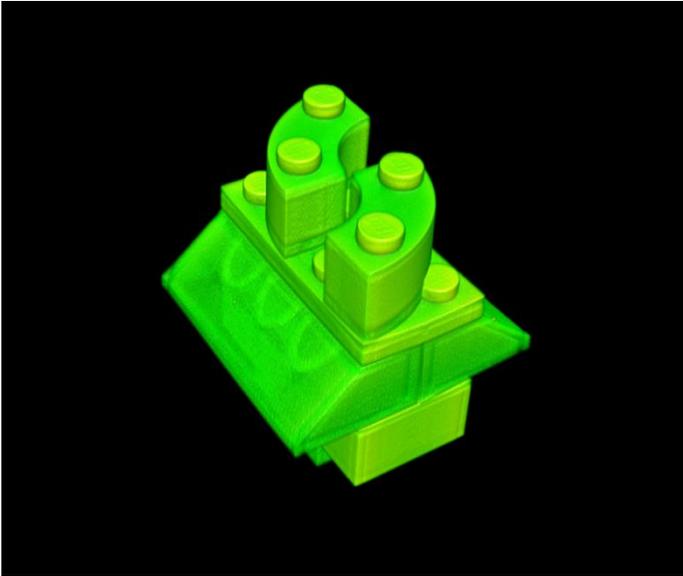
Comment: The perspective is inverted for the projections. In the projection, the parts closer to the X-ray source produce the larger "shadows". In the reconstruction, parts at this angle are further to the back and are therefore displayed smaller. This is e.g. clearly visible for the Lego brick on the left-hand side.

During or after the reconstruction process, the display can e.g. be rotated, zoomed and illuminated.

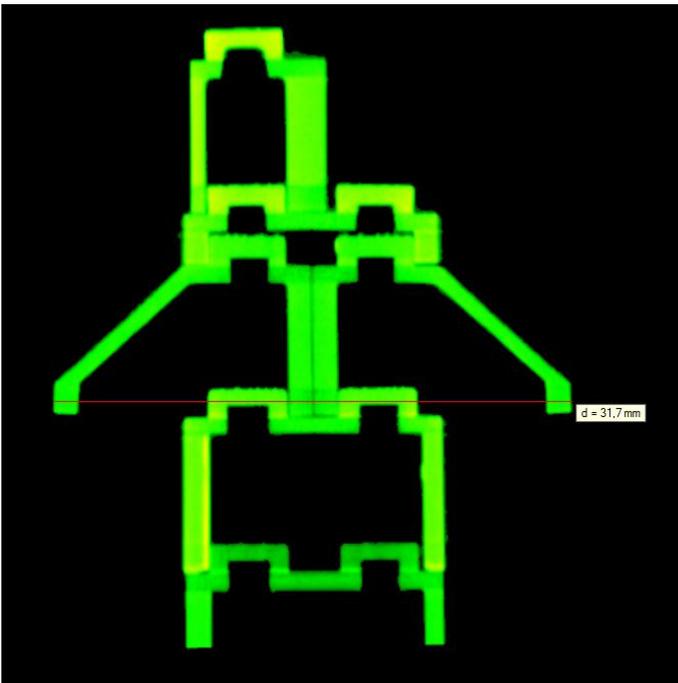
For the better clarification of the different attenuation coefficients  $\mu$ , the area of the displayed attenuation coefficients can be placed in a selectable colour spectrum. If in the menu the normal colour view is switched off, reds and greens are omitted from the colour spectrum.

### 10.2 CT scan of a frog

The computed tomography accessories (554 826) contain a Lego adapter with Lego object carriers and a small dried animal (e.g. a frog). If this animal is glued to the computed tomography accessories as described in the instructions, high resolution tomograms can be easily produced. The following two figures show a frog with an actual size of approx. 25 mm on its object carrier.



Any cutting plane can be displayed and measured:



If the intensity controller is pushed from the left-hand side towards the right, the volume parts filled with a lower attenuation coefficient  $\mu$  become progressively invisible until, in the end, only the bones are left.



**10.3 Hardness of the X-radiation**

For the recalculation of the measured attenuation coefficient as CT numbers, the attenuation coefficient  $\mu$  of water is required. The default value is set as  $\mu_{\text{water}} = 0.45 / \text{cm}$  and unfortunately it is not constant (see note). The CT numbers H are calculated from the measured attenuation coefficient  $\mu$  with

$$H = 1000 * (\mu - \mu_{\text{water}}) / \mu_{\text{water}}$$

Therefore air has the CT number  $H = -1000$  HU (Hounsfield Units) and water has the CT number  $H = 0$  HU.

**Note**

The default of 35 kV achieves a polychrome energy spectrum of the X-radiation reaching up to 35 keV depending on the anode material deployed. The basis of the reconstruction algorithm used is the attenuation of the X-rays when passing through material of thickness d with an attenuation coefficient  $\mu$ :

$$I = I_0 * e^{-\mu d}$$

However, the attenuation coefficient  $\mu$  depends on energy. For this reason the equation applies only for monochromatic X-radiation. Higher energy X-radiation is usually attenuated less.

This effect is already observable if a container filled with water of varying thickness is irradiated. The more the water attenuates the X-radiation the higher is the average energy of the X-radiation leaving it, because the lower energy component is attenuated more than that of a higher energy. The water therefore makes the X-rays harder.

The measured attenuation coefficient  $\mu$  is lower the more water is irradiated. In addition, the measured attenuation coefficient depends on the anode material of the tube, on the thickness of the outlet window and the setting of the high voltage.

In the software all these effects are not corrected for. For this reason the CT numbers displayed also depend e.g. somewhat on the thickness of the irradiated material.

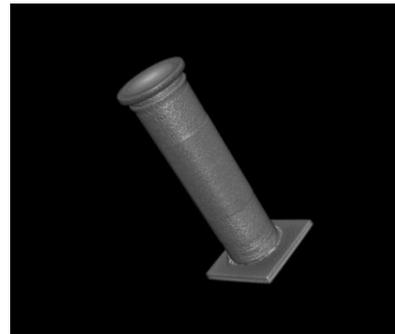
**Determining the hardness of the X-radiation**

The effective  $\mu_{\text{water}}$  is relatively easily determined. The object required for this is an enclosed plastic cuvette which is filled completely, i.e. free of bubbles, with water.

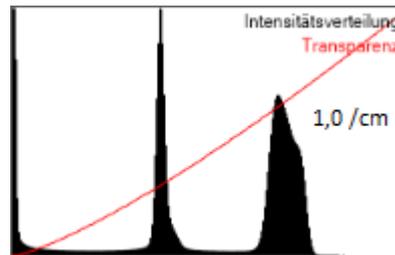
Then a CT scan is made of the water-filled cuvette with the W anode and the Mo anode or with a range of high voltages. To gain better quantitative information about the attenuation coefficient, it is recommended to carry out a flat-field correction in the camera settings before recording a CT scan. To do this, first of all an empty X-ray image (without an object or a holder) is recorded which is later used to standardise all subsequent images. This makes the background of all projections evenly white.

Of interest for the 3D representation is, in particular, the histogram of the distribution of the attenuation coefficients. In this histogram the water volume is visible and the average coefficient  $\mu$  can be read out. The value of  $\mu$  is displayed on the right-hand side above the 3D image.

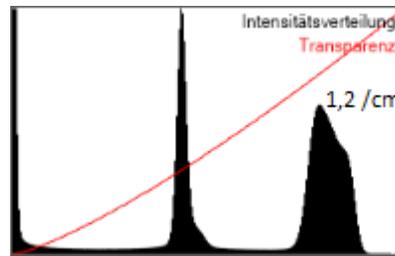
Only when the  $\mu$  determined in this way is provided in the settings for the X-radiation are the displayed CT numbers H sensible. As explained above, the CT numbers also depend somewhat on the thickness of the irradiated material.



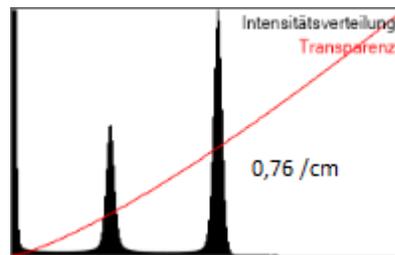
Water cuvette



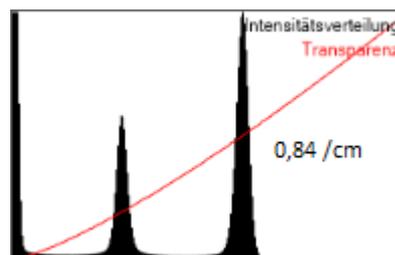
$\mu$ , measured with W (35 kV)



$\mu$ , measured with W (30 kV)



$\mu$ , measured with Mo (35 kV)



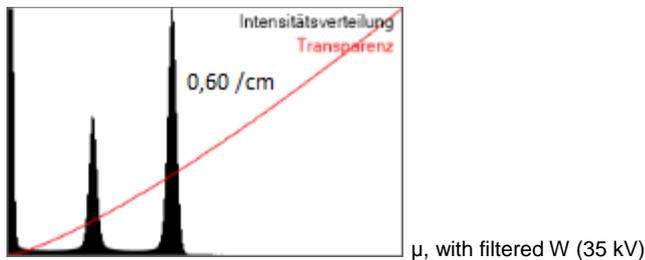
$\mu$ , measured with Mo (30 kV)

The harder the radiation the smaller the measured attenuation coefficient  $\mu_{\text{water}}$ .

Normally one would expect for the W tube a harder radiation than for the Mo tube. However, the Mo tube has a thicker exit window which counteracts the effect because it also hardens the X-radiation. Effectively, the Mo tube is a source of harder X-rays than the W tube, which is also apparent from the sharper water peak in the histogram, because the water does not make the radiation much harder.

### Hardening radiation by means of an Al filter

The W tube and the Au tube have a sufficient reserve for hardening the radiation by means of a  $d=1$  mm thick Al filter, which is much better at filtering the lower energy proportion of the X-ray radiation than the higher energy proportion. The integration time to be used should be 1750 ms, because then a similar intensity is found as for a Mo tube.



### 11 Simulation

In the installation CD the "Examples" sub-directory contains several recordings of computed tomograms. For space reasons they are not automatically installed together with the program. If you would like to copy one of these computed tomograms to your hard disk, please remember that a complete computed tomogram comprises several files:

- Projectname.ct contains the configuration
- Projectname.ct3d contains the actual 3D data
- Projections\Projectname is a directory where the recorded projections can be found. The projections are only required when the computed tomogram is to be recalculated.

These examples can be simulated by ► **CT** → **Recalculate CT scan** without a computed tomography module and displayed and evaluated in **2D** or **3D**. Alternatively, the example can be displayed and evaluated after opening a project without recalculation.

On our Youtube Channel <http://www.youtube.com/user/lddidactic>, CT videos (some of which are stereoscopic) are available. If you want to produce your own videos, the AVI export of the software is recommended. Then the videos can, for example, be cut and titles added using Windows Movie Maker.

### 12 Own objects

There is plenty of scope for one's own experiments because naturally there are plenty of different potential objects to be investigated. For the selection of the objects there are various criteria:

- **No living creatures**  
The radiation load in the X-ray apparatus is very high during a CT scan. Depending on the duration of the scan, it can be associated with a radiation dose of over 1 Sv.
- **Only rigid bodies**  
The object to be investigated must be attached to the goniometer and during the scan it must be rotated once around the goniometer axis. During this procedure its geometry must not change, otherwise shadow images will occur in the reconstruction.
- **No metals or very dense materials**  
The reconstruction algorithm assumes that for every point on the fluorescent screen the attenuation of the X-radiation can be calculated. However, if the attenuation is too high, clearly visible artefacts occur during the reconstruction because the projections of the fluorescent screen become inconsistent.
- **Only small objects**  
For a complete reconstruction, the objects must fit completely within the volume scanned. For the X-ray image sensor the recorded volume is max.  $4 \times 4 \times 4 \text{ cm}^3$ . The computed tomography module (554 821) offers a much larger recordable volume of  $8 \times 8 \times 8 \text{ cm}^3$  at a considerably lower resolution.