

08/13-W07-Hund



Instruction sheet 554 821

Computed tomography module (554 821)

- 1 Cover
- 2 Opening for the luminous screen with sealing ring
- 3 Camera
- 4 3 adjustment screws
- 5 USB connection to the PC
- 6 USB connection to the X-ray apparatus
- 7 Analogue video output
- 8 Mains connection

Safety notes

The computed tomography module 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.

The computed tomography module corresponds to the safety regulations for electrical measuring, control and laboratory devices according to DIN EN 61010 part 1, and is designed conforming to protection class I. It is intended for operation in dry rooms which are suitable for electrical devices or equipment.

If used as intended, the safe operation of the device is guaranteed. Safety is, however, not guaranteed if the device is used inappropriately or handled without care. If it has to be assumed that safe operation is no longer possible, the device must immediately be closed down (e.g. in the case of obvious damage).

- Before commissioning, check if the value on the plate (on the rear of the housing) corresponds to the mains voltage available locally.
- Check the housing for damage before starting the device up. If the function is faulty or if there is damage, switch off the apparatus and protect it against unintended operation.
- Connect the apparatus only to sockets with an earth connector and connect to PE (earth wire).
- Replace defective fuses only with another of the original rating.
- Have the apparatus opened only by a qualified electrician.

1 Description

The computed tomography module (554 821) is used for the recording, within a few minutes, of projections of the X-ray object as a function of the angle. During the recording, the included computed tomography software visualises the back-projection process in either two or three dimensions. After the recording, the complete 3D object is immediately available for inspection (rotating, zooming, transparency effect, sections, illumination similar to the Heidelberg raytracing model).

Despite the simple measuring method and 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 and of the evaluation.

Appropriate X-ray apparatus and a high performance computer are required in addition.

Technical data

Attachment of the object:	to the goniometer of the X-ray apparatus
Max. object size:	approx. 8 x 8 x 8 cm ³
Object resolution:	approx. 0.25 mm
Angular resolution:	1 - 720 projections per tomogram
Size of the computed tomogram:	200 - 340 pixels per dimension
Computer connection:	USB 2.0 port
X-ray apparatus connection:	USB 2.0 port
Separate video output:	cinch (CCIR)
Mains connection:	230 V, 50/60 Hz
Dimensions (w x h x d):	53 cm x 34 cm x 24,5 cm
Mass:	13.5 kg

Scope of delivery

Computed tomography module
 Computed tomography software
 Object (small dried animal, e.g. frog)
 Cuvette (e.g. for water)
 Object holder including expanded polystyrene holder and rubber rings
 USB cable

Accessories

Lego adapter (554 825)
 Computed tomography accessory (554 826)
 Red-cyan glasses (554 827)

Minimum requirements for the X-ray apparatus

The X-ray apparatus must be compatible with the computed tomography module, e.g.:

- X-ray apparatus Mo (554 801 or 554 811USB) including molybdenum tube and goniometer

The X-ray apparatus (554 81) with the serial interface cannot be used.

The X-ray tube used is responsible for the intensity of the images on the fluorescent screen. We recommend the use of a tungsten or gold tube:

- basic device, X-ray apparatus (554 800)
- goniometer (554 831)
- X-ray tube W (554 864) or X-ray tube Au (554 866)

or

- X-ray apparatus Mo (554 801) including goniometer
- X-ray tube W (554 864) or X-ray tube Au (554 866)

X-ray apparatus firmware

The firmware for the X-ray apparatus must be compatible with the computed tomography module:

- 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.

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>.

Minimum requirements for the computer

The real-time recording and evaluation of computed tomograms requires a large amount of processing on the processor and the graphics card. Despite the high degree of optimisation of the algorithms used, the minimum requirements below apply:

- Windows XP SP2 or Windows Vista/7/8 (32 bit or 64 bit)
- Dual-core processor 2 GHz
- 2 GB RAM
- 3D graphics card (Nvidia GT 610 / AMD HD 6450 or better)
- USB 2.0 port
- DVD drive

For larger computed tomograms we recommend a higher computer performance:

- Windows Vista/7/8 (32 bit or 64 bit)
- Quad-core processor 2.4 GHz
- 3 GB RAM
- 3D graphics card (Nvidia GT 630 / AMD HD 6670 or better)
- USB 2.0 port
- DVD drive

2 Installation

This installation is performed in two parts.

a) Installation of the computed tomography software

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 2.0 and Managed DirectX are installed during the software installation.

b) Installation of the USB video driver

The computed tomography module contains a USB video grabber for the conversion of the analogue video signal from the camera (3). The video grabber requires the installation of a driver which is available on the CD in the Driver subdirectory.

Depending on the installed video grabber, either an executable installation program (e.g. Driver\Setup.exe) or the actual video driver (e.g. Video.inf) are found there.

In the first case the installation program (e.g. Driver\Setup.exe) has to be run before connecting the computed tomography module to the PC. In the second case Windows searches for the driver on the CD after connecting the computed tomography module to the PC and switching on.

If you wish to use a different video grabber, it can be connected to the analogue video output (8) of the computed tomography module. Such video grabbers also require an installed driver which provides a DirectShow filter via which the computed tomography software accesses the video data.

Important: Even when the internal video grabber is not being used, the computed tomography module must be connected to the computer via a USB cable.



The Windows device manager with a correctly installed video grabber (here USB 2820 Video) In the case of problems the driver can be de-installed or updated by clicking on the right-hand mouse button.

3 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.

4 Operation

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.

Preparation

- Insert the W, Au, Mo or Ag (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. If the goniometer is further to the left the reconstructable volume is smaller.
- Attach the object under investigation to the goniometer axis and close the doors.
- Connect the computed tomography module to the X-ray apparatus and the computer via USB and switch the devices on.
- Start the computed tomography software.

Starting up

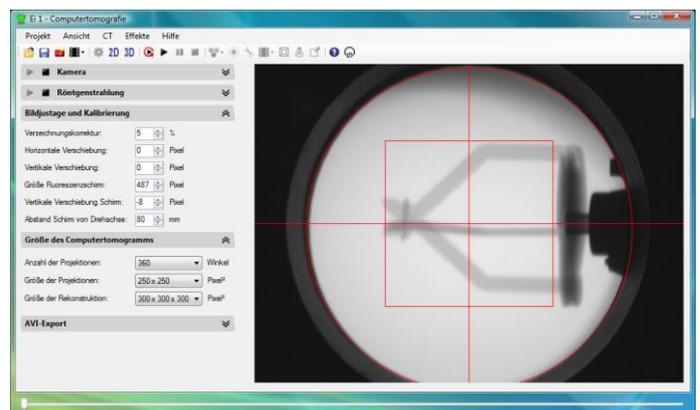
The computed tomography module will need to be adjusted prior to initial use and each time it is moved to a new location. The empty object holder is sufficient for an object under investigation provided that the three arms have been fastened with a rubber ring.

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

- The camera in the computed tomography module must record dark images. This is apparent by the flashing of the red dot (●) in the **Camera settings**. If not, check the connections, video device and video input in the camera settings.
- If light is entering the computed tomography module, check the alignment of the module and if necessary shift it closer to the X-ray apparatus.
- If the black camera image shows irritating light spots, these can be suppressed by means of a defective pixels list in the **Camera settings**. Here a flat-field correction is also possible, although this is not normally necessary. To do this the object to be investigated must briefly be removed and the X-rays switched on.
- The camera images are averaged to reduce noise. In the **Camera settings** an averaging of 20 video frames for every display image is the default setting. In this way every image recorded only requires just under a second. If a Mo or Ag X-ray tube is used, increase the number of frames to be averaged because this tube produces considerably less X-radiation than the W or Au X-ray tube.
- Switch on the **X-Rays** by clicking .
- Check the image brightness and the crispness. The aperture of the camera objective must be fully open and the objective must be focussed on the luminous coating. The luminous coating is located behind the glass surface.
- Perform **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 **distortion correction** corrects the barrel-shaped distortion usually observed for camera objectives with a short focal length. It is preset to 5%. This value can be checked and if necessary corrected by placing chequered paper in front of the opening of the computed tomography module.
- The **horizontal shift** of the red wire cross is set in such a way that the wire cross is horizontally in the centre of the fluorescent screen. If the shift is any larger, the installation of the camera in the computed tomography module must be checked.
- The **vertical shift** of the red wire cross from the centre of the rotational axis should remain at 0. It is recommended to correct the shift with respect to the rotational axis by means of a correction of the rotational axis (see below).
- For the length calibration of the tomography apparatus, the **size of the fluorescent screen** should be adjusted in such a way that the red circle exactly traces the limits of the depicted fluorescent screen. If this is not possible with precision, the **vertical shift of the screen** can be adjusted. The horizontal shift has already been adjusted.
- The **distance of the screen from axis of rotation** is also required for the length calibration of the tomograph. The recommended distance of 80 mm corresponds to the goniometer shifted to the very right.
- Set the **size of the computed tomogram** to 180 projections with a projection size of 350x350 pixel² and the size of the reconstruction to 256x256x256 pixel³.
-  Select **CT → Start CT scan**, 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.

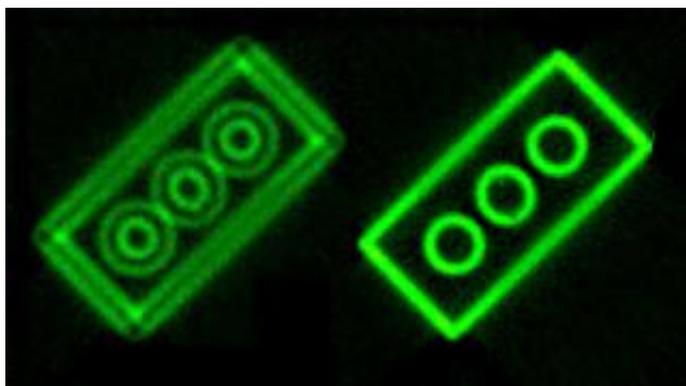


An adjusted computed tomography module with the empty object holder.

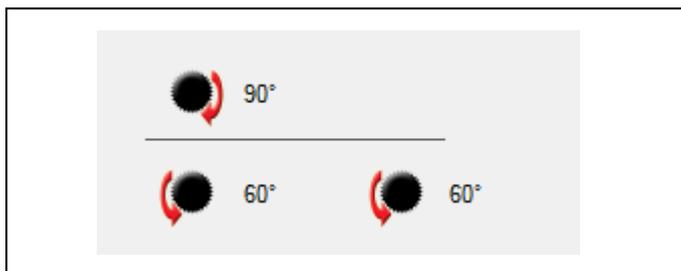
Correction (open with)

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 ± 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 ± 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 front thumbscrews have to be turned counter-clockwise by 60° and the back thumbscrew has to be turned by 90° clockwise.

Scanning

- Select the number and size of projections as well as the size of the reconstructions 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.

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 μ 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.

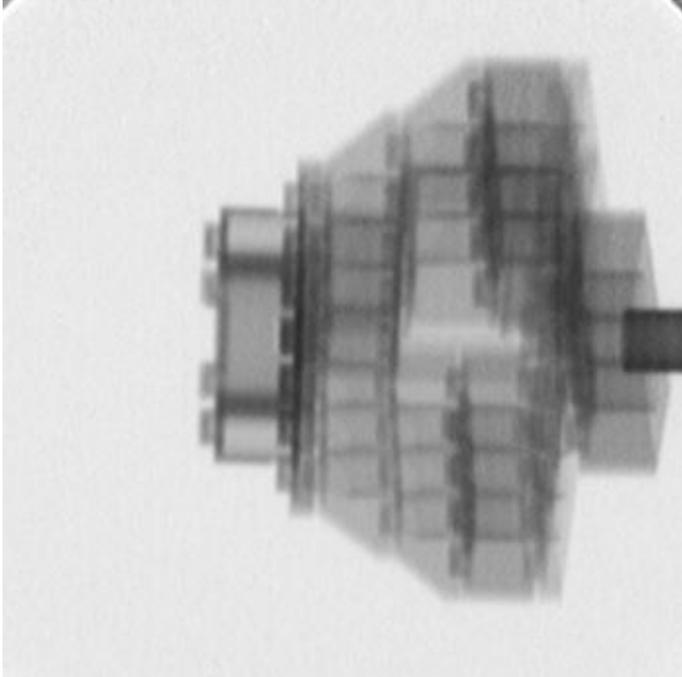
Further information about the 3D graphics settings is available in the handbook and the help.

5 Examples

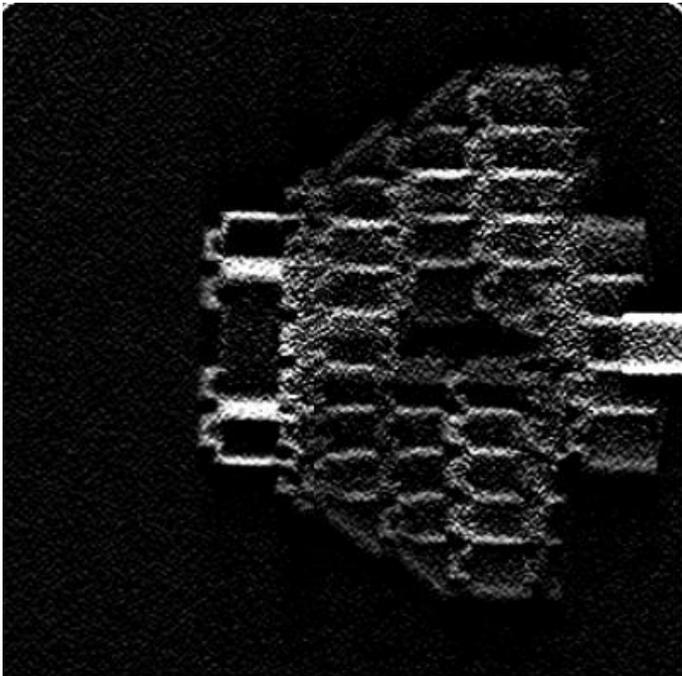
CT scan of Lego bricks

With the Lego adapter (554 825, available as an accessory) practically any of the smaller Lego structures can be investigated by tomography.

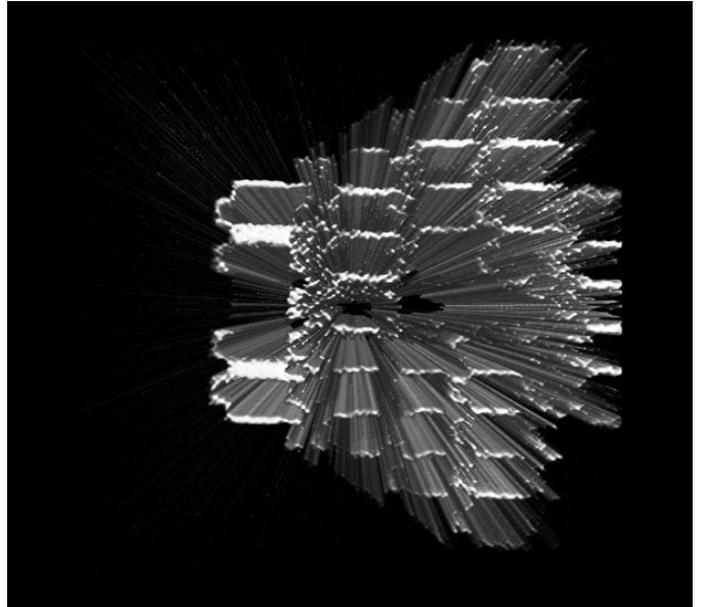
The fluorescence screen shows the projections of the object for the set angle:



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:

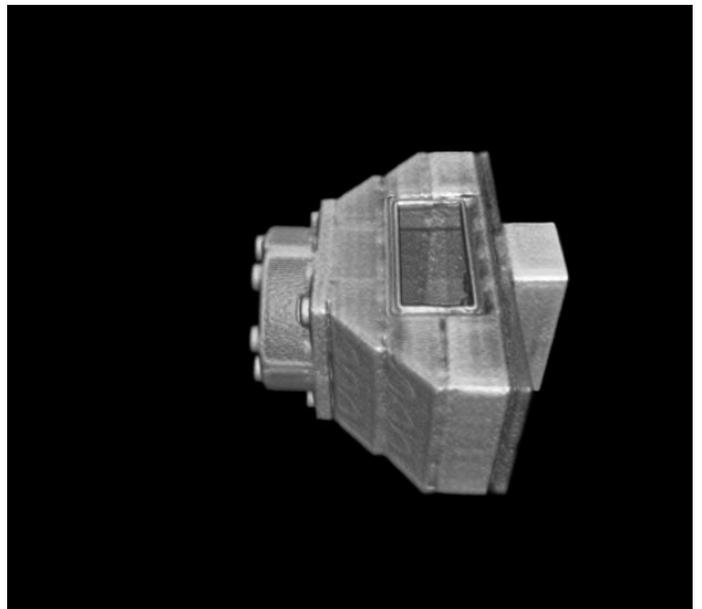


On back-projection of the beam cone towards the X-ray source, after the first back-projection the 3D reconstruction volume shown below is obtained. In order to show the volume from the same direction as the projections, it was rotated by 90° so that the line of sight is in the direction of the X-ray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



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

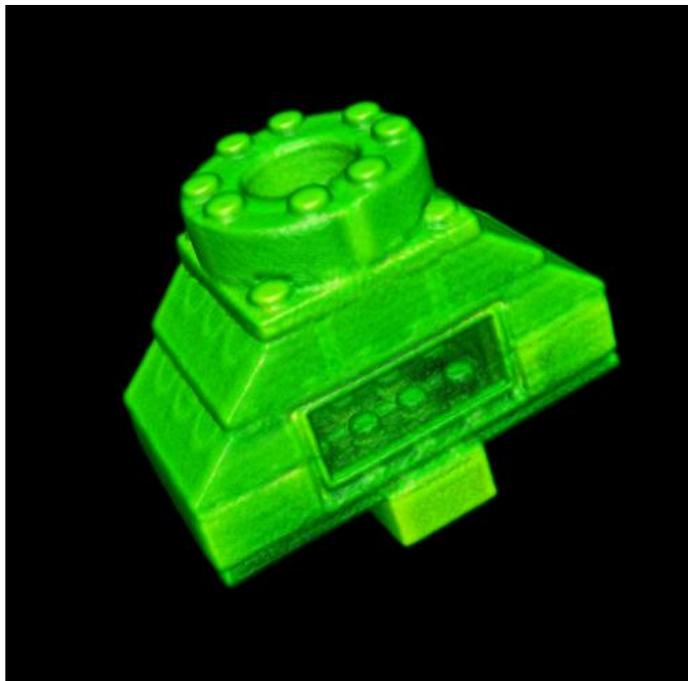
In this example, the reconstruction is complete after 360 recorded projections at 360 different angles and 360 totalled back-projections in the reconstruction volume. The reconstruction is again displayed for the same angle as the previous illustrations.



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.

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 μ , 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.



Any cutting plane can be displayed and measured:



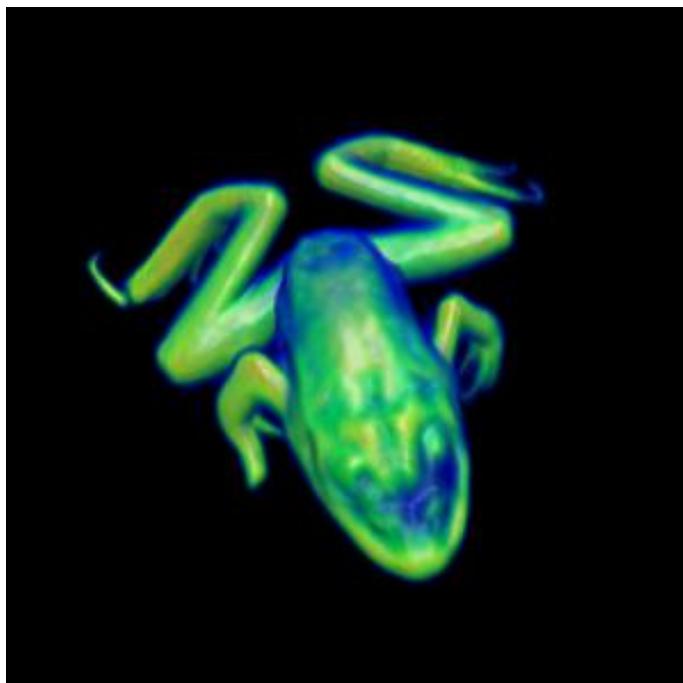
CT scan of a frog

If a freeze-dried frog is placed into the enclosed object holder with the expanded polystyrene holder, and if the remaining space is filled with cotton wool, the frog will not move in the holder during the CT scan.

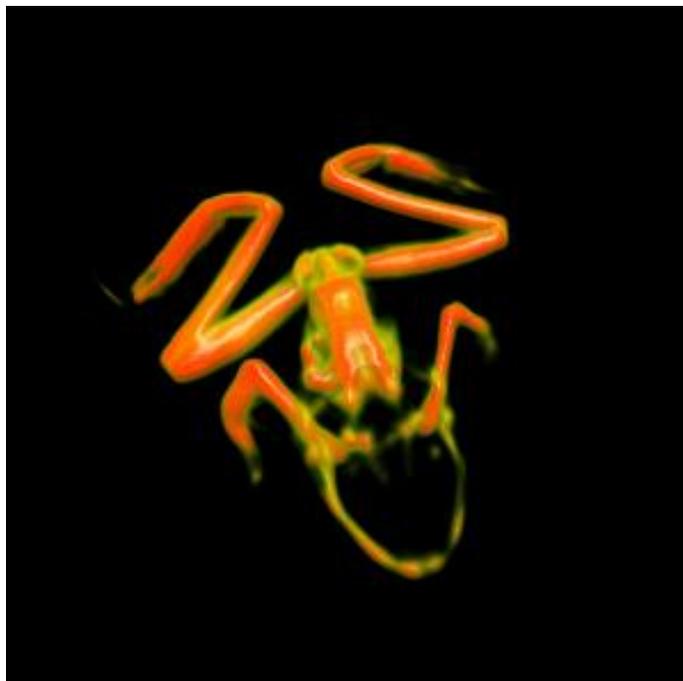
The expanded polystyrene holder is not visible in the CT scan. However, depending on the intensity settings, the cotton wool can lead to dark marks on the image. In this case in the colour spectrum bar below the histogram, the left-hand limit can be slightly shifted to the right. The volume elements with a smaller

attenuation coefficient μ are then no longer shown and the cotton is invisible.

The three grips and the rubber ring used to fix things into place are in principle visible. However, by an appropriate choice of the reconstruction size, it may be managed that they remain largely outside of the reconstruction volume.



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



Hardness of the X-radiation

For the recalculation of the measured attenuation coefficient as CT numbers, the attenuation coefficient μ 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 μ with

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

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

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 μ :

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

However, the attenuation coefficient μ 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 μ 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.

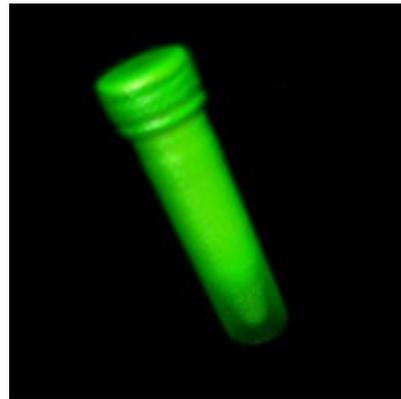
Determining the hardness of the X-radiation

The effective μ_{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.

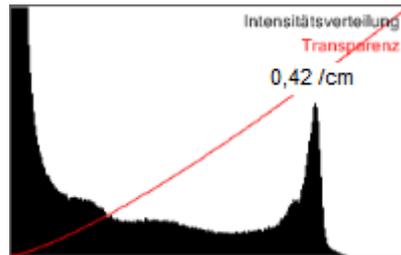
Then a CT scan is made of the water-filled cuvette with the W anode and the Mo anode or with a range of high voltages. To gain better quantitative information about the attenuation coefficient, it is recommended to carry out a flat-field correction in the camera settings before recording a CT scan. To 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 μ can be read out. The value of μ is displayed on the right-hand side above the 3D image.

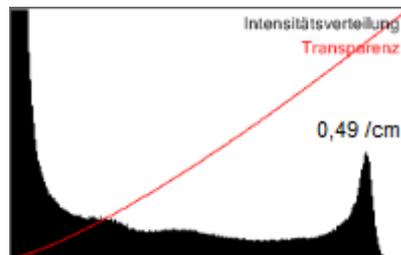
Only when the μ determined in this way is provided in the settings for the X-radiation are the displayed CT numbers H sensible. As explained above, the CT numbers also depend somewhat on the thickness of the irradiated material.



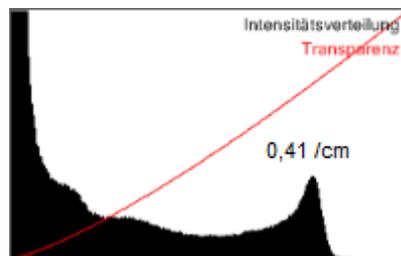
Water cuvette



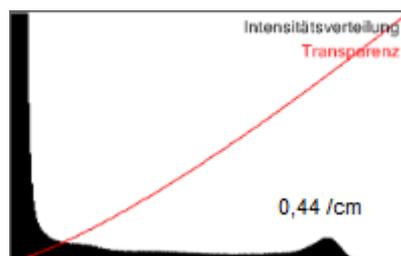
μ , measured with W (35 kV)



μ , measured with W (30 kV)



μ , measured with Mo (35 kV)



μ , measured with Mo (30 kV)

The harder the radiation the smaller the measured attenuation coefficient μ_{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.

6 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.

7 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. The scanned volume depends on the distance of the goniometer from the X-ray tube and at the right-hand stop is max. $8 \times 8 \times 8 \text{ cm}^3$.