

# Ultrasonic computed tomography

## Introduction

X-ray computed tomography (CT) is one of the most important diagnostics methods in modern medicine. Furthermore, it is widely used in industry and scientific research to obtain information on inner structure of an object without the need of destroying the object. A well-known application of this method, which has attracted much attention of mass-media, is study of mummies in archaeology.

A single image obtained in a CT procedure is a two-dimensional projection of a three-dimensional object, through which the irradiation has passed. In this projection different layers of the object are superimposed on each other, so this image is also called a superposition of images.

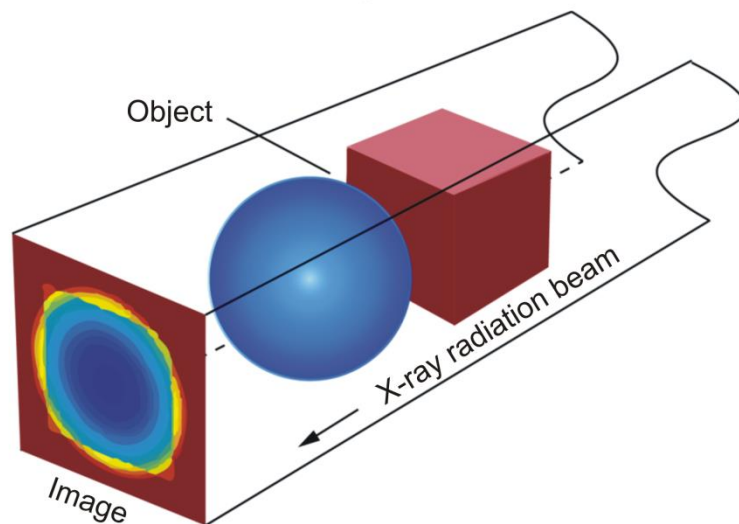


Fig. 1. Image obtained as a projection in a single relative position of the object, radiation source, and detector.

The principle of obtaining scans is the same for different CT methods; the only difference is in the radiation type used. An ultrasonic wave may be used instead of X-rays. In the X-ray CT, absorption of X-ray irradiation is registered, while in ultrasonic computed tomography (UCT), the decay time of ultrasound is measured. The image processing algorithms are the same in both methods.

Ultrasonic CT method gives also additional information about the propagation time of the sound wave in the object, which allows determining regions with different speeds of sound inside the object. However, to avoid loss of ultrasound energy on the way from the sensor to the object, the object (patient) should be immersed into water, and for this reason UCT is rarely used as a medical diagnostics method compared to X-ray CT.

Consider now the principles of obtaining CT scans.

In an X-ray CT investigation, X-rays from a source are passing through an object, and then the irradiation absorption level is registered in an array of points at the same time. The “source – sensor” system is then rotated around the object (patient) by a certain angle, and a new scan is acquired (Fig. 2a). This action is repeated several times until the whole required angle range is swept.

In an UCT study, there is only one sensor, which can measure the signal intensity only at a single point at a time. Therefore, signal intensity should be measured in a number of positions one by one. The smaller is the distance between neighbour points, the better is the resulting image. The sum of the distances between all points gives the scanning width. After the scan is acquired, the object should be moved back to the initial position in the “transmitter – sensor” system to start the next scan (Fig. 2b).

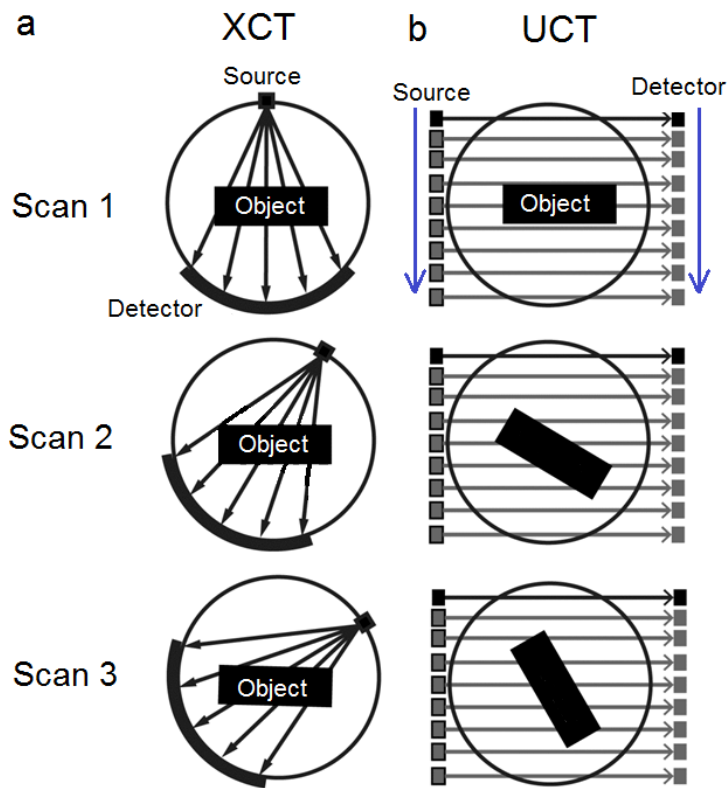


Fig. 2. General principle of obtaining images in (a) X-ray and (b) ultrasonic computed tomography.

After obtaining a series of scans, the reconstruction step begins. Usually, several scans are obtained, and then the patient is moved along the axis of the tomography apparatus, and the process is repeated until the whole region to investigate is covered.

Decay of a wave passing through a homogeneous medium fulfils the exponential law:

$$I = I_0 e^{-\mu x}, \quad (1)$$

where  $I$  is the radiation (wave) intensity which leaves the object,  $I_0$  is its initial intensity,  $\mu$  is the attenuation factor, and  $x$  is the thickness of the material layer.

If the medium is inhomogeneous and can be divided into volume elements (voxels) with the size of  $\Delta x$ , then

$$I = I_0 e^{-\sum_k \mu_k \Delta x}, \quad (2)$$

where  $\mu_k$  is the attenuation factor in the  $k^{\text{th}}$  element. If we move  $I_0$  to the left part of this equation and calculate logarithm, we derive

$$\sum_k \mu_k = \frac{1}{\Delta x} \ln \frac{I_0}{I}. \quad (3)$$

This expression allows us to divide the whole profile of the image into regions characterized by different attenuation factors in taken in different scans. If then the results obtained for all scanning angles are considered, the two-dimensional image with the pattern of distribution of the attenuation factors can be reconstructed.

Special envelope filters are used to allow for logarithmic decay profiles before the superposition procedure in order to obtain good images (without severely blurred details).

Which should be the angle increment? Superpositions of the directions in the 1 and 3 quadrants and in the 2 and 3 quadrants (Fig. 3) should not overlap. The rotation angles for different directions also should be constant. If these criteria are fulfilled in 1 and 3, and also in 2 and 4 quadrants, then we have:

$$nx = 180^\circ + x/2, \quad (4)$$

$$x = \frac{180^\circ}{n-1/2}. \quad (5)$$

Here  $x$  is the angle increment, and  $n$  is an integer number. Rational solutions of this equation are listed in the table.

| n  | x     | n   | x     |
|----|-------|-----|-------|
| 1  | 360°  | 23  | 8°    |
| 2  | 120°  | 38  | 4.8°  |
| 3  | 72°   | 63  | 2.88° |
| 5  | 40°   | 113 | 1.6°  |
| 8  | 24°   | 188 | 0.96° |
| 13 | 14.4° |     |       |

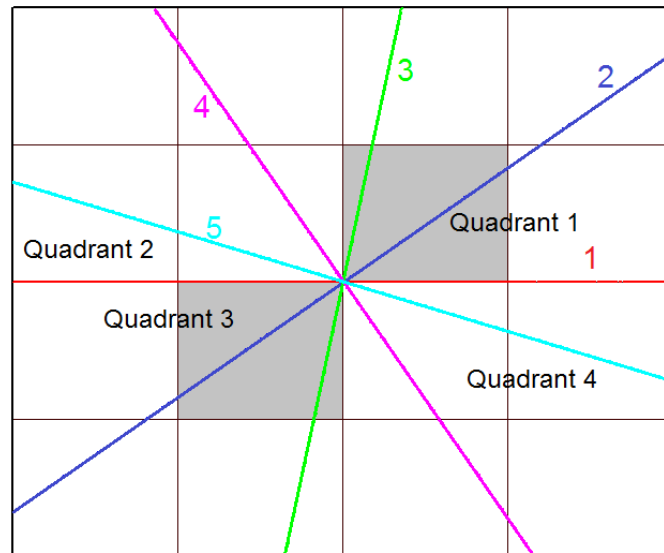


Fig. 3. Quadrants and an example set of scanning ray orientations for  $n = 5$ .

### Purpose

Study the principles of image formation in ultrasonic computed tomography.

### Accessories

1. Ultrasonic echoscope GAMPT GS-200
2. Ultrasound probes (1 MHz, blue; 2 MHz, red)
3. Test sample
4. Gel
5. Bath for water
6. Laptop
7. CT scanner

### Safety notes

1. The apparatus is connected to the 220 V power mains.
2. Do not cover openings on the apparatus which are necessary for ventilation.
3. Do not thrust any things into the apparatus: it can lead to short circuit.
4. Before using the ultrasonic probe, ascertain its integrity. If the sensor is broken, replace it.
5. Unplug the sensors by holding the socket. Do not pull the wire!
6. Peak voltage on the sensor's contacts can achieve 300 V. Do not touch the sockets while the apparatus is in work!
7. Do not apply the apparatus to people or other objects except special test samples used in this work.

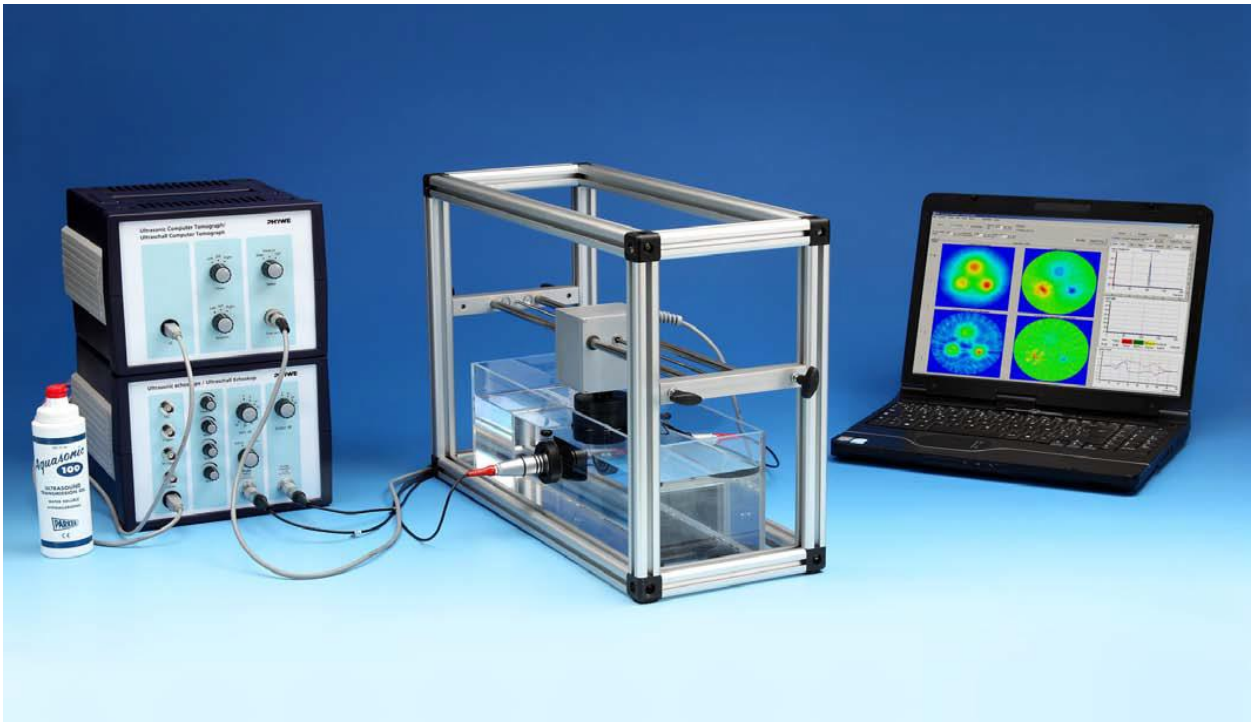


Fig. 4. Experimental setup for performing ultrasonic computed tomography.

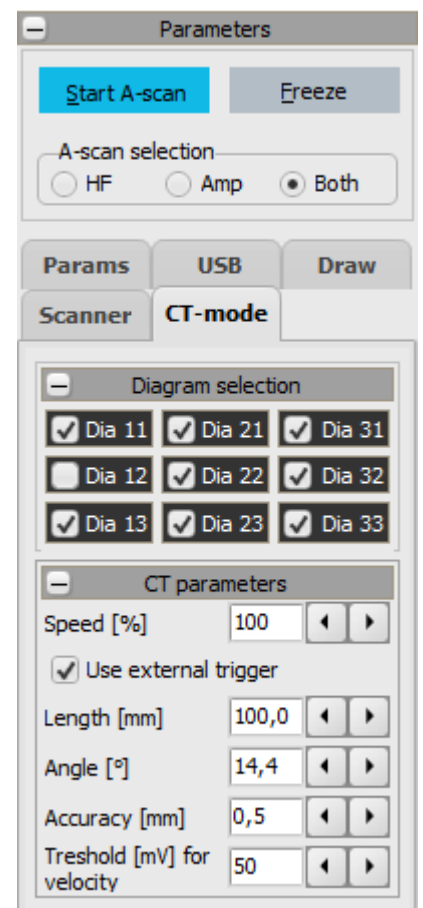
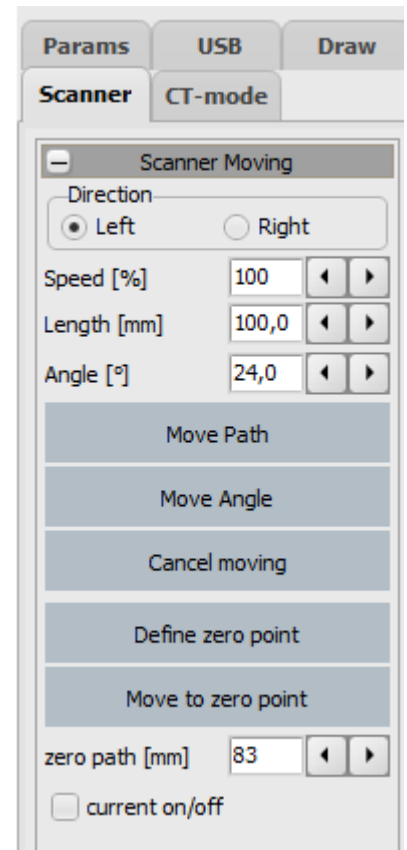
### Preparing the experimental setup for measurements

1. Fill the bath with water so that the water level is 5 cm above the holder of ultrasound probes.
2. Lower the scanning system using the screws until the magnetic holder of the sample is below the water surface (as in Fig. 4).
3. If necessary, clean the glass surface within the US probe holders to remove impurity and remaining gel.
4. Apply gel onto two 2-MHz sensors (red) and attach them to the holders in the opposite positions. Make sure that the amount of gel is sufficient and there are no air bubbles between the sensor and glass, since they would distort the image.
5. Connect the sensors to the echoscope's input jacks "Probe 1" and "Probe 2."
6. Check that the CT scanner is connected to the CT-Controller unit, and that the echoscope, Flow Doppler CT scanner, and the CT-Controller are connected to the computer (laptop).
7. Launch the GS-EchoView programme, choose the "CT-mode" tab, and press the "Start A-scan" button.
8. Set the "Gain" and "Output" selectors of the echoscope to 10 dB. Make sure that the signal observed by the computer does not exceed the sizes of the window. The TGC controls should be set to zero.
9. Signal amplitude can be regulated by accurate moving and turning of the US probes in their holders, if you slightly loose the holder screws. After you finish regulating, fasten the screws back again.

10. Attach the object to study (a black cylinder) to the scanner's magnetic holder (the magnet on the sample top has a lug which should be inserted into the scanner's holder).
11. Turn the "Gain" and "Output" selectors of the echoscope to 25 dB. (Do not move the TGC selector.)
12. Using the "Linear" control on the UCT200 sensor control unit, move the sample so that the centre of the cylinder is exactly between the probes. This position will be the initial position in all further experiments.
13. Go to the "Scanner" window in the GS-EchoView programme and choose the "Define zero point" option. After you make it, the control unit will move the sample to the limit position of the rail and return it back.
14. Then you should define the scanning length so that the measurements start before the sample goes between the probes and complete after it leaves the region between the probes. In the leftmost and rightmost positions ultrasound should pass through water but not through the sample. To do this, set the value of 100 mm in the "Length" input line in the "CT parameters" tab of the GS-EchoView programme.
15. Set the resolution of the image as 0.5 mm in the corresponding input line "Accuracy." The smaller is this value, the more detailed image you will obtain, and the longer will be the experiment duration.
16. Set the angle to 14.4° in the same tab. The measurements will be done until the sample makes one full revolution with this angle step.

### Algorithm of measurements

1. Switch to the "CT scan" mode and press the "Smart CT scan" button.
2. Six pictures will appear on the screen (Fig. 5). Two upper images correspond to the absorption spectrum of ultrasound waves by the sample and the sound propagation time in the sample obtained in the last scan (without image filtering). Two panels in the middle show the



absorption spectrum and propagation time averaged over all scans (without filtering). Two bottom pictures are the same images processed using the filtration algorithm.

3. Save the obtained images (menu Save → Save Images).
4. Repeat the experiment with other transmitter and amplifier settings:  
output 20 dB, gain 25 dB;  
output 30 dB, gain 30 dB;  
output 30 dB, gain 35 dB.
5. Compare the obtained images and determine which parameter set was the best. Repeat the measurements with these settings.
6. Analyse obtained tomograms; make conclusions on the inner structure of the investigated object.

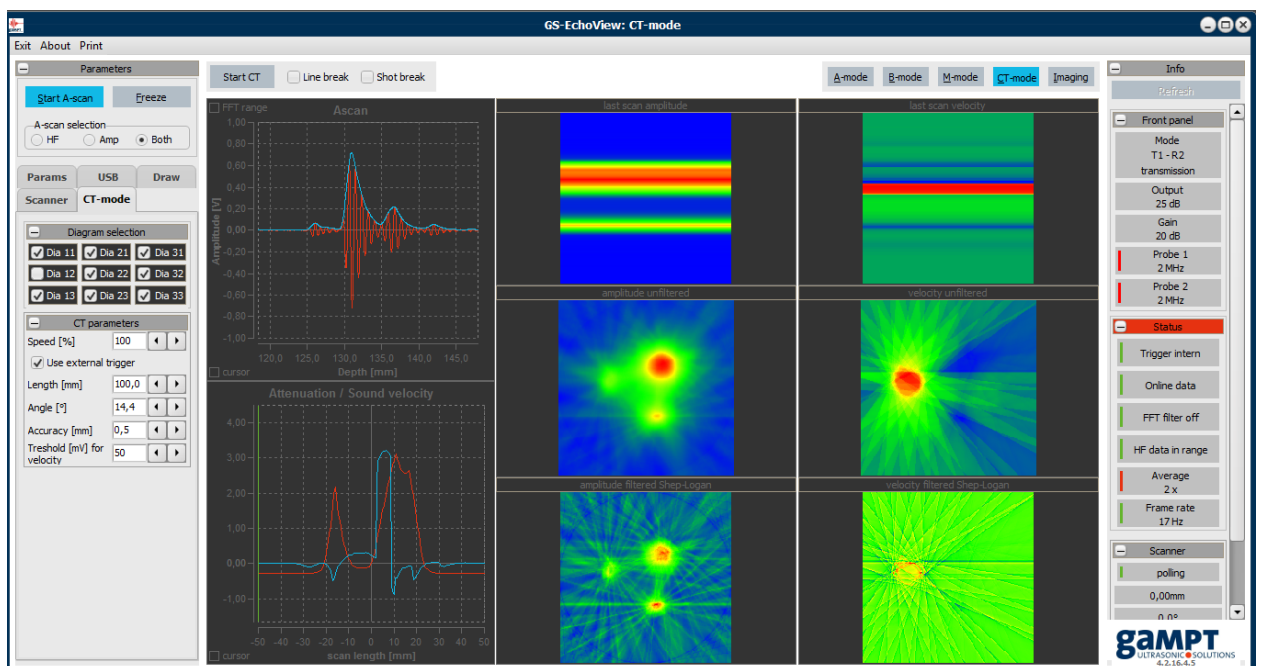


Fig. 5. A typical screenshot of the GS-EchoView programme.