

THEORETICAL BACKGROUND - ULTRASONOGRAPHY AND IMAGE ARTIFACTS

Note! This is only an outline of the theory required to perform the experiment.

Ultrasonography is currently one of the most important diagnostic tools in medicine. It is used both to image a patient's internal organs (B-mode and A-mode presentations, the latter also available in a 3D version) and to analyze blood flow in vessels (Doppler methods). Information about the condition of internal organs and blood flow in vessels can also be collected and displayed simultaneously on a monitor (color Doppler).

Imaging of the patient's anatomy is based on the pulse-echo principle. An ultrasound transducer emits a very short ultrasonic pulse that penetrates the tissues and undergoes reflections, producing echoes. These echoes then return to the transducer, which has in the meantime switched from transmit mode to receive mode. If an echo reaches the transducer after a time t , measured from the moment the pulse was emitted, the distance S between the transducer and the anatomical structure reflecting the ultrasound beam is given by the following equation:

$$S = \frac{vt}{2} \quad (1)$$

where v is the average velocity of ultrasound in the tissues. It should be remembered that t is referred to as the time of flight or time of return. This terminology may be somewhat misleading, since it refers to the total time taken by the ultrasonic signal to travel to the reflecting structure and back.

In addition to the time of flight, another physical quantity recorded by an ultrasound device is the echo intensity, which provides information about differences in acoustic impedance between the media at the interface where the reflection occurs.

In this experiment, an ultrasonic probe (transducer) is used to visualize an unknown spatial structure that is not directly visible to the person performing the experiment. The structure consists of three rectangular cuboids, which may be stacked on top of one another. Visualization is performed by determining, using the pulse-echo method, the positions of the cuboids within the scanned area and their dimensions.

Knowing in advance the geometry and internal structure of the elements of the investigated system (i.e., assuming that they are homogeneous rectangular cuboids) is necessary because, unlike in an actual ultrasound examination, in this experiment a single ultrasonic beam is reflected only once, producing only one echo. This limitation is caused by the presence of air between the transducer and the investigated system. At the air–solid interface, almost complete reflection of the ultrasound occurs. Consequently, the ultrasound cannot penetrate the cuboids and produce any additional echoes.¹

¹ Thus, for illustrative purposes, we can say that the ultrasonic beam “sees” only the surface of the cuboid that is closest to the probe (or, if the beam does not encounter any of the cuboids, the bottom of the container in which the investigated system is located).

As in diagnostic ultrasound examinations, it is assumed in this experiment that the reflection occurs along the axis of the ultrasonic beam.

In methods using ultrasound to spatially locate elements of an investigated structure, including diagnostic ultrasound examinations, image artifacts are almost always present. The same applies to the present experiment. Figure 1 shows an ultrasonic image of the upper surface of a cuboid placed inside the container, obtained using the pulse-echo method.

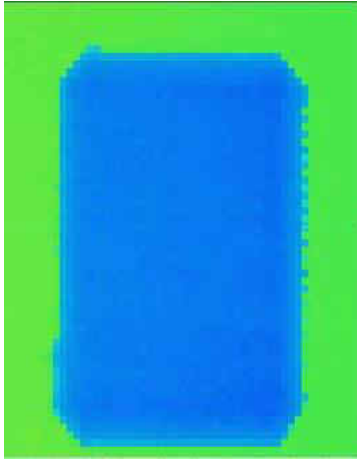


Fig. 1

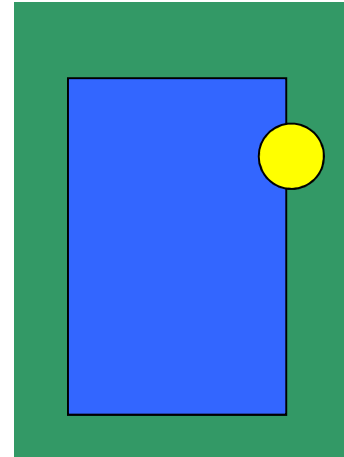


Fig. 2

The ultrasonic beams used during the scan were perpendicular to the bottom of the container. For each position of the transducer, the echo time of flight is represented in the figure using a color scale. A longer time of flight (green) corresponds to the bottom of the container, whereas a shorter time of flight (blue) corresponds to the upper surface of the cuboid.

As can easily be seen, the corners of the cuboid in the image appear “cut off.” The cause of this artifact, known in the English-language literature as the beam-width artifact, is the non-zero width of the ultrasonic beam (Fig. 2).

When the beam, whose cross-section is shown in yellow, is aimed at the bottom of the container but passes sufficiently close to the cuboid, part of the beam is simultaneously reflected from the upper surface of the cuboid. If the intensity of the resulting echo is sufficiently high, the ultrasonic transducer will detect the echo signal.

Because the transducer used in this experiment records only the first echo at each of its positions, the portion of the container bottom adjacent to the cuboid is incorrectly represented in the image as part of the upper surface of the cuboid.

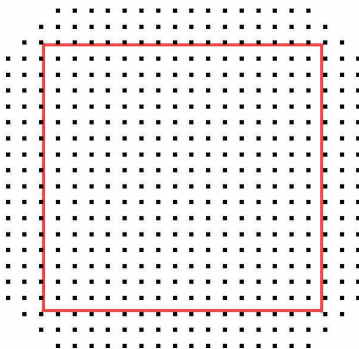


Figure 3 presents the results of a computer simulation of this artifact, obtained assuming that the beam width is significantly greater than the distance between adjacent measurement positions of the transducer, which corresponds to the conditions during the experiment. The black squares indicate positions identified as belonging to the upper surface of the cuboid, while the actual contour of this surface is shown by the red line.

As can be seen, the artifact causes both an apparent increase in the linear dimensions of the cuboid surface and, less intuitively, the effect of apparently truncated corners, as shown in Fig. 1.

This artifact will inevitably occur during the experiment. Understanding its nature will therefore allow us to improve the accuracy of the measurements.

² The image also contains “excess” edge pixels (“teeth”), occurring either individually or in small groups. These should not be confused with the “steps” observed near the corners. The echoes corresponding to these pixels have intensities very close to the sensitivity threshold of the transducer, but still above this threshold. The presence of these “teeth” is therefore independent of the artifact discussed above. On the other hand, as will be explained below, the artifact causes their apparent displacement.