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Investigation of the influence of the transducer positioning angle deviation on the 3D reflections from a triangle reflector

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Abstract:
Objective of this study was to investigate the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from a triangle reflector. For that an acoustic computer model using the Huygens approach, which enables calculation of the signals reflected by the triangles in 3D space was used. Modelling was performed at different deflection angles of triangles with respect to the transducer and at different transducer deflection angles from its supposed position for each triangle angle. The performed simulations show that even small deflection of the transducer from its supposed position deteriorate the obtained image of the inspected object.
Keywords: 3D modelling, ultrasonic, Huygens, transducer positioning.

Introduction

There are many factors which may influence measurement accuracy essentially, such as measurement conditions, positioning of the transducer and etc. Performing different measurements using ultrasonic waves, especially *in-situ*, it is not always possible to orient the ultrasonic transducer accurately, i.e. the measurement errors due to angular positioning of the transducer have to be taken into account. If the transducer is deflected by a small angle from its supposed position, the reflected signal can be distorted in comparison with the signal, received by a nondeflected transducer.

In order to predict if small deviations of the transducers angular position can affect the reconstructed image of the inspected object, modelling was performed. The objective of this work was to investigate the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from triangle.

This investigation was performed using an acoustic computer model, because often one of the ways to solve complicated inspection tasks is to use the acoustic computer model, which enables to simulate propagation of ultrasound in different media and to calculate the signals reflected by the objects, having a complicated structure. Several modelling approaches for approximation of objects through the series of different facets (rectangular, circular and triangular) are available [1-3]. The triangle objects were selected for the investigation, because in a widely used CAD model all surfaces are given in terms of triangles. Each facet in the three-dimensional space is represented by its vertex points and the unit surface normal vector pointing out of the body [1].

The main objective of the developed acoustic model is to calculate ultrasonic signals reflected by the components of a complicated geometry, approximated by triangles, taking into account position, orientation and parameters of the ultrasonic transmitters and receivers. The reflected signal according to this approach is calculated as a sum of the signals reflected by elementary segments of the reflecting surface - a part of the triangle which is in the intersection zone of the directivity patterns of the transmitter and the receiver.

Main steps of the used method

In the used acoustic computer model [4] it is assumed that a triangle reflector is arbitrally oriented in space. The main idea of the model is that the triangle plane is rotated in space in such a way, that after the turn the triangle would be located in one plane (z=0) and all calculations could be performed in 2D space. This approach reduces the amount of the data, and, consequently, increases the speed of calculations.

The modelling of 3D reflections from triangles using the proposed Huygens approach consists of the following steps [4]:

- The triangle is moved to the origin of the coordinate system;
- The triangle is rotated in such a way, that after the rotation the triangle would be located in one plane (z=0);
- The transmitter and receiver are translated and rotated in the same way as the triangle in order to keep the position of the transducers with respect to the triangle plane unchanged;
- The zone of the triangle which is completely in the intersection zone of the directivity patterns of the transmitter and receiver is found;
- This triangle zone is divided into elementary segments with a step, which is smaller than the half of the wavelength;
- The distance between these elementary segments and the transducers (transmitter and receiver) centres is calculated:

$$d_1 = \sqrt{(x_{rt} - x_{el})^2 + (y_{rt} - y_{el})^2 + (z_{rt} - z_{el})^2}\,, \qquad (1)$$

where x_{rt}, y_{rt}, z_{rt} are the coordinates of the transducer centre, x_{el}, y_{el}, z_{el} are the coordinates of the elementary segment in the triangle plane.

- The amplitude of the signals is calculated taking into account the directivity pattern and the distance from the transmitter to each of the elementary segments;

$$A = \left(\exp\left(K_{dir} \cdot \alpha_a^2\right)\right)^2, \quad (2)$$

where $K_{dir} = \log(0.5)/\alpha_r^2$; α_a is the angle from the transducer axis, α_r is the limiting angle of the transducer.

- The signal propagation time from the transmitter to the elementary segment in the triangle and to the receiver is calculated, because all elements are assumed to be the sources of ultrasonic waves:

$$t = \frac{d_{et} + d_{er}}{c}, \quad (3)$$

where d_{et} is the distance from the elementary segment in the triangle plane to the centre of the transmitter, d_{er} is the distance from the elementary segment in the triangle plane to the centre of the receiver, c is the ultrasound velocity.

- According to the Huygens's principle the total received signal is calculated as the sum of reflections from the elementary segments as

$$u(t) = \sum_{k=1}^{N_e} u_t(t) \otimes h_k(t), \quad (4)$$

where the $u_t(t)$ is the transmitted ultrasonic signal $h_k(t)$ is the pulse response of k-th elementary segment, $\otimes$ denotes convolution.

Modelling of 3D reflections from a triangle reflector at different transducer deflection angles

In order to investigate the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from triangle, simulation of ultrasonic signals reflected by a triangle immersed in water was carried out. The geometry of the triangle is given in Fig. 1.

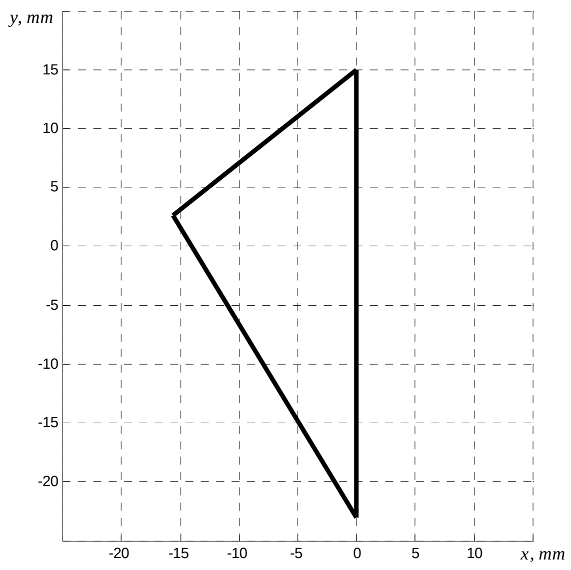

Fig. 1 **Geometry of the simulated triangle**

The simulation was performed using a single 5 MHz ultrasonic transducer, operating in a pulse-echo mode. The transducer was at the 300 mm distance from the object and was consequently shifted in a plane z=300 mm. The simulated reflected signals in the time domain were used to construct a C-scan type image of the triangle. For formation of the C-scan image only the area, which was inside the directivity pattern of the transducer, was used (Fig. 2). The scanning step was 0.5 mm.

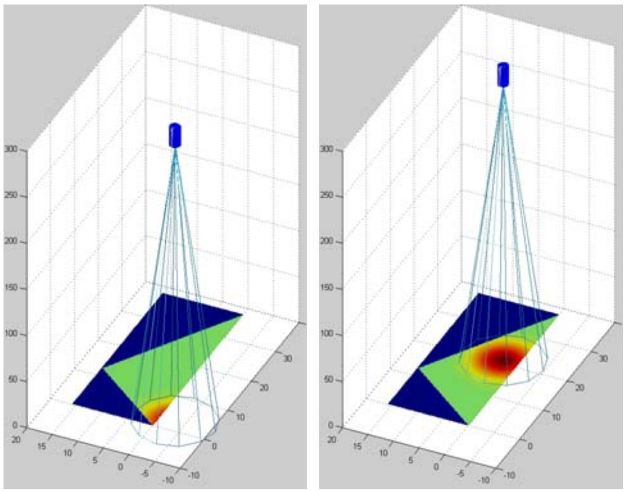

Fig.2 **Explanation of C-scan image formation using a single ultrasonic transducer at different time instants**

Modelling of the 3D reflections from the triangle was performed in the case when an ultrasonic beam is reflected by triangle reflector, reflecting surface of which is inclined with respect to the symmetry axis of the directivity pattern; therefore the signals which are picked up are not specularly reflected by the object. For this purpose the single triangle was rotated around the longest leg.

The simulated ultrasonic images of the triangle reflector obtained under different orientation angles and different transducer deviation angles from its supposed position are presented in Fig. 3 - 10. It is necessary to take into account that the true value of the maximum amplitude in each image differs essentially. In all images the presented amplitudes are normalized with respect to the maximum amplitude in each image.

The images of the triangle at the angle 1° (Fig. 3 - 6) and 2° (Fig. 7 – 10) were modelled at different transducer deflection angles from its supposed 0° position (Fig. 3 and 7). The transducer deflection by 0,5° (Fig. 4 and 8), by 0,75° (Fig. 5 and 9) and by 1° (Fig. 6 and 10) were investigated.

The simulation results clearly show that even small deflection of the transducer (<1°) from its supposed position affects the obtained image of the triangle, and, if more complicated structures are inspected, it can considerably affect the recognition of the inspected object. One can observe that a strong linear reflection from the longest leg of triangle reflector (Fig. 3) starts to bend when the deflection angle of the transducer is increased (Fig. 4 - 6). When the triangle is rotated by 2°, and the transducer is not deflected, the reflection from the middle side of the triangle can be observed. When the transducer is deflected, the reflection form the shortest side of the triangle is observed instead.

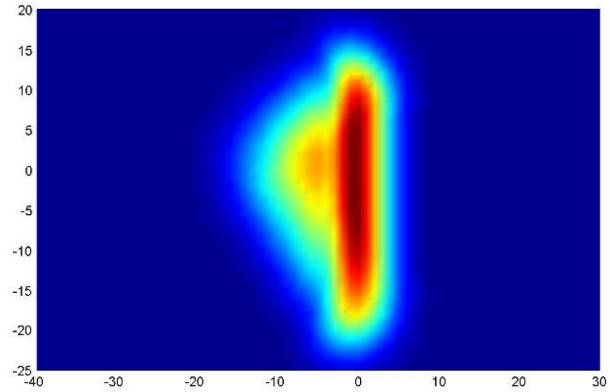

Fig.3 **The simulated C-scan image of the triangle at the angle 1°, transducer deflected by 0°**

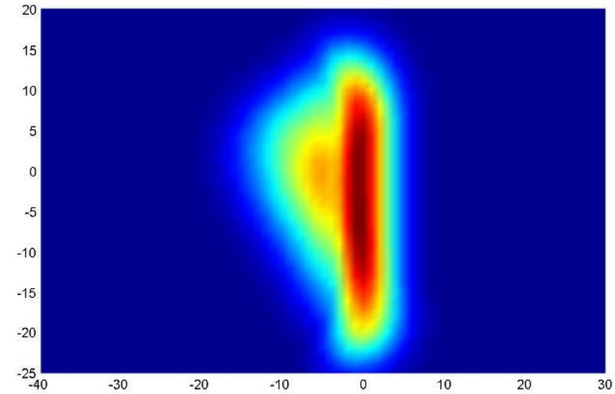

Fig.4 **The simulated C-scan image of the triangle at the angle 1°, transducer deflected by 0,5°**

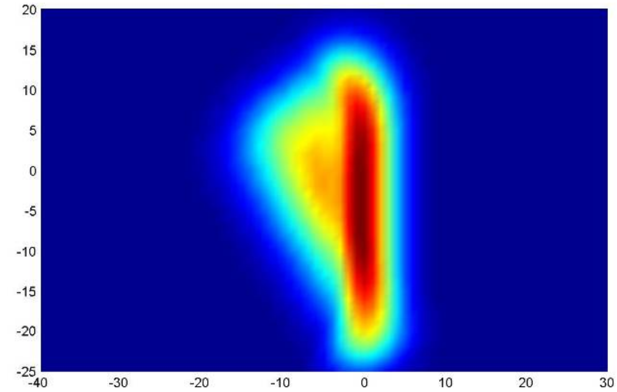

Fig.5 **The simulated C-scan image of the triangle at the angle 1°, transducer deflected by 0,75°**

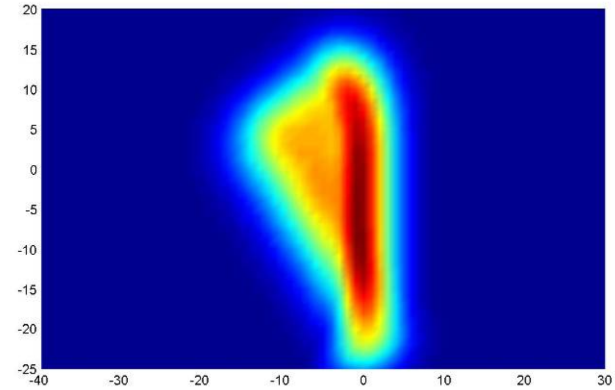

Fig.6. **The simulated C-scan image of the triangle at the angle 1°, transducer deflected by 1°**

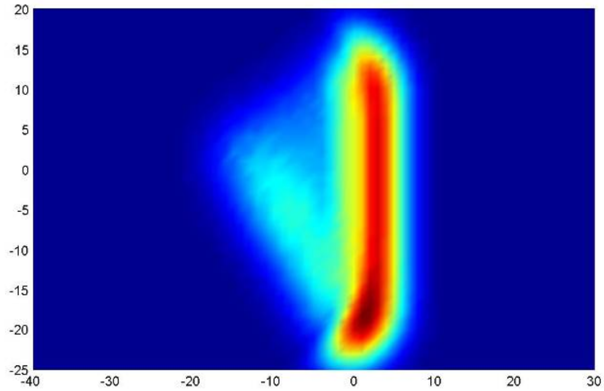

Fig.7. **The simulated C-scan image of the triangle at the angle 2°, transducer deflected by 0°**

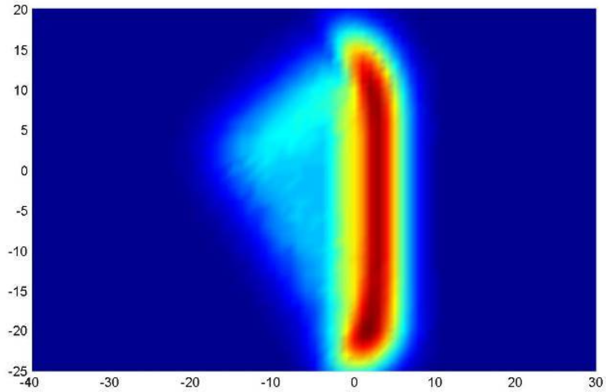

Fig.8. **The simulated C-scan image of the triangle at the angle 2°, transducer deflected by 0,5°**

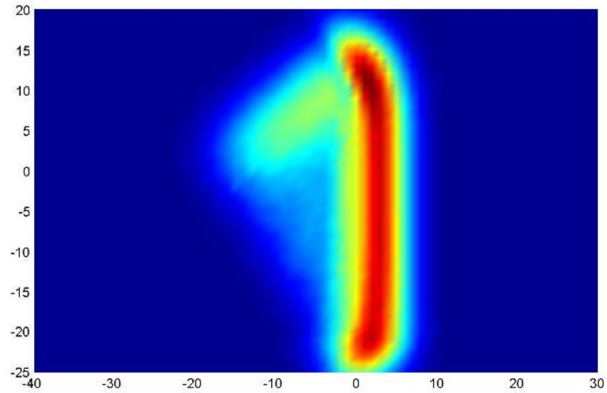

Fig.9. **The simulated C-scan image of the triangle at the angle 2°, transducer deflected by 0,75°**

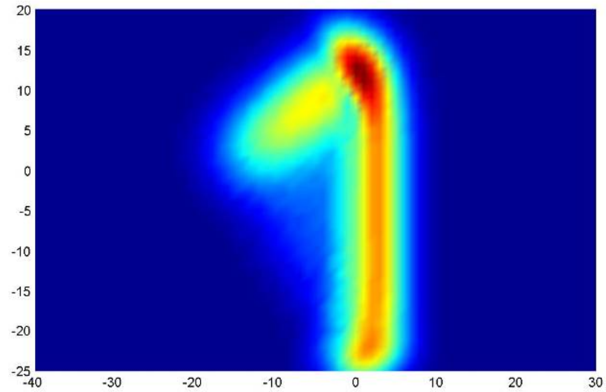

Fig.10. **The simulated C-scan image of the triangle at the angle 2°, transducer deflected by 1°**

Conclusions

The proposed acoustic model using the Huygens approach enabled to calculate the signals reflected by triangle reflectors in 3D space. The rotation of the triangle plane in space in such a way, that after the turn the triangle would be located in one plane (z=0) and all calculations could be performed in 2D space allowed to reduce the amount of data and, consequently, to increase the speed of calculations.

In order to investigate the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from a triangle reflector, simulation of ultrasonic signals reflected by a triangle reflector immersed in water was carried out. The simulated ultrasonic images of the triangle reflector obtained under different orientation angles and different transducer deviation angles from its supposed position show, that even small deflection of the transducer ($<1°$) deteriorates the obtained image of the object and if more complicated structures are inspected it can considerably affect the recognition of the inspected object.

Often in experiments it is impossible to carry out adjustments of the transducers angular position with a such high accuracy, therefore more deep investigation of the transducer's angular deflection from its supposed position on the reconstructed images should be performed.

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E. Jasiūnienė

Keitiklio kampinio pozicionavimo nuokrypio įtakos atspindžiams nuo trikampių trimatėje erdvėje tyrimas

Reziumė

Šio darbo tikslas buvo ištirti, kokią įtaką turės keitiklio kampinio pozicionavimo nuokrypis atspindžiams nuo trikampių trimatėje erdvėje. Tam buvo naudojamas pagal Hiuigenso principą sudarytas akustinis kompiuterinis modelis, kuris leidžia modeliuoti ultragarso signalo atspindžius nuo bet kaip orientuotų trikampių trimatėje erdvėje. Modeliuota esant įvairiems trikampio pasukimo kampams ir įvairiems keitiklio nuokrypio kampams. Atspindžių nuo trikampio modeliavimas parodė, kad net maži kampiniai keitiklio nuokrypiai turi įtakos gaunamam vaizdui.

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