Analysis of Acoustic Characteristics of Aero Ultrasonic Sensor Calculated by 3D-FDTD

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Recently, the ultrasonic sensor is utilized in the car for obstacle-detection. The improvement of its performances, however, is literally a continuous process of trial and error. In this paper, the detection characteristic of an ultrasonic sensor is analyzed used by three dimensional Finite Difference Time Domain method. The reflected pulses from obstacles were calculated using short pulses of 40kHz. TOFs and amplitudes from obstacle were determined changing with its height and outer shape. Two results calculated by 2D and 3D-FDTD were compared.

1 Introduction

Aerial back sonar of a car is very useful to detect the obstacles in the rear of an automobile. However, it is very difficult to predict receiving pulse waveforms from obstacles, because an aerial back sonar system has been using in many kind of circumstances. Because of the limitation of the car design, the outer size of aerial back sonar is almost fixed. The new calculation method has been desired to predict the detection ability of sonar to obstacles. In this paper, the Finite Difference Time Domain (FDTD) method is proposed to calculate the reflection characteristics of the back sonar system. The FDTD calculation method that is common in the electromagnetic field [1] has ability to calculate an instantaneous pressure of a sound pulse. The recent development of computer system enables FDTD method to be applied in the acoustics filed although it requires the huge computer resources.[2] To confirm the validity of the FDTD method to a back sonar system, the receiving waveforms from the targets were calculated as changing target’s height. A snap shot of propagation pulses from a target was obtained because the FDTD was capable of calculating the instantaneous sound pressure along the propagation of pulse. The large difference of echo signals was obtained for the difference of target’s shapes.

2 Finite Difference Time Domain

2.1 Formulation of FDTD

The basic equations of the 3D-FDTD method, that is taking account of attenuation, are given as follows [3]:

\[-\rho \frac{\partial v_x}{\partial t} = \frac{\partial p}{\partial x} + \eta v_x,\]

\[-\rho \frac{\partial v_y}{\partial t} = \frac{\partial p}{\partial y} + \eta v_y,\]

\[-\rho \frac{\partial v_z}{\partial t} = \frac{\partial p}{\partial z} + \eta v_z,\]

where $p$ is sound pressure, $v$ is the particle velocity, $K$ is the bulk modulus, $\rho$ is the density and $t$ is time. The second part of the right hand side in (2) shows an attenuation of the medium caused by absorption

\[
\frac{\partial^2 P}{\partial x^2} + \left( \frac{\omega^2}{c^2} - j \frac{\omega \eta}{\rho c^2} \right) P = 0
\]

\[
P = P_0 \exp \left[ -j (\gamma_1 - j \gamma_2) x \right]
\]

where $P_0$ is the constant and $\gamma_1$ and $\gamma_2$ are the wave number and attenuation constant, respectively. The velocities of sound $c$ and resistance coefficient $\eta$ are obtained where $\omega$ is angular frequency. In this paper, the resistance coefficient that is proportional to the particle velocity is ignored because of low attenuation in air.

\[
c = \omega / \sqrt{\gamma_1^2 - \gamma_2^2}
\]

\[
\eta = \frac{2 \gamma_1 \gamma_2}{\sqrt{\gamma_1^2 - \gamma_2^2}} \rho c
\]

The finite differential equations are obtained as a function of discrete positions $x$, $y$, $z$ in space and a discrete time $t$ as shown in (5)

In these equations, superscripts show the time and $i$, $j$ and $k$ are the grid-numbers in the $x$, $y$ and $z$ directions in space, respectively. For simplification, $\Delta x = \Delta y = \Delta z$ in this paper.
FDTD requires satisfying the next Curant’s equation for the stability in calculation.

\[
P^n(i, j, k) = P^{n-1}(i, j, k) - C_p \left[ v_x \left( \frac{n-1}{2} \right) + v_y \left( \frac{n-1}{2} \right) + v_z \left( \frac{n-1}{2} \right) \right]
\]

\[
\begin{align*}
\Delta x & = \Delta x \\
\Delta y & = \Delta y \\
\Delta z & = \Delta z
\end{align*}
\]
3.2 Calculated sound source by 2D-FDTD

Figure 2 shows the calculated sound source by 2D FDTD that was assumed to be composed of 25 discrete point-sources on the calculating grids. Gaussian weighting function was assumed to the vibrating velocity of sound source. This results agrees well with the measured sound pressure field of the aero sensor.

![Sound pressure field](image)

The first echo, so called “the first wave”, was generated by the upper-left corner of the target or surface of the target. Also the third echo, we called it as “the second wave” in Proc. of Forum Acoustica 2002, was generated by the corner of the target and the earth.

Figure 5 shows the amplitude of the first and second wave as a function of height of target h.

![3D Calculation model](image)

The amplitude of the first wave increased with target’s height as shown in Fig. 5.

In Fig. 4, the second wave (third echo) was the biggest. It had almost the same amplitude and propagation time \( t = 4.2 \text{ms} \), even thought the height of target was changed from 0.2 to 0.7m. This results show that aerial back sonar can detect the objects whose height is over 0.1m using the second wave as shown in Fig. 5.

Figure 6 shows the snap shot of propagation pulse sound calculated by 3D-FDTD when \( h = 0.3 \text{m} \). We can clearly see the pulse propagation in air.

3.3 Estimation of receiving pulse-waveform from target

The receiving pulse waves were calculated when the height of target \( h \) was changed as shown in Fig. 3. The objective target was place at \( x = 0.5 \text{m} \) and the earth was assumed to be rigid plane. For the accurate calculation, calculation increments in space \( \Delta x = \Delta y = \Delta z = 0.85 \text{mm} \) and in time \( \Delta t = 1.44 \text{µs} \). Mur’s first order absorbing boundary conditions were provided to eliminate the reflection wave from the outer boundaries of the calculation space. Figure 4 show the typical receiving echo signals from the target. The reflected pulse was composed of a few echoes. Each echo shown by the circled number is corresponding to the sound pass shown in Fig. 3.

![Sound pressure filed of sensor](image)

4 Summary

The 3D-FDTD using the parallel computing with MPI obtained the receiving waveforms from the target and the propagating snap shots of aerial back sonar. A sensor had been assumed to project a 40kHz pulse whose pulse-width was about 0.15ms. We obtained the reflected echo signal from the target as a function of its height. Aerial back sonar detects the rectangle target whose height is over 0.1m. The snap shot of sound propagation was also clearly shown in the figure. These results show the validity of the 3D-FDTD method for estimation of receiving waveform.
Fig. 4 Receiving waveform from the target.

Fig. 5 Amplitude of receiving waveform as a function of height of target.

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Fig. 6 Snap shots of propagating pulse.

References


