Designing ocean acoustic waveguide remote sensing for target detecting and tracking

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Abstract. Acoustic sensor used sound wave to transmit pulses into the underwater in order to gain underwater environment information. We developed Ocean Acoustics Waveguide Remote Sensing (OAWRS) instrument. The acoustic signal acquisition system has been designed which used to record the direct, reflected, scattered or echoed signals originated from transmitter transducer, targets or underwater objects. The acquisition system compose of interconnected hardware and software with a simple working principles. The software, which is written under Windows™ and Matlab, controlled the hardware by sending commands to the Transmitter Module located somewhere to generate a sound pulse and the Receiver Module to be ready to receive sound signals. The received sound data may be recorded for further analysis to developed OAWRS algorithm.

1. Introduction
Sound waves provide the efficient method to explore ocean environments since these waves can propagate to ranges orders of magnitude beyond the attenuation limits of electromagnetic waves [1]. This makes the application of active sonar systems useful for imaging, detecting, and classifying targets of interest, such as seafloor morphology, man-made objects, and marine life in an underwater environment [2]. Standard acoustic used for surveying and monitoring fish populations often produce abundance and behavioral records that are ambiguous, incomplete and have high uncertainty [3]. This is because these methods rely on highly-localized measurements that are restricted to the immediate vicinity. The limited temporal and spatial coverage of conventional systems often lead to a gross undersampling, in time and space, of the vast ocean environments that fish typically occupy [4].

To overcome these problems, we designed Ocean Acoustics Waveguide Remote Sensing (OAWRS) instrument to be capable of instantaneous wide-area sensing of marine fish. Continuous monitoring with OAWRS enables the production of wide-area coverage that detail the spatial and temporal distributions of fish population. These wide area can reveal behavioral patterns that may enable better modeling and prediction of fisheries condition.
2. Method

2.1. Sonar Equation for OAWRS

Projector source level, SL\text{projector} is defined for acoustic pressure at reference range of 1 m from acoustic centre. Sound intensity is calculated by:

\[ I = \frac{P_{tx}}{\text{Area}} \text{ (W/m}^2\text{)} \quad (1) \]

and measure in dB re 1\,\mu Pa. For omni directional projector, the surface area of the sphere \((4\pi r^2 = 12.6\,\text{m}^2)\). Then,

\[ SL_{\text{projector}} = 10 \log \left(\frac{P_{tx}/12.6}{I_{\text{ref}}}\right) \text{ dB} \quad (2) \]

\(P_{tx}\) is total acoustic power used by projector and sound reference intensity become:

\[ I_{\text{ref}} = (P a_{\text{ref}})^2 / \rho c \text{ (Wm}^2\text{)} \]

where reference of level pressure \(P a_{\text{ref}}\) is 1\,\mu Pa, \(\rho\) is medium density and \(c\) is sound speed. Equating of transmitter acoustic signal level \((SL_{\text{projector}})\) at 1 m for omni-directional projector is:

\[ SL_{\text{projector}} (P) = 170.8 + 10 \log P_{tx} \quad (3) \]

Projector for directional type with directivity index:

\[ DI_{tx} = 10 \log \left(\frac{I_{\text{dir}}}{I_{\text{omni}}}\right) \quad (4) \]

\(I_{\text{omni}}\) is intensity and distributed spherically and \(I_{\text{dir}}\) is intensity along the acoustic axis of beam pattern. \(SL_{\text{projector}}\) become:

\[ SL_{\text{projector}} (P, \eta, DI) = 170.8 + 10 \log P_{tx} + 10 \log \eta_{tx} + DI_{tx} \quad (5) \]

where \(\eta_{tx}\) is efficiency of projector.

2.2. Designing of OAWRS transmitting and receiving system

The Signal to Noise Ratio (SNR) for OAWRS is expressed by [5]:

\[ SNR = \frac{P_v^2}{P_N^2} \quad (6) \]

where \(P_v\) is the volume scattered echo pressure amplitude, \(P_N\) is the noise pressure amplitude. Influencing the absorption and spreading attenuation, the square echo pressure is calculated by:

\[ P_v^2 = P_o^2 (c \tau/2) \Psi r^2 \exp(-4\alpha r) Sv \quad (7) \]

\[ P_o^2 = \rho c a^2 Ic D_1/2 \quad (8) \]

where \(P_o\) is the source pressure, \(c\) is sound speed in the seawater, \(\tau\) is pulse width, \(c \tau/2\) is range resolution, \(\Psi\) is the equivalent beam width, \(r\) is range, \(\alpha\) is absorption coefficient (neper/m), \(Sv\) is the linear variable of \(SV\), \(\rho\) is density of seawater, \(a\) is radius of the transducer, \(Ic\) is cavitation threshold, and \(DI\) is the directivity index. The equivalent beam width \(\Psi\) is calculated by [6]:
\[ \psi' = \left( \frac{2}{\pi} \right) \left( \frac{\lambda}{2a} \right)^2 \]  \hspace{1cm} (9)

where \( \lambda \) is the wave length. The directivity index \( DI \) is shown by:

\[ DI = (ka)^2 \]  \hspace{1cm} (10)

For a circular piston transducer, where \( k = \frac{2\pi}{\lambda} \) is the wave number. In order to gain high \( SNR \), the full capability of transducer was obtained. Therefore, the source pressure should be determined by \( Ic \), which is calculated by [7]:

\[ Ic = 1.7 \tau^{0.22} \times 10^{b+3(1+r/10+Ta)}^2 \]  \hspace{1cm} (11)

\[ b = 0.116 f^{0.52} \]  \hspace{1cm} (12)

where \( \tau t \) is the transducer depth from sea surface in m, \( Ta \) is tensile strength of seawater in atm, \( f \) is frequency in kHz. The noise spectrum level \( Np \) is calculated by [7]:

\[ NP = Np \log f^{1.8} \]  \hspace{1cm} (13)

\[ NP_o = 10 \log Np = 145 \text{ dB (0 dB = 1} \mu\text{Pa/Hz}^{1/2}) \]  \hspace{1cm} (14)

The received noise pressure is calculated by:

\[ P_N^2 = Np^2 \Delta f / DI \]  \hspace{1cm} (15)

where \( \Delta f \) is the bandwidth of the receiving system. The final expression of SNR [8]:

\[ SNR = 2 \pi^3 \rho \tau a^4 f^{5.6} Ic \exp (-4 \alpha r) n Ts/\tau^2 Np^2 \Delta f \]  \hspace{1cm} (16)

2.3. Data Acquisition

Designing of acoustic transmitter and receiving system is shown in Figs. 1 and 2.

![Figure 1. Designing of acoustic transmitter system.](image-url)
3. Results and Discussion
Detail designed of transmitter was shown in Figure 3. The transmitter consist of 4 Integrated Circuit (IC), Trigger Generator, Signal Generator, and Amplifier, Matching Impedance Transformer.

The signal from the receiver transducer is inputted to the Linear Amplifier through a voltage divider circuit in the form of a ring diode and a 10 kohm resistor. The diode serves to limit the signal voltage to no more than 0.7 volts. IC CA3140 is configured as a linear amplifier through a 10 kohm feedback back resistor and a 500 kohm potentiometer. The gain value is determined by the ratio of the feedback resistor and the input resistor, in this design the gain can be set from 1 to 500 times. Windows Console of acquisition system was shown in Fig. 5. Figure 6 show the receive echo signal obtained from ocean acoustic tank.
Sound propagation in the ocean is influenced by the physical and chemical properties of seawater and the geometry of the channel. Transmission Loss of OAWRS was shown in Figure 7. Underwater acoustic signal experiments are affected by attenuation caused by spreading and absorption. Propagation of acoustic ray was shown in Fig. 8. This figure show the characteristic of ray is multipath propagation. The sound intensity level was decreased in long ranges. This condition is agreed with the previous research [9][10].
4. Conclusions

In this research has successfully designed transmitter system to transmit acoustic signal and receiver system (hydrophone). Measurement of transmitting power and transmission loss parameters has been done. Sonar equation for ocean acoustic waveguide propagation has been successfully conducted and applied to OAWRS instrument. Acoustic ray computations are based on the wave propagation properties of different propagating mediums.

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