Feasibility Study of Using Acoustic Signal for Material Identification in Underwater Application Using a Single Transceiver

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***Abstract*—Structural inspection is a process to evaluate the condition of a structure in order to determine whether cracks, flaws defects or damages occur in structural build. This work explores the feasibility study of using acoustic signal as a sensing modality for material identification in underwater application with a single transceiver. Using the measured reflected signal, a reflection coefficient for different material types is calculated and compared to that of an ideal or standard case. Various materials with different density and surface reflection properties were used as test objects with respect to the optimum operating frequency in this work. Early results indicate that there is potential for further exploration in utilizing acoustic signal for structural inspection underwater.**

Keywords - structural inspection, material identification, acoustic signal, underwater application

I. INTRODUCTION

Non-destructive testing (NDT) is a group of analysis techniques that is used to evaluate the properties of material, component and structural build without having to cause any damage to the test object [1]. The field of NDT is a very broad and challenging one, which plays a critical role in assuring that structures are in reliable and safe condition. Several commonly used methods for NDT are visual inspection, ultrasonic, dye penetrant, magnetic particle, acoustic emission, electromagnetic and radiography.

Ultrasonic testing is commonly used for structural inspection as it can be employed in underwater to detect and locate discontinuities or cracks, as well as to measure the thickness of steel, concrete and wooden structures, and is capable of detecting internal material defects [2]. However, ultrasonic method has its limitation on the medium used in testing as it has a huge impact on the signal-to-noise ratio (SNR). Noise and thermal noise occur as a result of molecular agitation of water in sea state [3]. On top of that, this method cannot be used to test on high attenuating materials due to the high crest factor of the excitation signal decreases the SNR [4].

This work explores the idea of using acoustic signal for underwater structural inspection as they propagate well in water medium, unlike electromagnetic waves. Acoustic signal has been widely used in basic underwater acoustic where real time communication between the underwater instruments and a control center within a network configuration was established [5]. As a preliminary study, this paper presents early results of using acoustic signal as a sensing modality to differentiate various materials using a single transceiver. This effort serves as a preliminary effort for exploring the potential of utilizing acoustic signal for underwater structural inspection with NDT. Literature review will be shown in section II while experiment setup will be explained in terms of hardware design and experimental design in section III. Preliminary result in testing with various materials is presented in section IV while conclusion and future work will be discussed in section V.

II. LITERATURE REVIEW

A. *Acoustic Signal and its Application*

Acoustic waves originate from the propagation of a mechanical perturbation where local compressions and dilations are passed from one point to the surrounding due to the elastic properties of the propagation medium. The main aspect of using acoustic signal in underwater application is related to the propagation of acoustic waves in underwater. The most significant effect of propagation is to decrease the signal amplitude through the geometrical spreading and the absorption.

Acoustic signals propagate better than light and radio waves of any other types of energy in underwater applications [6]. The commonly used acoustic signal falls in the range of 100 Hz to 100 kHz [7]. Acoustic signal has been utilized to fulfill the needs of underwater communications in scientific explorations, commercial exploitations, defense surveillances and environmental protection. Acoustic signal transmission and detection encounter significant challenges due to the dynamic properties and extreme nature of the ocean [6]. Some of the issues that are related to acoustic signal have been discussed and researched extensively at theoretical level including the multi-path propagation, time variation of acoustic channel, strong signal attenuation, propagation speed and many more.

B. Techniques involving Acoustic Signal

1) Acoustic Emission

Acoustic emission is widely used as a non-destructive technique in inspecting structure build. It is fundamentally different from other techniques that use stress waves as it relies on signals originating from within the test object rather than outside it [7]. It is transient elastic waves generated by the rapid release of energy from localized sources within a material [8]. This is a technique to monitor crack formation and failures in structural materials. When a material is subjected to stresses such as mechanical stresses, acoustic emission is generated when cracks develop in the concrete and stress waves are emitted.

This method has been used in areas that are known to be at high risk of fatigue cracking where inspection is difficult, unreliable and costly. Acoustic emission can provide real time information on fatigue crack initiation and crack growth, and can be used to detect fatigue cracks at early stages. The numerical processing procedures can locate flaw anywhere on the structure without the necessity to test and scan the large proportion of its surface. However, its main limitation is that the method is unable to detect cracks unless they are growing. Hence it only detects flaws while damage has already begun to occur. It is difficult to determine the size of the cracks and locate the crack using acoustic emission. This technique is also prone to background noise which can affect its accuracy and reduce the probability of detection.

2) Acousto-ultrasonics

Acousto-ultrasonics is a technique in which the received signal is processed in a similar manner as in acoustic emission testing, with the exception that the acoustic signal is externally introduced to the specimen with a transmitter [7]. Two ultrasonic transducers are placed at a fixed distance from the specimen surface, one acting as a transmitter while the other acting as a receiver. Any flaws or damages which affect the test object's mechanical properties will affect the way in which stress waves travel in it. Stress wave factor, which are computed from the received signal can provide a numerical index that allows one state of the test object to be distinguished from another.

The advantage of this technique is that the object under testing does not have to be stressed. However, acousto-ultrasonics is unable to detect small individual localized flaws because these do not affect the mechanical properties as mechanical properties will only influenced by large flaws or diffuse populations of small flaws.

C. Wave Propagation Model in Underwater

The transfer function of the wave propagation model was derived by expressing boundary conditions for normal stresses and displacements at the two interfaces of the layered system water-material-water. Reflection coefficient gives the information on how much of the signal is being reflected after it hit the test material. When the signal hit the material, part of the signal will be absorbed while the remaining signals will be reflected and return towards where it is originated. The extent of signal reflection depends on the reflection coefficient. Reflection coefficient can be calculated by taking the ratio of amplitude of the reflected wave and the amplitude of incident wave.

III. EXPERIMENTAL SETUP

A. Hardware Design

One of the important criteria and the basic feature that needs to be considered when choosing a suitable sensor is the maximum operating depth. Maximum operating depth reflects the ability of the sensor to work efficiently under certain amount of hydrostatic pressure. Beyond the limit of maximum operating depth, the sensor might be damaged by maximum diaphragm deflection or sustaining collapse voltage inside electro-acoustic transduction medium. Another important parameter that varies with depth is the temperature. Fulfilling operating temperature range will ensure that the data obtained are reliable and valid.

A transceiver is a device comprising both a transmitter and a receiver which are combined and share common circuitry or a single housing. There are many option of transceiver available in the market and PROWAVE transceiver was chosen due to its low cost and availability. Table I shows the comparison among the suitable PROWAVE transceiver.

TABLE I. COMPARISON OF AVAILABLE SENSORS

Category	400EP18A	400EP14D	400EP250
Frequency (kHz)	40	40	40
Transmit sensitivity (dB)	108 @ 30cm	103 @ 30cm	113 @ 30cm
Receive sensitivity (dB)	-75	-78	-72
Beam width (°)	85 @ -6dB	65 @ -6dB	30 @ -6dB
Operating temperature (°C)	-30 to 80	-30 to 70	-30 to 80
Diameter (mm)	18	14	25
Length (mm)	12.1	9.1	12

Comparison has been done in all aspect on all the commercially available ultrasonic transceiver and PROWAVE 400EP18A is chosen due to its larger beam angle to have more coverage area. Although it is not designed for underwater operation, it could be adapted to allow underwater use. A simple connector circuit has been built using SRM400 module board to ensure transceiver works properly for the experiments.

B. Experimental Design

Experiments were done in a vessel of diameter 45 cm with height 45 cm. Fig. 1 shows the front view of the experiment setup. The transceiver was sealed at the end of a plastic buoy, which was held in place using a polyvinyl chloride (PVC) pipe. The wire of the transceiver was enclosed within the pipe and connected to the circuit that was located elsewhere to avoid direct contact with water.

The transceiver transmits acoustic signal at a perpendicular angle to the test object placed at the bottom of the vessel. The reflected signal was received by the same transceiver, which was set to be in receiving mode through the module. The reflected signal will then analyzed after logged and stored in digital oscilloscope.

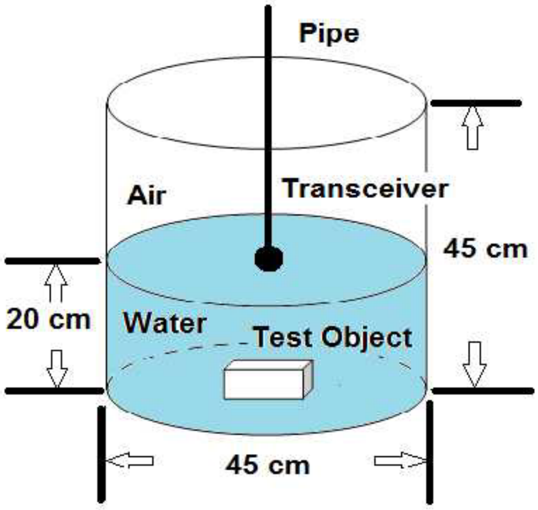

Figure 1. Front view of the experiment setup.

C. Characterization of Transceiver and its Distance to Test Object

Optimum operating frequency needs to be obtained to get the lower noise level signal. The characterization is done underwater as the originally specification provided by the transceiver manufacturer is for operation in air. This was done by setting the operating frequency ranging from 5 kHz to 35 kHz with a 5 kHz interval for the transceiver to determine the optimum operating frequency. Three readings were taken for each set of different variable and the average was calculated. Table II shows the mean and standard deviation of reflected signal at different frequency.

TABLE II. MEAN AND STANDARD DEVIATION OF REFLECTED SIGNAL AT DIFFERENT FREQUENCY

Frequency (kHz)	Mean (V)	Standard Deviation (V)
5	1.818	0.407
10	2.483	0.771
15	1.950	0.372
20	1.722	0.100
25	1.487	0.039
30	x	x
35	x	x

The mean and standard deviation for each frequency were studied and compared. Data was unreadable for 30 kHz and 35 kHz when the transceiver was placed in underwater environment. Results show that 25 kHz produced the lowest standard deviation, indicating that the measurements are the most susceptible to noise underwater. This is chosen as the optimum operating frequency for subsequent work presented in this paper.

The effect of distance between the test object and transceiver was also studied to obtain a favorable working distance. The distance is varied from 10 cm to 40 cm with a 10 cm gap to observe the difference in wave propagation of the acoustic signal underwater, in order to determine the relationship between the distances, signal noise level and the loss of signal amplitude as the signal propagate underwater. Three readings were taken for each set of different variable and the mean was calculated. Table III shows the mean and standard deviation of reflected signal across different distance. The operating frequency was set at 25 kHz.

TABLE III. MEAN AND STANDARD DEVIATION OF REFLECTED SIGNAL ACROSS DIFFERENT DISTANCE

Distance (cm)	Mean (V)	Standard Deviation (V)
10	1.42	0.010
20	1.42	0.005
30	1.42	0.010
40	1.40	0.015

The experimental results show that the standard deviations of the peaks when the distance between the transceiver and test object increased are negligible. As the increase in distance does not affect the measurements, a distance of 20 cm is chosen as it has the lowest standard deviation value for the subsequent experiment presented in this paper.

IV. PRELIMINARY RESULTS: TESTING WITH VARIOUS MATERIALS

As mentioned before, different material has different properties. For this study, various types of material are used to test the feasibility of using acoustic signal to distinguish between different materials. The materials used included aluminum, brick, ceramic, glass, plastic and wood. The reflected amplitude is expected to differ depending on the type of materials. The reflected waveform is received and measured by the transceiver, which is sent to the digital oscilloscope for analysis purpose.

Based on the result in the previous section, the operating frequency of the transceiver is set at 25 kHz, while the test object and the transceiver are kept 20 cm apart. The peak value of the signal is used to compute the reflection coefficient of the material, and these are compared to the ideal reflection coefficient. The reflection coefficient is computed by taking the ratio of the reflected signal amplitude to the incident signal amplitude.

Table IV shows the results and the difference between the ideal and experimental reflection coefficient. Calculation has been done between the ideal reflection coefficient and the mean of experimental reflection coefficient to compute the percentage of difference.

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TABLE IV. DIFFERENCE BETWEEN IDEAL AND EXPERIMENTAL REFLECTION COEFFICIENT

Material	Ideal Reflection Coefficient	Mean of Experimental Reflection Coefficient	Percentage of Difference (%)
Aluminium	0.85	0.83	2.35
Brick	0.70	0.89	2.71
Ceramic	0.63	0.83	31.75
Mirror	0.76	0.45	40.79
Plastic	0.41	0.89	117.07
Wood	0.28	0.90	221.42

Aluminum is expected to have high reflected coefficient because of its metallic properties, as it will reflect most of the signal energy when signal comes into contact with its surface. The experimental result indicates a close match to that of the ideal case.

On the other hand, wood is expected to have the lowest reflection coefficient among the selected test material. It tends to absorb a portion of the signal energy when the signal comes into contact with the surface of the wood. However, the experimental result obtained show otherwise, as it produced the highest reflection coefficient.

One of the reasons that may results in such big differences in reflection coefficient might be the effect of acoustic impedance. Acoustic reflection is a simple function of the impedance of the two medium. There will be no reflection if the two medium have same impedance. When acoustic signal travels from one medium to another, there will be changes in acoustic impedance, hence part of the signal will be reflected. The larger the difference between the acoustic impedance of the two medium, the larger the amount of signal will be reflected. The difference in the velocity or the density of the material will affect the acoustic impedance and this causes differences in reflection coefficient as acoustic impedance is the product of velocity and density.

The ideal reflection coefficient is calculated by assuming that the material properties in water are exactly the same as in air. In reality, the acoustic velocity of the material in air might be different with the acoustic velocity of material in water. The difference in the acoustic velocity will cause the change in acoustic impedance and lead to different reflection coefficient.

Another factor that may contribute to the difference between the ideal reflection coefficient and the experimental reflection coefficient is the material itself. Materials such as plastic and wood do have variety of kind, and therefore a standard reflection coefficient is not readily available. Different types of plastic and wood may be made up from various portions of mixture compound or composite materials. This results in different density for different types of plastic and wood, hence causes difference in acoustic impedance, and thus the reflection coefficient.

V. CONCLUSION AND FUTURE WORK

For underwater investigation, there are some specific properties that must be taken into consideration in order to obtain accurate result. The parameter that has to be taken care of is the propagation speed and the attenuation. The propagation speed is utilized to calculate the propagation delay while the attenuation contributes to the understanding on how the signal travels along the medium.

In order to provide information about the internal structural integrity and surface inspection, acoustic signal can be transmitted via a transmitter towards an object under inspection and the reflected signal received by the receiver can be measure and studied. Characterization process of the sensor underwater plays an important role in obtaining the optimum operating frequency and distance for acoustic signal transmission.

The work presented in this work indicates potential in using acoustic signal to distinguish between different materials, although the preliminary results indicate that there are more work that is required before further work can proceed. At the time of writing, follow-up work has begun with a one transmitter-one receiver experimental layout, which may be better suited for this work than using a single transceiver. Experiments will also be done to explore the possibility of varying optimum operating frequency when different test materials are used. Upon finalizing the experimental setup, further work using a single type of material but with different structural integrity will be conducted. The effect of the salinity of water towards the reflected signal of various materials will also be studied.

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