UNDERWATER OBJECT DETECTION BASED ON DISTANCE MEASUREMENT USING ULTRASONIC

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ABSTRACT

Detecting the underwater object with Sound Navigation and Ranging (SONAR) in various fields such as fisheries, maritime, oil and gas industry, and autonomous underwater vehicles. SONAR is needed for detecting the underwater object for a larger area by determining object characteristics (e.g. The object sizes and the object types). This thesis also uses a 1-Dimensional technique to identify the underwater object visual information such as the shape of the object. SONAR is a technique for detecting objects that are buried under the water surface by using the sound signal that is reflected on the object to locating the object and knowing the shape of the object.

This thesis is to observe a SONAR system on detecting the underwater object by obtaining information on the object distance and the object dimension to the data processor. The object detection experiments with different distances are conducted on water medium at Situ-Techno and swimming pool of Telkom University. The objects are alumunium and ceramics. The working frequency of the AJ-SR04M module with a fish finder transducer sensor is 40 KHz with a minimum detection distance of 20 cm and a maximum distance of 800 cm. To use the sensor, we must program the sensor on the microcontroller.

By the performance of underwater object detection at finding the information of the object position distance and the object dimension. The first experiment will show the sensor accuracy value on detecting the object by comparing the actual distance with the reference distance to the object is capable to detecting the object position distance with accuracy level for alumunium position distance is around 92.85% to 98.73% and for ceramics is around 84.61% to 88.71%. The second experiment will show the dimension of the object we should determine the horizontal plane and the vertical plane to know the shape of the object and the inclination angle between the first sensor and the second sensor on alumunium is around 21.30° and for ceramics is around 22.60°.

Keywords: Underwater Object Detection, SONAR, Arduino Mega 2560, AJ-SR04M Waterproof Ultrasonic Module

1. Introduction

The underwater object detection based on Sound Navigation and Ranging (SONAR) technique could give reliable information by navigating and detecting in various fields such as fisheries, maritime, oil and gas industry, and autonomous underwater vehicles deem information about the underwater object is important [1]. There are many methods that can be conducted to determine the underwater object surface. One of its methods is SONAR technique that began rapidly developed during and after the second world war as an eye for national defense to help the marine reach the object at underwater surface area and to know the characteristic of sea level [2], [3].

SONAR is a technique for detecting objects in the underwater surface by transmitting a sound signal that reflected in the object surface area to locate the object distance position and know their shape [4]. This technique uses echoes to measure the object characteristics in the water [5]. There are two types of SONAR which are active SONAR, and passive SONAR [6]. Active SONAR transmits and also receives the echo signals from the object to measure the signal strength by determining the range of the object position with different distances to provide the transducer flexibility in directing the echo signals [7]. Passive SONAR is only receiving echo signals from the object, which only one-way propagation that only detects the echo signal coming towards it.

This thesis is a development of the previous thesis of Miftahul Firdaus with title "2D Target Detection using Transducer Array for SONAR Application", it was conducted in the air medium with an array transducer SONAR on detecting the object and knowing the shape of the object [8]. The performance of the underwater object detection system is used Arduino Mega 2560 and AJ-SR04M waterproof ultrasonic module with a fish finder transducer sensor to obtain the underwater object information. AJ-SR04M module with fish finder sensor for receiving the reflection of the echo signals from the object to the data processor to obtain its position, and the dimension of the object. Arduino for processing the SONAR data is according to the Doppler effect on detecting the object. A simple Experiment on certain distances is expected to show the underwater object detection system is to be implemented efficiently for detecting the underwater object.

2. Basic Concept

Underwater object detection with Sound Navigation and Ranging (SONAR) provides great exploration by giving reliable information on the object recognition with sound pulse in its operating range. The reason of using SONAR for underwa- ter applications is the beam attenuation and dispersion that works less effective in the water than in the air. Objects with bigger ranges can be detected by utilizing echolocation in the water rather than in the air. The radiation surface through un- derwater transducer controls small displacement to generate larger sound pressures. SONAR is a technique for detecting objects and knowing the object characteristics in the water surface by transmitting and receiving echo signals. SONAR system can be applied to many fields such as fisheries, maritime, oil and gas industry, and autonomous underwater vehicles [9]. The SONAR system manages the desired signal from unwanted noise. There are two types of SONAR: passive and active. Passive SONAR only receives a sound signal from the target, while active SONAR transmits and receives echo signal from the object. The implementation of SONAR systems is more rapid than the radar system because of the lower frequencies and the smaller bandwidth. The functions of SONAR techniques are detecting fish, rock or sand, and underwater navigation.

2.1 Distance Measurement

The distance measurement from the sensors to the object by using Active SONAR that enable to measure the distance from the transmitted and received acoustic waves within a bounded sound wave time. While the mean speed of sound medium throughout the pulse travel path [10] is calculated using equation (2.1).

$$R = \frac{v \; x \; \Delta t}{2} \qquad (2.6)$$

which R is the distance between the source and the target, v is the mean speed of sound, t is the delay between pulse emission and reception, and the 2 as the denominator is a consequence of time measuring pulse two-way trip. When the medium cannot be considered homogeneous, as long the distance travels in the ocean must be calculated (e.g. medium stratification) [11].

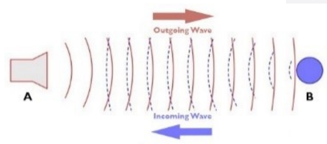


Figure 2.1 Principle of Active SONAR

In Figure 2.1 which A as a transducer that responsible for transmitting, and B is for receiving acoustic waves. When A transmit sound wave to B and it reflected from B surface then the sound wave is well receive by the system. Active SONAR outputs affect various factors that are considered to be relevant and explored in this chapter, as follows: ranging accuracy, SONAR resolution pulses and bearing.

2.1.1 Ranging Accuracy

The ranging has also been used to map the underwater area by providing depth charts that are commonly used in navigation. The actual ambient speed of sound is used for all ranging accuracy calculation. Range readings accuracy is obtained from the transmission sources to the object surface, range threshold detection and beamwidth. The first object producing an echo above the threshold point and other objects are spreading an acoustic beam. Therefore, the object range might not accurately safe in guiding the machines. The water properties may limit the ranging accuracy, especially at low frequencies.

It is particularly useful when the ranges of concerns are less than several water depths also when diffraction effects (shadow regions) and bottom penetration are not important. In shallow water, however, the ranges of interest are generally many times the water depth leading to a large number of multipath and bottom interactions. The actual depth was not constant but varied around 20 cm - 2 m at any given time. Over the duration of each run, the water depth changed on the order of 2 m – 8 m.

These results along with the ranging system set the timing for an instant echo wave to transmit. The long transmission pulse with irregular target surface based on the strong echoes transmitter can easily trigger the threshold ranges. The difficult part is to determine the echoes wave transmitted to keep it short and possible. Other error results from the echo amplifiers could increasingly gain in time discrete [12]. If the increase occurs in the midst of an echo, the range reading results can be false.

2.1.2 SONAR Resolution Pulses

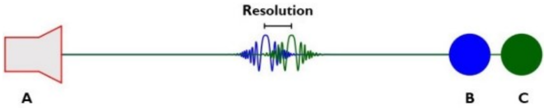


Figure 2.2 SONAR Resolution Pulses

In Figure 2.2 shows the minimum discernible resolution distance between echoes, which echo is a delay at minimum distances can be optimized based on the emitted pulse SONAR types. High resolution also implies the ability to accurately estimate the values of parameters of interest (such as angle, frequency, range, depth, or Doppler compression/dilatation) for each of the closely spaced sources.

There are two main types of of the pulse, which are single frequency and chirp [13], [14]. For single frequency, the resolution limit (δR) directly depends on the pulse length (ΔL) which is calculated using equation (2.2).

$$\delta R = \frac{v\ x\ \Delta L}{2} \quad (2.2)$$

While chirp overcomes the limitation on similar multi-frequency system, which the resolution is related to the bandwidth (BW), calculated using equation (2.3).

$$\delta R = \frac{v}{2\ x\ BW} \quad (2.3)$$

2.1.3 **Bearing**

The echoes direction cannot be directly obtained by using only one hydrophone (underwater sound transducer). The bearing estimation has two main elements, which are beamwidth and arrays hydrophone. Simple SONAR only has one acting hydrophone as a transmitter and receiver but cannot distinguish the incoming wave direction. The use of beamwidth is to narrow down the origin echoes region. It is necessary to rotate the transducer in order to capture other directions.

The hydrophone beam shape is directional strengthening through emitted signal with maximum intensity and a certain direction. The intensity reduces when it receives an incoming signal from any directions. The arrays hydrophone can infer the sound direction by revealing the distance between the transducer, then calculate the direction of the incoming sound wave [15], [16]. Another possible action is by using the beamforming to find which direction gives the strongest echo signal. The transducer sequentially can be made into one-dimensional arrays to detect the full direction in 1D which is able to work well on delivering the information and providing a good detection on the object.

2.2 AJ-SR04M Waterproof Ultrasonic Module Combine with Fish Finder Transducer Sensor

Figure 2.3 AJ-SR04M Waterproof Ultrasonic Module Combine with Fish Finder Transducer Sensor

In Figure 2.3 AJ-SR04M AJ-SR04M waterproof ultrasonic module combined with the fish finder transducer sensor is a waterproof emitter to prevent failure on a probe that caused by water and dust. The AJ-SR004M module will be connected to the processor to run the program on Arduino and the fish finder transducer sensor uses SONAR to locate and defines the object structure, bottom contour, and composition, as well the water depth directly below the transducer. The transducer sends a sound wave signal to determine distance by measuring the transmission time between the transducer to detect the object and the signal that is reflected to interpret the location, size, and composition of the object. AJ-SR04M operating on fresh and salt water, working temperature range between -20°**C** to -40°C and can read depth from 20 cm to 800 cm to detect objects. The SONAR can read from the bottom contour and the object location together including water depth, temperature, underwater vegetation, and structure. The yellow cylindrical shape at the front of the portable fish finder is the transducer. The round transducer sensor with 7.5 m to 9 m cable and the sensor beam angle is 45°. The transducer sensor has high acoustic power radiation and works at the frequency range of 13 KHz to 60 KHz [17].

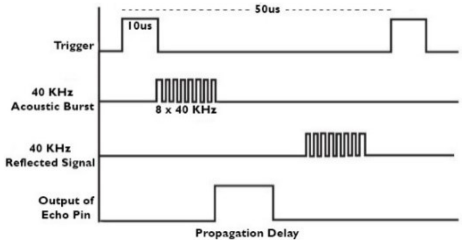


Figure 2.4 Transmitted Echo Pulse

In Figure 2.4 the output time diagram of ultrasonic wave transducer is trans- mitted from one pulse signal to generate echo signals for 10 µs TTL to transmit 8 ultrasonic wave cycles at a frequency of 40 KHz [17]. The object distance has a wide pulse signal after receiving echo pulses for underwater depth that uses equation (2.1), which the time of flight is 10 µs until 50 µs shows the minimum or maximum distance of sensor to detect the object distances.

Since we are more interested in detecting the underwater object, we require SONAR range of echo pulses which are limited to two major losses:

1. Beam-spreading loss
2. Acoustic absorption

This SONAR range can be limited by beam-spreading loss and acoustic absorption. This SONAR wave influencing the environmental factors such as temperature, salinity, and water density. The speed of sound is calculated using equation (2.4).

$$v = 331.4 + (0.606\ x\ T) + (0.0124\ x\ \rho) \quad (2.4)$$

which v is the speed of sound and 331.4 is the speed of sound at the temperature of 0◦C. T is the temperature (◦C). ρ is the water density (kg/m³) [17].

2.3 Arduino Mega 2560

Open source hardware to support all the microcontrollers needs for connected to USB cable is called Arduino Mega 2560. Arduino has 54 digital input/output pins which have 15 pins as PWM output, 16 analog input pins, 4 pins for UART communication, 16 MHz ceramic resonators, USB connector, a power jack, ICSP header and resets button [18].

Figure 2.5 is Arduino Mega 2560 that is utilized to program the AJ-SR04M waterproof ultrasonic module combines with fish finder transducer sensor system to get an object distance position since Arduino emitted echo echo signals,

which consist of several frequency variants according to Doppler effect to detect the object. The program code uses the speed of sound value that is calculated using the time of flight formula (2.3). Then, the AJ-SR04M is receiving the reflected of the sound signal wave from object to data processor in Arduino Then, the AJ-SR04M receives the reflected sound signal wave from the object to the data processor in Arduino

Figure 2.5 Arduino Mega 2560

Table 2.1 Arduino Mega 2560 Specifications

Microcontroller chip	ATmega2560
Operating voltage	5 V
Input voltage (recommended, via DC jack)	7 V - 12 V
Input voltage (limit, via DC jack)	6 V - 20 V
Digital I/O pin	56 pieces, 6 of them provide PWM output
Analog input pin	16 pieces
DC current per I/O pin	20 mA
DC current pin 3.3 V	50 mA
Flash memory	526 Kb, 8 Kb has used for boot loaders

SRAM	8 Kb
EEPROM	4 Kb
Clock speed	16 MHz

3. Results and Analysis

3.1 Results

This chapter discusses the obtained result of the experiment and its analysis. The experiment is used the SONAR technique to performed in obtaining distance position of the object and dimension of the object that processed using Arduino software. The underwater object detection system generates and transmits a narrow pulse with the frequency between 13 KHz – 60 KHz. There are two experiments; The first experiment is using one sensor in a static place with stationary objects, and the second experiment is using two sensors arranged vertically and horizontally with the stationary object. The objects are alumunium and ceramics.

3.1.1. The First Experiment

Figure 3.1 shows the realization tools design for this experiment is to obtain the object position distance by using a sensor that is carried out statically. The transmitted signal is obtained by configuring the AJ-SR04M waterproof ultrasonic module combine with fish finder as the transducer. The transmitted signal on the object surface area and reflected the sensor then the signal is received by the Arduino to processes the reflected signal to determine its distance position of the object.

Figure 3.1 Realization of the design of one trial scenario

In Figure 3.2 the received signal on microcontroller processor is mea- sured by an oscilloscope with frequency of 36.5 MHz. The signal output is in digital waveform type with the initial V_{pp} of 5.5 mV then the V_{pp} is decreasing into 3.2 mV. We assume the decreasing V_{pp} is because of the attenuated signal due to the ambient noise or even the noise from the sensor itself. If the noise is too much, it makes the signal is not accurate and it will give a bad resolution of the object.

Figure 3.2 Transmit and Receive Signal

Figure 3.3 shows the results of the sensor accuracy level on the transmitted signal with a different range of sensor distances. The distance position experiment of the sensor to the object is around 10 cm to 900 cm. The sensor cannot detect the object at a distance of less than 20 cm or more than 800 cm. The results accuracy level sensor of position distance for alumunium is around 92.85% to 98.73% and for ceramics is around 84.61% to

88.71%. So, it can be concluded that the accuracy level of the sensor AJ-SR04M module with a fish finder sensor to detect the objects is at the maximum distance of 800 cm.

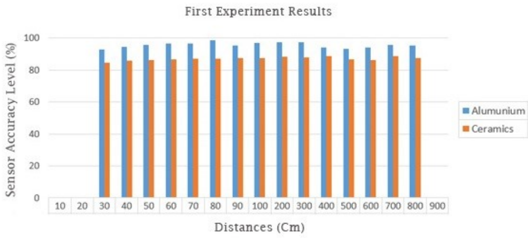


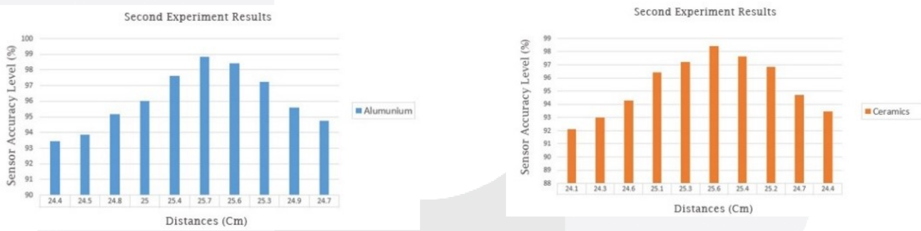
Figure 3.3 The First Experiment

3.1.2. The Second Experiment

In Figure 3.4a and Figure 3.4b shows the second experiment on estimating the dimension of the object and also the inclination angle between the first sensor and the second sensor by arranging the sensor direction into horizontally and vertically. The reference distance between the first sensor with the second sensor is about 26 cm from the sensor to target is dynamically driven according to the experimental scenario which is moved the sensor gradually every 1 cm to each direction.

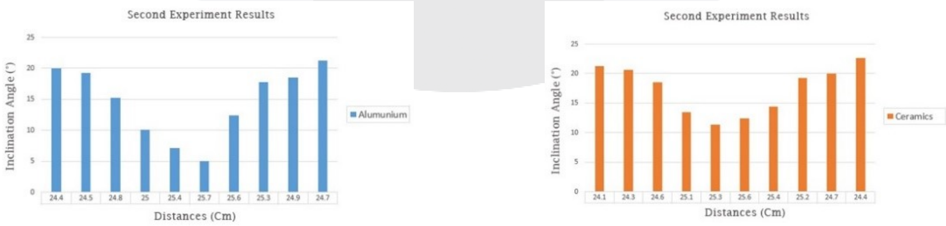
Figure 3.4 The Motion Direction of The Sensor. (a) Alumunium. (b) Ceramics

Figure 3.5a and Figure 3.5b shows the second experiment on the sensor accuracy level of position distance for alumunium is around 81.11% to 99.19% and for ceramics is around 77.25% to 97.95%. Figure 3.6a and Figure 3.6b shows the maximum range inclination angle between the first sensor with the second sensor on alumunium is around 21.30° and the maximum range inclination angle between the first sensor and the second sensor on ceramics is around 22.60°. The obstacle for transmitting and receiving the reflected signal from the object to the sensor at the underwater surface area is because of the permittivity of the water, the water depth, and the sensor ability on detecting the object.



(a) Alumunium (b) Ceramics.

Figure 3.5 The Second Experiment on accuracy level of moving sensor



(a) Alumunium (b) Ceramics.

Figure 3.6 The Second Experiment on inclination angle between 1st sensor with 2nd sensor

3.2 Analysis

Analysis are conducted to find the differences between this thesis with the previous thesis of Miftahul Firdaus [8] on accuracy level of the sensor that the data is being obtained and processed from the Estimated position distance of the object, the dimension of the object, and also the inclination angle between the first sensor and the second sensor. The results show an acceptable accuracy level of the sensor on detecting the object.

From both experiments, the accuracy level of the sensor on detecting the object is better in the air medium than in the water medium. Because the strength of sound waves propagated into the water is attenuated proportionally with a distance of the reflected wave from the object surface to the sensor. This is caused by attenuation loss on the object surface due to diffraction phenomenon and absorption loss, the energy is absorbed by the medium and also effects the time delay of each reflection while the propagation time is plotted against horizontal distance and vertical distance. The reason is because the volume constraint and density of the underwater medium properties and accordingly on external condition, for instance, pressure and temperature.

So, we can analyze that increasing the distance between the sensor to the object surface may increase the accuracy of data but the distance must be adjusted properly because the increase in the distance also means that the signal that received at the receiver of the object surface will attenuate. To increase the signal received it can be done by increasing the power transmitted from the transmitter antenna. Another parameter such as human error, cable loss may also significantly affecting the accuracy of the result. The experiment on estimating the position distance and dimension of the object must be conducted on a good set-up and in a good environment with less or no possible electromagnetic interference. The cable loss also can affect the result by decreasing the signal transmitted and received. In general condition of SONAR has one complication, which gives different response results of the object with the same signal level frequencies. We can see the object dimension from the SONAR data pattern in 1-Dimensional from the horizontal way and vertical way. The higher frequencies give shorter wavelengths and better resolution, so smaller objects also can be detected and the object is more viewable. We can see that using object detection with a good sensor can give a better vision.

4. Conclusions

From several experiments that have been conducted to detects the object accurately based on the SONAR technique was in the range of acceptable because of the accuracy still in permit-able value. To find the distance position and the dimension of the object are uses Arduino Mega 2560 and the combination of the AJ-SR04M waterproof ultrasonic module with fish finder transducer sensor must be adjusted so that the direct echo wave to the surface and reflected wave to the AJ-SR04M sensor.

In the first experiment shows that the accuracy level is around for alumunium position distance is around 92.85% to 98.73% and for ceramics is around 84.61% to 88.71% with the maximum distance to detect the object is 800cm. The second experiment with the moving sensor into vertically and horizontally to detect the object dimension with the maximum range inclination angle between the first sensor and the second sensor on alumunium is around 21.30° and the maximum range inclination angle on ceramics is around 22.60°. It shows the alumunium surfaces is efficiently reflected better than ceramics surfaces.

So, we can know the 1-Dimensional shape of the object and the inclination angle between the first sensor and the second sensor. The processed of SONAR technique will give the results efficiently, which can be used in many fields and the result are shown in acceptable accuracy with higher frequencies gives shorter wavelengths and better resolution, so smaller object also can be detected and the object is more viewable. We can see that using object detection with a good sensor can give a better vision.

5. Suggestion

For further work or research, finding the better value of the distances between the sensor to the surface may improve the accuracy of the data. Creating the GUI using MATLAB also can improve mapping the object in the underwater surface.

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