

## ENGINEERING OF ACOUSTIC TECHNOLOGY FOR UNDERWATER POSITIONING OBJECT

### REKAYASA TEKNOLOGI AKUSTIK UNTUK PENENTUAN POSISI OBJEK BAWAH AIR

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#### ABSTRACT

Underwater Positioning System (UPS) is a system to track the existence of the position of an object by utilizing the arrival time of the signal measurement. On land, the system uses an electromagnetic signal called GPS. However, because it cannot penetrate water effectively, an acoustic signal is used as an alternative. The purpose of this research is to engineer the control system of data acquisition and underwater acoustic device to measure arrival time (TOA) and apply equation model for underwater sound source positioning system. the effective frequency resonance of the transducer and the hydrophone is at a frequency of 6 kHz. The acquisition control device is able to measure the TOA signal with an error on a digital channel smaller than an analog channel. The difference between the TOA values measured by oscilloscope and acquisition control system is caused by inaccuracy of threshold estimates at the receiver's peak detector circuit. The position of the sound source coordinates obtained from the equation model shows the highest difference in depth point (z) compared to points (x) and (y), caused by the equation model used is limited to four hydrophone units forming a horizontal baseline.

**Keywords:** engineering, hydrophone, transducer, acoustic technology, underwater positioning

#### ABSTRAK

*Sistem posisi bawah air adalah sistem untuk melacak keberadaan posisi suatu objek dengan memanfaatkan waktu pengukuran kedatangan sinyal. Di darat, sistem ini menggunakan sinyal elektromagnetik yang disebut GPS. Namun, karena tidak dapat menembus air secara efektif, digunakan sinyal akustik sebagai alternatif. Tujuan dari penelitian ini adalah merencanakan perangkat sistem kontrol akuisisi data dan perangkat akustik bawah air untuk mengukur waktu kedatangan (TOA) dan menerapkan model persamaan untuk sistem penentuan posisi sumber suara bawah air. resonansi frekuensi efektif transduser dan hidrofona berada pada frekuensi 6 kHz. Perangkat kontrol akuisisi mampu mengukur nilai TOA sinyal dengan nilai kesalahan pada saluran digital yang lebih kecil dari saluran analog. Perbedaan antara nilai-nilai TOA yang diukur oleh osiloskop dan sistem kontrol akuisisi adalah karena ketidaktepatan perhitungan threshold pada rangkaian puncak detektor penerima. Posisi koordinat sumber suara yang diperoleh dari model persamaan menunjukkan selisih titik kedalaman (z) yang paling tinggi diantara titik (x) dan (y), diakibatkan oleh model persamaan yang digunakan terbatas empat unit hidrofona membentuk baseline horizontal.*

**Kata kunci:** rekayasa, hidrofona, transduser, teknologi akustik, penentuan posisi bawah air

#### I. INTRODUCTION

Underwater Positioning System (UPS) is a system for tracking the presence of objects such as underwater rides or divers

by utilizing measurements of travel time and /or direction measurements (Alcocer *et al.*, 2007). For example, positioning of car using global positioning system (GPS). GPS works with 24 GPS-satellites that orbiting station-

nary around the earth. Satellites transmit signals according to time and Data location. The signal from the satellite is then captured by GPS users. When GPS users lock at least four or more satellites, users triangulate the locations from known satellite positions. GPS signals are electromagnetic signals, which spread effectively in the air but not working effectively under water due to its high electromagnetically absorption rate (Eustice *et al.*, 2011).

Due to GPS cannot work effectively underwater, then, the role of an underwater positioning system as an alternative to underwater GPS systems becomes essential. With regard to the benefits of this system, indispensable in the field of marine science for the utilization and supervision of the marine resources, for example includes monitoring of marine habitat, marine border surveillance, dive surveillance, instrument placement, marine exploration, and so forth. The form of signal radiation capable of propagating well in water is only a sound/acoustic signal (Urick, 1975). Thus, acoustic technology becomes the most appropriate solution for underwater positioning.

Acoustic technology can be engineered for underwater positioning (Zhang *et al.*, 2015). Standard components of acoustic technology required for positioning include transceivers, transducers, and data acquisition units (Jiang and Osler, 2014). Transceivers and transducers transmit and receive acoustic signals for distance and direction measurement.

The basic equation model used in the underwater positioning system is generally divided into two models: measuring the travel time of the signal by distance and/or by phase. The purpose of this research is to engineer the control system of data acquisition and underwater acoustic device to measure arrival time (TOA) and apply equation model for underwater sound source positioning system.

## II. METHODS

### 2.1. Time and Location

The design and manufacture of instruments is done in the Laboratory of Acoustics and Instrumentation of Marine, IPB. An experimental test was conducted at ITK IPB water tank and swimming pool.

### 2.2. Supporting Devices

The required devices are transducer, hydrophones, transmitter and receiver as the main means of underwater communication. Arduino IC ATmega 328P microcontroller is the main data control and acquisition tool.

Some Piezoelectric were used as transducers and hydrophones. Benthos AQ-1 has a cylindrical shape, and used as Piezoelectric. Piezoelectric materials have been designed for underwater communication applications. Benthos aq-1 piezoelectric with the beam pattern is an omnidirectional scattered signal. This is important for UPS, because the signal will propagate to all directions and received the signal from all directions.

Transmitter is a device for generating signals. Sinusoidal signals are generated by Signal Generators that are controlled by Trigger and are governed by the Acquisition System. In this device there is a Power Amplifier and Matching Impedance components to optimize the signal amplitude of piezoelectric transducer.

Receiver is a device consisting of Pre-Amplifier, Filter, and Peak Detector. Pre-amp circuits are used to restore lost signal by attenuation of water. Filter Circuits are used to filter certain signals according to the frequency of the sender. The Peak Detector circuit is used to provide HIGH or LOW information to the output pin when the hydrophones detect the signal even in a weak state.

The acquisition control system is a signal processing center consisting of a microcontroller and an acquisition algorithm. Microcontroller used is Arduino IC Atmega

328P. The first simple acquisition algorithm system is to enable a digital channel to generate transmitter signals and at the same time enable the analogue/digital channel to record signals. The maximum time for a cycle is one second. If during one measurement cycle process has been detected peak signal, data sampling will stop before one second. The acquisition module will display TOA information from channels that are enabled for recording (Figure 1).

In the system design, microcontroller module needs to be added optical isolator as trigger interface to overcome the large resistance burden caused by the length of the transmission cable as well as speed up the transmitter activation process.

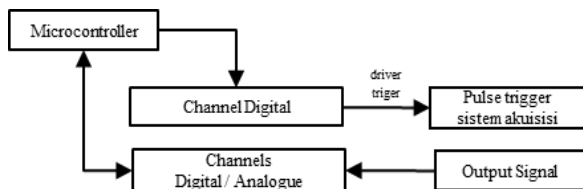


Figure 1. System of data acquisition control and trigger devices.

### 2.3. Instrument Performance and Data Analyses

Some of the tests performed are looking at the character of the signal, the system test of the acquisition algorithm. Data analysis performed on the instrument is to test the ability of the acquisition system to measure the TOA.

The test is also aims to see the hydrophone response to the frequency of the transmitted signal. The output will obtain the most effective frequency resonance value as well as effective pulse width. The campaign test is illustrated as in the acquisition system will control the transmitter to transmit acoustic waves through the transducer (Tx), then the signal will be received by the hydrophone (Rx) reinforced by the receiver. The positioning method in this system, utilizing measurements of signal TOA which propagation of the transducers to each of the hydrophones (Figure 3).

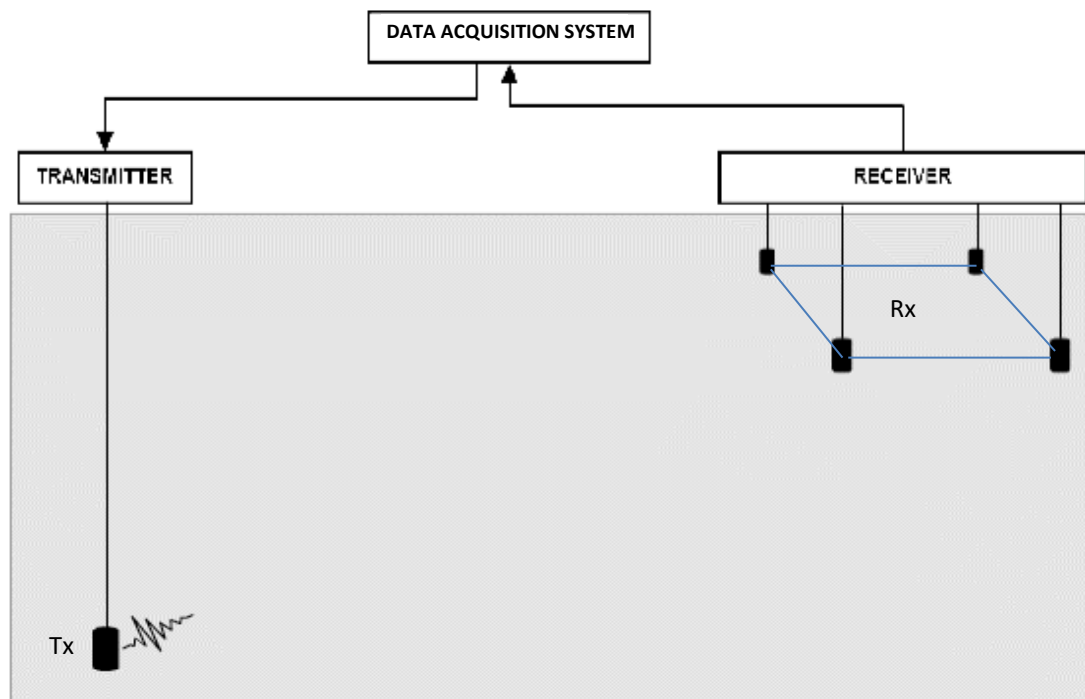


Figure 3. The illustration of the test determines the position of the sound source.

Engineering acoustic technology is only able to measure the travel time of the signal based on the distance difference. According to Takeuchi (2009), the accuracy of determining the position of this system depends on the operating range and frequency of work. When the operating range is short, the system works at frequencies higher than 10 kHz and achieves accuracy of up to centimeter. Illustration of hydrophone point placement used as reference baseline from sound source is shown in Figure 4 (Milne, 1983). This model is generally called Short Baseline. The installed hydrophone position/coordinate information will be known from GPS/artificial coordinates. From this model we will get the sound source position information of an object against the installed baseline coordinates.

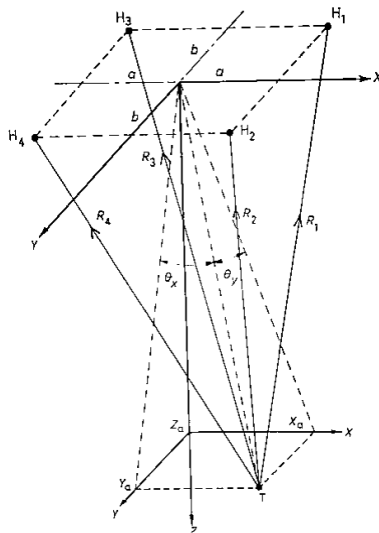


Figure 4. Illustration of short baseline system.

The equation used is as follows;

$$R_i = C(t_i - t_0) \dots\dots\dots (1)$$

Information:  $R_i$  ( $i = 1,2,3,4$ ) : distance between the sound source and the hydrophone  $i$  as much as  $n$ ,  $c$  : underwater sound speed,  $t_i$  : the time of arrival (TOA) of the signal from the sound source to the hydrophone,  $t_0$  : time when the signal is sent (0 microseconds).

The sound speed ( $c$ ) is calculated by entering the water temperature data to the equation proposed by Grosso (1974), this equation only applies to freshwater. Researchers used the equation because the research was conducted on fresh water.

$$C = 1402.388 + 5.03711T - 0.0580892T^2 + 0.3342 \times 10^{-3}T^3 - 0.1478 \times 10^{-5}T^4 + 0.315 \times 10^{-8}T^5 \dots\dots\dots (2)$$

The placement of a number of hydrophones is placed on a horizontal plane and bounded by a rectangular angle  $2a$  with a width of  $2b$ . The distance between the hydrophone  $i$  and the sound source of an object can be calculated by the following equation (Stockton and McLeannan, 1975) and (Hodder and Woodward, 1986).

$$R_i = \sqrt{(x \pm a)^2 + (y \pm b)^2 + (z)^2} \dots\dots (3)$$

This equation will produce  $R_i$  as much as the number of hydrophones. By taking a symmetrical pair of  $R_i$ , then it will get two patterns as in below.

$$\Delta R_{ai}^2 = 4ax \dots\dots\dots (4)$$

$$\Delta R_{bi}^2 = 4bx \dots\dots\dots (5)$$

This Equations can be used for searching  $x$  and  $y$  coordinates. The value 4 in this equation is obtained from the substitution result between  $R_i$ . To provide the same assessment of each hydrophone data, the solution form for  $x$  and  $y$  coordinates is as follows;

$$x = [\sum(\Delta R_{ai}^2)]/8a \dots\dots\dots (6)$$

$$y = [\sum(\Delta R_{bi}^2)]/8b \dots\dots\dots (7)$$

If the depth information is known, the position is known in 3D. However, if is unknown, it can be found by substituting for  $x$  and  $y$  from the previous equations. However, to maintain symmetry and equal

weighting as before, it is recommended to use a number of hydrophone equations and average the result, giving:

$$z = \sum \{ [R_i^2 - (x \pm a)^2 - (y \pm b)^2]^{0.5} + \dots \} / 4 \dots \dots \dots (8)$$

### III. RESULT AND DISCUSSION

#### 3.1. Hydrophone Response to Frequency and Pulse width Transmitter

Variable resistor in the signal generator circuit is used to change the frequency value. Result performed at frequencies 500 Hz up to 20 kHz with a fixed number of pulse, indicating that the transducer has an effective working area at a frequency range of 6 kHz (Figure 5a).

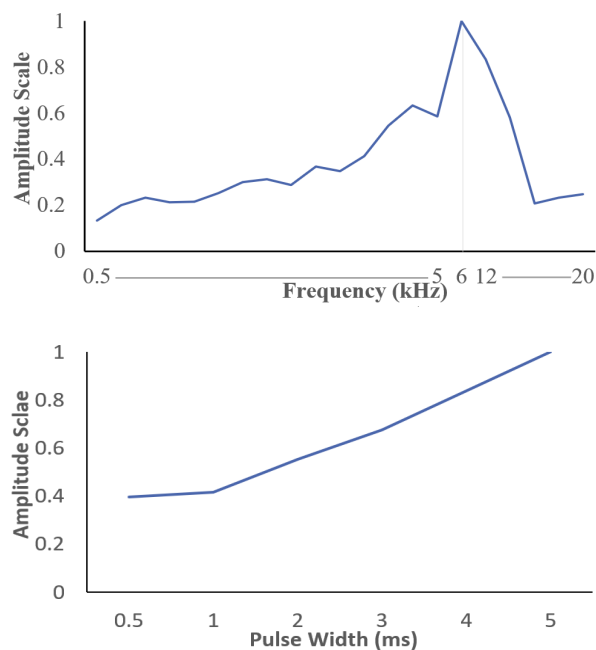


Figure 5. Hydrophone response test, (a) frequency, (b) pulse width.

Referring to data sheet information Benthos (2015) from piezoelectric Aq-1 regarding frequency response, 6 kHz has entered the range of sensor response ranges. This explains that the transmitter and receiver engineering devices are in accordance with the transducer specifications. Variable

resistor in a one shoot circuit is used to change the value of the pulse width. Figure 9b shows, the width of the highest effectiveness pulse is 5 microseconds. The likelihood that the enlarged pulse width will result in a higher amplitude response. However, this will cause a high signal reverberation in the restricted pool area. So, when the distance between the sound source and the hydrophone is too short will result in a larger TOA error.

Microcontroller needs IC 4528 on the transmitter to perform signal generation. The width of the transmitted signal depends on the setting of the RC circuit. The required current IC is small so it can still work when the device acquisition with the remote distance transmitter.

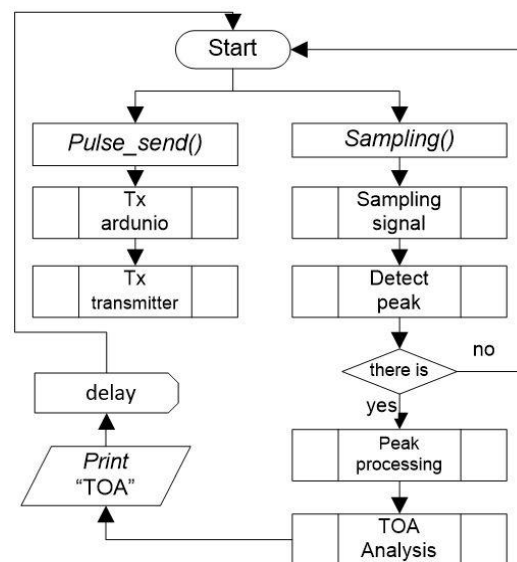


Figure 6. Algorithm of acquisition system.

The program algorithm used to measure TOA values is as follows (Figure 6); ordered the acquisition system to activate the trigger pin sending the signal with the code '*pulse\_send()*' and ordered the acquisition system to enable the analog / digital channel to record the signal with the code '*sampling()*'. When the channel detects peak, the acquisition system will process peak detection time, and the sampling activity stops. Then TOA is sent to serial.

### 3.2. Testing Microcontroller

The capability of configuring analog and digital channels from IC 328P microcontroller during sampling is as follows; the sample rate measured by the analog channel is 8929 data while the four analog channels are 2219 data and the digital channel is 61687 data while the four digital channels is 53546 data. Based on these results, digital channel capability is much higher than analog channel. Based on the Nyquist Theorem, most likely when an analog channel is used as a data acquisition channel will occur signal aliasing. This will be one cause of the error.

Information for long time when the trigger pin acquisition is activated until the transmitter output sends the required signal as the correction data for the measured TOA value of the acquisition. TOA values

measured by the acquisition are reduced by correction data resulting in corrected TOA data to be used for the advanced process.

Figure 7 is an example of TOA data matching on an oscilloscope with TOA on a corrected acquisition. The results of this test show still have errors. Use of a digital channel, error rates ranging from 1 to 21  $\mu\text{s}$ , and use of four digital channels, error rates ranging from 43 to 77  $\mu\text{s}$ . While the results of using an analog channel, error rates ranging from 173  $\mu\text{s}$  / d 189  $\mu\text{s}$ , and the use of four analog channels, error rates ranging from 618  $\mu\text{s}$  / d 668  $\mu\text{s}$ . The error range value is obtained from the repetition of the data retrieval. The source of the error may come from the acquisition capability when sampling the data especially for analog channels, and the suitability of peak detector circuit.

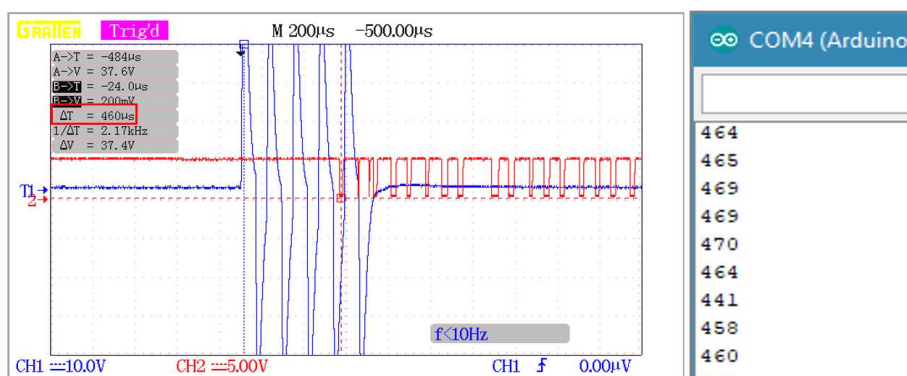
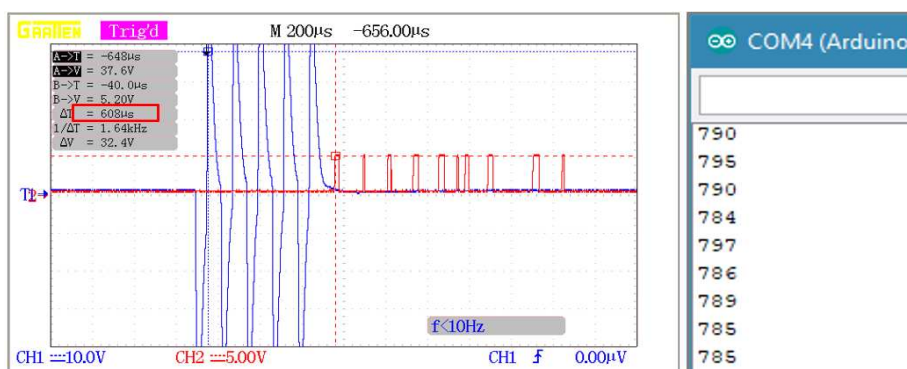


Figure 7. Sample of TOA acquisition system with oscilloscope and digital channel.



Note:

- the blue line is the transmitter signal
- the red line is the receiver's signal

Figure 8. Sample of TOA acquisition system with oscilloscope and analogue channel.

### 3.3. TOA and Distance Measurements

This test is done by placing the distance Tx with Rx as far as 500 cm. Changes in the type of treatment being tested were to place Tx and Rx at different depths as shown in Table 1. The measured result is the TOA. The actual distance measurement "Real Distance" is performed using a manual measuring instrument as comparison data. In Table 3 the subtitles 'TOA' on analog channel and digital channel are the results measured by the acquisition system, whereas in the 'Direct Path' subtitles are the results obtained from the formulation. An example error measurement of TOA has been discussed in the microcontroller testing section. The TOA errors for this data range from 4 to 11  $\mu$ s for digital channel and 173 to 189  $\mu$ s for one

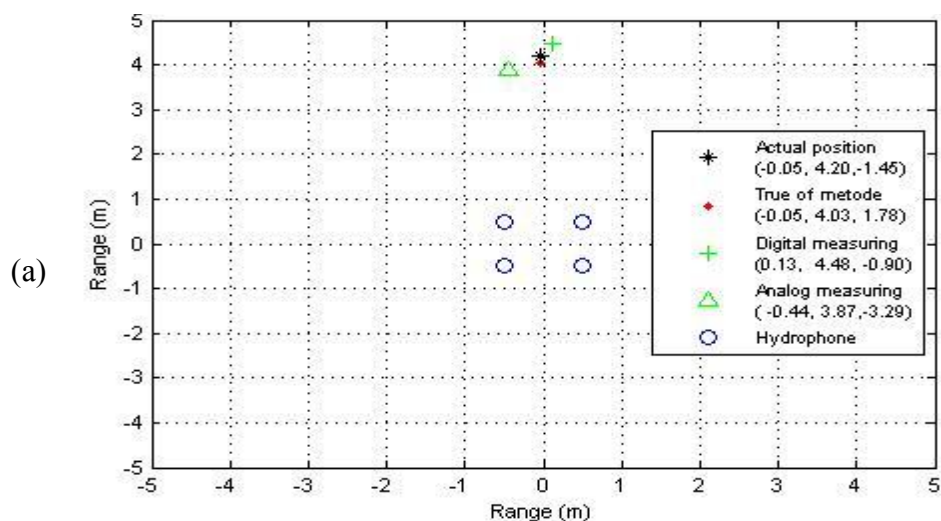
analog channel. The error rates of direct paths with acoustic methods range from 33 s / d 75 cm for analog channel and 7 s / d 48 cm for digital channel. The value of the error from a distance is strongly influenced by the accuracy of the measurement of the underwater sound speed. Thus, the use of measuring equipment should have high accuracy.

### 3.4. Positioning

To verify the result of the position of the algorithm, manual measurement results are required as comparison data. The required data is position x, y, and z from the sound source to the baseline reference point. The results are shown in Figure 9.

Table 1. Measurement results from TOA and distance processing.

| Depth (cm) |     | Manual Distance (cm) | Chanel Analog  |                  | Chanel Digital |                  |
|------------|-----|----------------------|----------------|------------------|----------------|------------------|
| Tx         | Rx  |                      | TOA ( $\mu$ s) | Direct Path (cm) | TOA ( $\mu$ s) | Direct Path (cm) |
| 50         | 50  | 500                  | 3609           | 542              | 3420           | 514              |
|            | 150 | 510                  | 3738           | 562              | 3559           | 535              |
|            | 287 | 553                  | 4177           | 628              | 3998           | 601              |
| 150        | 50  | 510                  | 3640           | 547              | 3459           | 520              |
|            | 150 | 500                  | 3546           | 533              | 3373           | 507              |
|            | 287 | 518                  | 3694           | 555              | 3519           | 529              |
| 287        | 50  | 553                  | 4158           | 625              | 3978           | 598              |
|            | 150 | 518                  | 3700           | 556              | 3519           | 529              |
|            | 287 | 500                  | 3579           | 538              | 3393           | 510              |





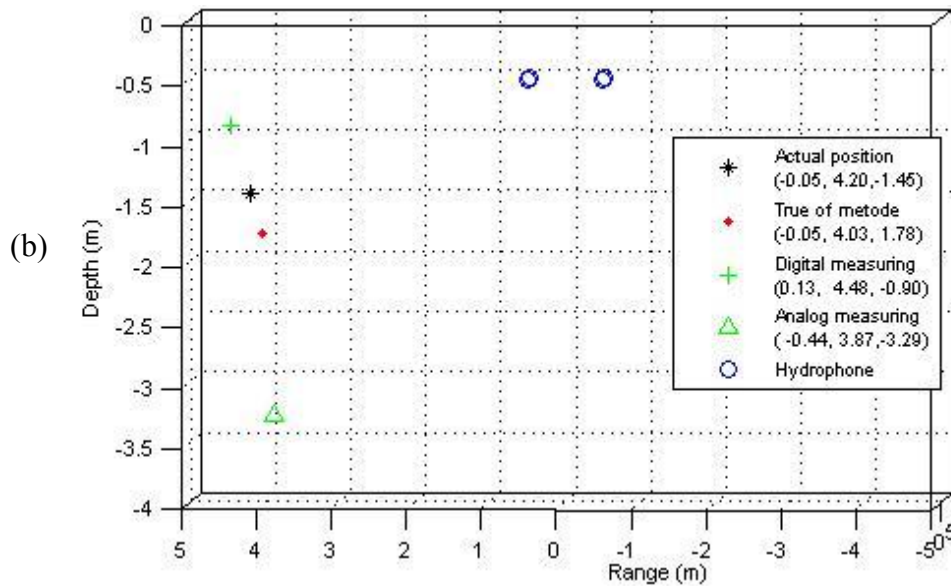


Figure 9. Positioning testing, (a) appears over 2D (b) side view of 2D.

Figure 13 shows, the 'actual position' point is the coordinate of the position measurement result manually. The 'true of method' point is the coordinates of the result of manual distance measurement by positioning by method. While point 'analog data', and 'digital data' is the coordinates of distance measurement using acquisition system with positioning based on method. Each point is in coordinates that are not exactly the same. Between 'true position' and 'method position' has error  $x$  equal to 0 m,  $y$  equals 0.17 m, and  $z$  equals 0.33 m. Then the 'real position' with 'analog data' has an error  $x$  equal to 0.39 m,  $y$  equals 0.33 m,  $z$  equals 1.84 m, and 'real position' with 'digital data' has error  $x$  equal to 0.08 m,  $y$  equals with 0.28 m,  $z$  equals 0.55 m. The value of errors is allegedly derived from the accumulated error, from the measured TOA value of the acquisition system, the error rate of sound speed, and the error of the equation method.

#### IV. CONCLUSION

The acquisition control device is capable of measuring the signal TOA value with an error value on a digital channel smaller than the analog channel. The

frequency of the acoustic device transmitted by the transducer is the optimal frequency responded by the hydrophone, which is 6 kHz. The difference between the TOA values measured by the oscilloscope and the acquisition control system is due to the inappropriateness of the threshold parameters in the receiver peak detector circuit. The coordinate position of the sound source obtained from the equation model shows that the difference in the depth point ( $z$ ) is very high because in this study, the two equation models used are limited to four hydrophone units placed by forming a horizontal baseline.

#### ACKNOWLEDGMENT

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