The improvement of ultrasonic sensor-based device for direct ocean wave measurement program at Western Java Sea – Indonesia

D Adrianto\textsuperscript{1,3}, E B Djatmiko\textsuperscript{2} and Suntoyo\textsuperscript{2}

\textsuperscript{1}Post Graduate Program – Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS), Surabaya – Indonesia
\textsuperscript{2}Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya – Indonesia

Abstract. Sea wave measurement program in the Western Java Sea has been carried out comprehensively over a full one-year period. This activity requires tools that can work robustly and accurately in the long run in the open ocean environment; one of which is the result of modified tidal gauges based on ultrasonic sensors. Testing of modified device has been carried out simultaneously with the RBR\textit{duo} wave recorder which is installed close to one another. The test was conducted at Ancol beach, Jakarta Bay, with a sampling frequency of 6 Hz, and the measurement time was carried out for 15 days. Measurement data were analyzed by applying the harmonic sea level elevation method, single wave evaluation, and statistical correlation methods. The results of the harmonic analysis show similar types of daily sea level elevations, as well as 9 (nine) daily elevation constituents that are mutually compatible with each other. Results of the wave analysis from the modified device show $H_{av} = 11.9$ cm, $H_s = 15.4$ cm, and $H_{max} = 41.1$ cm, while the RBR\textit{duo} instrument shows $H_{av} = 11.8$ cm, $H_s = 18.1$ cm, and $H_{max} = 39.9$ cm. Statistical analysis of the wave data shows that the values produced indicate the results of measurements with the two devices have a high correlation. Therefore, it can be concluded that the modified instrument will be ready and reliable to be used for long-term wave measurements. A sample of measurements from the wave station at the Western Java Sea is shown by the end of this paper.

1. Introduction
The need for reliable and appropriate wave data from various sea regions in Indonesia is an urgent matter that must be met immediately. Comprehensive wave data is highly needed in the development of national marine technology fields related to various sectors and strategic activities. The need for wave data and information for Indonesian waters today is met through daily wave forecasting provided by the Meteorology, Climatology and Geophysics Agency (BMKG) obtained from measurements via satellites, e.g. GEOSAT - ALT [1]. The wave forecast is obtained by converting data of wind intensity and direction using Sverdrup-Munk-Bretscheider (SMB) method [2,3], in which its accuracy is improved using the fuzzy logic method [4,5]. In line with efforts to develop sea wave data in Indonesia, researchers [6,7] have contributed in providing additional data, utilizing other sources and processing them using a different approach. In this case, significant temporal variations in wave height have been assessed using the ERA-Interim reanalysis approach. The processed data comes from the ECMWF (European Center for Medium-Range Weather Forecasts) which has been accumulated for 35 years, starting from 1980 to 2014.
Although much effort has been made in wave forecasting based on wind data and numerical modeling, many considerations keep directing the importance of obtaining wave data from direct measurements in the field. Direct measurement data from the field, followed with precise analysis, will produce reliable and accurate wave data to be applied in various marine activities [8,9]. Related to this issue, direct sea wave measurements in the Western Java Sea (WJS) have been programmed. This sea region is one of the territorial waters that has very dense national and international marine activities, especially with the stipulation as the Indonesian Archipelagic Sea Pathway – I (ALKI-I). In addition, in these waters, there is the spread of oil and gas drilling and production platforms which operate intensively.

The sea wave measurement program at WJS is carried out in the context of research with personal funding. Personal scale wave measurements must pay attention to several aspects, namely operational costs, environmental safety and durability as well as the robustness of tools in the measurement area and its surroundings, so that the continuity of measurements can be carried out according to plan. To meet the needs of these tools, it needs to modify ultrasonic sensor-based sea level elevation recording device that has been available previously and are used as a tidal height recording device. This tool, after being modified, is hereinafter referred to as the Modified Ultra Sonic Device (MUSD). Modifications made aim to increase the sampling frequency up to 6.0 Hz or obtain 6 sea level elevation data at each time interval of 1.0 sec. MUSD testing before being used in the site of the study was carried out through joint measurements with another wave-gauge based on water column pressure meter, designated as the RBRduo. Furthermore, the use of MUSD that has been tested is shown by the results of the wave measurements at WJS, as presented at the end of this paper.

2. Method
Stages and steps of implementing testing and evaluation of the tool can be seen in the flow chart of Figure 1. The initial stage of testing is simultaneous measurement using MUSD and RBRduo at the same time and place, i.e. the Ancol beach, Jakarta Bay. Sea level elevation data obtained from MUSD and RBRduo is first checked with additional CBS station data, which is used for tidal processing and analysis. The next step is wave analysis and statistics to obtain representative wave heights and correlation coefficients and linearity. The final stage of the implementation of the trial is the discussion and final conclusions stating the overall results of the tool testing.

![Figure 1. Procedures of device testing for wave measurement.](image-url)
2.1 Devices
Modified Ultra Sonic Device (MUSD) as the main device being tested is a modification of the tide gauges, with a sampling period capacity of 1.0 minute or more. Modification is made by replacing some instruments to increase the sampling period to 0.167 seconds or 6.0 Hz.

RBR, as the testing tool, is a wave recorder that works based on the pressure due to sea surface water column height, which can also simultaneously measure the tidal height. The tool is set at a sampling frequency of 2.0 Hz, but the results displayed by the instrument are the average value of the wave height every 10.0 minutes. The measurement results are then presented in terms of the average wave height of \( H_{av} \), the significant wave height of \( H_s \), and the maximum wave height of \( H_{max} \). In addition to the three wave height data above, we also obtain the depth change data as a function of time due to the rising and falling sea levels. This sea level change is eventually the tidal data.

To ensure the accuracy of MUSD and RBR, it is considered important to check using a third measuring device. This device operates on the basis of a pressure sensor against air bubbles or OTT Compact Bubble Sensor (CBS). The data generated is tidal height data with sampling every 10 minutes.

2.2 Time and location of the test
Simultaneous measurements using the two devices as aforementioned were carried out for 15 days, starting from October 27, 2015 - November 10, 2015. The measurement location was at Ancol beach, Jakarta Bay, as shown in Figure 2. MUSD and RBR instruments were placed close one to another in a distance of about 2.0 meters. CBS tidal station as a comparison was in the waters of the port of Pondok Dayung (PD), Tanjung Priok, North Jakarta. The CBS location is about 5 km from the MUSD and RBR test sites.

![Figure 2. The Location of simultaneously measurement with the devices used.](image)
Furthermore, the data collected as presented above is analyzed including tides, waves and statistical correlations. Tidal analysis is carried out for data from all three devices, while wave and statistical analysis is performed for data generated from MUSD and RBR, as described below.

3.1 Tidal analysis

Tidal analysis is carried out to determine the accuracy of the modified tool on tidal changes. The accuracy can be known to the suitability of the measurement results obtained between the MUSD instrument with the two comparison devices. Figure 3 has been prepared to see the suitability of sea tidal data shown from the overlay of the curves generated from measurements.

![Tidal Diagram of 3 stations of measurement](image)

**Figure 3.** Tidal Overlay Diagram of 3 stations of measurement on 27 October 2015 - 10 November 2015.

Analysis to see the suitability of the three tools is done through the calculation of harmonic constants and tidal types, using the Admiralty method [10]. The resulting tidal parameters are nine (9) main constants, obtained from equation (1). The nine tidal constants are M2, S2, N2, K1, O1, M4, MS4, K2, and P1 [11]. Whereas the tidal type is generated by calculating the Formzal number (F) using equation (2).

\[ h(t) = H_0 + \sum_{i=1}^{n} f_i A_i \cos \left( (V_0 + u)i + a_i t - g_i \right) \]  

(1)

The variables in equation (1) comprise \( h(t) \) as the elevation in time \( t \), \( H_0 \) as Mean Height above water level of the Datum, \( i \) as indices of tidal constituents, \( n \) as number of constituent, \( f \) as node factor, \( A \) as amplitude, \( (V_0+u) \) as equilibrium argument, \( a \) as the angular speed of tidal constituent, and \( g(\circ) \) as the phase.

\[ F = \frac{K1 + O1}{M2 + S2} \]  

(2)

The results of calculations using equations (1) and (2) of the data from the three equipment used are as presented in Table 1. The data in Table 1 shows that the calculation of Formzal numbers produces a value of \( F > 3 \). This means that all three devices indicate the similar tidal type.
Table 1. Tidal constituents resulted from the three devices.

| No | Name of Device                  | Amplitude A (cm) | Phase φ (°) | Tidal Constituent | Number of FORMZAL (F) | Tidal Type |
|----|---------------------------------|-----------------|-------------|-------------------|-----------------------|------------|
| 1  | Modification Ultra Sonic Device | g (cm)          | 5 3 3 27 13 1 1 1 9 | M2 S2 N2 K1 O1 M4 MS4 K2 P1 | 5.3     | Diurnal |
| 2  | Wave Recorder                   | g (cm)          | 7 7 4 28 14 1 0 2 9 |                     | 3.1     | Diurnal |
| 3  | OTT Compact Bubble Sensor (CBS) | A (cm)          | 6 5 3 31 15 1 0 1 10 |                     | 4.2     | Diurnal |

3.2 Wave Analysis
One technique of analyzing the wave data generated by the MUSD and RBR devices is by comparing the wave height [12,13]. Wave data which constitute sea level elevations generated from the MUSD are then grouped every 10 minutes. By using the zero-crossing method [14,15], one obtain the number of wave cycles, which are then used to determine the value of $H_{av}$, $H_s$, and $H_{max}$.

The determination of $H_{av}$ is obtained by using equation (3), and the significant wave height $H_s$ is determined using equation (4). Whereas the maximum wave height of $H_{max}$ is obtained from the highest value of the entire data reviewed.

$$H_{av} = \frac{1}{N} \sum_{i=1}^{N} H_i$$
(3)

$$H_s = H_{1/3} = \frac{2}{N} \sum_{i=1}^{N} H_i^{1/3}$$
(4)

In equations (3) and (4), $i$ is the sequence of wave heights with the value $i = 1, 2, 3, ..., N$, while $N$ is the total number of wave cycles and $H_i$ is the wave height of the $i^{th}$-cycle. The next wave analysis is carried out based on the data presented in Figure 4.

![Diagram of Average Wave Height $H_{av}$](image-a)

![Diagram of Significant Wave Height $H_s$](image-b)

![Diagram of Maximum Wave Height $H_{max}$](image-c)

![Daily Value of Wave Height $H_{av}$, $H_s$, and $H_{max}$](image-d)

Figure 4. Wave heights overlay diagrams from MUSD and RBR for 15 days period of measurement.
Figure 4 (a) - 4 (c) show overlays of $H_{av}$, $H_s$ and $H_{max}$ data obtained directly for every 10 minutes by MUSD and RBR. While Figure 4 (d) is the result of $H_{av}$, $H_s$ and $H_{max}$ calculated from daily data recorded by the two devices for the period of 15 days. The result of the calculation can be seen from the Table 2. From the overall graphs, it can be observed that the suitability of $H_{av}$ is the best and is coincidental, compared to $H_s$ and $H_{max}$. Further findings of this subject are explained in more detail in the analysis of correlation and linearity.

| Days of Measurement | $H_{av}$ (cm) | $H_s$ (cm) | $H_{max}$ (cm) |
|---------------------|---------------|------------|----------------|
| 1 27/10/2015        | 13.6          | 13.1       | 20.6           |
| 2 28/10/2015        | 12.7          | 14.0       | 19.1           |
| 3 29/10/2015        | 14.6          | 15.1       | 22.6           |
| 4 30/10/2015        | 13.4          | 13.8       | 20.4           |
| 5 31/10/2015        | 10.7          | 11.0       | 16.4           |
| 6 01/11/2015        | 13.0          | 13.5       | 20.4           |
| 7 02/11/2015        | 14.1          | 14.4       | 22.4           |
| 8 03/11/2015        | 12.0          | 12.1       | 18.7           |
| 9 04/11/2015        | 11.4          | 11.4       | 18.2           |
| 10 05/11/2015       | 12.9          | 12.9       | 19.3           |
| 11 06/11/2015       | 11.9          | 12.0       | 17.9           |
| 12 07/11/2015       | 6.3           | 6.3        | 9.9            |
| 13 08/11/2015       | 14.1          | 13.7       | 20.6           |
| 14 09/11/2015       | 11.6          | 11.5       | 18.3           |
| 15 10/11/2015       | 4.5           | 4.4        | 6.5            |

| Average $H_{av}$ $H_s$ and $H_{max}$ | $H_{av}$ (cm) | $H_s$ (cm) | $H_{max}$ (cm) |
|--------------------------------------|---------------|------------|----------------|
| 11.8                                 | 11.9          | 18.1       | 15.4           |

The results of comparison of average wave height values from calculations using 15 days measurement data between RBR and MUSD show a pretty good agreement and a fairly good agreement, especially for $H_{av}$ and $H_{max}$. As for $H_s$, the height difference obtained was 2.7 cm. This is due to the difference in data that caused a larger divisor, so the results were smaller.

3.3 Statistical analysis on correlation and linearity

When wave measurement was conducted using two different devices, it was important to do it simultaneously in order to obtain the appropriate relationship between the two devices. One device was used as the reference or fixed variable $X$, while the tested device was designated as the dependent variable $Y$ [17]. For the current case, the reference or independent variable $X$ was the data from RBR and the dependent variable $Y$ was the data from MUSD. Both of these variables were checked statistically through correlation and regression.

The purpose of statistical analysis of regression and correlation between two variables, both linear and non-linear, is to measure and estimate the closeness of the relationship between the two [18]. It is easy to understand that the measurement results between RBR and MUSD must provide the same value. Therefore, the nature of the relationship between the two must be linear and have a perfect correlation. However, the correlation coefficient ($R^2$) of the two variables that are linearly related shows the closeness of the relationship if it has a correlation coefficient of 1.0 [19]. If the two variables do not have a relationship, the correlation coefficient value is equal to 0.
Figure 5 contains a correlation diagram and linear regression of the wave height values measured using RBR and MUSD. In the figure, it can be seen that both data were gathered around a linear line, and only a few spread far from the line. For an example, in Figure 5 (a), the correlation coefficient value obtained was 0.9781, or very close to 1.0. This value indicated a very strong relationship in terms of linearity and correlation.

Figure 5 was created based on different data. Figure 5 (a), 5 (c) and 5 (e) are the diagram based on the data from every 10 minutes. However, Figure 5 (b), 5 (d) and 5 (f) are the diagram based on daily measurement recorded with RBR and MUSD. In general, the results of correlation and linearity diagrams for the average wave height $H_{av}$, shown in Figures 5 (a) and 5 (b), respectively show very strong correlations and linearity. The correlation coefficient values of $R^2$ of the two cases were close to 1.0, namely 0.9781 and 0.9792. The same thing is shown by the linearity of the two devices, where the gradient in the line equation was 1.0191 and 1.0295, which basically approaches the same value.

Correlation values that were close to 1.0 meaning that both variables or both devices obtained measurement values that were close one to another.

The correlation coefficient $R^2$ for the significant wave height $H_s$ in Figure 5 (c) and 5 (d) shows relatively similar values, namely 0.7182 and 0.7279. This value indicated that the correlation between the two tools was quite strong. But the interesting thing was that both of the line gradient values were relatively different, namely 0.8149 and 0.6915. The difference was likely due to the amount of one-third of the different data related to the data sorted in advance, causing a discrepancy with the time of the
event. Another thing was the existence of different sampling periods, so there were waves with certain periods that were not recorded with the instrument. However, both figures show that more data had a higher level of linearity when viewed from higher gradient lines.

In Figures 5 (e) and 5 (f), it is shown that the correlation coefficient $R^2$ for $H_{\text{max}}$ was 0.5904 and 0.8717. This shows $R^2$ decreased with increasing of data, which may also be brought about by differences in the number of waves associated with the maximum wave height at certain times, so the correlation decreased. Unlikely for $H_{\text{max}}$ line gradient, where the linear gradient value of 0.781 and 0.998 indicated an increase in value if the amount of data decreased. This fact exhibits that the linearity value had increased with a smaller amount of data, meaning that some data were uncorrelated, so the strength of correlation was also reduced.

3.4. Example of Measured Wave Data from WJS
An example of sea wave data obtained from direct measurement using MUSD at WJS is presented in Figure 6 i.e. the wave time-history. Meanwhile, Figure 7 shows a wave energy density spectrum derived from time-history data. The data was measured on August 13, 2015 for 30 minutes, starting at 00:00:00 to 00:30:00 Western Indonesia Time. Furthermore, based on statistical analysis of time-history and wave spectra obtained values of random wave quantities as presented in Table 3. A more detailed discussion of the wave data directly measured at WJS will be given fully in a paper prepared for future publication.

![Wave time history recorded at WJS station on August 13, 2015 between 00:00:00 – 00:30:00 Western Indonesia Time.](image)

**Figure 6.** Wave time history recorded at WJS station on August 13, 2015 between 00:00:00 – 00:30:00 Western Indonesia Time.
Figure 7. Energy spectra of the waves recorded at WJS station on August 13, 2015 between 00:00:00 – 00:00:30 Western Indonesia Time.

Table 3. Values of wave quantities recorded at WJS station on August 13, 2015 between 00:00:00 – 00:00:30 Western Indonesia Time.

| Parameter                                | Value   |
|------------------------------------------|---------|
| Number of wave peak (Nc)                 | 559     |
| Number of wave trough (Nt)               | 560     |
| Number of zero up-crossing (Nzu)         | 558     |
| Number zero down-crossing (Nzd)          | 558     |
| Average wave height (Hav)                | 17.0 cm |
| RMS wave height (Hrms)                   | 29.0 cm |
| Significant wave height (Hs)             | 32.0 cm |
| Extreme wave height (Hext)               | 129.0 cm|

4. Conclusions
Based on the three analysis above, it can be concluded that the MUSD and RBR are in good agreement and suitable for use in sea wave measurements, by reviewing the following facts:

- Tidal analysis shows the similarity of tidal types and the suitability of tidal diagrams, as well as tidal constituents;
- Wave analysis shows the values of daily wave heights are relative indifferent, either for \( Hav \), \( Hs \), and \( H_{max} \);
- Statistical analysis in terms of correlation and linearity shows a very high agreement on \( Hav \). In the case of \( Hs \), the more data will increase the value of the line gradient, but relatively not significantly affect the correlation coefficient. For \( H_{max} \), more data decrease linearity and the correlation coefficient.

Considering the results of the study, the MUSD is believed to be able to reliably and accurately be applied as a wave gauge at the research station in the Western Java Sea.
References

[1] Djatmiko Eko B 2012 *Perilaku Dan Operabilitas bangunan Laut Di Atas Gelombang Acak* ITS Press Surabaya Indonesia.

[2] Sverdrup H U and Munk W H 1947 *Wind, Sea and Swell: Theory of Relations for Forecasting*. US Navy Hydrographic Office Publication No. 601 USA

[3] Bretschneider CL 1952 *The Generation and Decay of Wind Waves in Deep Water* EOS 33 Is 3 pp 381–389

[4] Aisjah A S and Arifin S 2011 *Maritime Weather Prediction using Fuzzy Logic In Java Sea for Shipping Feasibility Prof. 2nd Int. Conf. on Instrumentation Control and Automation ICA 2011 Banding 15-17 Nov*

[5] Dhanistha W L, Aisjah A S dan Widjiantoro B L 2016 *Prediksi Ketinggian Gelombang Signifikan Menggunakan Metode Numerik dan Jaringan Syaraf Tiruan Dalam Pelayaran Surabaya – Banjarmasin Pros. Pertemuan Ilmiah Nasional Tahunan XIII Ikatan Sarjana Oseanologi Indonesia Surabaya 1-2 Des.*

[6] Zikra M, Ashifar P and Mukhtasor 2016 *Analysis of Wave Climate Variations Based on Era-Interim Reanalysis Data from 1980 to 2014 to Support Wave Energy Assessment in Indonesia* ARPN J.Engineering and Applied Sciences 11 No. 2 pp 879-884

[7] Anggara D, Alam T M, Adrianto D and Pranowo WS 2018 *The wave characteristics in Natuna Sea and its adjacent for naval operation base purposes* IOP Conf. Series: Earth and Environmental Science 176 012003 p 1

[8] Arinaga R A and Cheung K F 2012 *Atlas of Global Wave Energy from 10 years of Re-analysis and Hindcast Data Renewable Energy* 39 pp 49-64

[9] Sakhare S and Deo M C 2009 *Derivation of Wave Spectrum using Data Driven Methods Marine Structures* 22 pp 594-609

[10] Wicaksono P P, Handoyo G dan Atmodjo 2016 *Analisa Peramalan Pasang Surut dengan metode Admiralty dan Autoregressive Integrated Moving Average (ARIMA) di perairan pantai Widuri Kabupaten Pemalang* J. Oceanografi 5 No 4 p 491

[11] Schureman P 1941 *Manual of Harmonic Analysis and Prediction of Tides* US Dept. of Commerce S P No 98 US Govt. Printing Office Washington p102

[12] Hauser D, Kahma K, Krosdag Harald E, Lehner Susanne, Monbaliu Jaak A J and Wyatt Lucy R 2005 *Measuring and analysing the directional spectra of ocean waves*, (From the European COST Action 714) COST office, Luxembourg

[13] Cornejo-Bueno L, Borge J C Nieto 2016 *Accurate Estimation of Significant wave height with Support Vector Regression algorithms and marine radar images* Elsevier

[14] Tucker M J 1991 *Waves in Ocean Engineering, Measurement, Analysis and Interpretation* Ellis Horwood Ltd. England pp 50-54

[15] Chakrabarti S K 1986 *Hydrodynamics of Offshore Structures* Computational Mechanics Publications Southamton Boston pp 29-135

[16] Goda Y 1985 *Random Seas and Design of Maritime Structures* Univ. of Tokyo Press, Japan pp1-14

[17] Smith T A, Chen S, Campbell T, Martin P, Rogers W E, Gabersek S, Wang D, Carroll S and Allard R 2013 *Ocean – wave coupled modeling in COAMPS-TC: A study of Hurricane Ocean Modelling* 69 p 190

[18] Zou Kelly H, Tuncali Kemai and Silverman Stuart G 2004 *Correlation and Simple Linear Regression*, RSNA, Boston.

[19] Furqon 2004 *Statistika Terapan untuk penelitian* penerbit Erlangga Bandung pp 95-100

Acknowledgements

The first author is very grateful to the Indonesian Navy for extending permission and awarding financial support to carry out doctoral studies at ITS. The authors sincerely thank Dr.-Ing. Widodo S Pranowo,
Marine Research Center - Ministry of Marine Affairs and Fisheries Republic of Indonesia, and Dr. Suhartono, Head of the Statistics Department – ITS for constructive advice and support to the current sea wave research.