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Tidal Phenomena and GPS-Based Monitoring System for Sea Level Measurement

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Abstract

Measuring sea surface height in open waters is very important for understanding tidal patterns and ocean wave dynamics. Most of the instruments currently used are based on pressure or acoustic sensors and are generally placed on the coast, making them less effective for measurements in open waters. This research develops a sea surface height measurement system based on the U-Blox NEO-8M GPS, which is placed on a buoy to obtain real-time elevation data. This system consists of an Arduino Mega 2560, a GPS U-Blox NEO-8M, and a Micro SD storage module. The measurement data were analyzed using the Fourier method to identify the main components constituting the sea surface height. The test results show a Mean Tide Level (MTL) of 4.27 m, a High-Water Level (HWL) of 11.30 m, and a Low Water Level (LWL) of -6.90 m. Fourier analysis revealed eight main components that make up the sea surface height pattern, with the dominant component having a wave period of 4.29 hours and an amplitude of 6 m. The comparison between the measured data and the Fourier model resulted in an average difference of 1.0798 m, likely caused by the influence of satellite signals, multipath, and atmospheric conditions. The results of this study indicate that the GPS NEO-8M can be used as an alternative for monitoring sea surface height in open waters, although it still requires accuracy improvement through signal correction techniques and more precise geoid references.

Keywords: Sea surface height, GPS U-Blox NEO-8M, buoy, Fourier analysis, tides.

1. Introduction

1.1 Sub Introduction

Tides are the regular rising and falling of sea levels caused by the gravitational pull of the moon and the sun on Earth (Fitriana et al., 2019; Julianto et al., 2021; Rosida et al., 2022; Sagala et al., 2021). These tidal patterns vary from one location to another, influenced by factors like the shape of the ocean floor and local ocean conditions (Rosida et al., 2022). Tides play a crucial role in many maritime activities, such as fishing, shipping, and port operations (Nerfita, 2018). Because of this, accurate tidal monitoring is essential for the maritime sector.

Traditionally, tides are measured using tools like acoustic sensors, radar, and tide boards (Intergovernmental Oceanographic Commission (IOC), 2014). Some manual methods, such as tide poles and float gauges, are still in use, but they come with limitations. These methods often lack accuracy, are affected by weather conditions, and can be expensive to maintain. Most tidal measurement devices are also installed along coastlines, even though tides occur in the open sea as well (Indrayanti et al., 2020).

Satellite altimetry has been developed to monitor sea levels globally, but it has its drawbacks, mainly in terms of time resolution. Satellites take a long time to revisit the same location, making real-time monitoring difficult (Safi'i et al., 2018). Because of these limitations, alternative methods are needed.

One promising alternative is using the Global Positioning System (GPS) to measure sea level changes. Researchers have studied how GPS can be used for tidal surveys, either by placing GPS receivers on fixed stations or on moving platforms like ships (Khomsin et al., 2019; Salamah et al., 2022). However, using GPS on floating buoys for continuous tidal monitoring is still uncommon and presents some challenges. These challenges include sensor stability issues due to wave movements and environmental factors that may affect data accuracy.

This study aims to develop a GPS-based tidal monitoring system that is placed on a buoy. Unlike traditional tide gauges, this system is more flexible and can be used for measurements in offshore areas. To improve accuracy, the collected GPS data will be processed using the Fourier method, which helps identify dominant tidal frequencies more precisely. This method is effective in separating tidal components and filtering out noise caused by buoy movement.

With this system, a more reliable and efficient tidal monitoring tool can be created. It has potential applications in ship navigation, port management, and disaster prevention, such as reducing the risks associated with tidal floods.

2. Section headings

2.1 Research Location

This research was conducted in Berakit Village, Teluk Sebong District, Bintan Regency, as the field testing location (Figure 1). The selection of this location is based on its water characteristics, which are suitable for testing the sea level monitoring system. Berakit Village has varying tidal dynamics, allowing for the evaluation of system performance in real environmental conditions.

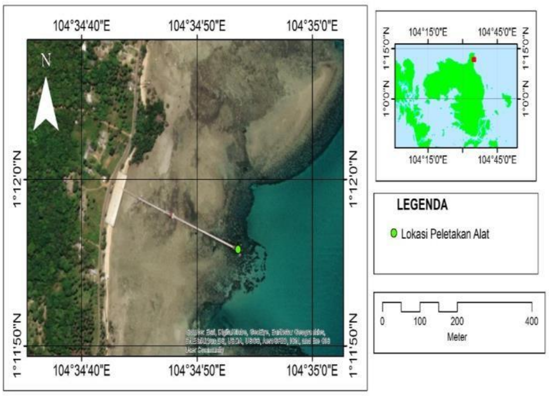


Figure 1. Research Location

In addition, this region has quite high maritime activities, such as fishing and sea transportation, so the implementation of a monitoring system in this location is expected to contribute to supporting the operations of the maritime sector. With direct field testing, this research aims to ensure that the developed system can operate optimally in real conditions and provide accurate and reliable data.

2.2 System Design

Several devices used in this research to measure sea surface height include a micro SD module for data storage, a GPS Neo-8M for measuring elevation, and an Arduino MEGA Pro 2560 as the main controller. The components are connected with cables, and the device is mounted on a buoy in open waters. To ensure effective wiring, all components are assembled on the PCB. The system can operate in the field thanks to battery power, which is used to solder the components. With these materials, it is hoped that the research will yield accurate results.

The designed sea level measuring instrument consists of several main components, namely the Arduino MEGA Pro 2560, GPS NEO-8M, and Micro SD Card Module. The GPS NEO-8M is responsible for receiving GPS signals in the form of coordinates and other parameters. This data is then processed by the Arduino MEGA Pro 2560, which is responsible for retrieving data from the GPS in the form of coordinates and altitude, and then storing it in a Micro SD. The system design is shown in Figure 2 .

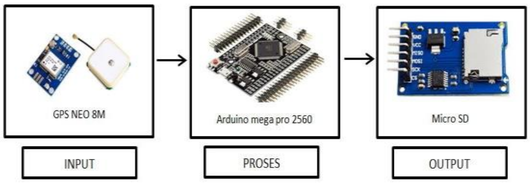


Figure 2 System Design Diagram.

2.3 Data Analysis

The sea surface height data obtained from GPS is analyzed visually to determine the tidal type by observing the tidal data curve over a 24-hour period. This data is also processed using Fourier analysis to obtain its constituent components. This analysis uses the Signal Processing Toolbox. Then, the Fourier reconstruction signal is compared with the GPS sea surface height signal to obtain the difference. The difference used in this data analysis is RMSE (root mean square error).

$$\begin{aligned} F(x) = {} & a0 + a1 * \cos(wt) + b1 * \sin(wt) + a2 \\ & * \cos(2 * wt) + b2 * \sin(2 * wt) + a3 \\ & * \cos(3 * wt) + b3 * \sin(3 * wt) + a4 \\ & * \cos(4 * wt) + b4 * \sin(4 * wt) + a5 \\ & * \cos(5 * wt) + b5 * \sin(5 * wt) + a6 \\ & * \cos(6 * wt) + b6 * \sin(6 * wt) + a7 \\ & * \cos(7 * wt) + b7 * \sin(7 * wt) + a8 \\ & * cos(8 * wt) + b8 * sin(8 * wt) \end{aligned} \quad (1)$$

3. Results and Discussion

3.1 Functional Test of GPS (Global Position Sensor) NEO 8M

The NEO-8M GPS module is connected to the Arduino via the TX, RX, VCC, and GND pins (Figure 3). The testing was conducted using the Full Example GPS program from TinyGPS++ on the Arduino IDE to obtain coordinate data (longitude and latitude), HDOP, altitude, and other parameters. After the program was uploaded to the microcontroller, the test results showed that the GPS was functioning well and successfully displayed all measurement parameters.

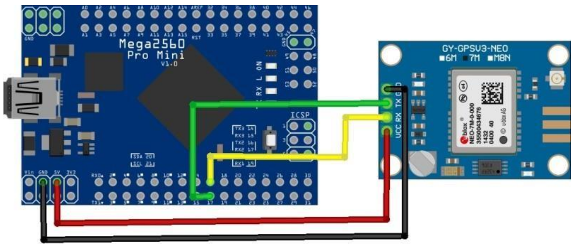


Figure 3. GPS circuit for Arduino MEGA Pro 2560.

In addition to using the tiny GPS++ program, GPS performance is checked using U-Center V21.02. This software is a program made by U-BLOX used for evaluation, performance analysis, and configuration of GNSS signal reception. Testing of the GPS NEO-8M shows that this device is capable of receiving GPS and Glonass satellite signal data (Figure 4).

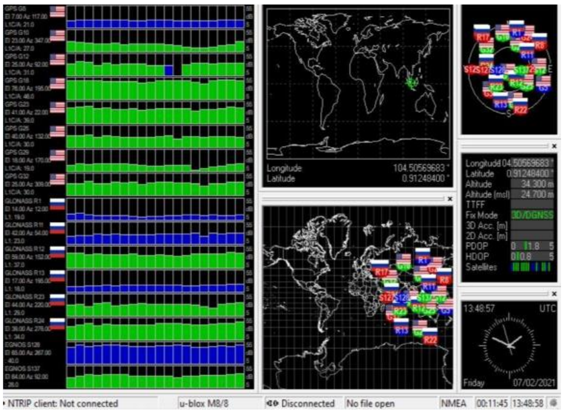
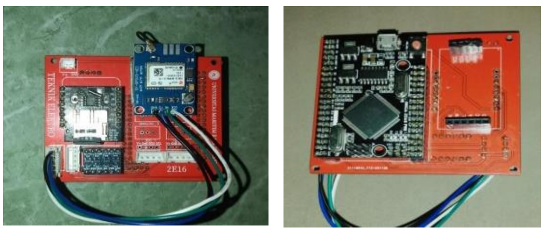


Figure 4. Checking GPS performance using U-Center.

3.2 Component Integration

Integration is carried out after each component passes the functionality test. This process integrates various components into a single complex circuit. The initial stage includes soldering the pin header and installing the JST, followed by soldering the components onto the PCB. The PCB consists of two parts: the top part (Figure 5a) and the bottom part (5b). The top part includes the GPS NEO-8M, micro SD module, and level shifter, while the bottom part only contains the Arduino Mega 2560.



(a) (b)

Figure 5. Part of the PCB (a); Top Part (b) Bottom Part

Field tests were conducted to evaluate the performance of the device. The device was placed in the waters near the Berakit Port dock, positioned on a buoy inside a waterproof box (Figure 6). This location was chosen because it is deep enough to ensure that sea surface height measurements can still be taken during low tide. The device receives data every 5 seconds, which is then stored on a micro SD card (Figure 7) in UTC time format.

Figure 6. Placement of devices in the middle of the sea.

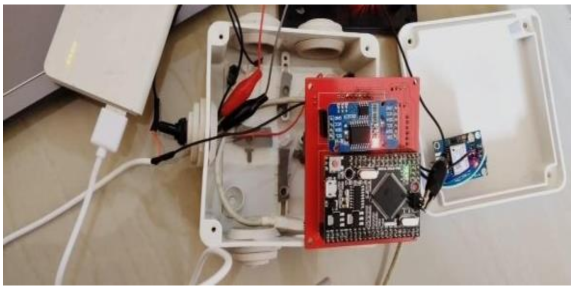


Figure 7. device series

log1 - Notepad

File Edit Format View Help

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DateTime, Bujur(deg), Lintang(deg), Alt(m),  HDOP, Jumlah Satelit
2021/7/3 8:52:38,104.57826232,1.20217931,12.50,1.28,4
2021/7/3 8:52:43,104.57828521,1.20213997,15.30,0.72,12
2021/7/3 8:52:48,104.57826995,1.20213150,14.20,0.62,12
2021/7/3 8:52:53,104.57829284,1.20213186,12.50,0.62,12
2021/7/3 8:52:58,104.57830047,1.20214772,10.50,0.64,12
2021/7/3 8:53:3,104.57830047,1.20215284,9.30,0.75,12
2021/7/3 8:53:8,104.57830047,1.20215320,8.50,0.76,12
2021/7/3 8:53:13,104.57829284,1.20215106,7.70,0.69,12
2021/7/3 8:53:18,104.57829284,1.20214915,7.10,0.78,12
2021/7/3 8:53:23,104.57830047,1.20215320,7.00,0.78,12
```

Figure 8. GPS data stored on the micro SD card

3.3 Analysis of Sea Level Rise

The sea surface height data obtained from field tests were analyzed to determine the Mean Tide Level (MTL), High Water Level (HWL), and Low Water Level (LWL). The shape of the sea surface elevation during the field test and its data can be seen in Figure 9. The analysis results show an MTL value of 4.27 m, HWL 11.30 m, and LWL -6.90 m.

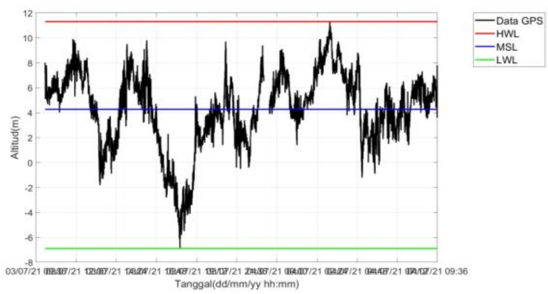

Figure 9. MTL, HWL, and LWL Chart Datum

3.4 Fourier Analysis of Tidal Data

The observational data were analyzed using Fourier to obtain a mathematical equation. The analysis was conducted using the Curve Fitting Toolbox in MATLAB. The resulting Fourier equation f(t)f(t) is then visualized in the form of a line graph, compared with the GPS measurement results (Figure 10).

The red line on the graph represents the Fourier equation resulting from curve fitting, which is a combination of several sine and cosine curves from Fourier analysis. This graph shows a mixed semi-diurnal tidal type, characterized by two high tides and two low tides with different amplitudes. These results indicate that the tidal type in the eastern waters of Bintan Island is a mixed semi-diurnal tide, consistent with calculations based on data from the period 2015–2019 (Khairunnisa et al., 2021).

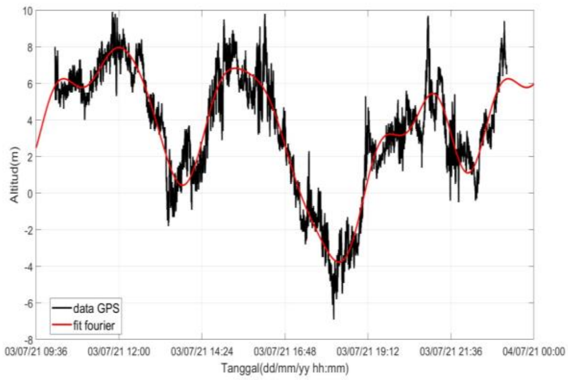

Figure 10. Fourier equation graph with GPS results.

From the obtained Fourier equation, each component is analyzed to determine the highest amplitude (Table 1). The signal from each component is visualized in a graph based on its frequency (Figure 11).

Table 1. Amplitude values of different components.

NO	COMPONENT	AMPLITUDE (M)
1	a0	3.383
2	a1	-0.8418
3	b1	2.603
4	a2	0.6733
5	b2	1.066
6	a3	1.304
7	b3	-2.685
8	a4	-0.291
9	b4	0.2365
10	a5	-0.04546
11	b5	-0.5617
12	a6	0.6085
13	b6	0.4401
14	a7	0.2896
15	b7	0.3591
16	a8	0.2964
17	b8	0.3863
18	w	11.73

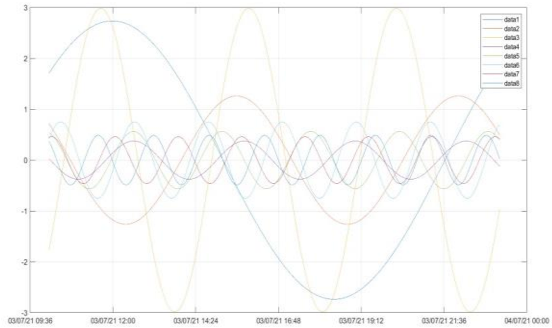

Figure 11 Fourier equation graphs at each frequency

Based on the graph in Figure 11, the third component has the highest amplitude of 6 m. The frequency of the third component is obtained as:

$$3\omega = 2\pi f$$
$$11.73 \times 3 = 2\pi f$$
$$\frac{11,73}{6,28} = f$$
$$f = 5,6 \ cycle \ per \ day$$

From this frequency, a wave period value of 0.1786 days or equivalent to 4.29 hours was obtained. The difference between the sea surface height data and the Fourier analysis data was calculated using the RMSE value. The result obtained was 1.0798 m.

4. Discussion

The sea level measuring instrument has undergone various developments with diverse technologies. Most of the research focuses on the use of pressure sensors and acoustic sensors as the main methods in measuring sea surface height (Erol, 2011; Khairunnisa et al., 2021; Knight et al., 2021; Larson et al., 2013; Quraisy et al., 2019). Meanwhile, the use of GPS as an alternative method in measuring sea surface height more often employs GPS RTK technology (Larson et al., 2013; Míguez et al., 2012). On the other hand, the U-blox Neo-8M GPS is generally used for obtaining coordinate and elevation data, but it has not yet been specifically utilized in measuring sea surface height (Specht et al., 2019).

The existence of sea level measuring devices plays an important role in understanding tidal phenomena (Khairunnisa et al., 2021; Solom et al., 2020; Suhaemi, Raharjo & Marhan., 2018). Information on sea surface height is crucial for various sectors such as ports, maritime transportation, fisheries industry, coastal engineering, and coastal area mitigation (Suhaemi, Raharjo & Marhan., 2018). Sea surface height data produces tidal datum values that serve as control points in hydrographic surveys, remote sensing, and various coastal-related activities (Scherer et al., 2001).

Tidal datum consists of several values, including HWL, MHHW, MHW, MSL, LWL, MLW, MLLW, and MTL (Scherer et al., 2001; Sudirman Adibrata., 2007). In this study, only three main parameters were used, namely MTL, HWL, and LWL. The results of the field measurements show a difference with the tidal datum values obtained by (Khairunnisa et al., 2021). This difference is caused by the different types of sensors and measurement references used. Previous research used pressure sensors with a zero reference at the water surface, while GPS used the geoid reference as the zero point of the sea surface (Sinaga et al., 2020).

The data obtained from GPS shows a sinusoidal pattern resembling a tidal pattern. To determine the frequency of its components along with the amplitude of each component, Fourier analysis was used (Ziemer et al., 2014). In this study, eight main components contributing to the formation of sea surface height were identified. The combination of these eight components produces a sinusoidal signal that closely approximates the measured sea surface height. The difference in value between the measurement and the analysis results reaches 1.0798 m. This difference is referred to as the residual value, which can be caused by external factors such as the number of satellites received, multipath effects, and atmospheric conditions.

Conclusion

Based on the research results and field tests, it can be concluded that this study is capable of developing an instrument to measure sea surface height using GPS NEO 8M. This instrument is capable of measuring sea surface height in the waters of Berakit. The results of the Fourier analysis show that the highest component forming the GPS signal is in the wave with a period of 4.29 hours. The difference value between the measurement and the Fourier analysis was obtained as 1.0798 m. This is due to the measurements being taken in waters measured from the geoid depth.

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