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IoT Application in Designing Ship Trim Reading and Monitoring Tools

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***Abstract*— The shipping industry is widely adopting appropriate technologies in various areas to overcome challenges and improve efficiency. However, ship loading and unloading efficiency remains a significant concern in terms of cost and time. Monitoring the loading and unloading process relies heavily on Android-based manual input calculations, indicating the potential for technological application in the draft survey process. This research initiates the development of an Internet of Things (IoT) application to monitor trim readings during the draft survey of a ship. The planning involved initial stability calculations to add data to the IoT module planning. The resulting tool aims to improve efficiency by providing real-time trim and ship balance data during loading and unloading operations. Additionally, this research demonstrates the potential of IoT technology in optimizing shipping logistics and can be further developed with more advanced technology to advance the maritime industry.**

Keywords— IoT, Draft Survey, Web Monitoring.

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I. INTRODUCTION

The draft survey process, which is still done manually, is made more accessible by the trim reading module. The correction calculations still use automatic calculations such as Android systems [1] and other computations. This module aims to display the ship's original condition in real-time without correcting [4] the draft to determine the balance position using the three-axis notation: X (roll and surge), Y (sway and pitch), and Z (heave and yaw). The module takes readings every 500 milliseconds, and the processed data is displayed on the monitor's web server. The system allows monitoring of the ship's position through the web server. The monitor displays a 2-dimensional ship image based on the original primary data. This system can simplify the monitoring and planning cargo loading and unloading without requiring draft mark readings or calculation corrections. This simplification makes it easier for loadmasters and crew to plan loading and unloading activities [2], save time during these operations, and ensure the ship's safety balance during the voyage [3]. This research significantly advances maritime monitoring technology, particularly in enhancing the efficiency and accuracy of ship stability monitoring [7].

II. METHOD

The current simplification of the draft survey process involves automatic calculations by inputting data obtained from manual draft surveys. The technology must be applied to provide accurate and fast data [4] by using built-in modelling tools that represent real-time conditions, where every data element in the system affects each other and enables more comprehensive data analysis [5]. The development of this trim reader module involves planning the placement of sensors and determining the number of sensors based on the vessel's dimensions [6]. This module will read the primary size data, hydrostatic table, and capacity plan to automatically generate the actual draft at midship, afterpeak, and forepeak using gyro and accelerometer sensors and an ESP32 microcontroller, which offers an efficient and affordable solution [8]. These results will be visualized in real time on the web server. Figure 1 illustrates the research methodology flow.

In this study, the authors designed a system model to develop a tool that provides information and real-time actual drafts through an Internet of Things (IoT)-based [9] sensor data integration network. This system can connect directly to a laptop wirelessly, allowing for ease of monitoring the ship's draft position, thereby facilitating loading, unloading, and ballast planning. Designing and creating prototypes require special tools and materials to achieve results that align with the research objectives. Below is a diagram illustrating the process of making a ship trim monitoring device prototype. This prototype uses an ESP32 as a data sender, with a data receiver device programmed using

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VS Code. Figure 2 explains the prototype schematic diagram.

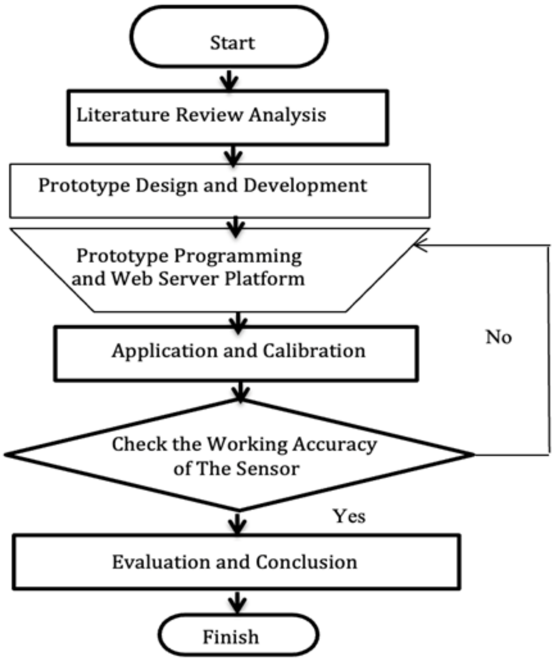

Figure 1. Research Methodology

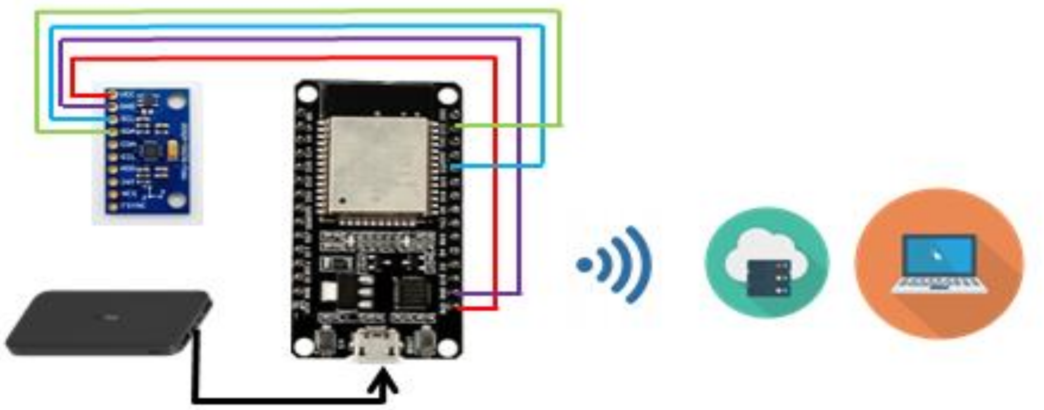

Figure 2. Prototype Schematic Diagram

Figure 3. Server Design

As described above, the next step is hardware planning. We will place this device at the midpoint of the ship lengthwise, precisely at the ship's centre. After that, we will develop the device/laptop monitoring stage using VS Code programming software. This sequence of stages is called a software planning system using Firebase, which is faster and more efficient [11]. Figure 3 shows the server design.

III. RESULTS AND DISCUSSION

3.1 Monitoring Web Interface

The design of the web application interface aims to monitor the system and collect data into the database, resulting in an integrated set of information that can be analyzed in this study. The framework used to build this web application is 'Vue.js' because it supports single-page application capabilities and can be integrated with other tools and libraries. Figure 4 shows a view of the web interface

The basic structure of the web page view consists of six components, including a header customized to meet the schematic needs of the project in this study. These components are 'header,' 'gyroscope,' 'ship,' 'results,' 'linear gauge,' and 'capacity plan.' Each component file, developed using 'Vue.js,' incorporates HTML templates, JavaScript scripts, and CSS styles, integrating functionality within the 'Vue' file.

3.2 Sensor Working Patterns

The MPU6050 sensor has been proven effective for real-time detection [10] of tilt angles in the X (roll and surge), Y (sway and pitch), and Z (heave and yaw) axes, resulting in degree and θ (radians per second) values. The degree values are used for calibration and testing, while the θ values represent the processed data used to calculate the draft. The relationship between θ (radians) and degree values is as follows:

$$1 \text{ round} = \frac{2\pi r}{r} = 2\pi \, rad = 360°, \quad \text{until} \quad \pi \, rad = 180 \quad (1)$$

Then the result is given,

$$1 \, rad \times \frac{180°}{\pi} = 57{,}2958° \text{ , or} \quad (2)$$

$$1° \times \frac{\pi}{180°} = 0{,}01745 \, rad \quad (3)$$

3.3 Midship Formula

The MPU6050 sensor's raw data from the Z-axis accelerometer is used to determine the midship draft reading. The accelerometer Z sensor, or ACCZ sensor, measures a moving object's dynamic and static acceleration [13]. Identifying the midship draft involves using a double integration process with the accelerometer sensor to obtain the object's displacement value. However, to improve accuracy [12], additional variables beyond the capabilities of the accelerometer sensor must be considered. The double integration of acceleration results in the following equation:

$$a = \frac{dv}{dt} \quad (1)$$

$$dv = a \, dt \quad (2)$$

$$v(t) = \int a \, dt$$

$$v(t) = \frac{a}{0+1} t^{0+1} + C \quad (3)$$

$$v(t) = at + C$$

$$x(t) = \int (at) \, dt \quad (4)$$

$$\int x^n dx = \frac{x^{n+1}}{n+1} + C \quad (5)$$

$$x(t) = \frac{a}{1+1} t^{1+1} + C$$

$$x(t) = \frac{1}{2} at^2 + C \quad (6)$$

After performing the integration and substitution process, the resulting distance formula for ‘x’ is obtained as shown above. By defining the value of the variable ‘C’, we can determine the result of the position calculation ‘s’. The position calculation formula:

$$s = v_0 t + \frac{1}{2} at^2 \quad (7)$$

3.4 Afterpeak dan Forepeak Formula

The relationship between the system value and the sensor value is established based on the fundamental principles of trigonometric functions [14], aiming to ascertain the position or location of a point within the X-Y plane. Determining a point's position requires an understanding that it can be represented using either polar or Cartesian coordinates. This study focuses on presenting the system value results regarding of Cartesian coordinates. The relationship between the system value and the sensor value:

$$\sin \alpha° = \frac{y}{r} = \frac{front\ side\ \angle \alpha}{hypotenuse} \quad (1)$$

so that,

$$\sin \alpha° = \frac{y}{r} = \frac{front\ side\ \angle \alpha}{hypotenuse} \quad (1)$$

so that,

$$y = r \sin \alpha° \quad (2)$$

$$\cos \alpha° = \frac{x}{r} = \frac{side\ side\ \angle \alpha}{hypotenuse} \quad (3)$$

so that,

$$x = r \cos \alpha° \quad (4)$$

The variable' r' in the above formula is the triangle's hypotenuse in the trigonometric function [14], which can be interpreted as the arm's length between the sensor and the draft at AP or FP. For this reason, the variable 'r' is an additional supporting data variable that needs to be known separately in the primary data reference as a review of the ship's transverse stability [15]. The variable 'r' as the arm length between the sensor and the AP draft is called 'lap,' while the arm length between the sensor and the FP draft is called 'life.' The naming schemes 'lsap' and 'lsfp' simplify the identification of additional data variables required in formulating draft readings.

3.5 Starboard Side, Port Side Formula

In the Starboard side and port side formulas, the variable 'r' represents the arm distance between the sensor and the draft starboard side (Length of sensor-to-SS), denoted as 'lcss.' Conversely, for the port side, 'r' signifies the arm distance between the sensor and the draft port side, referred to as 'lcps' (Length of sensor-to-PS). The naming convention 'lcss' or 'lcps' aims to simplify the identification of additional data variables necessary for formulating draft readings.

Ship Main Data

Attribute	Data	Unit
Displacement	1000	ton
Lpp	80	m
B	20	m
T	8	m
H	15	m
Cb	0.75	
MCTC	10	ton/cm
Lsap	40	m
Lsfp	40	m
Lcss	10	m
Lcps	10	m
π number	3.14	

Figure 4. Ship Main Data

3.6 Formula and Data Processing

During the testing phase and the application of sensors to a prototype vessel, various data must be input and processed to support the formulation of maximum manoeuvrability. This includes information about the vessel's principal dimensions, configurable settings, and critical additional variables such as Lsap, Lsfp, Lcss, Lcps, and MCTC, which are necessary for determining the draft survey results and the suitability of the two-dimensional visualization. The output values include draft at AP (after perpendicular), FP (fore perpendicular), midship, port side, and starboard side. The primary and additional data can be entered into the main ship data table in the web interface shown in Figure 5.

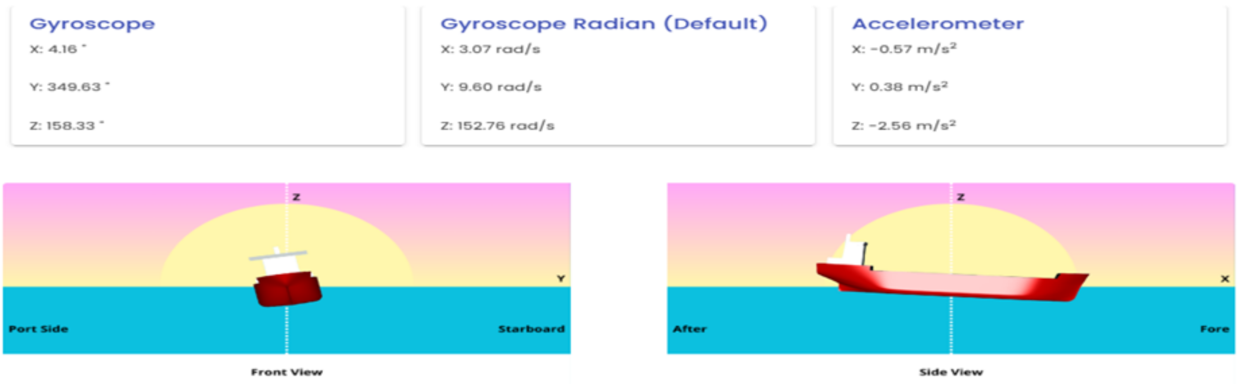

Figure 5. Raw Data Result and Ship 2-dimensional Real Condition.

The data mentioned above is crucial for the user to understand when installing the sensor on the ship. The determination of these variables is influenced by the distance between the sensor placement and the point where draft readings are taken on the ship. This distance can be determined using the stability booklet provided for each ship, which includes the centre of Floatation (CoF) distances to the AP and FP points.

3.7 Data Result

The results of sensor readings are divided into two parts: raw sensor readings and processed sensor readings. Raw sensor data consists of gyroscope measurements in rad/s, degree measurements, and accelerometer readings in m/s^2. These readings are divided into three axes: X, Y, and Z. Additionally, a 2-dimensional view of the ship's condition is provided, which includes both front and side views to support visualization when monitoring the ship's position. Figure 6 shows the display of the raw data and the 2-dimensional view.

Processed data is derived from raw data processed using the formula described above, resulting in actual draft data. This draft data can then be further analysed for the draft survey calculation. Figure 7 shows the results of the processed data display.

Figure 6. Processed Data Preview

Figure 7. Draft Overview

3.8 Draft Overview

This section shows the draft condition parameters of the ship parameters of the vessel with the applied sensors, displaying the draft from 0 meters to the maximum draft of the vessel. This draft preview can be adjusted if the vessel has a higher draft. The planned layout for development will be developed by applying capacity plan data that will automatically match the draft generated by the sensor readings. This will generate TPC, MCTC, displacement, and deadweight data under real-time draft conditions. Figure 8 shows the draft parameters read from the processed data.

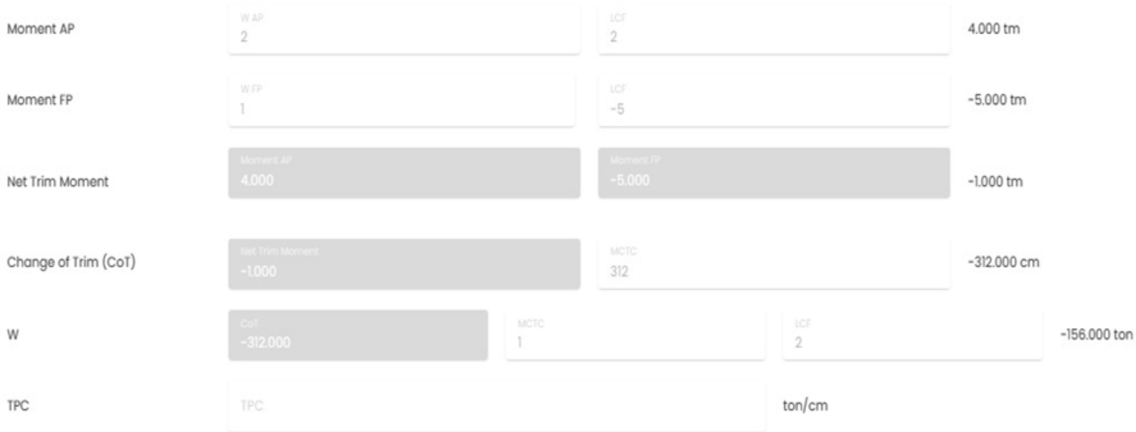

Figure 8. Capacity Plan Data

3.9 Capacity Plan Data

This section requires specific data for draft calculations, including moments and net trim moments, to obtain MCTC, W (Weight), and TPC. Input values such as WAP (Weight Aft Perpendicular) and WFP (Weight Fore Perpendicular) are crucial. They will be multiplied by the LCF (Longitudinal Centre of Flotation) value to calculate the moment. Once the moment values are determined, the net trim moment can be obtained by averaging the moments at AP and FP and dividing the average by the MCTC value obtained from the draft marks or readings on the draft preview layout. This process results in a TC (Ton Centimetre) value. Figure 9 shows the calculation results to be correlated with the capacity plan.

IV. CONCLUSION

This study focuses on developing an Internet of Things (IoT)--based ship trim monitoring system utilizing MPU6050 sensors and programming via VS Code integrated with a Vue—js-based web platform. The system employs Firebase email authentication to ensure data security and integrity to differentiate access privileges between administrators and guests. The findings demonstrate that sensor data can be effectively processed to present real-time ship trim predictions, aiding in more precise ship stability analysis. Integration of the Vue.js framework facilitates the creation of a responsive and user-friendly interface, streamlining the input of crucial ship data and monitoring processing outcomes. This research significantly advances maritime monitoring technology, particularly in enhancing the efficiency and accuracy of ship stability monitoring.

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