REAL-TIME BOAT MONITORING SYSTEM WITH AUTOMATIC TILT DETECTION AND SAFETY MECHANISMS

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ABSTRACT
This paper introduces a boating monitoring system to enhance boat safety and reliability by monitoring speed and pitch. The system uses an MPU6050 sensor that continuously monitors the boat's speed to detect excessive slowing or sinking. In an emergency, such as when the ship begins to sink, the system automatically deploys airbags to help stabilize the vessel and ensure the safety of the passengers.
An ESP8266 microcontroller runs the system, which processes real-time data from the sensors and delivers it to a user-friendly web interface. This allows users to check the status of the boat on their mobile devices or laptops without a special application. The simplified design makes it easy to use, making the monitoring system easier for any boat operator. By providing daily updates on the boat's status, the system helps boaters respond quickly, reducing the risk of accidents.

Keywords:
Boat safety, tilt detection, MPU6050 sensor, ESP8266 microcontroller, real-time monitoring, airbag deployment.

I. Introduction
Shipping serves as a widely utilized method of transportation for various activities, including travel, leisure, and business. However, it presents considerable safety risks, particularly for smaller vessels that are vulnerable to environmental conditions such as waves, wind, and currents. These factors can lead to hazardous scenarios like capsizing, overturning, or sinking. Traditional safety measures, including handheld monitors and basic alarms, may not be sufficient for real-time risk management. Consequently, there is a pressing demand for advanced and dependable boat safety systems that can deliver timely information and facilitate accident prevention.
To address this need, we developed a real-time boat monitoring system that continuously tracks the vessel's tilt and speed. This innovative system ensures that potential dangers are swiftly identified and managed without the necessity for constant human oversight. By integrating an axis accelerometer with a 3-axis gyroscope, the sensor can detect minute changes in the boat's orientation, effectively monitoring for excessive lean that could signal instability or the risk of sinking.
The system utilizes the ESP8266 microcontroller, a cost-effective and energy-efficient chip that processes sensor data and wirelessly transmits it to a cloud-based server. This setup enables real-time communication, allowing the boat and its operator to manage the network via a web-based dashboard accessible from any smartphone, tablet, or laptop. The dashboard provides crucial information regarding the boat's tilt, speed, and other functionalities, ensuring that users can monitor the vessel even when they are not physically present at the control station. This remote access significantly enhances safety, as operators can receive updates and execute necessary actions from any location on the boat.
What sets this system apart is its innovative feature of automatically deploying airbags during emergencies. When the MPU6050 sensor detects substantial submersion or indicates that the boat is

starting to sink, the system promptly activates the airbag mechanism. These airbags are inflated to maintain the boat's buoyancy and stability, preventing further rocking or sinking. This automated response minimizes the need for manual intervention, which is vital in critical situations and can be the deciding factor between a minor incident and a serious accident.

A significant aspect of the boat tracking system is its user-centric design. It requires minimal setup and does not necessitate any specialized knowledge from the user. The web interface is crafted to be straightforward and user-friendly, featuring clear visual cues that indicate the boat's current condition. Users can quickly determine if the boat is overly submerged or facing other complications, enabling them to make well-informed decisions. Beyond its role as a safety tool, the system operates efficiently, ensuring that the boat can function effectively with minimal battery consumption.

The vessel tracking system is designed to address the shortcomings in existing vessel safety technologies by combining advanced motion detection, real-time analysis, and automated safety management into a cohesive solution. It offers boat crews a dependable, hands-free method to monitor their vessel's condition. The accessibility of this system serves as a vital resource for enhancing boat safety, particularly in critical situations.

Ultimately, the system significantly enhances the overall safety and security of vessels, aids in the early prevention of accidents, and delivers essential feedback when necessary. As the maritime sector continues to advance, fleet inspections guarantee that vessels, from small recreational boats to large commercial ships, operate efficiently. Systems like this will increasingly play a crucial role, leveraging modern sensor technology and internet connectivity to provide innovative solutions to pressing maritime security challenges.

II. Literature

Recent years have witnessed significant advancements in the development of maritime safety systems, primarily motivated by the imperative to avert accidents and safeguard both passengers and cargo. This progress also emphasizes key research trends within the industry, shedding light on the current landscape of emerging technologies.

A pivotal focus within maritime security has been the implementation of sensors designed to identify abnormal or unstable movements aboard vessels. Research in this domain has thoroughly explored the application of accelerometers and gyroscopes, such as the MPU6050 sensor, to track the heading and pitch of ships. These sensors are capable of detecting even minor fluctuations in a vessel's pitch, providing critical data that may signal instability. Research has demonstrated the efficacy of these sensors in recognizing maneuvers and forecasting hazardous conditions that could result in capsizing, thereby establishing them as essential components of contemporary maritime safety systems.

A critical component of boating safety research involves the gathering and analysis of real-time data. Various systems have been created to continuously track the condition of the boat and relay information to remote devices, including smartphones, tablets, and laptops. Microcontrollers like the ESP8266 are recognized for their energy efficiency and wireless connectivity, facilitating effective real-time monitoring.

These systems are particularly advantageous as they enable operators to perform remote control, updates, and maintenance by initially exploring the feasibility of networked vessels to maximize their capabilities. A user-friendly platform has now emerged.

Additionally, the role of automation in security systems has been a significant focus in existing literature. Automation can lessen the dependence on human intervention, particularly during emergencies that require swift action. Numerous studies have examined systems that activate safety protocols, such as deploying airbags when sensors identify hazardous conditions. While airbags are typically linked to automotive safety, they also serve as an effective method for emergency stabilization in marine settings. This equipment can mitigate impacts, provide extra buoyancy, and maintain the vessel's stability until further assistance is available. This facet of automation demonstrates significant advancements in marine safety technology.

In addition to physical safety measures, several studies have examined the user interface and overall usability of boat monitoring systems. The accessibility of such systems is critical to their success, as boat operators must be able to interpret data quickly and make informed decisions based on real-time updates. Research has shown that well-designed user interfaces, particularly those that utilize clear visual indicators and simple navigation, can significantly improve the effectiveness of monitoring systems. Studies have also highlighted the importance of real-time alerts, which can notify users of immediate dangers, allowing them to take precautionary measures before a situation escalates. This emphasis on usability and real-time feedback has informed the design of many modern boat safety systems, ensuring that they are both functional and user-friendly.

Previous literature has also explored the challenges associated with implementing these technologies on boats, particularly in terms of power management and connectivity. Boats, especially smaller vessels, often operate in remote locations where power resources are limited. Studies have focused on optimizing the energy efficiency of monitoring systems to ensure that they can operate continuously over long periods without draining power sources. Similarly, reliable wireless communication is essential for real-time monitoring, but it can be difficult to achieve in maritime environments due to interference and signal limitations. Research has explored various strategies for overcoming these challenges, such as the use of energy-efficient microcontrollers and robust communication protocols, to ensure the system remains operational and effective even in difficult conditions.

In recent years, there has been an increasing focus on the incorporation of artificial intelligence (AI) and machine learning into marine safety systems. Numerous studies have suggested leveraging AI to interpret sensor data and forecast potential dangers. For instance, AI technologies could identify signs of instability or potential sinking by monitoring the boat's movements, thereby providing users with additional time to respond. While these AI-driven systems are still in the early stages of development, initial findings indicate that they have the potential to greatly enhance the predictive accuracy of boat-tracking systems. Furthermore, much of the existing literature highlights anticipated advancements in this domain, particularly concerning sensor technology, automation, and remote sensing. As sensor technology evolves, new models may emerge that offer improved precision and compactness, making them more applicable for smaller vessels. Advanced controllable systems are beginning to take shape, and the integration of this technology into user-friendly systems is poised to define the future of boat inspection and safety. Many researchers stress the necessity for ongoing innovation in this critical field.

III. PROBLEM STATEMENT

Boat safety is a significant concern, particularly for vessels that operate in unpredictable environments such as open waters, rivers, and lakes. Boats, especially smaller or mid-sized ones, are vulnerable to sudden tilting, instability, and even sinking due to various factors including high waves, strong winds, improper weight distribution, and mechanical failures. These situations can escalate quickly, leading to severe accidents, loss of cargo, and, in extreme cases, loss of life. The primary challenge is that traditional boat safety measures often rely heavily on human intervention, which may not be timely or effective in critical situations.

The absence of real-time monitoring systems capable of detecting early signs of instability is a key issue. In many cases, boat operators may not realize that their vessel is in danger until it is too late to take corrective action. Manual monitoring systems are prone to human error, and operators might be unable to detect subtle changes in the boat's tilt or movement, especially in rough conditions. Without advanced warning, there is limited time to respond to situations such as excessive tilting or the risk of capsizing, which can result in delayed action and disastrous outcomes.

Moreover, the lack of automation in traditional safety systems is another critical limitation. In emergencies, the human response may be slowed by panic, distractions, or even accessibility to safety mechanisms. For instance, when a boat begins to sink or tilt dangerously, passengers or crew might struggle to manually deploy safety equipment such as life jackets or airbags in time. This issue highlights the need for automated systems that can respond immediately to critical situations without relying on human intervention.

1. A significant issue is the intricacy of current monitoring systems. Many existing boat safety technologies necessitate specialized expertise or involve complicated setups, rendering them difficult for operators with limited technical abilities to use. The importance of having intuitive, user-friendly interfaces cannot be overstated, as it ensures that all personnel, regardless of their experience level, can comprehend and act on the data provided. Additionally, employees may require extra time to interpret information or navigate a convoluted interface, particularly when under pressure.

Furthermore, reliable communication poses a challenge in marine settings. Vessels frequently operate in regions with weak wireless signals, complicating real-time monitoring and data transmission. Numerous systems face difficulties in maintaining consistent functionality over long distances or in harsh conditions, leading to communication failures at sensors and monitoring devices. This unreliability hampers the internal monitoring system's operational efficiency and jeopardizes fleet safety.

Moreover, there are issues related to power usage. Smaller boats, in particular, often have limited power resources, necessitating that any safety or surveillance systems be energy- efficient to extend operational time without frequent battery recharging or replacement. Current solutions may demand more energy, making them impractical for long-distance journeys where energy storage is crucial.

In light of these challenges, there is a significant demand for a comprehensive ship surveillance system that not only responds promptly to the vessel's condition but also facilitates essential safety measures. The system should feature an intuitive and accessible interface, enabling individuals on board with minimal technical expertise to operate it effectively.

Furthermore, it must be energy-efficient and designed to function reliably in remote and challenging environments where connectivity may be limited. The creation of real-time vessel tracking systems to tackle these concerns will address a vital need in maritime security. By integrating cutting- edge sensor technology, automation, and user-friendliness, this system will enhance the protection of boats, cargo, and passengers against instability and various risks or accidents.

IV.PROPOSED SYSTEM DESIGN

The suggested vessel monitoring system aims to address the safety challenges encountered by vessel operators by offering real-time tracking of vessel speed and navigation, facilitating automated safety interventions.

A. Hardware Components

1. MPU-6050 Sensor Module:

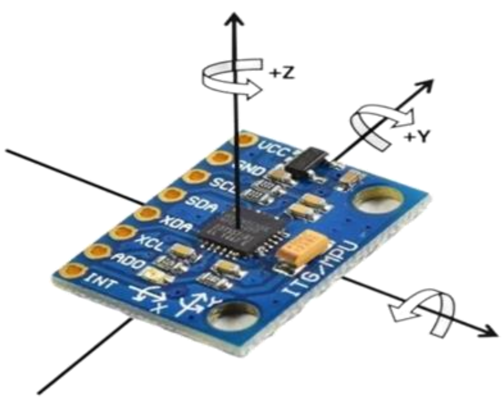

Fig. 1. MPU-6050 module.

The sensor module integrates an axis accelerometer and a 3-axis gyroscope. This module continuously monitors the boat's tilt and orientation by detecting minute changes in its angular position and acceleration. This data helps in identifying potential instability or risk of capsizing.

The MPU-6050 module has 8 pins,

- INT: Interrupt digital output pin.
- AD0: I2C Slave Address LSB pin. This is the 0th bit in the 7-bit slave address of the device. If connected to VCC then it is read as logic one and slave address changes.
- XCL: Auxiliary Serial Clock pin. This pin is used to connect other I2C interface-enabled sensors' SCL pins to MPU-6050.
- XDA: Auxiliary Serial Data pin. This pin is used to connect other I2C interface-enabled sensor's SDA pins to MPU-6050.
- SCL: Serial Clock pin. Connect this pin to the microcontroller's SCL pin.
- SDA: Serial Data pin. Connect this pin to the microcontroller's SDA pin.
- GND: Ground pin. Connect this pin to the ground connection.
- VCC: Power supply pin. Connect this pin to the +5V DC supply.

2. Microcontroller Unit (MCU):

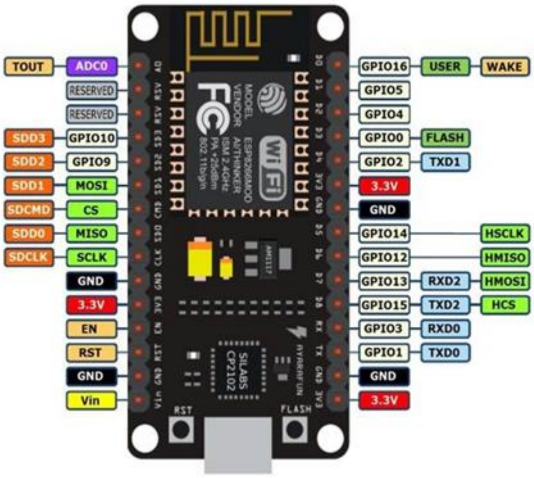

Fig. 2. NodeMCU ESP8266 Pinout.

Component: The system uses the ESP8266 microcontroller. Function: This low-cost, energy-efficient chip processes the data collected from the sensor module. It handles the real-time analysis and decision-making processes required for effective boat monitoring. Additionally, it manages the wireless communication between the boat and the cloud server.

Air Conditioning: To maintain stability during emergencies, the boat tracking system features an automatic airbag mechanism. These airbags serve as a protective measure, activating when the system identifies a risk of capsizing or sinking. They are strategically positioned around the vessel to enhance buoyancy and stability throughout transport. The deployment of the airbags is governed by data from an MPU6050 sensor, which continuously tracks the boat's heading and orientation. If the deviation surpasses a predetermined threshold, the system recognizes this as instability, prompting the airbag to deploy. Additionally, the system can incorporate sensors to identify leaks.

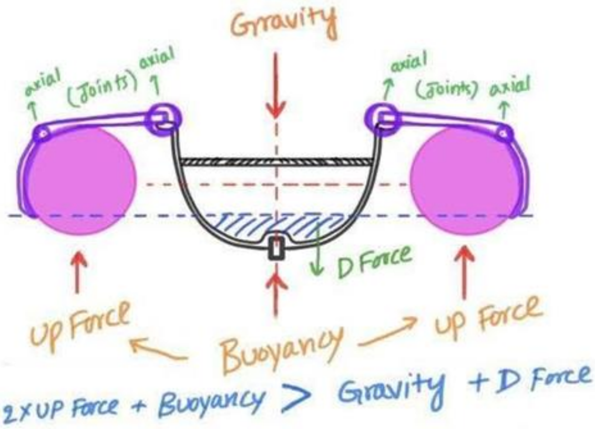

Fig. 3. Air Bags Opening View.

When the hull reaches critical levels, the airbags are deployed to avert sinking. This dual-trigger approach based on rotational movement and fluid levels provides an added layer of safety.

The airbags are engineered to rapidly channel air, bringing the boat to a halt within seconds of detection, thereby minimizing the risk of capsizing. The materials and construction of the airbags have been selected for their resilience, enabling them to endure extreme conditions while keeping the vessel afloat. Once activated, the airbags function as mechanical ventilation systems, providing crucial time for rescue efforts or allowing crews to perform necessary maintenance.

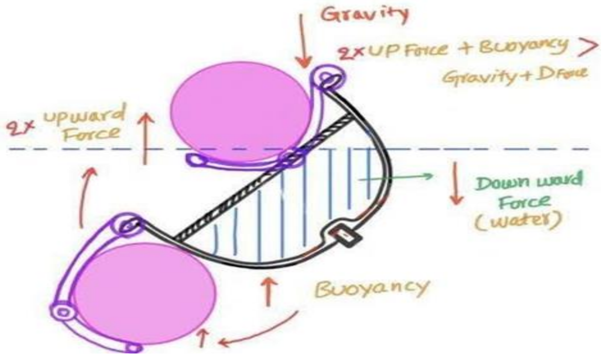

Fig. 4. Tilt Mechanism View.

Power Supply: Given that this system is designed for prolonged use on boats, effective and dependable energy management is essential. The system operates on rechargeable batteries that are engineered for extended longevity, particularly during lengthy voyages where recharging may not be feasible.

B. Software Components

1. HTML/CSS/JavaScript: The system incorporates a web-based dashboard that offers real-time insights into the boat's condition. HTML is utilized for structuring web pages, CSS is applied for visual design, and JavaScript enables interactive functionalities. This web interface empowers users to monitor the boat's status from any device equipped with a web browser, including smartphones and laptops.

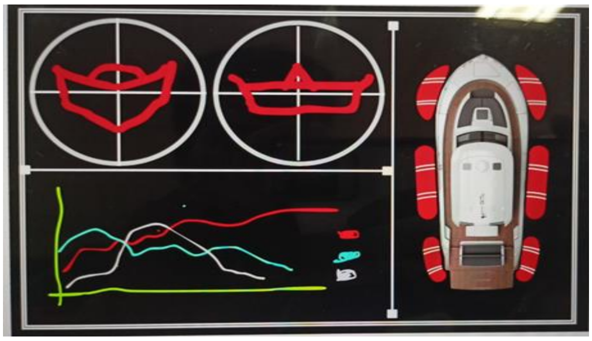

Fig. 5. Software Interface.

2. Wi-Fi connectivity: The ESP8266 microcontroller lever- ages Wi-Fi to relay tilt and speed information to a web server. This real-time data is continuously updated on the web

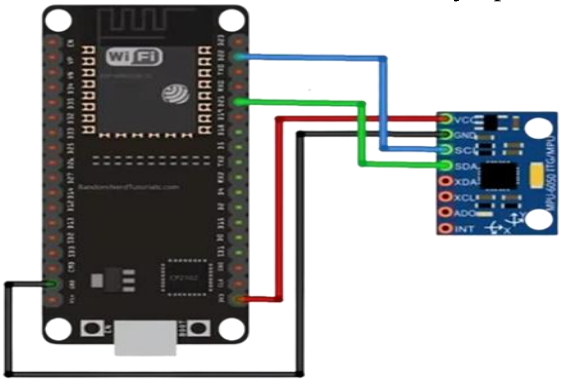

Fig. 6. Hardware Connection.

dashboard as new sensor information is received, ensuring that the boat operator has access to the most current data.

3. Cloud-based server: Sensor data is sent to a cloud server for processing, making it accessible for visualization on a web interface. This architecture supports scalability, allowing for the integration of additional features such as data logging and historical analysis in future updates.

C. Functional Overview

The system is fundamentally composed of two key elements: the MPU6050 sensor and the ESP8266 microcontroller.

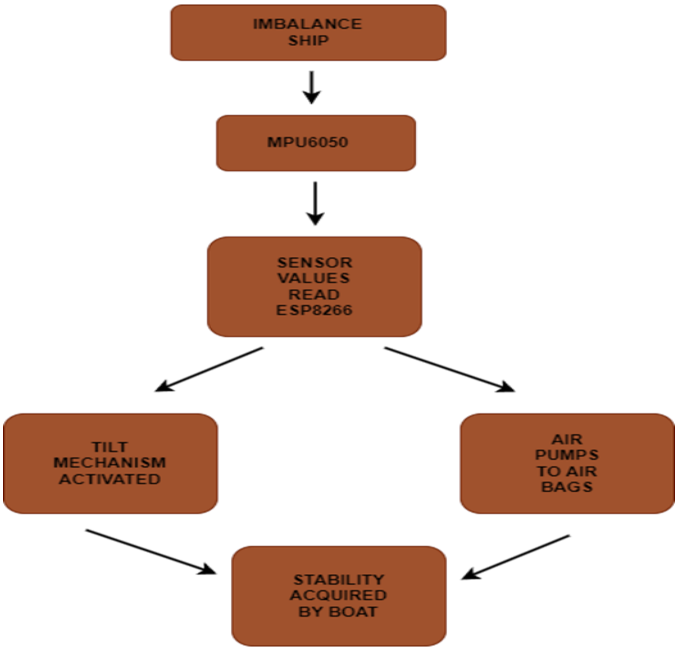

Fig. 7. Imbalance Ship flowchart.

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1. Monitoring Functionality: The MPU6050 sensor is re- sponsible for continuously monitoring the orientation and movement of the boat. It captures data on the boat's lateral tilt (roll) and its forward or backward inclination (pitch). This ongoing observation is crucial for identifying any significant shifts in the boat's balance, which could pose risks to the crew or passengers.
2. Data Analysis: The information gathered by the sensor is transmitted to the ESP8266 microcontroller for real-time analysis. The system is equipped with pre-defined safety thresholds that outline acceptable operational parameters. Should the boat's tilt or movement surpass these thresholds, the system identifies this as a potential hazard and activates an alert.
3. Immediate Notifications: The ESP8266 microcontroller relays the analyzed data through Wi-Fi to a web server. This data is then presented on a web-based dashboard accessible from any mobile device or laptop. This functionality enables users to monitor the boat's status in real-time and receive alerts if there is a risk of capsizing or sinking.
4. Automated Safety Mechanisms: In situations where excessive tilting or water ingress is detected, the system can autonomously deploy airbags to stabilize the vessel. These airbags inflate rapidly to enhance buoyancy, thereby helping to avert sinking.
5. User-Friendly Interface: The web interface of the system is designed to be straightforward and user-friendly, offering clear updates regarding the boat's status. Users can monitor tilt angles, receive alerts about potential risks, and take appropriate actions. The interface is compatible with any device that has a web browser and Wi-Fi connectivity, eliminating the need for specialized applications or software.

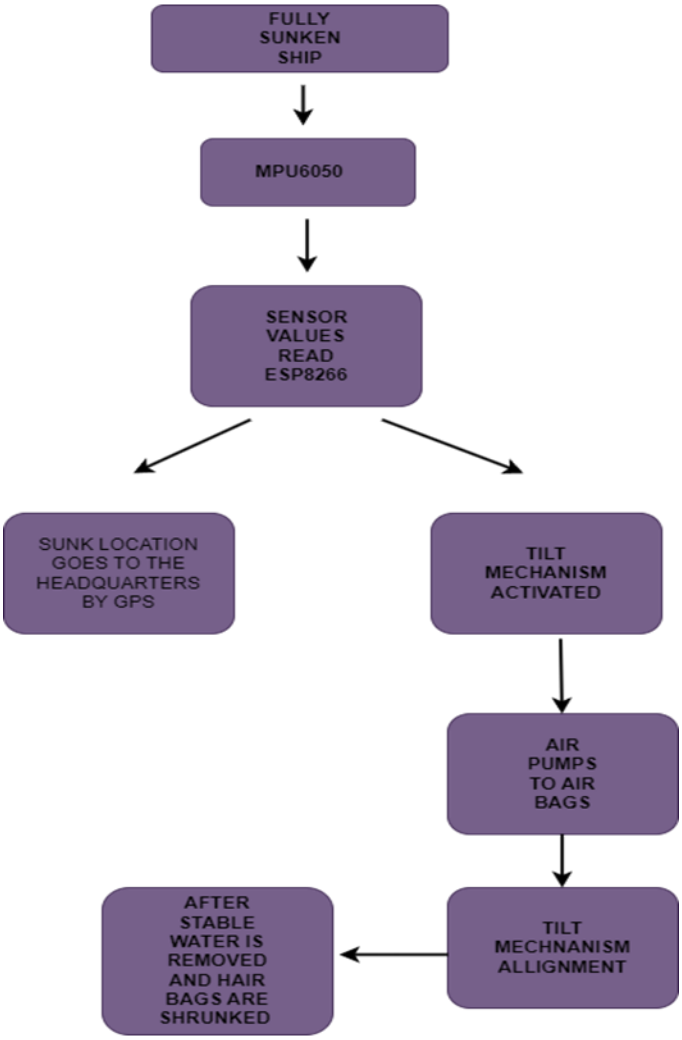

Fig. 8. Fully Suken Ship flowchart.

V.IMPLEMENTATION METHODOLOGY

A. Hardware Implementation

The boat safety assessment system is integrated with advanced hardware that allows for continuous monitoring of boat speed and stability, automatically implementing safety measures as necessary. This system operates in real-time, utilizing the MPU6050 sensor, which is strategically placed on the vessel to monitor changes in speed and direction. The sensor consistently collects data on the boat's static position and any rocking movements, evaluating for indications of instability. It is designed for seamless operation, ensuring that even minor shifts are detected.

The information gathered by the sensor is relayed to the processing unit, which quickly assesses whether the boat's speed is within predefined safety limits. The system is programmed with specific safety thresholds, enabling it to identify acceptable ranges for turns and speeds before assessing potential hazards. When the boat operates within these safety parameters, the system continues to monitor automatically without requiring further safety actions.

However, if the boat surpasses safe turning angles or shows signs of potential collision or instability, the system responds immediately by activating safety protocols, which include the deployment of strategically located airbags. These airbags improve airflow to sustain buoyancy, enhancing the boat's stability and preventing damage or capsizing. Designed to deflate within seconds upon detecting a threat, the airbags facilitate a swift response to any hazardous situation.

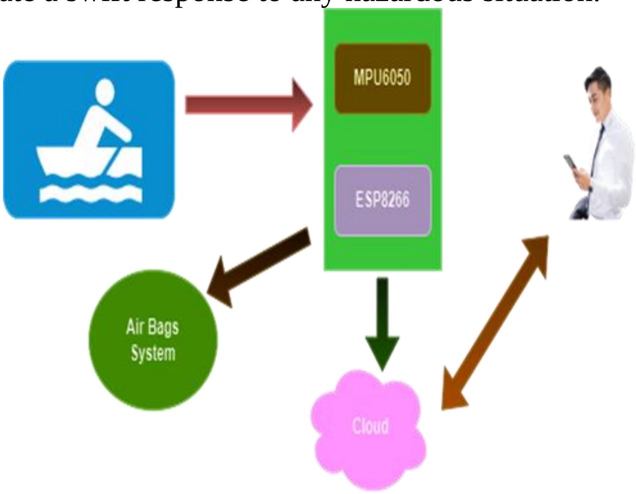

Fig. 9. Block diagram: overview of the developed system.

The system is integrated with a Wi-Fi network, enabling the transmission of real-time data to online dashboards. These dashboards can be accessed via mobile devices or laptops, empowering operators or crew members to monitor the boat's status remotely. In the event of a hazardous leak, the system promptly issues alerts through the dashboard, notifying users of potential risks. This functionality allows the crew to make swift decisions, such as altering the boat's course or redis- tributing weight to maintain stability.

Fig. 10. Side view.

The entire setup operates on a battery-powered system, ensuring functionality even during extended boat journeys. It is engineered to use minimal power during standard operations, preserving energy for critical situations. In emergencies, the system prioritizes power for essential components like sensors and airbags, guaranteeing effective operation when it is most needed.

Finally, the hardware applications encompass ongoing monitoring of boat stability, and swift data analysis to identify hazards and emergency safety protocols. This comprehensive approach facilitates remote monitoring through a web interface, providing the boat crew with a reliable safety net that aids in preventing accidents in real-time.

Fig. 11. Top view.

B. Software Development

User Interface Improvements The monitoring system plays a crucial role in the safety management of the boat, enabling users or crew members to swiftly assess the vessel's status in real time. The interface is crafted to be intuitive and user-friendly, accessible from any device with an Internet connection. Being web-based eliminates the necessity for any specialized applications or software installations.

Website Dashboards A prominent aspect of the interface is the web dashboard, which offers users a comprehensive overview of the boat's current condition. Developed using HTML, CSS, and JavaScript, the dashboard is designed to be visually straightforward while maintaining functionality. It provides real-time updates on the boat's direction and speed, with automatic data refreshes ensuring that users receive the most current information without needing to refresh the page manually.

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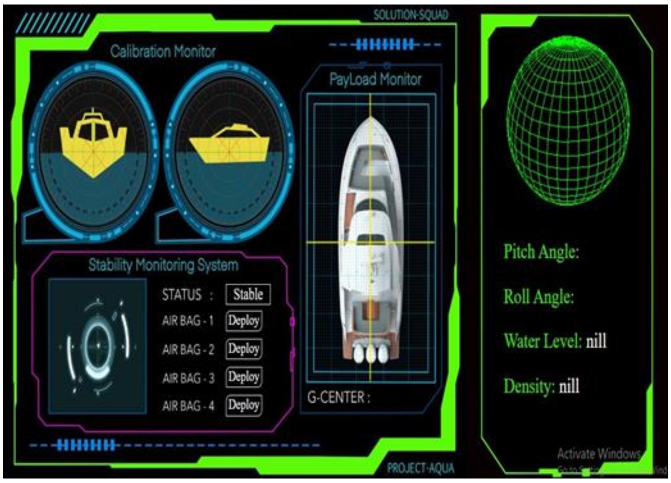

Fig. 12. Web Interface.

Real-Time Data Presentation The dashboard delivers critical information, including Tilt Angles (Pitch and Roll): This live measurement indicates the boat's tilt in both lateral and longitudinal directions. Position Alerts: Should the boat exceed safe maneuvering limits and face the risk of capsizing, the interface will issue a warning to alert the crew of the potential danger. Airbag Deployment: When the airbags are activated, the dashboard will inform the user that this safety feature has been engaged.

Utilizing straightforward graphs and visual indicators facilitates quick data interpretation for users, even those lacking technical skills. The primary objective is to deliver clear information, enabling operators to take necessary actions promptly. The interface is optimized for both mobile and desktop use, ensuring responsiveness across various screen sizes and devices. Whether accessing the dashboard via a smartphone or a laptop, users will find it easy to navigate and comprehend. This adaptability enhances the ability to monitor the boat from any location on board, thereby increasing safety and comfort. The design prioritizes ease of use, featuring a clean and organized layout that emphasizes essential information. It employs large fonts, distinct colors, and intuitive icons to draw attention to critical data, such as tilt angles and alerts. This design choice guarantees readability even in challenging conditions, such as low visibility or severe weather. The interface is equipped with immediate alerts for critical situations, such as when the boat reaches dangerous tilt angles or when the airbag system is triggered. These notifications are crafted to capture the user's attention through prominent messages or warning symbols. Additionally, the system can incorporate voice alerts to ensure that personnel remain informed about the circumstances.

VI.EXPERIMENTAL RESULTS

The boat safety system underwent a comprehensive evaluation across multiple conditions to illustrate its proficiency in real-time data processing, safety alerts, and emergency response protocols. A real-time monitoring MPU6050 sensor was utilized to consistently assess the boat's speed and rotation during the testing process. The system effectively provided real-time updates on tilt angles, such as pitch and roll, although there were some notable delays. Additionally, it accurately captured and displayed minor modifications to the hull, ensuring continuous monitoring. The design incorporated specific security features for the warning corners of the security door. When the boat's tilt exceeded established limits, an alert was instantly generated on the relevant web dashboard, prompting immediate intervention from the operator or crew to maintain stability. All test scenarios were managed with timely alerts, effectively mitigating potentially dangerous situations. Regard- ing airbag deployment, the system automatically activated the airbags when forward deflection exceeded critical safety parameters. The airbags deployed swiftly, within seconds, contributing to the boat's stability. The boat was routinely inspected during the tests to confirm its durability. The web-based dashboard underwent testing across various devices, including mobile phones, tablets, and laptops. It demonstrated rapid loading times on all platforms and offered a clear, user-friendly display of the boat's information. The real-time data visualization functioned as intended, showcasing vertical angles and safety alerts. Users indicated that the dashboard was easy to navigate and did not necessitate any specialized technical skills for operation.

VII. CONCLUSION

The Boat Safety Monitoring System exhibited remarkable performance during its testing phase, highlighting its ability to enhance boating safety through real-time monitoring and automated feedback mechanisms. The system's architecture, which integrates sensors, a microcontroller, and a web interface, has proven to be both dependable and effective in tackling issues related to boat stability. A key feature of the system is its real-time data processing capability, which allows for continuous monitoring of the boat's speed and turning dynamics, facilitating the early identification of minor stability fluctuations. This proactive strategy empowers operators to make necessary adjustments before problems escalate. The dashboard's tilt angle measurements were highly accurate, offering critical insights for informed decision-making. This design ensures the system is suitable for prolonged use, such as during extended boating excursions, without the need for frequent recharging. In summary, the system's ability to detect risks early, deliver real-time data, and respond to emergencies through automated actions underscores its potential as a dependable safety instrument. It presents a practical solution for enhancing boat stability and minimizing accident risks, making it an asset for real-world applications.

A. Advantages and Limitations

Real-Time Monitoring: The system continuously tracks the boat's tilt and movement, providing real-time data to the operator. This allows for quick detection of any instability, helping to prevent accidents before they happen.

Automated Safety Response: The automatic deployment of airbags when the boat tilts beyond a safe limit ensures that the system reacts immediately to potential risks. This fast response helps stabilize the boat and reduces the chances of capsizing. User-Friendly Interface: The web-based dashboard is easy to use and accessible from any device with an internet con- nection. It provides clear, real-time updates on the boat's condition, making it easy for operators to stay informed without needing technical expertise.

Power Efficiency: The system is designed to conserve energy by using low power when the boat is stable and only increasing power usage during critical moments, such as when airbags need to be deployed. This allows for continuous monitoring over long periods without frequent recharging.

Remote Access: Since the system is web-based, it can be accessed from anywhere on the boat using smartphones, tablets, or laptops, offering flexibility and convenience for the operator or crew.

Dependency on Internet Connectivity: The system relies on Wi-Fi for transmitting real-time data to the web dashboard. In areas with poor or no internet connectivity, remote monitoring and alerts may be delayed or unavailable.

Initial Cost of Implementation: Installing the system, including sensors, microcontrollers, and airbags, may involve higher upfront costs. However, the long-term safety benefits can outweigh this cost.

Battery Life: Although the system is power-efficient, it still requires regular battery charging or replacements, especially during long boat trips where charging facilities may be limited. Potential for False Alarms: In some cases, sudden but harmless movements (such as those caused by waves) could trigger the system to activate airbags unnecessarily, causing interruptions and added costs for resetting the system.

Limited to Specific Conditions: The system is designed to monitor boat movement and stability, but it might not detect other potential hazards, such as mechanical failures or weather-related issues, limiting its scope in comprehensive safety management.

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