Design of a Solar-Energy Wave Monitoring System for Eco-Friendly Marine Tourism Using Arduino

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ABSTRACT

This paper presents a cutting-edge and adaptable system designed to monitor ocean conditions, particularly wave activity, using a blend of readily available microcontroller technology and sensors. At the heart of the system is an Arduino Uno, which functions as the main processing unit and is connected to a GY-87 10DOF sensor to assess wave dynamics using data from an accelerometer and gyroscope. The gathered information was sent in real time to a remote server using the GSM 900A module, allowing continuous monitoring regardless of the system location. A solar panel was included to power the system, ensuring that it could operate over the long term without frequent maintenance. The findings and implementation strategies outlined in this study highlight the significance of innovative technologies in enhancing safety and sustainability in the marine tourism industry.

Keywords: Solar Energy, Wave monitoring, Marine Tourism, Arduino, GSM module, Gyro sensor

INTRODUCTION

The marine tourism sector has experienced notable expansion over the last ten years, establishing itself as a vital part of coastal economies worldwide. However, the ever-changing and often unpredictable oceanic conditions present considerable challenges for both tourists and operators in this industry [1], [2]. To ensure the safety of marine tourism activities and safeguard the environment, it is crucial to consistently and effectively monitor ocean conditions, particularly wave patterns and water temperature [3]. Although traditional ocean monitoring systems, which depend on large buoys and satellite communications, provide high accuracy, they are often costly and complicated to implement and maintain, especially in remote or resource-constrained areas [4], [5]. These challenges underscore the necessity for more accessible, affordable, and scalable solutions that can deliver real-time data to improve marine safety and operational efficiency.

Recent developments in microcontroller technology, especially the Arduino platform, have transformed environmental monitoring by providing a versatile and cost-effective means of integrating various sensors and communication modules [6]-[8]. Arduino-based systems have been effectively utilised in numerous environmental monitoring applications, offering a practical and economical alternative to conventional methods [7], [8]. These systems can be customised to meet specific requirements, such as tracking wave activity and water temperature, making them particularly advantageous in the marine tourism sector [9].

Monitoring wave activity is essential for ensuring the safety and success of marine tourism activities such as boating, diving, and coastal recreation. Precise and up-to-date wave information is crucial for forecasting and reducing the effects of severe weather events, such as storm surges and tsunamis, which can pose serious risks to tourists and coastal infrastructure [10]. Furthermore, understanding wave dynamics is vital for the design and upkeep of marine structures, including piers, docks, and breakwaters, where wave forces can significantly impact structural integrity and operational safety [11]. By delivering real-time wave data, monitoring systems can help avert accidents and enhance the overall safety and sustainability of marine tourism operations [12].

The incorporation of renewable energy sources, especially solar power, into ocean monitoring systems presents considerable benefits in terms of sustainability and operational effectiveness [1]. Solar-powered systems can function independently for long durations, even in isolated marine areas, minimising the need for frequent maintenance and supporting global initiatives to lower carbon emissions and advance renewable energy technologies [1], [13]. Utilising solar energy in monitoring systems is particularly advantageous for marine tourism activities, where conventional power sources are often limited. By leveraging solar power, these systems offer continuous monitoring capabilities without causing environmental harm.

Efficient communication technology is crucial for the effectiveness of real-time ocean monitoring systems [14], [15]. The Global System for Mobile Communications (GSM) provides a dependable and widely accessible platform for sending data from remote areas to central servers to facilitate real-time analysis and decision-making [16]-[18]. By integrating GSM modules with Arduino-based systems, wave and temperature data can be transmitted seamlessly, ensuring that essential information is readily available to marine operators and safety personnel [19]. This capability is especially beneficial in marine tourism, where timely access to precise data can enhance safety and improve the overall experience for visitors.

This study introduces a wave detection system powered by solar energy, which combines Arduino technology, renewable energy sources, and the capability for real-time data transmission. The system is designed to fulfil the demand for dependable, sustainable, and immediate monitoring of ocean conditions in marine tourism environments, thereby enhancing the safety and efficiency of the marine operations.

METHODOLOGY

The wave monitoring system designed for the marine tourism sector incorporates an Arduino microcontroller alongside a GY-87 10DOF sensor to deliver precise and real-time wave activity data. This system operates on solar power, ensuring sustainable operation with minimal maintenance. The data gathered are sent in real time through a GSM module, enabling continuous observation and prompt action by marine operators. This method not only boosts the safety and effectiveness of marine tourism activities but also encourages the adoption of renewable energy and eco-friendly technologies [20]-[22]. Fig. 1 illustrates a block diagram of the wave monitoring system, and Table 1 lists the hardware used to develop the proposed prototype and their respective functions.

Fig. 2 depicts a flowchart of the development process of the Wave Monitoring System. Upon activation, the wave sensor continuously records the wave heights. If a dangerous surge is detected, the system reacts instantly. The Arduino serves as the central processor, efficiently gathering and transmitting data using the GSM 900a module. In the case of hazardous waves, the system promptly collects information and sends real-time alerts to users' mobile phones via SMS, ensuring the safety of those engaged in marine tourism activities. Fig. 3 shows the primary hardware components that are integrated to form a complete system.

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TABLE I: List of Hardware Used

No	Component	Function
1	Arduino UNO	Controls all the operations of the entire system and acts as an interface between the other components.
2	GSM 900a module	Allows communication between devices using the GSM network.
3	GY-87 10DOF sensor	Detects the orientation, tilt, and acceleration when the device is placed on the water surface.
4	5-watt solar panel	Collects sunlight and transforms it into electrical energy.
5	Rechargeable battery (6600mAH battery rated at 5V)	Supplies power to the microcontroller unit and GSM.
6	Mobile device	Collects data received from GSM.

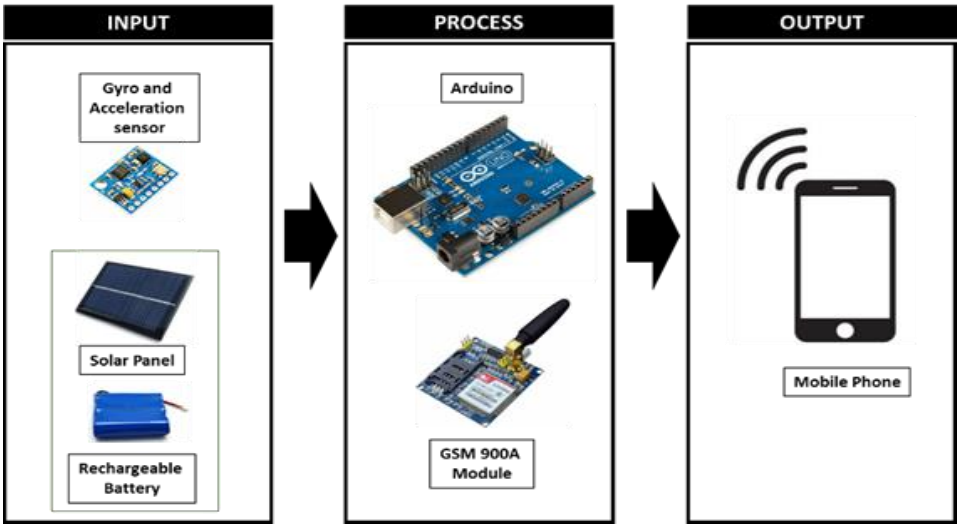

Fig. 1 Block diagram for the designed wave monitoring system

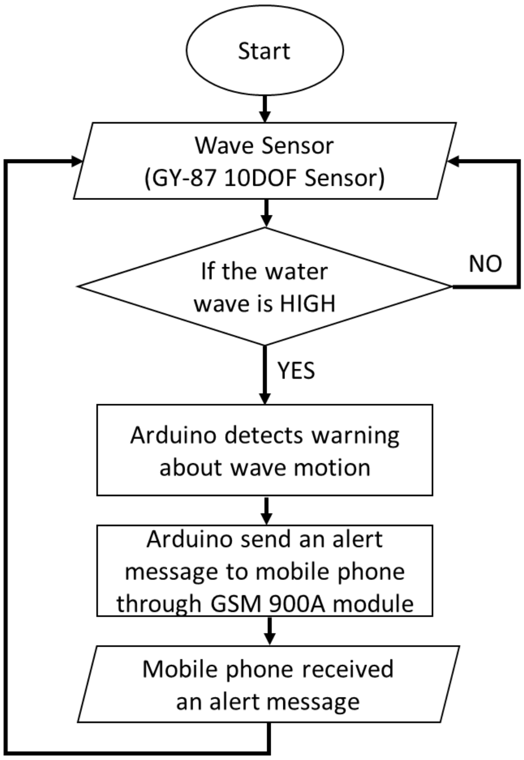

Fig. 2 Flowchart of wave monitoring system

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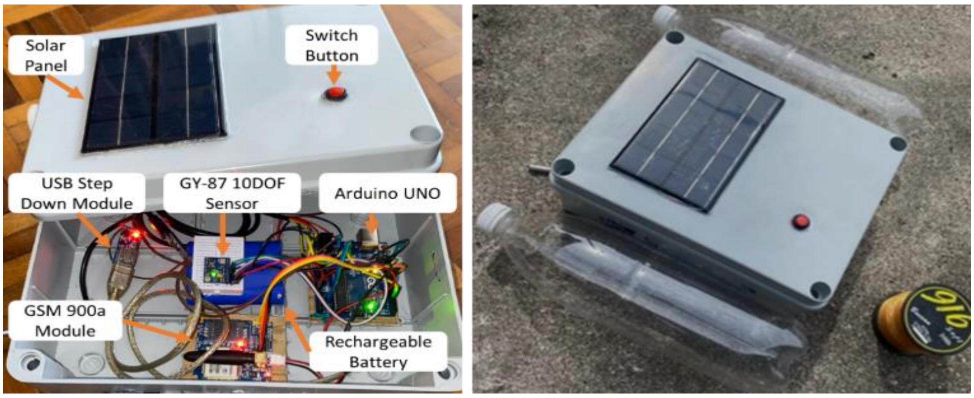

Fig. 3 Prototype of wave monitoring system

RESULTS AND DISCUSSION

Fig. 4 shows the setup and evaluation of the prototype system on the beach. The system activated an alert upon the detection of wave movements. To evaluate its performance, the system was subjected to several wave detection tests, with a maximum wave height threshold of 0.5 m. These tests were carried out at different times and wave heights across three distances from the shore: 50, 80, and 100 meters. Fig. 5 shows that the wave heights were greatest at 100 meters from the shore and smallest at 50 meters. This observation indicates that wave heights generally increase as they move away from the beach but gradually decrease as they approach the shore. The reduction of wave energy as it approaches land is well documented, as coastal wave energy diminishes owing to friction with the seafloor and other factors. The system's capability to detect wave heights before the waves reach the shore enhances its effectiveness in providing early warnings, potentially mitigating damage from strong waves.

Fig. 4 Prototype testing and deployment at sea beach

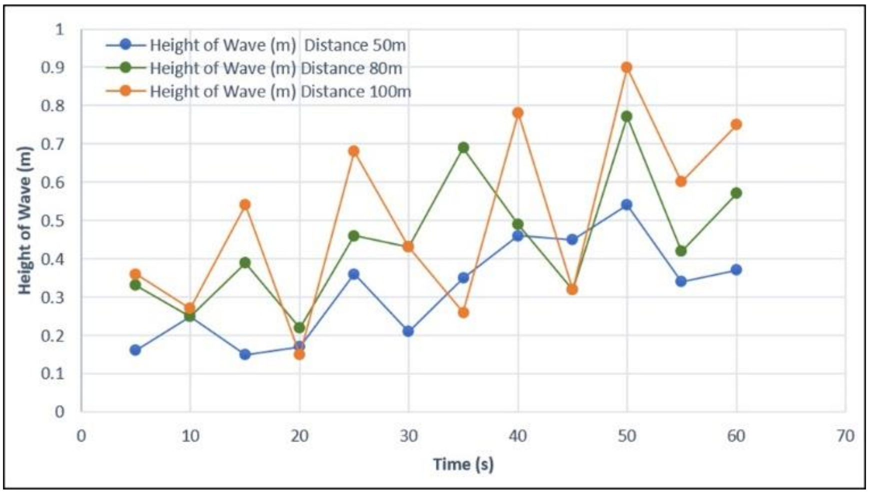

Fig. 5 Recorded height of the wave at three distances

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As shown in Fig. 6, the device had an average current of 2.1A and an average voltage of 4.94V over a span of three minutes. This information is essential for estimating the battery lifespan, suggesting that the device can function for approximately three hours under these conditions. The project employed a 6600 mAh battery with a 5V rating. The total load current was derived from the combined current usage of the device components, which included the Arduino Uno (150 mA), GSM Module (2000 mA), and GY-87 10DOF sensor (4 mA). Consequently, the total load current is determined as:

$$\text{Load current} = 150\text{ mA} + 2000\text{ mA} + 4\text{ mA} = 2154\text{ mA} \quad (1)$$

The battery life can then be estimated using the standard formula for battery life [23]:

$$\text{Battery life (hours)} = \frac{\text{battery capacity (mAh)}}{\text{load current (mA)}} \quad (2)$$

Substituting the values:

$$\text{Battery Life} = \frac{6600\text{ mAh}}{2154\text{ mA}} = 3.064\text{ hours} \quad (3)$$

According to Eq. 3, the device is anticipated to function for approximately 3.064 hours under the specified load conditions. To prolong the operational duration of the device, it is advisable to opt for a battery with a capacity exceeding 6600 mAh. Batteries with higher capacities, such as those rated at 10,000 mAh or more, can notably extend the runtime of devices. This is because the lifespan of a battery is directly linked to its capacity; a higher mAh rating means that the device can operate for a longer time under identical load conditions. A higher mAh rating enables the battery to store more energy, which is crucial for systems that require consistent and prolonged use without frequent recharging.

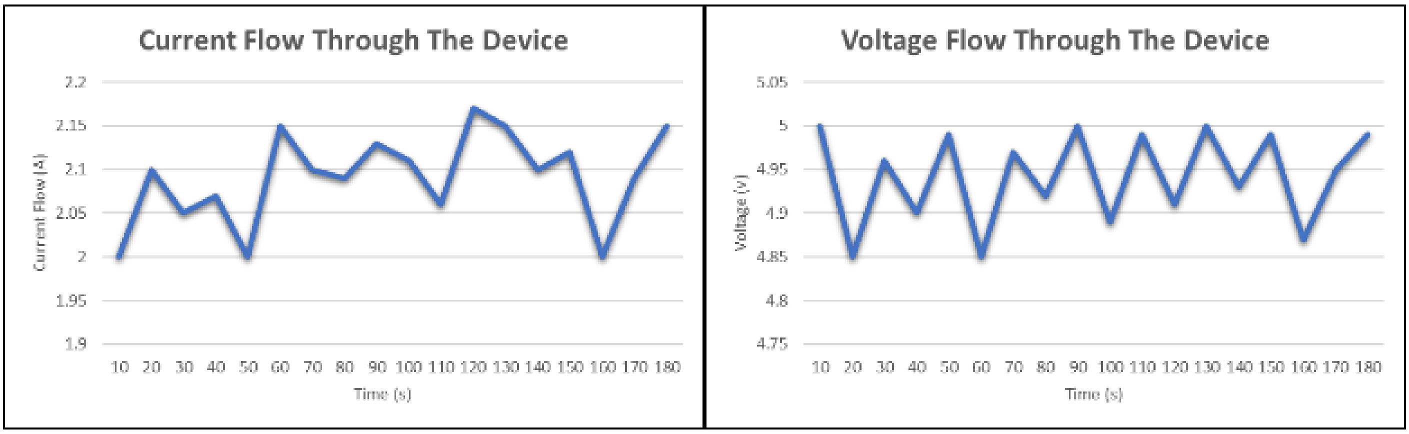

Fig. 6 Current and voltage flow through the device

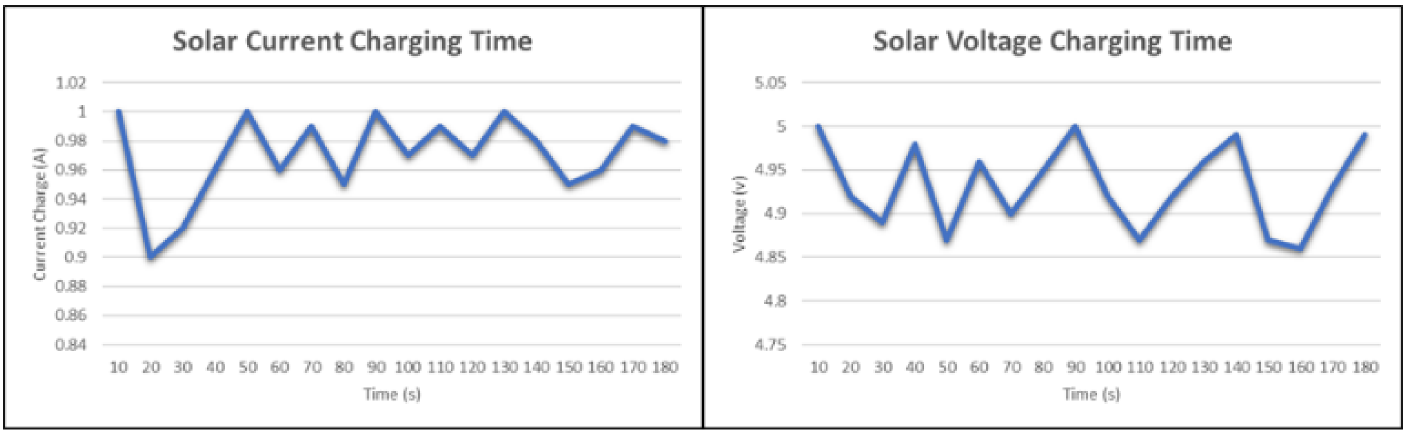

Fig. 7 Solar panel charging current and voltage

In addition, Fig. 7 presents the solar panel charging properties, indicating an average charging current of 0.97A and an average voltage of 4.93V. This information was used to compute the solar charging duration based on the specified parameters. A 5W solar panel was used for recharging. Assuming that the battery is depleted by 80% and employing a Pulse Width Modulation (PWM) charge controller with 75% efficiency, the solar charging duration can be determined as follows:

The total battery capacity in watt-hours (Wh) was calculated as:

$$\text{Battery Capacity (Wh)} = 6.6\text{Ah} \times 5\text{V} = 33\text{Wh} \qquad (4)$$

With the battery 80% discharged, the power to be replenished is:

$$\text{Power Discharged (Wh)} = 33\text{Wh} \times 80\% = 26.4\text{Wh} \qquad (5)$$

Considering the PWM efficiency, the usable power output from the 5W solar panel is:

$$\text{Solar Power Output} = 5\text{W} \times 75\% = 3.75\text{W} \qquad (6)$$

Thus, the estimated time required to fully recharge the battery is given by:

$$\text{Charge Time (hours)} = \frac{26.4\text{ Wh}}{3.75\text{ W}} = 7.04\text{ hours} \qquad (7)$$

Therefore, the device is expected to take approximately 7.04 hours to charge.

Upgrading the solar panel from 5W to a more robust option, such as 10W or 20W, can significantly reduce the time required for charging. A panel with a higher wattage delivers more energy to the battery during the same period of sunlight exposure, thus speeding up the charging process. This approach is especially effective when paired with ideal sunlight conditions. Furthermore, it is advisable to use high-efficiency solar panels, such as monocrystalline or polycrystalline panels. These panels boast superior energy conversion efficiency, capturing and converting sunlight into usable energy more effectively than conventional panels [24]. By integrating these higher-capacity batteries and more efficient solar panels, users can enhance both the operational duration and recharging speed of the device, resulting in a more reliable and energy-efficient system.

To decrease reliance on GSM networks, the use of hybrid communication technologies, such as IoT-based mesh networks or satellite links, should be explored. This strategy would enhance connectivity in remote coastal areas and extend the system functionality beyond regions with existing GSM infrastructure. Furthermore, it is vital to conduct comprehensive field trials across various marine environments to test the system's resilience, assess its long-term performance, and confirm its reliability in real-world tourism scenarios.

In addition to technical advancements, future research should consider economic and social aspects by evaluating system expenses, challenges in user adoption, and possible environmental effects. These evaluations would expand the system's applicability, ensuring its viability for sustainable marine tourism development. Moreover, incorporating predictive analytics through artificial intelligence (AI) and machine learning (ML) can convert the system into a proactive early warning mechanism, facilitating real-time risk forecasting and decision-making support for marine operators.

CONCLUSION

The solar-powered wave detection system effectively demonstrated its capability to track wave activity in real time and issue early warnings, proving beneficial for the safety of marine tourism. During prototype testing, the system successfully detected waves at various distances from the shore, with operational limits of approximately 3.064 hours and a recharge time of 7.04 hours when using a 6600 mAh battery and a 5 W solar panel. These results underscore the feasibility of the system while indicating areas for enhancement. Future improvements should focus on using batteries with greater capacity and more efficient solar panels to prolong the operational time and decrease the charging duration. Adopting hybrid communication methods, such as IoT mesh networks or satellite connections, could reduce reliance on GSM networks. Additionally, conducting extended field trials in varied marine environments, along with analysing costs, user adoption challenges, and environmental impacts would expand the system's applicability. Finally, integrating predictive analytics through AI/ML could improve its function as an early warning and decision support tool, ensuring increased reliability, scalability, and sustainability for marine tourism.

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