Implementation of IoT-Based Buoy Position Monitoring Using GSM Technology with SIM7000E Module

Hollanda Arief Kusuma, M Hasbi Sidqi Alajuri, Basyaruddin Ismail Harahap, Harmahara Saputra

Beacon buoys are essential for maritime safety, providing navigation guidance. However, loss of beacon buoys due to environmental factors or theft necessitates an effective monitoring solution. This study develops and tests an Internet of Things (IoT)-based monitoring system for beacon buoys, utilizing a SIM7000E GSM module and an ESP32 microcontroller integrated with GNSS to transmit real-time location data to the Ubidots IoT platform. The system design includes solar panels for power, a step-down module, a TP4056 battery charger, and local data storage using a micro SD card. The study was conducted from April to June 2024, with testing at the Dompak Water Navigation District Beacon Buoy. Test results showed an average power consumption of 0.64 W, enabling the device to operate for 78,625 hours. The 5-day field test recorded beacon buoy movement with a difference of up to 279 meters compared to Global Navigation Satellite System (GNSS) data, attributed to tides and sea waves. The packet loss ratio was 28%, indicating challenges in data transmission due to electromagnetic attenuation by seawater. The results confirm the potential of IoT systems in buoy beacon monitoring but also highlight the need for improvements in design and communication mechanisms to address packet loss and ensure data accuracy and reliability. This study contributes to the development of improved maritime monitoring technologies and has the potential to enhance navigation safety.

KEYWORDS
~ Monitoring
~ Internet of Things
~ SIM7000E
~ ESP32 microcontroller
~ GNSS
~ Packet loss ratio

Raja Ali Haji Maritime University, Tanjung Pinang, Indonesia
e-mail: hasbisidqi@umrah.ac.id

doi: 10.7225/toms.v15.n01.002

Received: 9 Feb 2025 / Revised: 10 Jun 2025 / Accepted: 7 Feb 2026 / Published: 20 Apr 2026

1. INTRODUCTION

Beacon buoys play a vital role in ensuring maritime safety and preventing accidents (R et al., 2020). These markers provide guidance for shipping lanes and aid safe navigation, typically as beacons or buoys (Zhang et al., 2023). Beacon buoys serve as essential navigational aids in specific water areas with precisely defined coordinates on nautical charts, significantly contributing to maritime security (Androjna and Perkovič, 2021). Accurate information about the position of beacon buoys is crucial for maintaining safe shipping lanes and avoiding navigational hazards. However, beacon buoys often experience positional changes caused by environmental factors such as extreme weather, high waves, and strong ocean currents, despite being designed to withstand these forces (Li et al., 2021).

The loss of beacon buoys is a significant problem (Zhang et al., 2018). Missing or displaced beacon buoys can severely disrupt ship navigation and increase the risk of maritime accidents (Pizzo et al., 2018). Several factors contribute to buoy loss, including biofilm development on buoy surfaces, which increases weight and reduces buoyancy, as well as seasonal variations that affect flotation performance (Chen et al., 2019). Additionally, declining water quality from anthropogenic activities has been shown to negatively impact buoy durability and operational lifespan (Alhmoudi et al., 2024). These challenges highlight the urgent need for reliable systems capable of continuously monitoring the position and operational status of beacon buoys.

The use of Internet of Things (IoT) technology to monitor buoy status has become an important approach to addressing the problem of missing beacon buoys. Previous studies have explored IoT-based buoy monitoring systems and developed platforms for maritime signaling and marine observation using low-cost hardware and simple computing architectures (Kim et al., 2017; Pizzo et al., 2018). Jeon et al. (2018) developed IoT technology based on Low Energy (BLE) Beacons for monitoring the marine environment, emphasizing low power consumption and suitability for continuous operation. Aziz et al. (2019) implemented IoT on a beacon buoy to determine position using a wireless power transfer system and a phased antenna array. Glaviano et al. (2022) developed smart buoy systems for marine ecosystem monitoring. Rezazadeh et al. (2018) implemented an IoT system using iBeacon technology, which is based on BLE, to improve positioning accuracy in a museum environment. Collectively, these studies demonstrate the potential of IoT, particularly BLE-based solutions, in improving the efficiency and accuracy of beacon buoy monitoring systems.

Monitoring the location of beacon buoys requires a reliable navigation and positioning satellite system, commonly referred to as the Global Navigation Satellite System (GNSS) (Kato et al., 2022). GNSS comprises multiple satellite constellations, including GPS, GLONASS, Galileo, BeiDou, IRNSS, and QZSS, which together provide global coverage for positioning and navigation applications. GNSS enables real-time positioning with high accuracy and precise timing information, making it well suited for maritime navigation and monitoring tasks (Jin et al., 2024). To further enhance positioning performance, Ashour et al. (2022) compared the accuracy of combined GPS, GLONASS, and BeiDou configurations, demonstrating that multi-constellation approaches can significantly improve positioning accuracy.

Therefore, integrating GNSS into IoT devices has become a key consideration for achieving efficient and cost-effective maritime monitoring solutions (Korb et al., 2020). However, the performance of GNSS chipsets embedded in IoT devices remains a critical factor, particularly under harsh maritime environmental conditions (Katsumoto et al., 2017). To address this challenge, Lee et al. (2020) and Choi et al. (2019) proposed an integrated solution combining NB-IoT and GNSS, with a specific focus on efficient GNSS chipset design to optimize system architecture, reduce power consumption, and enhance overall performance. One such implementation uses the SIMCOM SIM7000E module. Covenas et al. (2021) demonstrated the use of the SIMCOM SIM7000E for cellular communication, while Purbakawaca et al. (2022) employed this module to transmit data to a server. These studies indicate that the SIM7000E has strong potential for IoT-based applications in beacon buoy monitoring systems.

Despite the growing body of research on IoT-based buoy monitoring, BLE communication, and GNSS-enabled positioning, the integration of these technologies into a single operational system for continuous beacon buoy status monitoring in real maritime environments remains insufficiently explored. Existing studies largely focus on individual components, such as environmental sensing, indoor positioning, or communication efficiency, rather than evaluating an integrated system specifically designed for beacon buoy loss detection and operational reliability. This study aims to address this research gap by evaluating an integrated IoT framework that combines BLE-based communication, GNSS positioning, and NB-IoT connectivity within a single beacon buoy platform. Rather than proposing entirely new technologies, this work provides a systematic evaluation of how established technologies can be effectively integrated and optimized for maritime beacon buoy monitoring, offering practical insights into system performance, energy efficiency, and operational feasibility under real-world maritime conditions.

2. RESEARCH METHOD

2.1. System Design

This study proposes an IoT-based beacon buoy coordinate monitoring system designed to continuously track buoy positions and enable early detection of buoy displacement or loss. The overall system workflow and integration of data acquisition, processing, communication, and visualization components are illustrated in Figure 1 (System Planning Diagram). As shown in Figure 1, the system operates through a sequential process that begins with GNSS-based position acquisition, followed by data processing, wireless transmission, and real-time monitoring via a cloud-based IoT platform. Beacon buoy position data are obtained using a GNSS module embedded in the GSM SIM7000E, which provides latitude and longitude information at predefined intervals to represent the real-time buoy location. These coordinate data are processed by the ESP32 microcontroller, which serves as the main control unit responsible for data formatting, scheduling data acquisition to reduce power consumption, and managing data transmission. To ensure data reliability, a micro SD card is integrated as local storage, allowing coordinate data to be stored temporarily during network outages and retransmitted once connectivity is restored.

The processed data are transmitted to the Ubidots IoT platform via a cellular network using the GSM SIM7000E module. This communication architecture enables long-range data transmission suitable for both coastal and offshore environments, supporting continuous remote monitoring of beacon buoy positions. Ubidots serves as the user interface for real-time visualization and analysis of buoy location data. To support long-term autonomous operation, the system uses a solar-powered energy supply subsystem, as illustrated in Figure 1. Electrical energy is generated by solar panels, regulated through a step-down module, and managed by a TP4056 charging module to safely charge a Lithium-Ion (Li-Ion) battery. The battery serves as the primary power source for the ESP32 and GSM SIM7000E, enabling stable system operation under varying environmental and lighting conditions.

The physical implementation of the proposed system consists of several main components, including the GSM SIM7000E, ESP32, solar panels, step-down module, TP4056 battery charging module, Li-Ion battery, and micro SD card, as shown in Figure 2. Figure 2 presents the front and rear views of the device, illustrating the compact integration of hardware components within the beacon buoy enclosure.

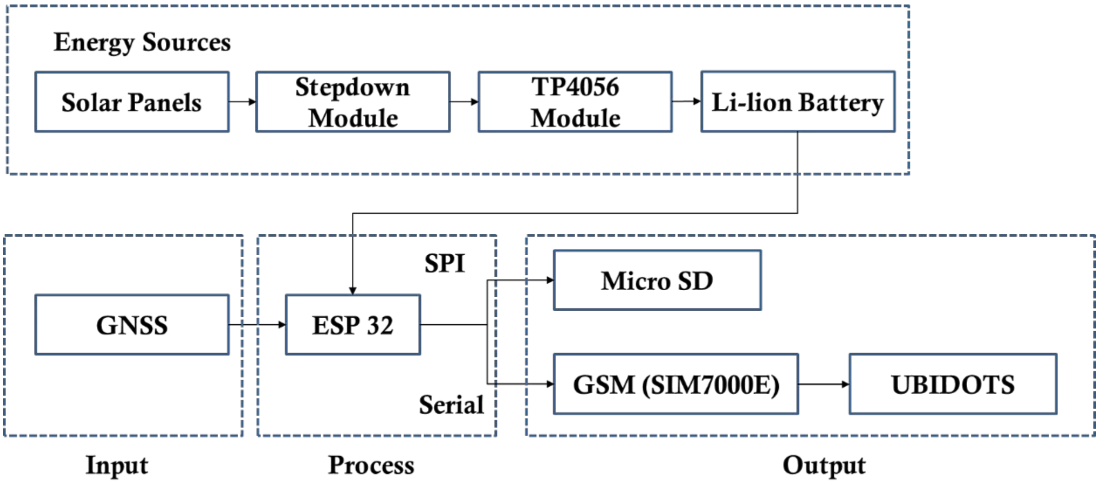


Figure 1. System Planning Diagram

Figure 2. Design Component, (a) Front View, (b) Rear View

2.2. Data Analysis

This research requires data analysis to determine the movement of the beacon buoys and determine the dominant pattern of the beacon buoys using Equation 1 (Pham *et al.*, 2017). The displacement distance Z represents the spatial deviation of the beacon buoy from its reference position and is calculated based on the difference between the measured beacon buoy coordinates and the GNSS reference coordinates. Specifically, x_2 and y_2 denote the latitude and longitude obtained from the beacon buoy GNSS measurements, while x_1 and y_1 represent the reference GNSS latitude and longitude. By computing the Euclidean distance between these coordinate pairs, Equation 1 provides a quantitative measure of buoy movement that can be used to assess positional stability and detect abnormal displacement events.

$$Z = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (1)$$

The calculated displacement values are further analyzed to determine dominant movement trends of the beacon buoys, which may be influenced by environmental factors such as ocean currents, wave activity, and weather conditions. This analysis allows for the identification of consistent movement patterns as well as sudden or irregular shifts that may indicate buoy drift or loss.

In addition to positional analysis, energy efficiency is a critical consideration for IoT devices deployed on beacon buoys due to their reliance on limited power sources. Battery life is evaluated by analyzing the power consumption of active system components, including the ESP32 microcontroller and GSM SIM7000E communication module. Power savings are estimated by measuring the voltage and current drawn during operation, as suggested by (Alegria, 2023). The operational active time, or system uptime, is calculated using Equation (2), which relates the available battery energy to the average power consumption of the device.

$$Uptime = \frac{battery\ energy}{device\ power} \qquad (2)$$

This calculation provides an estimate of how long the system can operate continuously under typical operating conditions, which is essential for assessing the feasibility of long-term deployment in remote maritime environments.

System communication performance is further evaluated by measuring the Packet Loss Ratio (PLR), which reflects the reliability of data transmission between the beacon buoy and the Ubidots IoT platform. PLR is determined by comparing the number of failed data transmissions to the server (PL) with the total number of data packets generated, including those successfully stored on the micro SD card (PTS), as described by (Purbakawaca *et al.*, 2022). Equation (3) is used to quantify the proportion of data packets that fail to reach the server.

$$Packet\ Loss\ Ratio = \frac{P_L}{P_{TS}} \times 100\% \qquad (3)$$

The PLR metric provides insight into network stability and transmission robustness, particularly under conditions of intermittent cellular connectivity. A lower PLR indicates more reliable data transmission, whereas a higher PLR suggests communication challenges that may affect real-time monitoring. Together, the displacement analysis, energy consumption evaluation, and PLR assessment form a comprehensive framework for evaluating the effectiveness, efficiency, and reliability of the proposed beacon buoy monitoring system.

3. RESULT AND DISCUSSION

3.1. Buoy Beacon Monitoring Device

This device is assembled according to the design as can be seen in (Figure 3). Component assembly by connecting all the components together in one place. Apart from assembling components, dashboard data receivers are created using several widgets that have been provided by the platform IoT. Ubidots displays location maps, graphs, and parameter values (Figure 4).

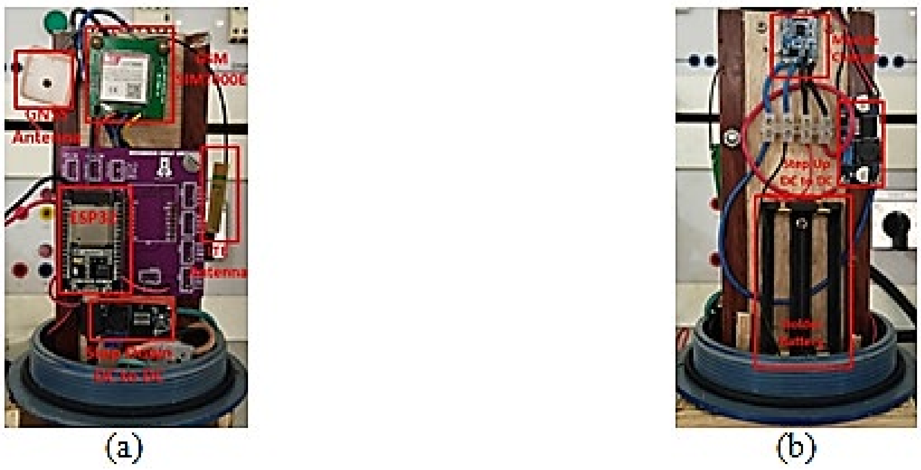


Figure 3. Component Placement on Device, (a) Front View, (b) Rear View

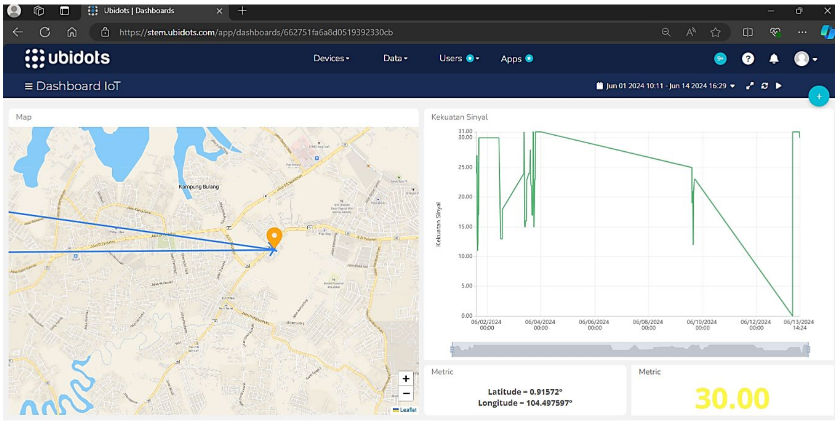


Figure 4. Ubidots Dashboard View

3.2. Power Consumption Test

The power consumption test shows that the average power consumption is 0.64 W. Figure 5 shows the results of measuring power consumption for one hour and 10 minutes. Power surges occur when the device is transmitting data. In this condition, the LED indicator lights up, and the GSM SIM7000E sends data to the Platform IoT Ubidots. The battery energy used is 50.32 Wh, allowing the device to work for 78.625 hours or around 3 days, 6 hours, and 37 minutes. Use sleep mode on the device, which is capable of providing power reduction (Jang *et al.*, 2020). However, this power reduction is not carried out on the GSM SIM7000E due to the need to avoid repeating coordinate searches that require high power and ensure the accuracy of coordinate retrieval (Parrino, Peruzzi dan Pozzebon, 2021).

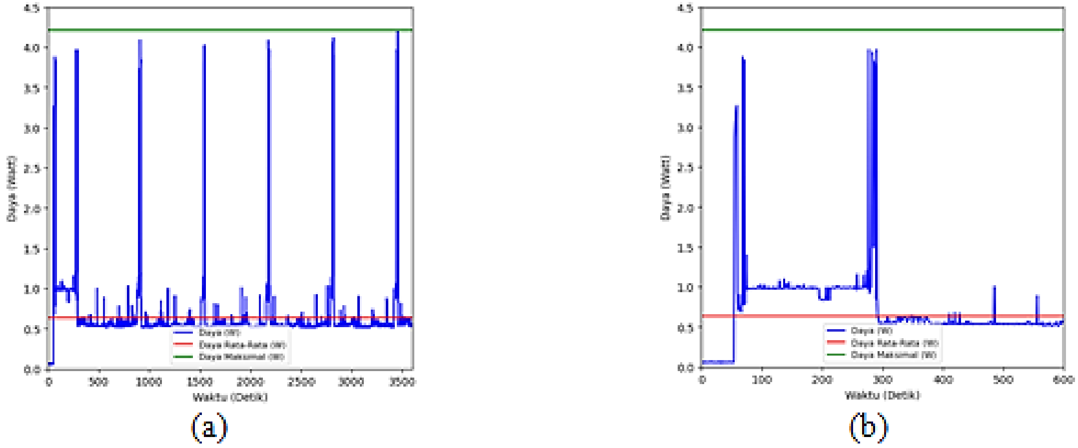


Figure 5. Power Consumption Measurement Results (a) For 1 Hour; (b) For 10 Minutes

3.3. Field Test

The field test was carried out by placing the device on one of the beacon buoys as in Figure 6 in the Sri Bintan Pura Tanjungpinang Harbor area. This buoy is used as a sign of shipping lanes (Figure 7a). These buoys are placed in waters to provide clear navigation markings for passing vessels, help avoid shallow areas, and maintain navigation safety. The device is placed on the side of the beacon buoy frame, and the solar panel placement is on the top side of the beacon buoy (Figure 7b).

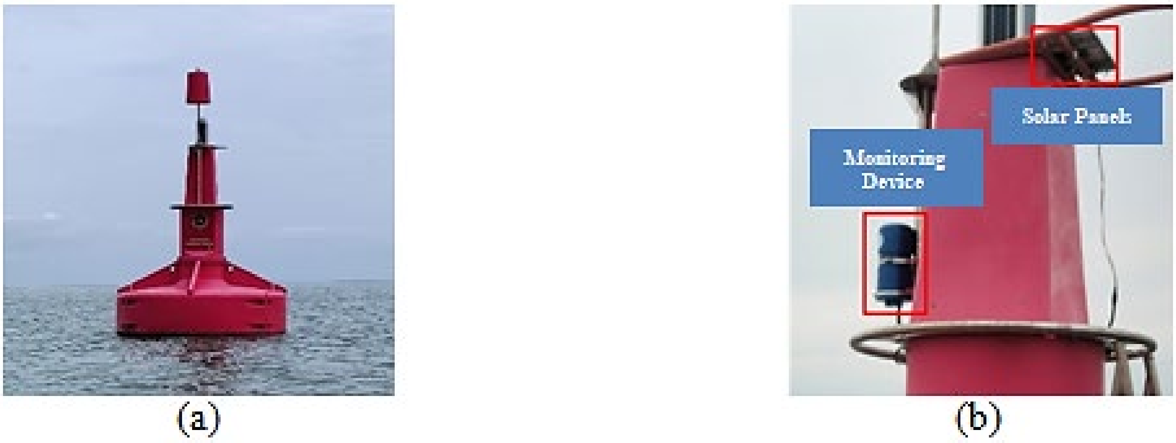
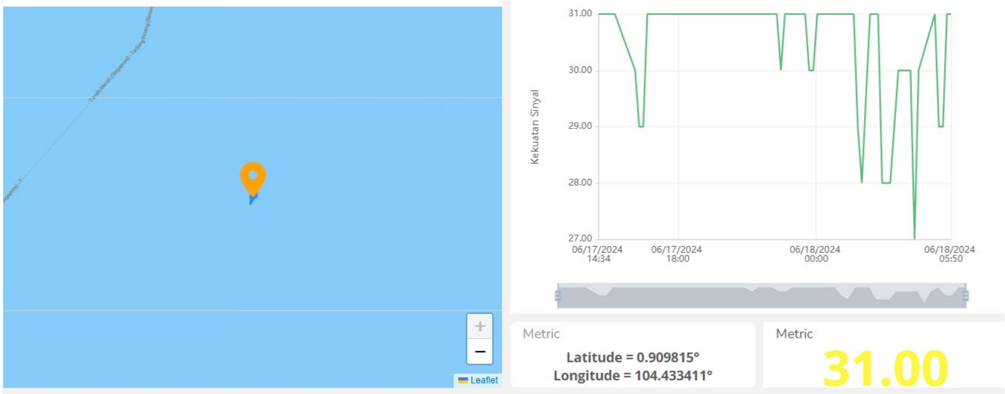


Figure 6. Beacon buoy equipped with a monitoring device and solar panels: (a) an overall view of the buoy in the water, (b) details of the monitoring device and solar panels

The field test was conducted over a period of five days, during which system performance data were continuously collected and visualized on the Ubidots IoT dashboard. The device acquired data at fixed 10-minute intervals, including latitude, longitude, and telecommunication network signal information. As part of the Internet of Things (IoT) framework, the beacon buoy operated as an autonomous sensing node that collected and transmitted data to the Ubidots cloud platform for remote monitoring (Bhuvaneswari *et al.*, 2020). The collected data were stored locally on a micro SD card to ensure data availability during temporary network disruptions and subsequently transmitted to the Ubidots IoT platform. The transmitted data were then displayed on the Ubidots dashboard using various widgets, including a beacon buoy location map, signal quality graphs, coordinate point information, and signal value indicators, as shown in Figure 7. This visualization enabled users to remotely monitor beacon buoy positions and assess communication performance in near real time..



Latitude = 0.909815°
Longitude = 104.433411°

31.00

Figure 7. Ubidots Dashboard View During Data Collection

3.4. Buoy Movement Pattern

The coordinates of the beacon buoy being tested are in the latitude position 0^{0}54’37.00’’ N and oval 104^{0}26’16.00’’ E based on DSI (Indonesian Beacon List). The beacon buoy coordinates were compared with the field test coordinates from GNSS, and a distance difference of 279 m was obtained, as can be seen in Figure 8.

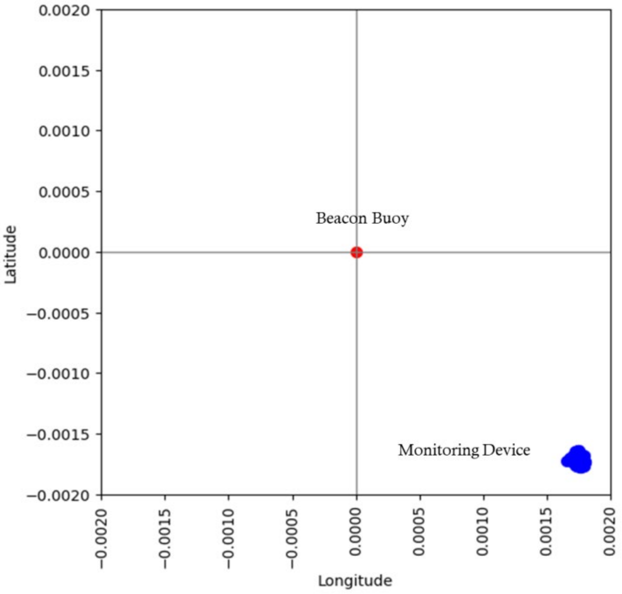


Figure 8. Difference in Distance between Beacon Buoy Points Based on DSI and GNSS Measurement Points

In the distribution of coordinate points obtained from GNSS, the beacon buoy experiences varying movements as seen in Figure 9. This is due to the tides and sea waves that occur combined with different weather. The farthest movement that occurred on the beacon buoy was 8.52 meters. This is due to the occurrence of ups and downs in field conditions. In addition, the accuracy of coordinate point readings can decrease due to ionospheric bias ((Caldeira *et al.*, 2020); (Marques *et al.*, 2018)). However, the furthest coordinate point obtained by GNSS is still within the limits set by astronavigation (International Hydrographic Organization, 2022). Meanwhile, the difference in the coordinates of the beacon buoy with GNSS is quite significant, which is possible due to inaccurate coordinates during the installation of the beacon buoy after it was released into the sea.

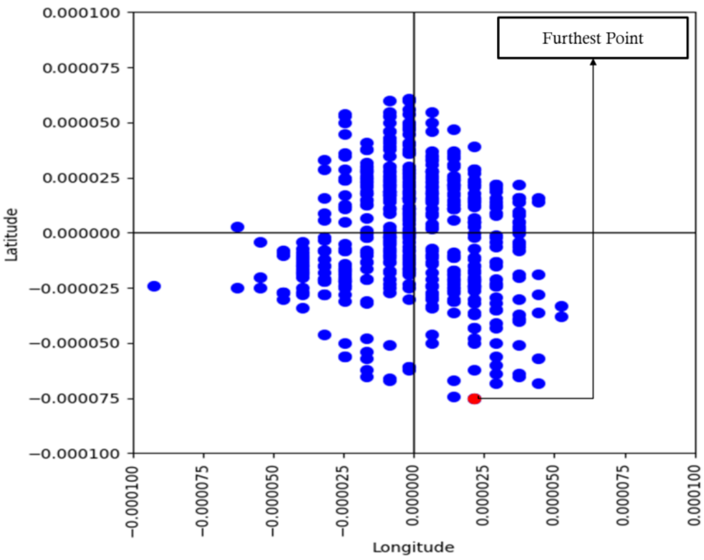


Figure 9. Distribution of Beacon Buoy Coordinates Based on GNSS

3.5. Packet Loss Analysis

Based on field testing, a packet loss ratio of 28% was observed. In IoT and wireless communication systems, this level of packet loss can reduce measurement accuracy and data transmission reliability (Omar *et al.*, 2020). This high packet loss ratio indicates the need for further evaluation and improvement of communication mechanisms to ensure effective data transmission (Solimini *et al.*, 2021). The high packet loss ratio is likely caused by the attenuation of electromagnetic wave propagation in seawater, which can degrade cellular communication performance in marine environments (Huo, Dong dan Beatty, 2020).

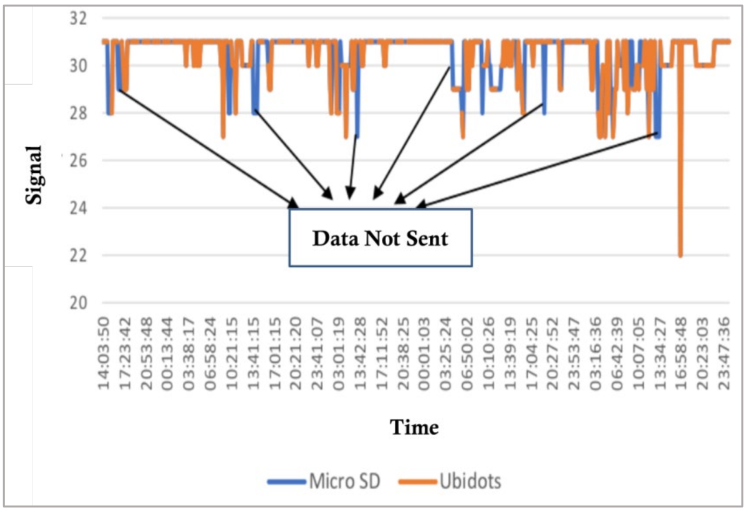


Figure 10. Data stored in micro SD (blue) and sent to Ubidots (orange)

4. CONCLUSION

This research demonstrated the effectiveness of the beacon buoy monitoring device, which was assembled according to the specified design. The device has an average power consumption of 0.64 W and can operate for 78,625 hours with the available battery energy. Using sleep mode helps reduce power consumption, although the SIM7000E's GSM must remain active to ensure accurate coordinate retrieval.

During the 5-day field test, the device collected and sent data every 10 minutes to the Ubidots platform. The data obtained included the location of the beacon buoy, signal quality, and signal value. However, there was a distance difference of 279 meters between the coordinates reported by DSI and the GNSS measurement results, caused by the movement of the buoy due to tides and sea waves. The farthest movement of the buoy recorded was 8.52 meters, which remained within the specified accuracy limits. Analysis of packet loss showed a packet loss ratio of 28%, indicating a problem in data transmission that could affect the accuracy and reliability of the system. High packet loss is believed to be caused by attenuation of electromagnetic waves by seawater.

Overall, the results of this research highlight the challenges faced by IoT-based monitoring systems in marine environments, such as power consumption, coordinate accuracy, and packet loss. This research underscores the importance of improvements in device design and communication mechanisms to increase the accuracy and reliability of beacon buoy monitoring systems, especially in extreme marine environmental conditions.

CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

REFERENCES

Alegria, F. (2023) ‘Using digital methods in active power measurement’, Acta IMEKO, 12(4), pp. 1–8. Available at: https://doi.org/10.21014/ACTAIMEKO.V12I4.1590.

Alhmoudi, S.A.O. et al. (2024) ‘Study the impact of anthropogenic activities on the marine environment of Fujairah offshore waters of UAE based on baseline surveys and buoy data’, Journal of Marine Sciences, 2024, pp. 1–6. Available at: https://doi.org/10.1155/2024/1998158.

Androjna, A. and Perkovič, M. (2021) ‘Impact of spoofing of navigation systems on maritime situational awareness’, Transactions on Maritime Science, 10(2), pp. 361–373. Available at: https://doi.org/10.7225/toms.v10.n02.w08.

Ashour, I. et al. (2022) ‘Performance of global navigation satellite systems (GNSS) in absence of GPS observations’, Ain Shams Engineering Journal, 13(2), p. 101589. Available at: https://doi.org/10.1016/j.asej.2021.09.016.

Aziz, A.A. et al. (2019) ‘Battery-less location tracking for Internet of Things: simultaneous wireless power transfer and positioning’, IEEE Internet of Things Journal, 6(5), pp. 9147–9164. Available at: https://doi.org/10.1109/JIOT.2019.2928313.

Bhuvaneswari, T. et al. (2020) ‘Internet of things (IoT) based smart garbage monitoring system’, Indonesian Journal of Electrical Engineering and Computer Science, 20(2), pp. 736–743. Available at: https://doi.org/10.11591/ijeecs.v20.i2.pp736-743.

Caldeira, M.C.O. et al. (2020) ‘Evaluation of GNSS positioning performance under influence of ionospheric scintillation’, Boletim de Ciências Geodésicas, 26(3), pp. 1–19. Available at: https://doi.org/10.1590/s1982-21702020000300014.

Chen, X. et al. (2019) ‘Sinking of floating plastic debris caused by biofilm development in a freshwater lake’, Chemosphere, 222, pp. 856–864. Available at: https://doi.org/10.1016/j.chemosphere.2019.02.015.

Choi, W. et al. (2019) ‘Efficient NB-IoT and GNSS chipset solution’, 2019 26th IEEE International Conference on Electronics, Circuits and Systems (ICECS), pp. 719–722. Available at: https://doi.org/10.1109/ICECS46596.2019.8965122.

Covenas, F.E.M. et al. (2021) ‘Design and development of a low-cost wireless network using IoT technologies for a mudslides monitoring system’, 2021 IEEE URUCON, pp. 172–176. Available at: https://doi.org/10.1109/URUCON53396.2021.9647379.

Glaviano, F. et al. (2022) ‘Management and sustainable exploitation of marine environments through smart monitoring and automation’, Journal of Marine Science and Engineering, 10(2). Available at: https://doi.org/10.3390/jmse10020297.

Huo, Y., Dong, X. and Beatty, S. (2020) ‘Cellular communications in ocean waves for maritime Internet of Things’, IEEE Internet of Things Journal, 7(10), pp. 9965–9979. Available at: https://doi.org/10.1109/JIOT.2020.2988634.

International Hydrographic Organization (2022) International hydrographic organization standards for hydrographic surveys (S-44), pp. 1–42.

Jang, G. et al. (2020) ‘Base station switching and sleep mode optimization with LSTM-based user prediction’, IEEE Access, 8, pp. 222711–222723. Available at: https://doi.org/10.1109/ACCESS.2020.3044242.

Jeon, K.E. et al. (2018) ‘BLE beacons for Internet of Things applications: survey, challenges, and opportunities’, IEEE Internet of Things Journal, 5(2), pp. 811–828. Available at: https://doi.org/10.1109/JIOT.2017.2788449.

Jin, S. et al. (2024) ‘Remote sensing and its applications using GNSS reflected signals: advances and prospects’, Satellite Navigation, 5(1). Available at: https://doi.org/10.1186/s43020-024-00139-4.

Kato, T. et al. (2022) ‘Developments of GNSS buoy for a synthetic geohazard monitoring system’, Proceedings of the Japan Academy, Series B, 98(2), pp. 49–71. Available at: https://doi.org/10.2183/pjab.98.004.

Katsumoto, T. et al. (2017) ‘GNSS system design and evaluation for IoT applications’, Proceedings of the 30th International Technical Meeting of the Satellite Division of The Institute of Navigation, pp. 3566–3572. Available at: https://doi.org/10.33012/2017.15386.

Kim, S.M. et al. (2017) ‘Development of an IoT platform for ocean observation buoys’, IEIE Transactions on Smart Processing and Computing, 6(2), pp. 109–116. Available at: https://doi.org/10.5573/IEIESPC.2017.6.2.109.

Korb, M. et al. (2020) ‘Dual-mode assisted-GNSS receiver for the Internet of Things’, 2020 IEEE/ION Position, Location and Navigation Symposium (PLANS), pp. 1273–1279.

Lee, J. et al. (2020) ‘NB-IoT and GNSS all-in-one system-on-chip integrating RF transceiver, 23-dBm CMOS power amplifier, power management unit, and clock management system for low cost solution’, IEEE Journal of Solid-State Circuits, 55(12), pp. 3400–3413. Available at: https://doi.org/10.1109/JSSC.2020.3012742.

Li, B. et al. (2021) ‘Maritime buoyage inspection system based on an unmanned aerial vehicle and active disturbance rejection control’, IEEE Access, 9, pp. 22883–22893. Available at: https://doi.org/10.1109/ACCESS.2021.3056561.

Marques, H.A. et al. (2018) ‘Accuracy assessment of precise point positioning with multi-constellation GNSS data under ionospheric scintillation effects’, Journal of Space Weather and Space Climate, 8. Available at: https://doi.org/10.1051/swsc/2017043.

Omar, N.B. et al. (2020) ‘Accuracy and reliability of data in IoT system for smart agriculture’, International Journal of Integrated Engineering, 12(6), pp. 105–116. Available at: https://doi.org/10.30880/IJIE.2020.12.06.013.

Parrino, S., Peruzzi, G. and Pozzebon, A. (2021) ‘Lopatran: low power asset tracking by means of narrow band IoT (NB-IoT) technology’, Sensors, 21(11). Available at: https://doi.org/10.3390/s21113772.

Pham, T. et al. (2017) ‘Distinct distances between points and lines in Fq2’, Forum Mathematicum, 30(4), pp. 799–808. Available at: https://doi.org/10.1515/forum-2016-0248.

Pizzo, S. Del et al. (2018) ‘IoT for buoy monitoring system’, 2018 IEEE International Workshop on Metrology for the Sea (MetroSea), pp. 232–236. Available at: https://doi.org/10.1109/MetroSea.2018.8657828.

Purbakawaca, R. et al. (2022) ‘Ambient air monitoring system with adaptive performance stability’, IEEE Access, 10, pp. 120086–120105. Available at: https://doi.org/10.1109/ACCESS.2022.3222329.

R, T. et al. (2020) ‘Channel buoys in ports for navigation’, pp. 144–148. Available at: https://doi.org/10.3233/apc200133.
Rezazadeh, J. et al. (2018) ‘Novel iBeacon placement for indoor positioning in IoT’, IEEE Sensors Journal, 18(24), pp. 10240–10247. Available at: https://doi.org/10.1109/JSEN.2018.2875037.

Solimini, D. et al. (2021) ‘Towards reliable IEEE 802.15.4g SUN with re-transmission shaping and adaptive modulation selection’, Journal of Signal Processing Systems, 93(9), pp. 1027–1044. Available at: https://doi.org/10.1007/s11265-021-01665-z.

Zhang, J. et al. (2018) ‘Design of seabed beacon positioning hardware platform based single hydrophone’, 2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO), pp. 3–7. Available at: https://doi.org/10.1109/OCEANSKOBE.2018.8559306.

Zhang, M. et al. (2023) ‘Recent developments and knowledge in intelligent and safe marine navigation’, Journal of Marine Science and Engineering, 11(12). Available at: https://doi.org/10.3390/jmse11122303.