

IoT-based Marine Life Tracking and Pollution Monitoring System

K.C. Nithyasree^{1*}, M.K. Mukesh², Kalaiselvan², P. Naren Kumar², R. Vedhanth²

Abstract

In the contemporary world, marine pollution stands as a significant challenge that has adversely affected oceans over the decades. This issue has been exacerbated by human activities, including the improper disposal of sludge, oil spills, and agricultural runoff entering marine environments without adequate regulatory oversight. The repercussions of ocean pollution are detrimental, impacting marine ecosystems, the environment, and ultimately human health. The Internet of Things (IoT) has emerged as a crucial tool in addressing the pressing issue of marine pollution detection and prevention. By incorporating IoT technologies into marine monitoring systems, a network of sensors, devices, and data analytics can enhance our capacity to identify, track, and respond to pollution incidents effectively. We propose an IoT framework named 'Smart Computing Sensor', which utilizes advanced detectors and intelligent computing solutions specifically tailored for the onsite monitoring of microplastics in natural underwater environments. Effective management of marine pollution necessitates the implementation of various strategies, activities, and regulatory measures. A primary focus should be on reducing plastic consumption, as it poses a significant threat to marine life. Governments can guarantee that proper waste disposal systems are in place by implementing efficient management strategies. Additionally, cleanup initiatives are critical; by removing marine debris such as plastic bags, fishing nets, and other waste, we can significantly reduce pollution levels. Comprehensive policy measures are essential in the prevention and control of marine pollution.

Keywords: Marine pollution, oceans, human activities, oil spills, agricultural runoff, marine eco systems Internet of Things (IoT), pollution detection, microplastics, cleanup initiatives

INTRODUCTION

The Internet of Things (IoT) is emerging as a groundbreaking framework that allows devices with sensing, identification, processing, communication, actuation, and networking functions to connect and interact. It is characterized as a dynamic global network infrastructure that effortlessly connects both physical and virtual entities, enabling intelligent interaction between them. A fundamental element of IoT is the wireless sensor network (WSN), which consists of numerous distributed sensors linked through wireless connections to monitor physical and environmental parameters. In recent decades, WSNs have been utilized in a wide array of smart applications, including smart homes, buildings, transportation, industrial automation, healthcare, energy grids, and urban environments. The potential applications of IoT technologies also extend to the monitoring and protection of marine environments, an area that is receiving increasing focus, as traditional monitoring systems, such as oceanographic research vessels, tend to be expensive, time-consuming, and provide low-resolution data [1].

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An IoT-driven marine environment monitoring system can employ various sensors to measure physical and chemical parameters, including water temperature, pressure, wind direction, salinity, turbidity, pH, oxygen density, and chlorophyll concentrations [2].

This sophisticated system not only collects data but also has the capability to control devices to modify environmental conditions, thereby improving marine ecosystems. Nevertheless, the design and implementation of such systems must tackle essential challenges such as autonomy, adaptability, scalability, simplicity, and self-healing, in addition to specific requirements imposed by the harsh marine environment [3]. Important factors to consider include the need for high water resistance in sensor nodes, durable hardware to endure turbulent conditions, low energy consumption combined with energy harvesting capabilities, and the stability of radio signals amidst varying weather conditions [4].

Marine Monitoring Sensors

The sensors are deployed in marine environments (oceans, lakes, rivers) to constantly acquire statistics on various pollutant parameters and marine life.

Detection Process and Method

The five layers consist of the perception and action layer, the transmission layer, the data processing layer, the application layer, and the business layer.

Managing Marine Pollution

Encourage the use of recyclable plastics; support legislation to reduce plastic use and waste; practice responsible recycle.

Literature Review

The authors suggest a security approach for wireless sensor networks that emphasizes the configuration of sensor nodes, communication protocols, and innovative methods for data recycling to identify issues.

Advantages and Applications

Real-time data; Remote monitoring; Data-driven decision-making; Monitoring water quality; Monitoring coral reefs; and Monitoring marine life.

Smart Computing Sensors

The advancement of the Smart Computing Sensor system can be enhanced through various structural and computational concepts.

Marine Monitoring Sensors

These sensors are deployed in marine environments (oceans, lakes, rivers) to constantly acquire statistics on various pollutant parameters and marine life. Sensors can detect:

- *Pollution Sensors:* For detecting pollution like oil, microplastics, toxins, and different contaminants.
- *Environmental Sensors:* For measuring parameters including water temperature, salinity, turbidity (clarity), and pH levels.
- *Marine Life Tracking Sensors:* Equipped with GPS, acoustic, or RFID generation to track marine species like fish, turtles, or whales (Figure 1).
- *Data Collection and Transmission:* Once sensors acquire facts, they ship this record to a vital device or cloud platform through Wi-Fi communication (e.g., cellular, satellite, or Wi-Fi). This fact is then processed and saved for similarly analysis (Table 1).

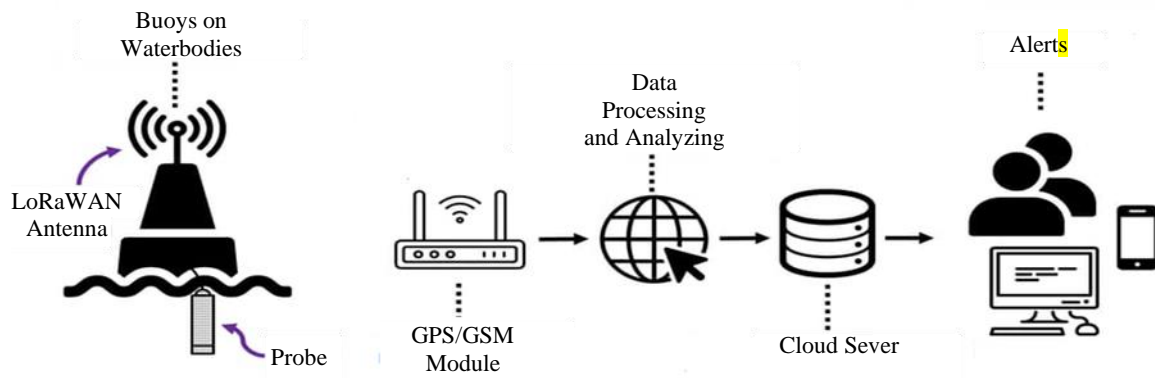


Figure 1. Architecture of working model of marine life tracking and pollution monitoring.

Table 1. Publications for Marine Debris (MD) mapping using Sentinel-2 data during the period 2018–2022.

General info			
Main purpose	Study Area	Time span	# of Sentinel-2 Classes
Marine Debris (MD) sources and pathways detection	Honduras Gulf	2014–2019	37
MD detection	Global	2018–2019	12
Float Objects detection	Global	2018–2020	15
MD detection	Manila Bay, Philippines	2019–2020	6
Windrows detection	Greece, Honduras	N/A	40
MD detection	Hawaii, N. Adriatic, S. Domingo	2020	6
MD detection	Global	2015–2021	63
MD detection	Global	2015–2021	63
MD detection	Global	2015–2021	63
MD detection	Mediterranean Sea	2018–2019 and 2021	27
River debris detection	Drina, Los Angeles and Yangtzee	2018–2020	30
MD detection	N. Adriatic, Australia	2020	6
MD detection	Global	2015–2021	89
MD detection and density mapping	Global	2015–2021	63
MD detection	Global	2016–2021	25

OBJECTIVES

The primary objective of the system is twofold: to track the movements and behaviors of marine species and to monitor pollution levels across various aquatic habitats [5]. By integrating advanced sensor technology with IoT connectivity, the project aims to create a comprehensive data ecosystem that informs conservation efforts and supports sustainable marine resource management.

The system employs a range of sensors, including GPS for tracking marine organisms and water quality sensors that measure critical parameters such as pH, turbidity, dissolved oxygen, and temperature [6]. This holistic approach provides a thorough understanding of both marine life and the surrounding environmental influences. The system utilizes microcontrollers, such as Raspberry Pi or Arduino, to collect and transmit data through reliable communication modules like LoRa or GSM [7].

This ensures long-range data transmission in remote marine areas, enabling continuous monitoring. All gathered information is safely stored in the cloud, allowing for processing and analysis [8]. A user-friendly interface, accessible through web and mobile applications, provides researchers and stakeholders with visualizations and alerts, making it easy to interpret complex data [9].

DETECTION PROCESS AND METHOD

The Internet of Things (IoT) is designed to enable the system to "perceive, understand, and control" the surrounding environment. This means the IoT can gather, process, and analyze data from the world, making intelligent decisions that affect the external environment. Various IoT system architectures have been proposed by researchers [10]. Similarly, we suggest that a standard IoT-based system for monitoring and protecting the marine environment consists of five key layers: the perception and execution layer, transmission layer, data pre-processing layer, application layer, and business layer.

Perception and Execution Layer

The perception and execution layer forms the base of the system architecture. It includes sensors and actuators, primarily focused on gathering sensor data and executing commands. In IoT-driven systems for marine monitoring and protection, this layer includes GPS sensors and energy harvesting devices, alongside sensors that track water quality and conditions. It is important to note that many existing marine environment monitoring systems lack execution capabilities and do not include actuators.

The data transmission layer's primary function is to send the gathered data to the data processing layer through communication networks, typically mobile or wireless networks. It also transfers user or intelligent application commands (from reference engines) from the application layer to the perception and execution layer, enabling devices or actuators to perform necessary actions, such as repositioning devices, adjusting temperature settings, or releasing food in fish farms.

The data pre-processing layer is a key component of the IoT system architecture, responsible for storing and analyzing raw data through sophisticated data mining techniques. It also manages tasks such as aggregating or breaking down information, cleaning and filtering data, sharing it when needed, and sometimes issuing alerts or warnings based on established criteria.

The application layer offers services based on different user requests. For example, it provides data on water conditions, quality, fecal waste, and uneaten feed in fish farms. The main goal of this layer is to deliver smart services tailored to user needs. In IoT-driven marine settings, this layer includes monitoring water quality, tracking coral reefs, overseeing offshore and deep-sea fish farms, and observing waves and currents.

The business layer is the topmost layer, responsible for overseeing the IoT system's overall activities and services, including developing business models, logic flowcharts, and graphical representations based on the data received from the application layer. It also tracks and verifies the results from other layers based on business models to enhance services and safeguard user privacy.

The IoT system is made up of sensor nodes, actuator nodes, sink nodes, a central base station, a system server, and user devices. Sensor nodes monitor environmental parameters like water temperature, pH, salinity, turbidity, oxygen levels, and chlorophyll, transmitting data to sink nodes through wireless communication protocols like ZigBee. Actuator nodes carry out commands from upper layers. Communication between sink nodes and sensor/actuator nodes is typically point-to-point. Sink nodes gather data from multiple sensors and send it to the base station or relay commands to actuator nodes via mobile networks (2G/3G/4G). The base station connects to the system server via the Internet. The server processes the data, conducts analyses for relevant applications, and sends commands to actuator nodes based on predefined rules. User terminals (desktops, laptops, tablets, smartphones) connect to the system server over the Internet. The design of a resilient, scalable IoT system for marine monitoring must consider factors like the harsh marine environment, communication protocols, node distribution, energy sources, and more. IoT systems typically comprise sensor and actuator nodes connected in a network based on a specific topology, influenced by the application and deployment environment. Dense sensor deployment improves data accuracy but increases energy consumption, collisions, and interference. Sensor nodes use topologies like linear, star, cluster/tree, or mesh.

The choice of the appropriate network topology for a given application depends on factors like data volume and transmission frequency, transmission distance, battery life requirements for maintenance, and sensor node mobility. Additionally, the physical network topology may change during operation due to energy fluctuations, node movement, equipment failure, connectivity issues (from noise, bad weather, or obstacles), and task changes for sensor nodes (Figure 2).

Managing Marine Pollution

Layer chromatography, gas chromatography, and high-performance liquid chromatography are among the most widely used instrumental methods for tackling the pressing issue of marine pollution. Nevertheless, when employing these techniques, it is essential to consider additional factors such as the need for substance pre-treatment, associated costs, time requirements, and the complexity of the analytical processes. Chemometric methods, including UNMIX and positive matrix factorization (PMF), serve as viable alternatives to these instrumental approaches.

Encourage the use of recyclable plastics to minimize dependence on disposable products such as bags, water bottles, straws, cups, utensils, and takeout packaging. Opt for reusable versions of these items and advocate for businesses to provide alternatives. By avoiding unnecessary single-use plastics, individuals can significantly reduce their environmental impact.

Support Legislation to Reduce Plastic Use and Waste

Legislative measures are essential to combat ocean plastic pollution. This involves cutting down on plastic manufacturing, enhancing waste management systems, and holding plastic manufacturers responsible. Support policies such as the 2021 Plastic Pollution Break-Free Act in the United States and state-level programs that enforce extended producer responsibility (EPR), making producers accountable for their products and packaging. International efforts, such as a global plastics treaty and laws limiting individual plastic use, have proven effective in curbing pollution.

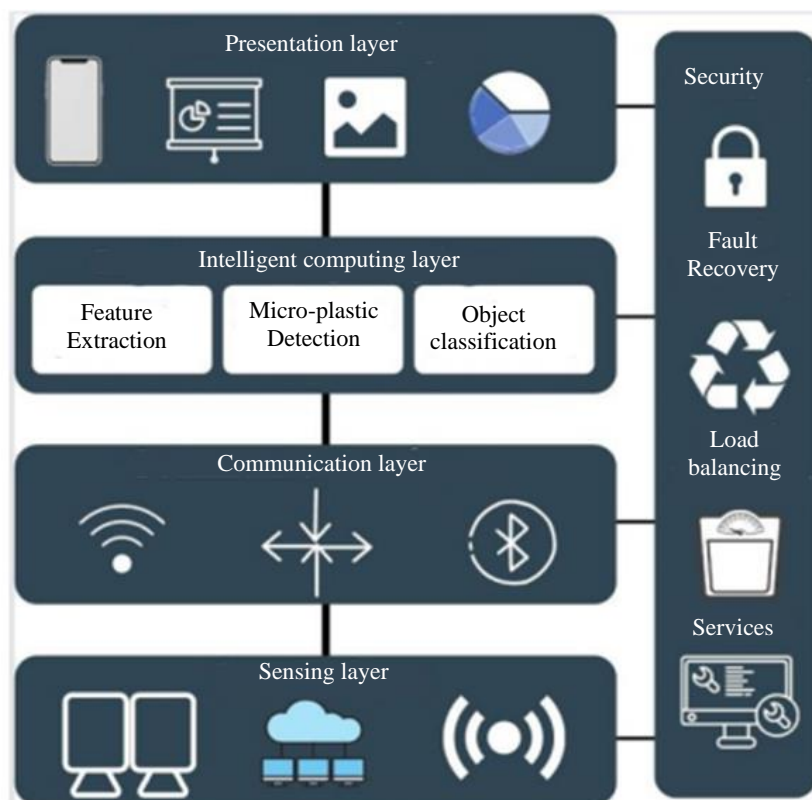


Figure 2. Smart computing sensors.

Practice Responsible Recycling

Globally, only 9% of plastic is recycled. Properly recycling single-use plastics can prevent them from entering the ocean and reduce the demand for new plastic. Use tools such as Earth911's recycling directory to find local recycling centers and identify the materials they accept.

LITERATURE REVIEW

The importance of real-time monitoring of maritime territories and borders for nonmilitary purposes, border security, and the protection of marine resources. They highlight the challenges posed by maritime surveillance, such as vast, unpredictable environments and the need for constant monitoring. The authors propose a security framework for wireless sensor networks (WSNs), which includes sensor node setup, communication protocols, and innovative data processing methods for threat detection. The system utilizes anomaly detection algorithms and data analysis to identify potential risks and alert nonmilitary authorities. They emphasize the advantages of WSN-based surveillance in improving situational awareness, preventing maritime threats, and enhancing response times.

The importance of addressing ocean pollution and the harmful impact of human actions on marine ecosystems. They evaluate conventional monitoring approaches and propose Undersea Wireless Sensor Networks as an effective alternative. The authors classify routing strategies into three categories: flat-based, location-based, and hierarchical-based, and assess their efficiency through simulations and comparisons. They emphasize the need to select routing methods that align with the specific needs of the application and the unique conditions of the underwater environment.

The importance of detecting anomalies in aquatic wireless sensor networks to ensure efficient data collection. Anomaly detection in underwater environments is particularly difficult due to factors like noise, significant propagation delays, and restricted bandwidth. The authors propose a new approach that integrates statistical analysis and machine learning techniques to accurately identify irregularities. By training the model with labeled data, it learns to recognize normal behavior patterns and detect deviations. The effectiveness of their proposed anomaly detection method is evaluated by applying it to real-world aquatic sensor data and comparing it with existing approaches.

The importance of Undersea Sensor Networks for marine exploration and monitoring is highlighted, alongside challenges such as limited bandwidth, delays in signal propagation, and harsh underwater conditions. The design of robust aquatic sensor nodes, featuring durable and waterproof enclosures, is emphasized. Communication strategies, including acoustic and hybrid approaches, are explored, with energy-efficient methods like duty cycling and adaptive power control being discussed. Additionally, the paper examines the significance of localization and node placement techniques for tracking sensors, offering solutions like ranging and trilateration. The survey also covers data collection and routing methods aimed at minimizing transmission needs and extending the network's lifespan. This research is a valuable resource for professionals in aquatic wireless sensor networks, advancing marine monitoring and exploration efforts.

It emphasizes the role of wireless sensor networks in marine environments, highlighting the need to manage and protect marine ecosystems. It discusses techniques for data collection, evaluating water quality, analyzing marine pollution, and monitoring biodiversity. The article focuses on acoustic communication and advanced surface propagation techniques, providing a review of sensor node design, deployment strategies, message protocols, and data transmission methods for underwater monitoring. The use of wireless sensor networks can enhance marine research and data acquisition, supporting essential tasks related to marine conservation and operations.

ADVANTAGES AND APPLICATIONS

- *Real-time data:* IoT sensors constantly gather and transmit data, offering real-time information on water quality, flow rates, and pressure.

- *Remote monitoring:* Data can be accessed from any location, enabling proactive management and timely issue resolution.
- *Data-driven decision-making:* By analyzing IoT data, trends can be recognized, system performance can be enhanced, and operational efficiency can be increased.
- *Cost-effective:* Operational expenses are reduced by minimizing water waste, detecting leaks early, and improving resource allocation.
- *Monitoring marine life:* IoT tags and satellite systems can track the movements of marine animals, including their breeding grounds and areas sensitive to human activity. For instance, IoT tags attached to whales can monitor both their health and surrounding environmental conditions.
- *Monitoring water quality:* IoT devices provide real-time data on water quality factors such as temperature, salinity, dissolved oxygen, and pH levels. This information helps identify potential risks like ocean acidification and supports the development of conservation strategies.
- *Monitoring pollution:* IoT-enabled smart boats and underwater drones can detect pollution, oil spills, and invasive species. These devices also identify anomalies and can initiate automated solutions to environmental challenges.
- *Monitoring coral reefs:* IoT technology assists in assessing coral reef health by tracking environmental conditions and identifying stress indicators.
- *Monitoring fisheries:* IoT enables real-time tracking of fish populations to prevent overfishing and ensure sustainable practices.
- *Monitoring waves and currents:* IoT systems can measure wave and current activity, contributing to safer waterway navigation.

PROPOSED METHOD

Smart Computing Sensor will integrate complex data fusion techniques, advanced computational strategies, and a control system aimed at identifying microplastics in oceanic environments. The data fusion process will utilize images across visible, infrared, and ultraviolet spectral bands, along with a range of specialized sensors, to accurately assess various physical and chemical properties in ever-changing conditions. Furthermore, the proposed system is required to be highly scalable and adaptable to cover extensive geographical regions.

In summary, the implementation of such hardware is typically cost-effective and readily available, rendering both methods feasible based on the specific requirements of a project.

SMART COMPUTING SENSOR

The advancement of the Smart Computing Sensor system can be enhanced through various structural and computational concepts. Below are two highly complementary strategies that may be employed:

Portable Sensors utilizing the Internet of Things (IoT)

Wireless sensors can be effectively outfitted with a range of sensors to monitor parameters such as temperature, salinity, and other two-dimensional variables, including images. These sensors are powered by batteries and wireless transceivers, eliminating the need for electrical cables. The integration of IoT and wireless sensors plays a crucial role in addressing challenges such as the monitoring of small marine particles.

Multimodal Camera-Based Detection Methods

In environments with limited lighting and other visual constraints, relying solely on a single camera may prove inadequate. The incorporation of additional modalities, such as infrared and ultraviolet, significantly enhances the detection capabilities by broadening the spectrum of available data. Various computational techniques, including data fusion and learning classifiers, can be employed to tackle data processing challenges.

IoT ENABLED SMART BUOYS FOR TRACKING MARINE POLLUTION

Smart buoys equipped with IoT technology are cutting-edge systems used for marine monitoring, utilizing the Internet of Things to gather and transmit vital information from oceans, rivers, and other bodies of water. Outfitted with a range of sensors and communication technologies, these buoys deliver real-time information on water quality, weather conditions, and pollution levels.

The advantages are clear: smarter monitoring enables smarter decision-making. Real-time data allows researchers, governments, and environmental groups to respond rapidly to emerging issues, enhance marine conservation efforts, and promote sustainable practices that protect the world's water resources.

FUNCTIONAL COMPONENTS

Marine Life Tracking

GSM Module

The GSM module plays a vital role in enabling communication between devices and the GSM network, handling the connection to ensure seamless data transmission and reception. Moreover, it handles data encryption and decryption, providing a secure communication link. In essence, the GSM module serves as the crucial link that keeps devices connected and ensures data security.

Animal Tag

RFID (Radio Frequency Identification) tags for animals are compact electronic devices that are either attached to or inserted into animals to help with identification and tracking. These tags are equipped with a microchip and antenna, allowing them to communicate wirelessly with RFID readers. The microchip stores a distinct ID number, which can be linked to a database containing detailed information about the animal. The main advantage of RFID tags is their ability to provide precise and efficient identification and management of livestock, pets, and wildlife.

Communication Module

The communication module facilitates data exchange and interaction between nodes. Since it is a significant consumer of power, selecting or designing this module is essential. Typically, wireless communication relies on Radio Frequency (RF).

Arduino Mega and ESP 32

The Arduino Mega 2560 is an open-source platform that uses the Atmega2560 AVR microcontroller, an 8-bit processor. It utilizes the ATmega16U2 microcontroller from Microchip Technology and can be programmed using the wiring/processing programming language.

The ESP32 is a chip designed to enable Wi-Fi and, in some versions, Bluetooth connectivity for embedded or Internet of Things (IoT) devices. While the term "ESP32" typically refers to the chip itself, it is also commonly used to describe the modules and development boards that integrate this chip.

Power Supply

Power supplies are essential in numerous Internet of Things (IoT) applications, supplying the electrical power required for components like sensors, processors, and communication modules to function. With the growth of IoT applications, the demand for AC/DC power supplies that consume less energy has become more important. These devices provide efficient voltage conversion, minimizing energy waste and ensuring the stable performance of connected devices.

Water Quality Monitoring

Water Quality Sensor

Water quality sensors are employed through two main methods. They either measure specific components of interest, such as chemical concentrations, or monitor surrogates, which serve as

indicators to detect contaminants. To ensure water quality, it is important to monitor factors like conductivity, dissolved oxygen, pH, salinity, temperature, and turbidity. Consequently, these sensors have become integral to many systems for maintaining water quality.

Data Loggers

Data loggers for water quality monitoring can be used to monitor a variety of water parameters, including temperature, pH, conductivity, salinity, dissolved oxygen, and light. They can be used in a variety of settings, such as remote streams or wells, and can be used for long-term monitoring. Some data loggers can also be used to control water samplers, sound alarms, and more.

Buoys or Floating Modules

Water quality monitoring buoys are vital tools used across various applications to assess and maintain the health of aquatic ecosystems. They provide real-time water quality data, enabling researchers to take timely actions to enhance water conditions. Anti-fouling screens, such as copper mesh, titanium mesh, and ceramic materials, are crucial elements of these buoys. With water quality becoming an increasing concern due to rising pollution levels, the importance of monitoring has never been greater. Water quality monitoring buoys stand out as one of the most efficient methods for tracking these changes.

Cloud Platform

Cloud platforms have transformed numerous sectors, including oceanography. Cloud computing has enhanced ocean monitoring systems by offering scalability, flexibility, and cost-effectiveness, making them more efficient, accessible, and insightful.

CONCLUSION

In recent decades, there has been a growing focus on monitoring the marine environment, with governments and research organizations dedicating significant resources to the development of innovative technologies. The incorporation of cutting-edge information and communication technologies has been essential in enhancing marine monitoring systems, with the Internet of Things (IoT) playing a pivotal role in these advancements. This study provides an updated review of technologies and systems that apply IoT to marine environmental monitoring. A thorough review of approximately 40 projects indicates that most systems focus on ocean sensing, monitoring water quality, and specific areas such as fish farms, coral reefs, and wave/current monitoring. Many efforts have been directed towards developing technologies or devices like buoys, energy-efficient systems, routing protocols, data transmission methods, and data analysis tools. It is important to recognize that the testing conditions for these projects can differ greatly. Nearly half of the systems have been tested or implemented in real marine or river settings, while others have been trialed in lab environments, outdoor pools, small ponds, or lakes, and some have only been tested through simulations.

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