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Research and Design Multifunctional Marine Buoys for Environmental Monitoring of Hai Phong Port, Vietnam

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ABSTRACT

Today, Marine environmental pollution is one of the leading problems and significantly impacts the world. Today's seas and seaports are increasingly heavily polluted, which is also one of the causes affecting human health and living activities. Seaport environmental pollution is caused by many causes, directly or indirectly. This article presents the steps to build a marine environment and air quality monitoring system integrated into navigational buoys. Port operating centres and state agencies can access and monitor the environmental situation at different seaports. Analyze air quality pollution indicators and give recommendations and warnings to people. In addition, build algorithms sensor systems and transmit data to the station through LoraWAN technology.

1. Introduction.

Marine environmental pollution and air quality are top concerns at some seaports in developing countries, including Vietnam. Today, the need to transport goods is increasing, causing the density of ships entering the port. This leads to severe air and marine environment pollution here and affects marine life. Sources of marine pollution in maritime activities, fisheries, tourism, oil and gas, and other commercial activities related to the use of marine resources are currently very diverse and complex: pollution caused by oil, pollution caused by liquid chemicals carried in bulk on ships, pollution caused by dangerous goods transported by ship; pollution due to garbage, pollution due to wastewater, air pollution. According to recent statistics, the number of ships operating in the Ho Chi Minh City seaport area has also increased rapidly in the past five years.

The number of ships entering Ho Chi Minh City increased from 18,667 (2014) to 20,550 (2018). In the first eight months of 2019, there were nearly 14,100 ships, and Inland waterway vehicles increased from 58,276 (2014) to more than 95,330 (2018). Similarly, the number of vessels arriving at the port in the Vung Tau seaport area has increased significantly in the past two years. Besides, the Hai Phong seaport welcomes about 18,590 ships (2022).

Among the three Vietnamese seaports ranked in the top 100 in the world by the UK maritime magazine Lloyd's List in 2022 with the world's most enormous port throughput of goods, Hai Phong seaport is considered to have shown growth steps most impressive.

One of the points that proves the growth of the Hai Phong Port is that the tonnage of ships arriving in the area is increasing. Currently, the TC-HICT port area can receive ships with a capacity of up to 145,000 DWT, while the Dinh Vu area can receive vessels of up to 48,000 DWT. On October 31, TC-HICT port received the Wan Hai A07 ship with a record tonnage of 144,571.9 DWT (13,000 Teus) to the port. With the increasingly rapid development of seaports in Vietnam, the marine environment and air quality are increasingly seriously affected. This issue has been and is currently being researched by scientists.

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Around the world, projects related to manufacturing smart buoys collect environmental data at Tianjin port in China. The built buoys help collect the port area's oceanographic data and weather parameters. These devices are tracked and monitored via the Internet (Zhang Hao, et. al.,2020).

Besides, other research groups are interested in salinity, ocean currents, temperature, and oceanographic meteorology related to marine air metabolism and climate change (E. Canepa et. al., 2015). Internet of Things (IoT) technology is accessible; some gateways have been installed with intelligent monitoring devices for quick access from different areas (Bojic, Filip, et. al., 2021). In the study, seven groups of authors designed a device with GPS navigation and integrated sensors drifting in the ocean. The machines are biodegradable and low-cost. In addition, the operating range allows the device to work in lakes, rivers, urban areas and sensitive areas (G. Novelli, 2017). Authors Bellsolà Olba and his colleagues have researched and proposed a method to assess the risk of ships entering and leaving the port based on assessment and monitoring indicators of the number of ships passing through VTS at seaports (Bellsolà Olba, 2019).

In addition, communication methods such as 4G, LoraWan, etc., are required to communicate between smart buoys and data stations on shore. The author team, Ramasamy Venkatesan and his colleagues, have designed and calculated data collection buoys. On the Indian coast, the period of use is up to 6 years, and the device has collected and monitored marine environmental parameters and included them in the software to calculate and analyze water pollution levels (R. Venkatesan, et.al.,2016). In the study conducted by S. L. Kao et al., historical database and AIS data were used to calculate safe ship manoeuvring speed to minimize the risk of air and maritime pollution risk at Port Keelung (Bellsolà Olba, et. al., 2020). The above methods have applied calculation technology to serve the maritime sector and the marine environment but have not yet developed software to manage and warn of the condition of navigational buoys on canals and ports.

In the work of the author group, Do et al. have built and designed a fixed monitoring device on the seabed to monitor and collect data on seabed sediment changes and data related to corals and seabed organisms (Do, J, 2019). Besides there are two types of buoys: floating buoys and anchor buoys. In which buoys move on the sea surface over a large area. The device is globally positioned using GPS. The device measures ocean wave energy and several other parameters (Herbers, 2012). Floating buoys are fixed by chains on the seabed in a narrow range and are used in coastal areas to measure biogeochemical, meteorological and physical data. These buoys are widely used in major seaports worldwide (Bailey, K, 2019)

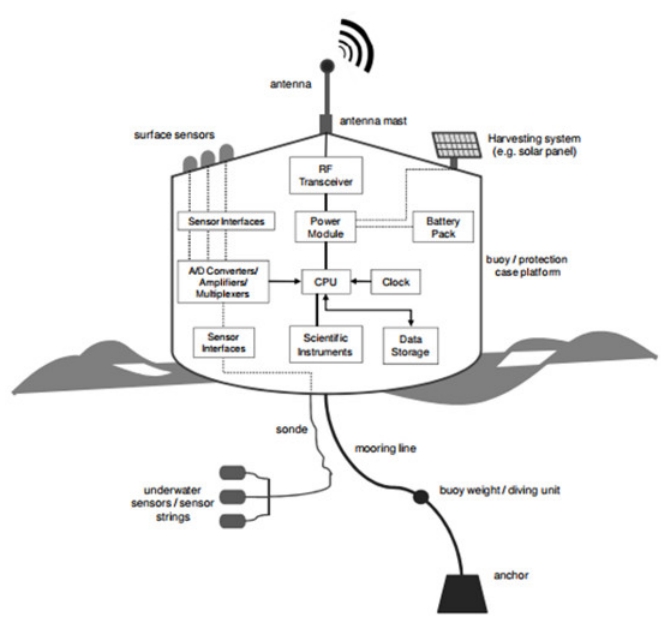
In Vietnam, several research groups have conducted monitoring of marine environmental quality in recent years. To propose a solution applying Internet of Things (IoT) technology to automatically monitor aquaculture water quality parameters, helping farmers proactively monitor and detect many sources of negative impacts on the pond environment farming, and at the same time support management agencies to quickly assess the environmental impact of aquaculture activities on the surrounding environment (Automatic monitoring,2023). In the work, the author group Hung and his colleagues designed an intelligent buoy system, applying LoraWAN wireless communication technology to monitor the marine environment in Vietnam (Hung. N. V, el.at., 2023). Vietnam has a long coastline, a diverse marine ecosystem, and many important international maritime routes passing through. Coastal ecosystems are vulnerable to the impact of human activities on industrial, tourism and urban development, leading to environmental pollution. From the above practice, research and design of a remote maritime monitoring system combined with monitoring the marine environment and air quality is extremely necessary. This helps save labour, management costs and ease of monitoring, increasing management efficiency. In addition, the system is built based on GPS and LoraWAN technologies, transmitting and receiving data remotely. The buoy coordinate monitoring software is designed based on Open CPN data to obtain buoy coordinates accurately. The system can retrieve status reports and control all necessary operational and technical parameters of the buoy (flashing/off cycle of lights on the buoy, battery power, etc.) in report form. And they are storing data for research.

The rest of the paper is described in Section 2, the hardware design of the water and air environment collection and monitoring system. Section 3 proposes to develop software to monitor the parameters of environmental components. Section 4 analyzes the system testing. Conclusions and future work are summarized in Section 5.

2. Smart Buoy Hardware Design.

2.1. Smart Bouy Structure Diagram.

Figure 1: The general structure of smart buoys (Albaladejo, 2010).



Source: Authors.

The authors researched an innovative buoy structure that integrates sensors to measure marine and air environment quality parameters (Albaladejo, 2010). Each buoy structure will allow data collection, storage and transmission to the monitoring centre. Many transmission technologies exist, such as Wi-Fi, WiMAX, GSM, RF, etc. Each type has outstanding technical characteristics and advantages and disadvantages. Figure 1 describes the general structure of a marine buoy with an integrated measurement function.

First, a buoy body to keep part of the float from sinking in the water. The surface buoy body includes an antenna for RF transmission and a solar panel to supplement battery power, and in some cases, one or more external sensors primarily for meteorological monitoring with data (air temperature, air humidity,...). The submerged part of the buoy consists of one or more sensors, which can be located at different depths (sensor wires), a transducer to transmit the obtained data to the buoy and finally, these buoys are connected with chains and fixed on the bottom of rivers and seas, allowing movement within limited distances (due to ocean currents, wind, waves,...).

2.2. Calculate VN_AQI Index.

According to Decision 1459/QD-TCMT dated November 12, 2019, of the General Department of Environment on promulgating technical instructions for calculating and announcing the Vietnam air quality index (VN_AQI), there are two ways to calculate the value. VN_AQI is hourly and daily (QCVN 05:2009/BTNMT, 2009). To calculate the hourly VN_AQI value, especially for PM2.5 and PM10 parameters, we need to calculate the NC value (NowCast). Call c_1, c_2, ..., c_{12} are 12-hour average monitoring values, with c_1 being the current 1-hour average monitoring value and c_i being the 1-hour average monitoring value i hours ago with the present. First, we need to calculate the weight value (Decision No. 1459/QD-TCMT,2019), (Vu Van Thanh, et. al, 2021):

$$W^* = \frac{c_{min}}{c_{max}} \quad (1)$$

where c_{min} and c_{max} are the smallest and largest values, respectively, among 12 hour average values.

- NC index (NowCast) is calculated as follows:

$$NC = \frac{\sum_{i=1}^{12} W^{i-1} c_i}{\sum_{i=1}^{12} W^{i-1}} \quad (2)$$

$$W = \begin{cases} \frac{1}{2} & if \quad W^* \leq \frac{1}{2} \\ W^* & if \quad W^* > \frac{1}{2} \end{cases} \quad (3)$$

- Calculate the AQI^h index of each parameter (AQI_x).

$$AQI_x = \frac{I_{i+1} - I_i}{BP_{i+1} - BP_i}(C_x - BP_i) + I_i \quad (4)$$

$$AQI_x = \frac{I_{i+1} - I_i}{BP_{i+1} - BP_i}(NC_x - BP_i) + I_i \quad (5)$$

where

- AQI_x: Parameter AQI value of parameter x;
- BP_i and BP_{i+1} are the lower and upper limit concentrations of the monitoring parameter values specified in Table 1 corresponding to level i;
- I_i and I_{i+1} are the AQI value at level i, respectively, and $i+1$ given in the table corresponds to the BP_i value;
- NC_x is the NC value of parameter x calculated in formula (2).

Table 1: BP_i values for parameters (Decision No. 1459/QD-TCMT,2019).

i	I_i	BPi value specified for each parameter (Unit: µg/m³)						
		O_3(1h)	O_3(8h)	CO	SO_2	NO_2	PM_{10}	$PM_{2.5}$
1	0	0	0	0	0	0	0	0
2	50	160	100	10.000	125	100	50	25
3	100	200	120	30.000	350	200	150	50
4	150	300	170	45.000	550	700	250	80
5	200	400	210	60.000	800	1.200	350	150
6	300	800	400	90.000	1.600	2.350	420	250
7	400	1.000	-	120.000	2.100	3.100	500	350
8	500	≥1.200	-	≥150.000	≥2.630	≥3.850	≥600	≥500

Source: Authors.

- Color scale for air quality index (Vu Van Thanh, et. al., 2021).

  To visually represent the results of the air quality index, the authors used a colour scale for the VN_AQI value ranges, as shown in Table 2.

Table 2: VN_AQI value range and air quality assessment (Decision No. 1459/QD-TCMT,2019).

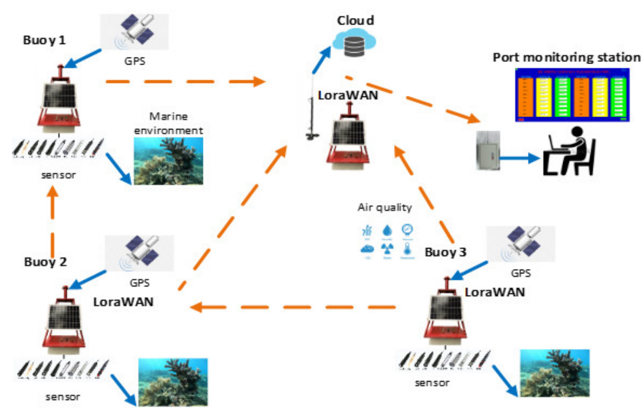
AQI value range	Air quality	Air quality Color	RBG color code
0 - 50	Good	Green	0;228;0
51 - 100	Medium	Yellow	255;255;0
101 - 150	Little bad	Orange	255;126;0
151 - 200	Bad	Red	255;0;0
201 - 300	Very bad	Violet	143;63;151
301-500	Dengoures	Brown	126;0;35

Source: Authors.

2.3. Communication module design.

Based on section 2.1, the authors build a buoy structure and measuring station for Hai Phong port. Figure 2 shows the LoraWan network connection between the beacons and the monitoring station. The marine buoy system includes a sensor system that collects parameters about the water environment and air quality through a converter to a PLC controller. At the same time, the GPS satellite positioning device sends signals through the NMEA message decoder to the central controller. Here, through the RF wireless data converter, it will be transmitted to an intermediate receiving station located onshore and uploaded to the Cloud for storage. Operators can access pre-encrypted buoy data at the monitoring centre to increase security (Hung. N. V, et. al., 2023).

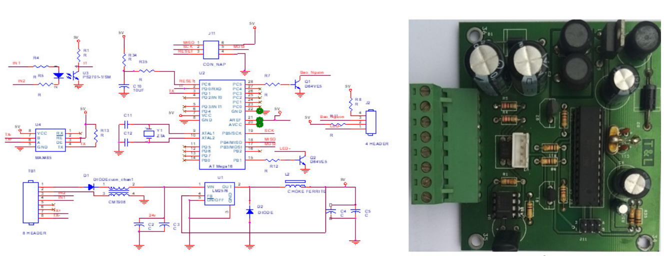
Figure 2: Data transmission structure of buoy system.



Source: Authors.

The Arduino central controller successfully receives data and will filter out the desired messages, including GLL, RMC, VTG, ZDA and GGA messages, based on detecting the characteristic first characters of each message. For example, the GLL message will start with the characters "$GPGLL,..." and end the message content with the character "*" before reaching the internal checksum code and newline characters. Thus, based on that, the content of the newsletters will be filtered. Figure 3 is the NMEA 0183 data conversion circuit design diagram that transmits data to the centre (Nguyen Dinh Thach, 2023).

Figure 3: a, Circuit diagram of the device; b, Communication circuit after fabrication.



a, b,

Source: Authors.

2.4. Design of water and air quality monitoring module.

a. Design of water quality data collection kit.
The authors use a 7-in-one sensor to measure water quality. However, this is a test model, so the accuracy is not yet high (Hung. N. V, el.at., 2023).

- EC: used to measure the conductivity of solutions and water environments.

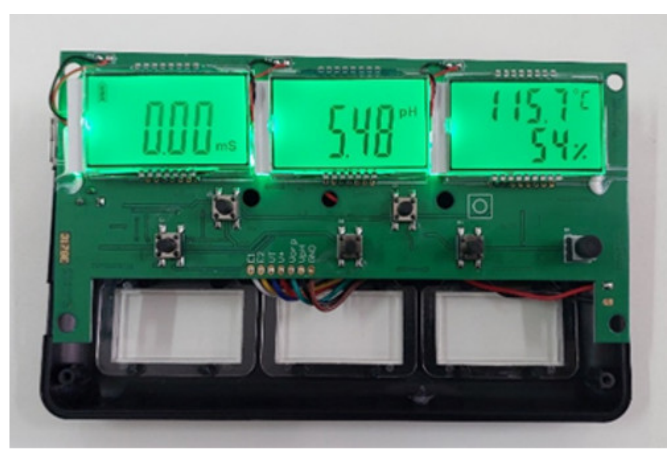
Figure 4: Types of Water Quality Sensors.

Source: Authors.

- TDS: is an index measuring the amount of dissolved solids in water, used to evaluate water quality.
- CF: used to measure the conductivity of water and determine the concentration of dissolved substances in water.
- pH: used to measure the acidity or basicity of a solution.
- ORP: is a measure of the oxidation - reduction ability of a solution, used to measure the amount of free electrons available in the solution and thereby evaluate the ability of the solution to oxidize - reduce other chemicals.
- Humidity (air): is the humidity of the surrounding air.
- Temp: is temperature, an index measuring the hotness and coldness of the environment.

After designing and drawing the diagram, the authors fabricated the system's hardware, as shown in Figure 5. The screens will help display parameters such as EC, TDS, CF, and pH for further monitoring. This device connects to Arduino via RS485.

Figure 5: Water quality monitoring hardware.



Source: Authors.

b. Air quality collector design.
Each monitoring station's hardware is designed and arranged in a waterproof electrical cabinet. The cabinet includes a 12V/200Ah battery, and a central processing board integrated Sim7600 module; RS485 connects measuring sensors: Temperature, humidity, light, noise, pressure, dust concentration, NO_2, SO_2, and CO.

Figure 6: Air quality data collection device hardware.

Source: Authors.

After designing the hardware, the authors build an algorithm flow chart and load the program in Section 3.

3. Build monitoring software.

3.1. Build data collection algorithms.

a. Smart buoy data transmission and reception algorithm.
In this part, the authors used Lora devices with lengths up to 20km to transmit data over long distances under ideal conditions. First, the algorithm will check the operating status of the buoy as the power supply for the sensors and systems in the buoy.

b. Data encryption algorithm.
Before sending data to the monitoring centre, the subroutine algorithm will sort and encode it as NMEA 0183 messages. This information is confidential, and the operator must have access to process it. Data initialize function modules, including SIM module, GPS module and MicroSD card module; Configure analogue read pins, timer, and UART interrupt to receive data from function modules. Next, the program performs an infinite loop for real-time reading through the DS3231 to periodically read sensor values and save data to the memory card. Figure 8 shows the algorithm for encrypting information before sending (Vu Van Thanh, et.al, 2021).

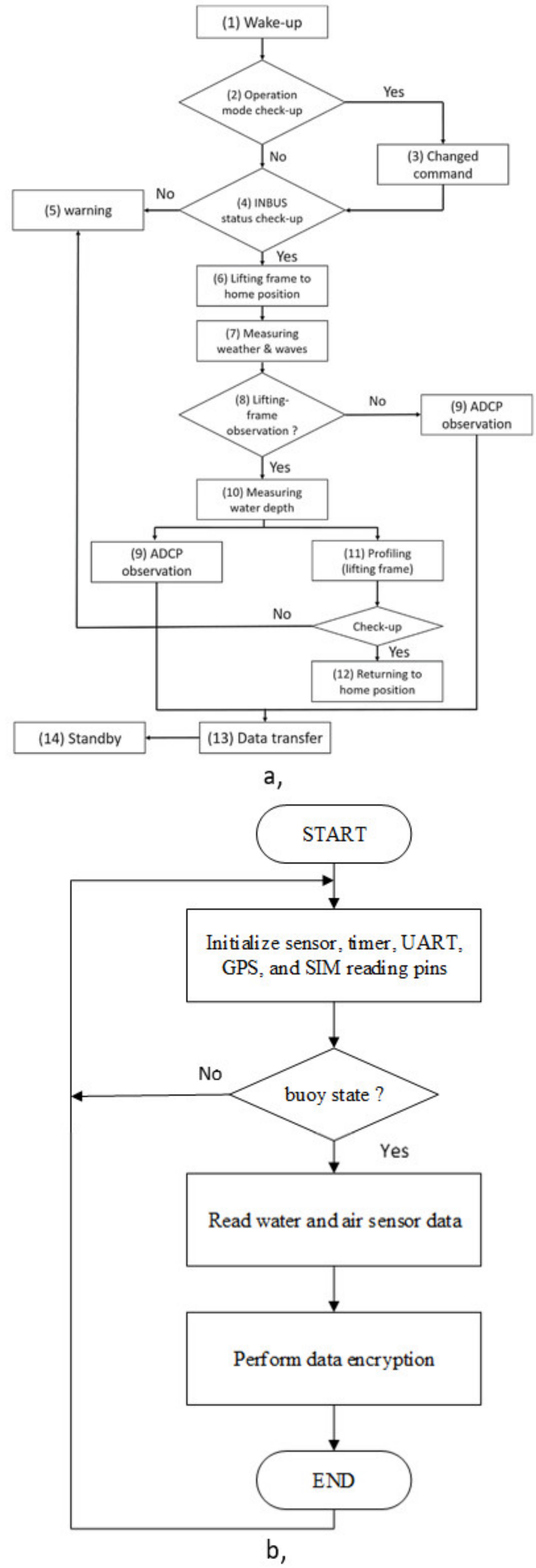
3.2. Data monitoring software.

OPEN CPN is a free and open-source ship positioning and routing software. It is designed to provide users with an accurate and reliable positioning and routing tool at sea and land. OPEN CPN can be used on many operating systems, including Windows, macOS, etc. In addition, the authors use Visual Studio software to program the monitoring interface on computers and websites.

To build a buoy monitoring map based on the OPEN CPN application, the team performs the following steps:

Step 1: Connect GPS or AIS with data analysis and decoding software to determine the buoy's location.

Figure 7: Air quality data collection device hardware.



Source: Authors.

Step 2: Create message boards to send buoy positions to OPEN CPN software via COM port.

Step 3: Download the GPX or KML data file into the software.

Step 4: Display the map and select options to display the buoy's location on the map.

Step 5: Track the buoy's location on the map and update the information to the GPX or KML data file.

Figure 8: Software interface a, OPEN CPN; b, Visual Studio.

a,

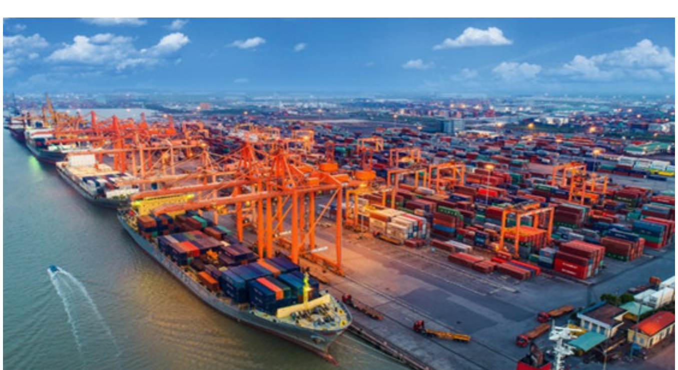
b,

Source: Authors.

4. Simulation and Results.

4.1. Test scenario.

Figure 9: Lach Huyen deep water port, Hai Phong.



Source: Authors.

To test the system, the authors performed it at Hai Phong port. The full name is Tan Cang International Container Terminal (HICT) in Hai Phong. This is the largest specialized container port in the North of our country, with increasing throughput, and will continue to develop shortly. Therefore, the quality of the water and air environment will be greatly affected (Archer, M, 2017).

The buoy map is shown in Figure 10, including five buoys with integrated water and air quality sensors. These buoys are placed at different locations. The authors calculated and tested the distance from the buoy body to the monitoring collection station with different lengths and weather conditions such as sunshine, rain,...

Figure 10: Data collection buoy layout map.

Source: Authors.

The distance of each buoy and the buoy coordinates are described in the Table 3.

Table 3: Parameter table of buoy distance to station.

Buoy	Position	Distance	Status
Station	20° 47.1434'N 106° 54.1911'E	-	On
Buoy 1	20° 48.1496'N 106° 54.2191'E	1.083km	On
Buoy 2	20° 48.1115'N 106° 54.2547'E	0.9815km	On
Buoy 3	20° 48.0515'N 106° 54.1147'E	0.8942km	On
Buoy 4	20° 48.1276'N 106° 54.1687'E	0.7968km	On
Buoy 5	20° 47.5297'N 106° 54.1215'E	0.8749km	On

Source: Authors.

4.2. Results.

After designing the hardware, the authors have created the hardware, as shown in Figure 11. The buoy is powered by a solar cell that can store for seven days. In addition, the authors' experience monitoring the Hai Nam Canal of Hai Phong City. This canal leads into the city's main seaport area, so the density of boats coming in and out is dense. The authors tested monitoring buoy coordinates and buoy status (U. Mittal, 2021).

Figure 11: Smart Buoy system hardware.

Source: Authors.

The buoy coordinates the monitoring interface on the software, and the main parameters collect environmental data of the buoy. NMEA 0183 messages are constructed and sent to the software. Here, the NMEA message decoding program will work and get data parameters displayed on the interface. The message structure is previously specified.

On the Hai Nam Canal, the authors changed the buoy's position to match the navigation buoy's position. Coordinate parameters are displayed similarly to the OPEN CPN software as Figure 12 and Figure 13.

The authors evaluate the buoy system based on two criteria, including:

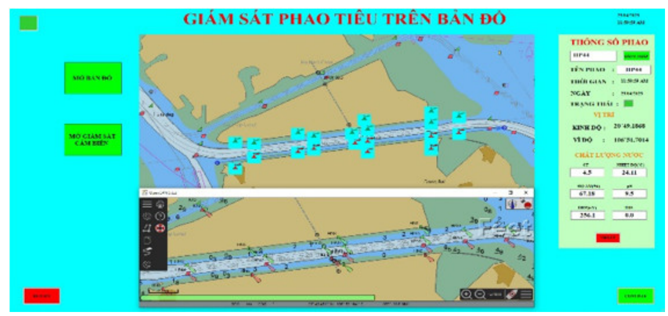
- Stabilization; Energy consumption.

For stability criteria, let the system operate continuously for seven days, and the sensor station will send data to the server every 1 hour. Data from sensors and VN_AQI values are displayed on the website for testing and evaluation. Through testing, the authors found that the values are transmitted evenly, without data loss, and the delay for transmissions is about 1 second. Demonstrates the ability to maintain energy for the measuring station to ensure operation during the rainy season (V. K. Tembhurne et al., 2023).

Figure 12: Location coordinates of the buoys.

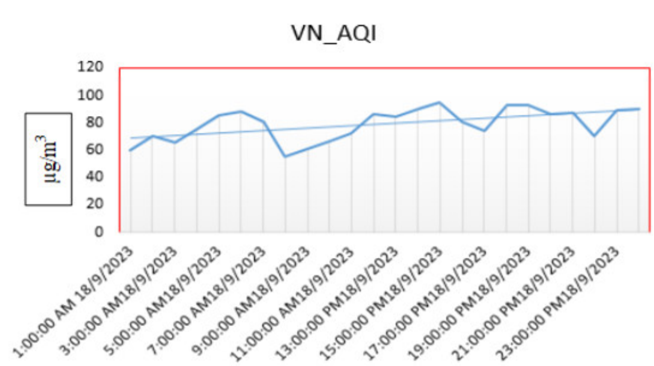
Source: Authors.

Figure 13: Sensor parameters on the buoy.



Source: Authors.

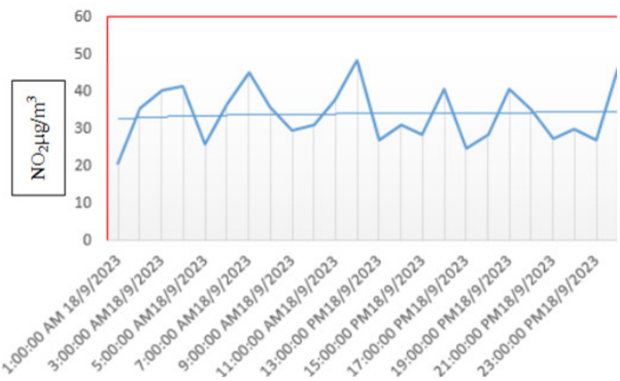
Figure 14: VN_AQI index of Lach Huyen Port.



Source: Authors.

From Figure 14, which collects the sampling value of 24 samples in 1 day and formulas (4), (5), the authors calculated the VN_AQI index at Lach Huyen Port, Hai Phong. At 13:00, the VN_AQI index reached its highest of about 95.1 ($\mu g/m^3$), while the lowest value of 55.2 ($\mu g/m^3$) was recorded at 1:00.

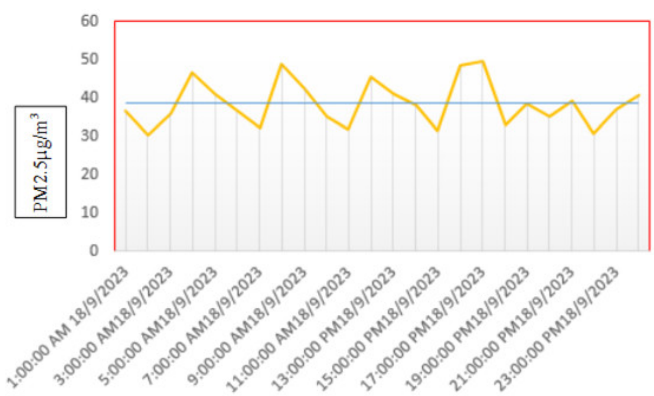
Figure 15: VN_NO_2 index of Lach Huyen Port.



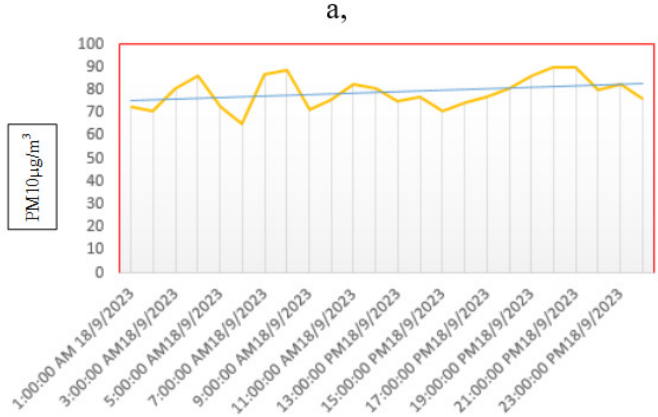
Source: Authors.

From formulas (2), (3), the authors calculated the VN_NO_2 index at Lach Huyen port, Hai Phong. At 14:00, the VN_AQI index reached its highest of about 49.7, while the lowest value of 20 was recorded at 2:00.

Figure 16: a, PM 2.5 index; b, PM 10 index.



a,



b,

Source: Authors.

Thus, compare with the standard values of Tables 1 and 2 and give a warning colour of yellow corresponding to the average pollution level, based on which people can know the air pollution status of their area port area. At the same time, propose solutions to improve the environment and monitor vessels passing through port areas.

From the process of collecting and processing buoy data, the system's evaluation results are shown in Table 4:

Table 4: System efficiency assessment results.

No.	Function	Other Brand	System
1	Collect buoy coordinates	100%	100%
2	Collect water quality	100%	95%
3	Collect air quality	100%	95%
4	Data transmission	100%	98%
5	Product price	Expensive	Cheap

Source: Authors.

Based on the table above, the author finds that the system meets 85% of basic feature requirements compared to foreign procedures and environmental standards prescribed by the Vietnamese Government.

Conclusions.

This article has successfully built a marine buoy structure that integrates the water environment and air quality sensors. In addition, design the hardware and software communication module to convert and encode the NMEA 0183 message containing weather information data from the buoy. Develop software to remotely monitor environmental parameters to help manage and have timely treatment plans. This device also monitors the number of ships entering and leaving the port that intentionally discharge waste into the environment and observe marine life. This article is the first step to building a green seaport and using renewable energy in Vietnam.

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