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Research and Application of LoRaWAN-Based IoT System for Water Quality Monitoring

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Abstract— Water is a valuable resource that serves various purposes for humans. However, with the rapid increase in industrial zones, urban areas, and population, water pollution has become a significant concern due to human activities such as production and exploitation. Recognizing the importance of water resources, this paper explores an IoT-based system for monitoring and LoRaWAN communication technology to issue pollution level alerts for water sources. The system consists of sensors and LoRa wireless technology to transmit and process data on a web server, enabling users to monitor water quality. The wireless sensors (measurement stations) can measure parameters such as electrical conductivity, temperature, turbidity, total dissolved solids (TDS), pH levels, and dissolved oxygen (DO) concentration in water.

Keywords— LoRa, water environment monitoring system, IoT, wireless sensor network

I. INTRODUCTION

Water pollution refers to negative alterations in the physical, chemical, and biological properties of water, caused by the presence of foreign substances in liquid or solid form, making the water harmful to humans and living organisms. Freshwater sources (rivers, streams, ponds, lakes, etc.) often become polluted due to excessive amounts of dissolved minerals and organic substances, which disrupt the aquatic ecosystems. These imbalances result in a sharp reduction in dissolved oxygen, an increase in toxic gases, higher turbidity levels, and eventually lead to the degradation of aquatic habitats.

Water pollution arises from several causes, such as untreated industrial waste discharged into river basins, infiltration of chemical fertilizers and pesticides into groundwater and surface water bodies, and untreated domestic wastewater from riverside residential areas. These activities severely contaminate water sources, posing significant health risks to humans, animals, and microorganisms in the vicinity.

Key water quality parameters include electrical conductivity (EC), total dissolved solids (TDS), temperature, turbidity, pH levels, dissolved oxygen (DO), and total suspended solids (TSS). These parameters are critical in assessing the extent of water pollution. Therefore, an effective water pollution alert system should rely on regular measurement, collection, and analysis of these indicators at critical points of water sources, such as rivers, streams, lakes, and industrial discharge areas.

Reference Standards for Evaluating Water Pollution Levels

To establish benchmarks for water quality, this study refers to national environmental standards to provide a table of permissible pollutant parameter values. These benchmarks serve as the basis for calculating allowable thresholds in domestic wastewater (Table 1) and industrial wastewater (Table 2).

The following regulations are used as references:

1. QCVN 14:2008/BTNMT: This is the National Technical Regulation on Domestic Wastewater Quality. It was drafted by the National Technical Regulation Compilation Board on Water Quality, reviewed by the Department of Legal Affairs under the Vietnam Environment Administration, and issued under Decision No. 2008/QĐ-BTNMT in 2008 by the Minister of Natural Resources and Environment, Vietnam [1].

2. QCVN 40:2011/BTNMT: This regulation replaces QCVN 24:2009/BTNMT and serves as the National Technical Regulation on Industrial Wastewater Quality. It was drafted by the National Technical Regulation Compilation Board, reviewed by the Department of Science and Technology, the Department of Legal Affairs, and the Vietnam Environment Administration. It was issued under Circular No. 47/2011/TT-BTNMT on December 28, 2011, by the Minister of Natural Resources and Environment, Vietnam [2].

TABLE I and TABLE II, based on these standards, define the maximum permissible values of key pollution parameters for domestic and industrial wastewater. These values are essential for monitoring and ensuring compliance with national environmental protection regulations.

TABLE I
TABLE OF POLLUTION PARAMETER VALUES IN DOMESTIC WASTEWATER

Nº.	**Parameter**	**Unit**	**Value C**	
			A	**B**
1	Temperature	°C	25	25
2	pH		5-9	5-9
3	BOD	mg/l	30	50
4	Total Suspended Solids (TSS)	mg/l	50	100
5	Total Dissolved Solids (TDS)	mg/l	500	1000

TABLE II
TABLE OF POLLUTION PARAMETER VALUES

Nº.	**Parameter**	**Unit**	**Value C**	
			A	**B**
1	Temperature	°C	40	40
2	pH		6-9	5,5-9
3	BOD	mg/l	30	50
4	COD	mg/l	75	150
5	Total Suspended Solids (TSS)	mg/l	500	1000

- C represents the concentration values of pollution parameters.
- Column A specifies the C values of pollution parameters as the basis for calculating the maximum allowable limits in domestic wastewater discharged into water sources used for drinking water supply.
- Column B specifies the C values of pollution parameters as the basis for calculating the maximum allowable limits in domestic wastewater discharged into water sources not used for drinking water supply.

The continuous development and remarkable advancements in electronics, microelectronics, digital technology, microcontrollers, telecommunications, and information technology have strongly driven the progress of information systems and mobile applications in monitoring and control fields [3].

In the current context of rapidly advancing mobile technologies and improving connectivity between devices, the concept of the Internet of Things (IoT) has emerged, enabling objects to connect and communicate with one another. IoT is not merely about connecting devices but also provides intelligent services, where sensor networks are integrated with the Internet to form specialized systems with diverse applications tailored to specific purposes [4].

Currently, research on the application of advanced technologies for remote monitoring of environmental parameters in agriculture, including water quality, often utilizes traditional communication technologies such as Zigbee, Wi-Fi, GSM/GPRS, and Bluetooth [5][6][7]. Among these technologies, Wi-Fi, Zigbee, and Bluetooth have limited operating ranges of 10 to 100 meters. Due to this constraint, these communication standards are only suitable for monitoring in small areas. In cases where the monitoring area is large or involves multiple regions, building sensor networks becomes more complex and expensive. Additionally, high energy consumption reduces the battery life of sensor nodes.

To address the need for connecting a large number of sensors across wide areas with low power consumption to facilitate operations and maintenance, the LoRa communication standard was developed, offering significant advantages over existing technologies [4].

The LoRa (Long Range) wireless communication technology is now widely used in the Internet of Things (IoT) and Machine-to-Machine (M2M) communication fields, thanks to its outstanding features, such as long transmission range, low energy consumption, and cost-effectiveness. This technology was initially developed by Cycleo (based in Grenoble, France) and later acquired exclusively by Semtech Corporation (USA) in 2012 [8]. LoRa uses spread-spectrum modulation and operates on 433 MHz, 868 MHz, and 915 MHz frequency bands, depending on the ISM regions worldwide. With these superior characteristics, LoRa can establish wireless sensor networks capable of transmitting and receiving data over distances of several kilometers while operating on battery power for extended periods.

Amid the Fourth Industrial Revolution, more than 100 countries have begun commercializing data collection and remote monitoring systems using LoRa technology, including neighboring nations such as Thailand, China, and Malaysia [9]. However, in Vietnam, the application of this technology in production and business sectors is still relatively new and has not been widely implemented.

In this paper, a wireless sensor network is designed and uses the LoRa communication standard between sensor nodes. The network adopts a star topology, transmitting data to a central node, which is connected to a web server. The servers communicate with the wireless network to process and monitor data.

The authors present the design and implementation of an automated water quality data collection system using LoRa communication technology. The system comprises three main components: sensors with data transmission capabilities, an intermediate gateway, and a central server.

The structure of the paper is as follows: Section II discusses the state of related research, Section III proposes the system, Section IV presents the research results and experiments, the final section concludes the study.

II. RESEARCH BACKGROUND

Recent studies have focused on applying IoT technology to monitor water environments more effectively. In [10] by Shao Hue Hu proposed a water environment monitoring system for aquaculture, combining IoT with wireless sensors. This system not only tracks critical parameters but also optimizes energy consumption by reducing the volume of collected data. In [11] emphasized flexibility and remote data accessibility. By integrating Raspberry Pi, Arduino, and the ZigBee protocol, the researchers developed a monitoring system compatible with mobile devices. This allows users to monitor and control water environments from anywhere while supporting data analysis by experts. In [12] introduced an innovative system for monitoring water quality in ponds and lakes using floating sensor buoys. These buoys measure critical parameters such as pH, temperature, dissolved oxygen, and conductivity. Collected data is transmitted directly to a LabVIEW platform, enabling visual tracking of water quality. However, the system is currently limited in long-term data storage and remote accessibility.

Compared to the mentioned studies [10][11][12], this paper focuses on the development of flexible, integrated sensor nodes that allow the system to be easily relocated across different areas with a sensor-to-central node range of 7–8 km. Similar to previous studies, the system utilizes mobile and computer applications to display information and store measurement results on a server.

The standout feature of this research is the design of wireless sensor nodes based on the LoRa standard. These nodes enable data collection and detailed analysis for specific environmental cases, optimizing resources and facilitating information sharing with other organizations and individuals. The system connects with various types of sensors to measure multiple parameters, enhancing the accuracy of data analysis and providing water pollution alerts.

This is particularly significant because the system is accessible to a wide range of users, helping to minimize risks when water anomalies occur, especially in domestic water sources.

III. Proposed System

Based on the aforementioned issues, this paper proposes a monitoring and alert system for water pollution levels, comprising sensor nodes for data collection and a central node.

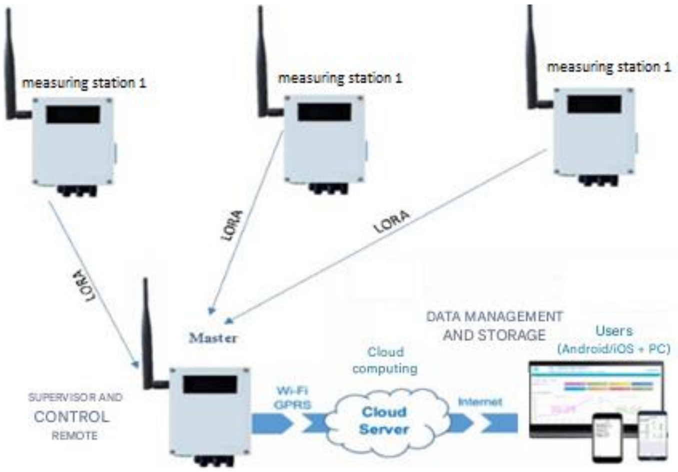

Fig. 1 System Structure for Water Pollution Monitoring and Alert

Fig.1 illustrates the system model for monitoring, comprising measurement stations that act as sensor nodes for data collection. The data is then transmitted to a central node through a LoRa wireless network. In the IoT domain, besides LoRa, other common wireless technologies such as Bluetooth, ZigBee, and Wi-Fi are also utilized, as shown in Table III [13].

The data in Table III highlights that LoRa technology is highly suitable for long-range applications, with coverage extending from 3 to 15 kilometers and superior energy efficiency, evidenced by a peak current consumption of only 28 mA compared to other wireless protocols. Long operational range and low energy consumption are among the most significant advantages of LoRa, achieved through its Chirp Spread Spectrum (CSS) modulation technology.

Table III also indicates that LoRa has the lowest bit rate, making it ideal for transmitting control signals and sensor data in IoT applications. However, it is not suitable for transmitting large amounts of data, such as images or video. Additionally, with a maximum of 10,000 connected nodes, LoRa is well-equipped to support large-scale wireless deployment models.

Table III.
Comparison of communication protocols [13]

	Bluetooth	**ZigBee**	**Wi-Fi**
Max. end-devices	255 (2 Billion in BLE)	more than 64000	Depends on number of IP addresses
Peak Current Consumption	30 mA	30 mA	100 mA
Range	10 m	10 to 100 m	100 m
Data Rate	1 Mbps	up to 250 kbps	11 Mbps and 54 Mbps
Relative Cost	Low	Low	Medium
Topology	Star	Star and Mesh	Star and Point-to-point
Transmission Technique	FHSS (Frequency Hopping Spread Spectrum)	DSSS (Direct Spread Spectrum Sequence)	OFDM (Orthogonal Frequency Division Multiplexing)

Table III demonstrates that LoRa technology overcomes the limitations of existing wireless technologies in the IoT field, offering a promising new direction for deploying wireless networks with wide coverage and energy efficiency. Therefore, the proposed system adopts LoRa technology for communication between the sensor nodes and the central node in a star network topology.

The structure of the central node, as shown in Fig. 2, includes additional components compared to the sensor nodes. Besides the basic elements of a sensor node, the central node incorporates a GPRS/3G transceiver.

The central node collects data from sensor nodes transmitted via LoRa and periodically uploads the data to a web server through the 3G/GPRS network. If the measured data exceed the permissible thresholds, the system will issue appropriate alerts.

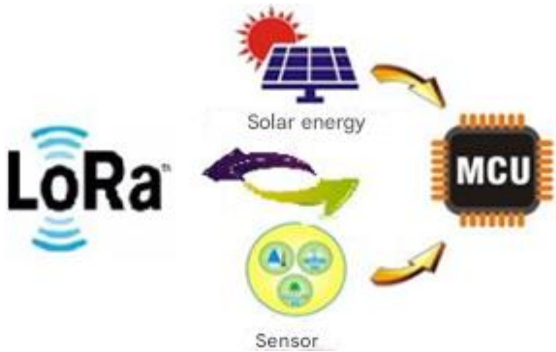

Fig. 2 Structure of the Central Sensor Node

Each sensor network node (measurement station) consists of the following components: EC sensor for measuring electrical conductivity, DS18B20 sensor for measuring water temperature, pH sensor for measuring pH concentration, Turbidity sensor for measuring water turbidity, Micro SD card reader, Real-time clock (RTC) using IC DS1307, PIC18F4550 microcontroller to process and calculate sensor values before transmitting them to the central node via the LoRa wireless communication protocol [14][15].

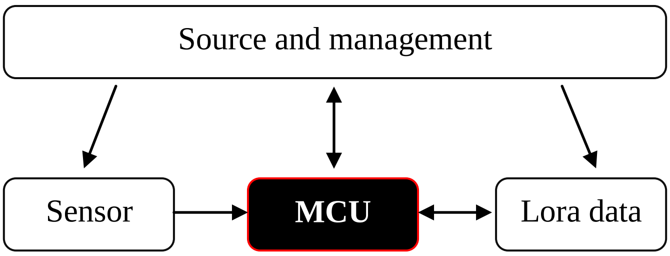

Fig. 3. Structure of the Wireless Sensor Node

A. Hardware design for the nodes

The hardware of each node is designed following components:

- A central processing board
- A LoRa module operating at a frequency of 433 MHz
- A SIM808 module with integrated GPS
- A multiplexer for connecting sensors, including:

- pH sensor
- Temperature sensor
- Dissolved oxygen sensor
- TDS sensor
- Turbidity sensor

Fig. 4 illustrates the hardware schematic of the node, showing the system's components, the diagram begins with the power supply, which provides energy to all the electronic devices in the node. The PIC18F4550 microcontroller handles central processing tasks. The LoRa module facilitates data communication between the sensor nodes and the central node, and the SIM808 module enables data transmission to the web server for storage and display.

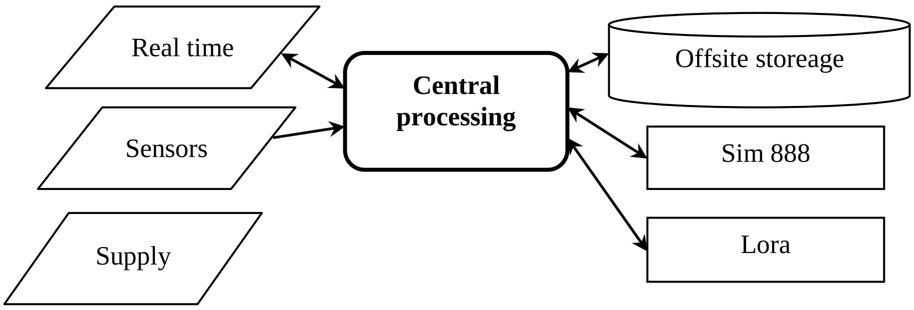

Fig. 4. Hardware Block Diagram of the Nodes

B. Description of the server and website

All monitoring information is transmitted to the server via the 3G. The data collected from the nodes is sent through the host and stored in a database hosted on the server. The online website retrieves data from this database and displays it in various formats, including parameter tables, dynamic charts, and maps. These features enable convenient monitoring and tracking of changes over time.

C. Warning system

The warning system is triggered whenever any parameter exhibits abnormal fluctuations exceeding predefined thresholds. Each parameter is associated with a specific threshold.

There are three alert levels:

- Normal: Displayed in green, indicating that all parameters are within permissible limits.
- Warning: Displayed in yellow, indicating a medium-level alert.
- Danger: Displayed in red, indicating a critical-level alert.

These alert levels are directly displayed on the web user interface using the color attribute of the markers.

D. Control program

The algorithm flowchart for the main program is illustrated in Fig. 5. Initially, the program initializes all sensor modules (DS18B20, DS1307, pH, DO, TSS, TDS) and functional modules (Sim808 module: GSM, GPS; SD card module). It also configures the analog input pins, timer, and RDA interrupt (for receiving data from the SIM module).

After initialization, the program enters an infinite loop that performs the following tasks:

- Reading sensor values.
- Storing data on the SD card.
- Processing alerts.
- Transmitting data to the web server.

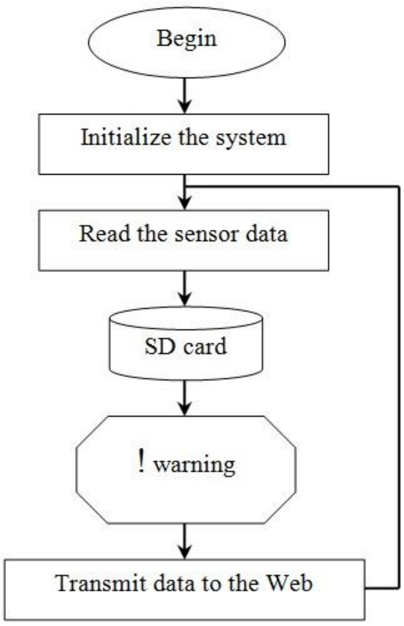

Fig. 5. System Initialization Algorithm Flowchart

Sensor data reading program: Fig. 6 illustrates the sensor data reading program, which uses the PIC timer to schedule periodic data readings. Each sensor is called upon at regular intervals for processing and value acquisition, following a method akin to using a Real-Time Operating System (RTOS) on the PIC platform. For TDS measurements specifically, the process requires repeating the measurement 40 times to achieve accurate results.

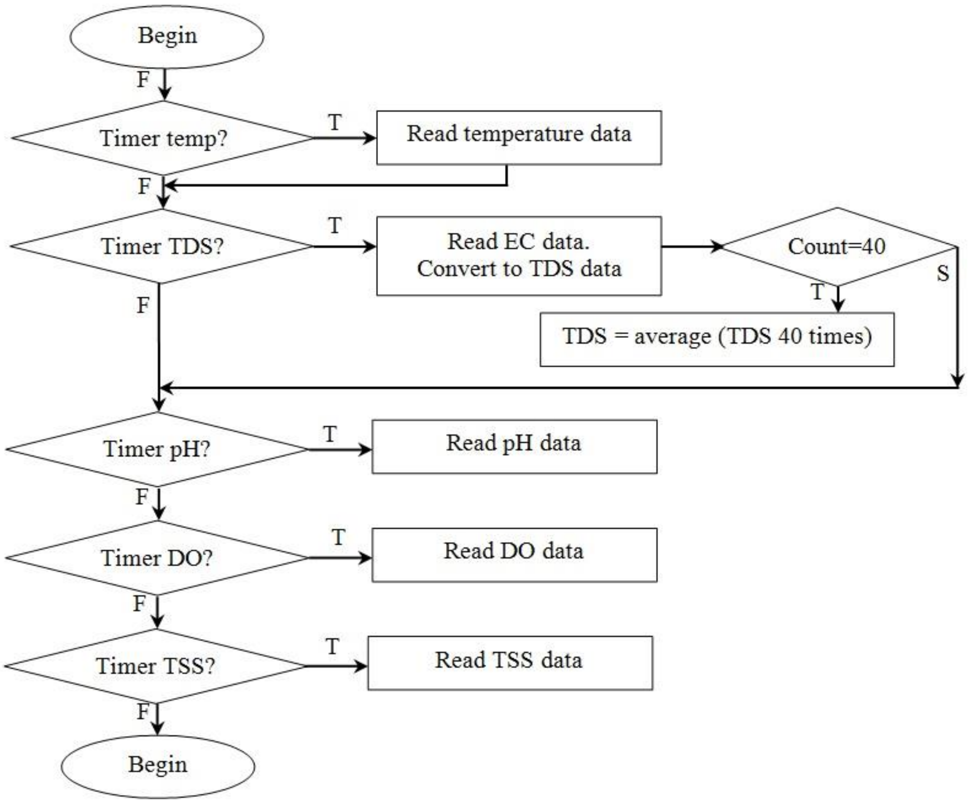

Fig. 6. Sensor parameter reading flowchart

IV. RESEARCH RESULTS AND EXPERIMENTS

The completed system consists of three wireless sensor network nodes: the first node can float on the water surface (ponds, lakes, rivers, etc.); the second node can be placed at a fixed location (channels, drainage pipes, lake shores, etc.); and the third node serves as the central node, collecting data from the sensor nodes and transmitting it to the web server.

TABLE shows the results, the values managed include: temperature, TDS, pH, DO, TSS (turbidity), time.

TABLE IV.
THE RESULT TABLE INCLUDE TEMPERATURE, TDS, PH, DO, TSS (TURBIDITY), TIME

VALUE TABLE:						
ID	**TEMP (^{O}C)**	**TDS (ppm)**	**PH**	**DO (%)**	**TURB (%)**	**TIME**
368	28.5	35.5	7.1	13.8	0.4	2024-15-11 15:52:33
367	28.0	33.5	7.2	14.5	0.4	2024-15-11 16:02:41
366	27.5	35.0	7.2	14.8	0.7	2024-15-11 16:12:25
365	27.5	35.0	7.2	15.3	0.8	2024-15-11 16:22:55
364	26.0	32.5	7.2	14.8	0.3	2024-15-11 16:32:45

The proposed system was successfully developed, including hardware and software based on the suggested architecture. Data was transmitted consistently, with no errors and minimal delay. The system was tested by deploying Sensor Node 1 to monitor water quality at the Raw Water Supply & Construction Consulting Enterprise. The distance from Node 1 to the central node was 1.5 km, while the distance from Node 2 to the central node was 700 meters.

V. CONCLUSION

We have successfully researched, developed, and tested a water pollution monitoring system that integrates sensor nodes and LoRa technology for data collection, transmission, and processing. The data is transmitted to a central node and displayed via a web server for monitoring purposes.

The wireless sensor network nodes (monitoring stations) can measure parameters such as electrical conductivity (EC), temperature, turbidity, pH level, and dissolved oxygen (DO). These are critical parameters for assessing water quality. By comparing these values against standard thresholds, the system can determine the pollution levels of the monitored water source. Additionally, it provides alerts to managers and shares information broadly with users accessing the monitoring website.

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