Design and Implementation of an IoT-based River Water Salinity Monitoring System Using MSP432

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Abstract. The drought and salinity intrusion in the Mekong River Delta in the years has become more and more serious, but the system automatically measures and collects water salinity data at either the river mouths or the canal has not been deployed and used widely in this region due to the high investment cost. The goal of this study is to design a monitoring and data acquisition on river water salinity based on the IoT (Internet of Things) technology. The sensor nodes are designed by using the Texas Instruments MSP432 microcontrollers to read data from sensors such as water level, temperature, and salinity. This information is encapsulated and then send to a gateway via a LoRa network. The gateway uses the Raspberry Pi 3 B+ board allowing to receive the data from the sensor nodes and upload data to the cloud server through the Internet connection. A webpage is designed to offer everyone to observe measured parameters rapidly so that the people can take a proactive plan to take water for domestic use and production activities. An experiment to evaluate the performance of our proposed system was carried out in Soc Trang province, Mekong Delta, Vietnam with initial positive results.

1. Introduction
If the record was considered to be the effect of saline intrusion in the Mekong River Delta in 2015-2016, the record is broken for the year 2019-2020. Apart from hydroelectric dams constructed on the main Mekong River retain water, the amount of water flowing into the downstream region is also affected by low rainfall because of the El Nino weather. It has an increasingly serious impact on the lives and livelihoods of people, especially farmers due to the lack of freshwater in cultivation. Currently, the saline intrusion has been tens of kilometers inland and has been seriously affecting coastline provinces in Mekong Delta such as Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, and Ca Mau [1, 2]. In 2020, the saline drought comes one month earlier, so people cannot store enough water for quantities of safe water for domestic use and crop irrigation demand. The continued rise in salt intrusion would destroy hundreds of hectares of rice, crops, fruit trees, etc. that will have a significant effect on agriculture and the lives of farmers [3]. Currently, the salinity monitoring systems have been deployed in most of the major rivers and manage by the local authorities. Thus, local people hard to update salinity-related information promptly and conveniently. This leads to the low adaptability of local people with the saline intrusion problem. Most of the existing systems have not achieved significant results in helping local people to be aware of the effects of the intrusion of saltwater and to implement proper strategies towards adaptation and development sustainability in living and farming practices. It is necessary to have more convenient and rapid measuring equipment so that it helps farmers to be aware of salinity and implement preventative and management actions to combat the problem. For these reasons, the goal of this work is to design and implement a salinity measuring system based on IoT technology with a case study in a river in Soc Trang province, one of the provinces in the Mekong Delta, where has been suffering the heavy consequences of saline intrusion.
The rest of this paper is organized as follows: after stating various causes, effects of salinity intrusion in Mekong Delta, Vietnam in Section 1, Section 2 presents the electronic component being used to implement the proposed river water salinity monitoring system. The system utilizes innovative sensor technologies and Semtech's LoRa to deploy a low-power wide-area wireless network for automatically collecting the values aiming at estimating river water salinity. Hardware and software development are described in detail in Section 3. In Section 4, the significance of the experimental results is evaluated. Finally, Section 5 concludes this paper before discussing future works.

2. Background

2.1 MSP432P401R Microcontroller

The MSP432 is the new generation of TI's microcontroller with advanced mixed-signal features targeting low-power consumption systems while providing significant performance processing thanks to 32-bit ARM Cortex-M4 MCU and an IEEE 754-compliant single-precision Floating-Point Unit (FPU). Its operating time base can be configured enabling a system clock rate up to 48 MHz. It is analog to digital conversion (ADC) capabilities that allow data digitization at a maximum conversion rate of 1 Msps with a configurable resolution from 8 to 14-bit. The system's power supply is from the battery, so the energy-saving problem is extremely significant. Choosing to use the MSP432P401R processor and LoRa wireless communication technology helped solve the energy problem. The data retrieval stored in MSP432P401R memory at the sensor node side, then sent to the gateway after the encapsulation process complete. TI has created the low-cost MSP432 Launchpad and provided the CMSIS (Cortex Microcontroller Software Standard) library to allow facilitate embedded system development as well as XDS110, an on-board emulator for programming, debugging, and energy measurements (see Figure 1) [4, 5].

![MSP‑EXP432P401R LaunchPad](image)

**Figure 1.** A photo of MSP-EXP432P401R LaunchPad [5].

2.2 Raspberry Pi 3+ Embedded Computer

Raspberry Pi 3 B+ is a powerful, compact embedded computer. The Raspberry Pi 3 B+ features a 64-bit quad-core 1.4 GHz clocked chip that supports dual-band 2.4 GHz and 5 GHz Wi-Fi, Bluetooth 4.2, and high-speed Ethernet ports (300Mbps). It not only is inexpensive, but it also has a capacity of less than 5W, so the power consumption is low and the applicability is very high [6]. In the proposed system, the Raspberry Pi 3 B+ board is used with an embedded operating system that allows for two simultaneous tasks: wireless data transmission via the LoRa-02 transceiver modules with sensor nodes within the WSN. The information was then processed and uploaded to the cloud server via a Wi-Fi connection.

2.3 LoRa Technology

LoRa uses a modulation technique called Chirp Spread Spectrum (CSS). With this principle, the data is hashed with high-frequency pulses to produce a signal with a frequency range higher than that of the original data (this is called chipped). Then in chirp signal chains, this high-frequency signal continues to be coded. According to the technical documents of Semtech, this technique helps to reduce the
complexity and accuracy of the crystal oscillator required for the receiver circuit to be able to demodulate the data. Furthermore, LoRa technology does not need a large transmission power but can still transmit long distances because its signals can be received at long distances even with a lower signal strength than ambient noise. By using a chirp signal, LoRa signals with different chirp rates can operate in the same area without interfering with each other. This allows multiple LoRa devices to exchange data on multiple channels simultaneously [7, 8]. Table 1 describes the connection between a Ra-02 module and an MSP432P401R microcontroller.

Table 1. Connection specification between a Ra-02 module and an MSP432P401R microcontroller.

| MSP432P401R | LoRa Ra-02 |
|-------------|------------|
| P5.1        | NSS        |
| P1.5        | SCK        |
| P1.7        | MISO       |
| P1.6        | MOSI       |
| P5.0        | DIO0       |
| P5.2        | RST        |
| VSS         | GND        |

This design used an Ai-Thinker Ra-02 module which is a 433 MHz LoRa wireless transmission board using Semtech’s SX1278 wireless transceiver. The SX1278 provides a maximum link budget of 168 dB with a high sensitivity of -148 dBm and a power output of +20 dBm for long distance communication and high reliability. With a programmable bit rate of 300 kbps, it is fast enough for wireless sensing systems in which most of the data is formatted into strings for transmission [9].

2.4 TDS Meter Sensor
Total Dissolved Solids (TDS) is a measure of the cumulative dissolved content of both inorganic and organic substances present in the water. Typically, the higher the value of the TDS, the more substances dissolved in water. Therefore, higher Total Dissolved Solids (TDS) levels suggest that water has more pollutants that can pose health risks. It can work with a wide range of dc supply (3.3~5.5 V) with the analog signal output from 0 to 2.3 V which corresponding to TDS values ranging from 0 to 1000 ppm with an accuracy of 10% FS (at 25 ℃). Because salt is a part of TDSs and therefore will be either a part or all of the reading values. In this work, we use the TDS meter sensor to estimate the amount of salt in water. For example, if there is only salt in the water, and the reading value is 500 ppm, then it is 500 ppm (mg/L) of salt [10].

2.5 DS18B20 Thermometer
In this work, we use the waterproofed version of the DS18B20 temperature sensor to measure water temperature. The sensor is jacketed in PVC and put inside a stainless steel tube 6mm diameter that is suitable to measure in water conditions. This is a 1-wire digital temperature sensor allowing avoid any signal degradation even over long distances. It can measure temperature values ranging from -10 to 85 Celsius degree with an accuracy of ±0.5 and query time is less than 750 millisecond [11]. Besides being considered an environmental parameter value, the water temperature value is also used in calculating and calibrating the quantity of salt in water.

2.6 Ultrasonic Sensor HY-SRF05
For non-contact water level measurement, HY-SRF05, an ultrasonic emitter/receiver, is used to measure the water level by finding the distance between the transceiver and the surface of the water with a precision of ~30 mm. It sends out a short ultrasonic pulse (40 kHz) that reflects on objects in front of the sensor. This signal is then read back by the sensor and the duration of the received signal is reflected in the ECHO pin [12]. We can measure the water level through the travel time of that pulse to the water and back. The PVC pipelines with 250 mm diameter are used to protect and improve the system performance in wet or dusty environments.
3. Design and Implementation of System

![Figure 2](image)

**Figure 2.** The architecture of the proposed system.

The wireless sensor network aims at establishing radio links for collecting information on environmental parameters from sensor nodes to a gateway. In this system, we use a Raspberry Pi 3+ board and MSP432P401R microcontrollers for control units at a gateway and sensor nodes respectively. We designed and implemented a printed circuit board stacked on both control boards. It helps to wire a radio transceiver and sensors up to the control board for reducing attenuation and interference if any. For wireless data communication, a compact LoRa transceiver namely Ra-02 of Ai-Thinker offers low power consumption and long distance radio link for sensing applications [9]. Figure 2 presents the block diagram of the proposed system.

3.1 Sensor Node

![Figure 3](image)

**Figure 3.** Block diagram of a sensor node.

Four peripheral interface standards are being used in this sensor node design such as SPI for connection between MSP432P401R and LoRa Ra-02 as well as ADC, 1-Wire, and PWM for sensor connections (see Figure 3). In the design communication protocols should be appropriate so that data received and sent can be up to accurate. The antenna is located outside the box to ensure good radio signal connections. Table 2 specifies the connections between sensors and an MSP432P401R in a sensor node.

| MSP432P401R pins | DS18B20 - Digital thermometer |
|------------------|------------------------------|
| P2.5             | Data                         |
| P5.5             | Total Dissolved Solids (TDS) meter |
| P2.7             | Trig                         |
| P2.6             | Echo                         |

The sensors record parameters of water quality and send them to the ARM microprocessor for data processing. For instance,
Figure 4 illustrates a flow chart of the routine in C programming language for reading, calculating water level, temperature, and salinity, and then sending data to the gateway.

```
Begin
  System initialization
  Read: ultrasonic sensor (HY-SRF04), temperature sensor (DS18B20) and TDS
  Calculate: water level, salt concentration
  Send captured values to gateway
    Receive “ACK” from gateway
      False
      True
          End
```

**Figure 4.** Flow chart of reading sensor values in the sensor node.

Figure 5 shows the electric circuit board of sensor nodes with a battery for power supply is placed inside a waterproof plastic box.

![Figure 5](image)

**Figure 5.** A photograph of the sensor node: the electronic parts placed in a plastic box to shield them from external effects.

3.2 **Gateway**

As can be seen in Figure 6, an adaptor printed circuit board (PCB) is designed for electronic devices using conductive tracks to improve the stability of the system as well as reduce interference. An ASM117, a fixed low dropout voltage regulator, is utilized to provide a stable voltage at 3.3 V with load current up to 250 mA for LoRa Ra-02 operation [13]. Both of them are soldered onto the adaptor PCB to wire them together. The adaptor connects with Raspberry Pi via GPIOs header.
3.3 Web Application

In this work, the monitoring values are reported on a public website based on Amazon Elastic Compute Cloud (Amazon EC2, a web service that provides secure, resizable compute capacity in the cloud) [14]. It is convenient for people to access the information from any web browser running on a variety of hardware platforms and operating systems. The captured values, such as water level, the salt concentration in water, are presented on separate graphs to facilitate observation. Such graphs are automatically refreshed whenever the relevant data is updated. It has been designed comprehensively to provide well-informed information on the water salinity at the local river, the people can take a proactive plan to take water for domestic use as well as production activities.

4. Result and Discussion

The proposed system has been deployed to monitor water parameters at two different places along were carried out on an actual system for monitoring at Nha Tho Canal (a branch of Hau River), Dai An commune, Cu Lao Dung district, Soc Trang province, Vietnam. Figure 7 depicts the LoRa network deployment, in reality, locations showing on the map with a gateway and sensing nodes (red makers). Although the radius from the gateway to the furthest sensing node is just around 670 meters, the transmission paths were obstructed by many big trees. To overcome this issue, LoRa technology was chosen for data communication within the network. The sensor nodes were placed in the river and the gateway was located in a bridge, as shown in Figure 8 and Figure 9.
Figure 9. The gateway with antenna gain 3 dBi (tower height of 2 meters).

After the experimental measurement of the system to monitor salt concentration in river water, the obtained results show that the system operates stably. Values being captured from the sensors are quite accurate. The proposed system could be implemented with a reasonable budget and could be monitored and maintained conveniently. It allows for measuring water parameters and then displaying data visually by creating graphs (see Figure 10). It does not only allow both governors and local people to observe, analyze, and assess salinity intrusion situations but also raises public awareness about the impact of climate change and severe weather.

Figure 10. Typical graphs showing water level and water salinity in a sensor node.

5. Conclusion
In this paper, we presented the design and implementation of an IoT-based river water salinity monitoring system. The system allows water level and salinity monitoring for a wide area in real-time with a visual web map application in light of long-distance wireless technology and cloud database service. The system proposed in this study has a compact hardware design, low-cost implementation, and stable software that allows the sensor network to transmit data stably in a rural environment with many obstacles such as big trees. The system also includes a webpage to present the sensing parameters in the form of graphs to observe easily. To evaluate the performance of the system, we deployed a LoRa star network consisting of a gateway for data collection, then uploading to the cloud server and two sensing nodes at Nha Tho canal, Cu Lao Dung district, Soc Trang province, Vietnam. Apart from the
advantages achieved, the system still has some limitations due to the use of sensors with low accuracy as well as the measurement results that have not been compared and calibrated carefully. To improve the system, the authors will need to conduct more experiments as well as expand the number of sensor nodes to be able to monitor a larger area. Besides, it is very suitable to use solar panels for the power supply of the system.

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