LORAWAN-BASED REMOTE MONITORING AND CONTROL SYSTEM FOR CANAL GATES OF PADDY FIELD IRRIGATION SYSTEMS

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Abstract - Irrigation systems are crucial for water management in paddy fields, but manual operation of canal gates often results in localized water shortages or excesses. Previous studies have developed remote monitoring and control systems using Wi-Fi and Internet protocols, but these approaches face difficulties when applied to large-scale irrigation areas. This paper presents a LoRaWAN-based remote monitoring and control system for canal gates of paddy field irrigation systems. The proposed system employs the LoRa technique to create a network of sensor nodes that covers a wide geographical area, making it well-suited for large irrigation systems. Unlike previous studies, which often implemented small-scale models, this system was deployed in a real-world setting in An Trach village, Da Nang. Experimental results showed that the proposed system can transmit data over distances up to 2 km and consumes less energy compared to the MQTT-4G-based solutions, making it ideal for large-scale irrigation systems.

Key words - LoRaWan; MQTT; IoT; Automatic water irrigation; Smart irrigation

1. Introduction

Irrigation systems play an important role in water management, ensuring field productivity. Currently, many irrigation systems for paddy fields have been concreted, helping to avoid water loss and ensure seasonal availability. These systems are managed manually by the field irrigation staff. Due to the limited number of employees and large management area, combined with the lack of management tools, the implementation of closing and opening canal gates to regulate irrigation is not synchronized, causing local water shortage or excess in many places. Therefore, developing a remote monitoring and control system for canal gates of paddy field irrigation systems is essential to improve the efficiency of water management.

The irrigation system consists of main canals and field canals leading water to paddy fields. Canal gates are placed in the canals to regulate the amount of water entering the canals. For brevity, the gates in the main canals are called main canal gates; and the gates in the field canals – field canal gates. While the number of main canal gates is limited, the number of field canal gates is very large. The main canal gates are continuously controlled according to the plan and through monitoring the water levels in front and behind the gate, and the opening levels of the gates. Meanwhile, the field canal gates are only opened and closed on demand.

The remote monitoring and control systems for canal gates of paddy field irrigation systems face the following challenges. First, the paddy field irrigation system spread over a large area, requiring the system to be able to transmit and receive signals over long distances. Second, the power supply to irrigation systems for paddy fields is limited, leading to the problem of energy consumption of the system that needs to be considered.

Sanjula et al. [1] proposed a system to control canal gates of paddy fields irrigation systems based on sensor nodes connected in a peer-to-peer network. A node plays the main role in connecting to the Internet via Wi-Fi. Based on information collected from the sensor nodes, canal gates are opened or closed by a stepper motor. A PID algorithm was used to control the motor to ensure the water flow into the field. Desnanjaya and Nugraha [2] used a website platform to control canal gates. The SIM module 900 was used to transmit information to the database. The message queuing telemetry transport (MQTT) protocol has been widely used in many studies [3-5] to collect sensors data and deliver it to the cloud or server through wireless communication modules. Such an approach usually uses 4G modules to connect to the Internet. For brevity, we call this protocol MQTT-4G. A direct motor control system based on data from sensors was proposed in [6]. Liu et al. [7] used NB-IoT (Narrowband Internet of Things) to transmit data from sensors.

Although several solutions have been proposed to remotely monitor and control canal gates of paddy field irrigation systems, some limitations still exist. First, the existing systems were mainly based on the Wi-Fi and Internet communication protocols that are difficult to deploy for paddy field irrigation systems, which spread over a large area. These solutions are suitable mainly for main canal gates, where data packets need to be exchanged continuously in real time. However, it is difficult to deploy for a large number of field canal gates due to the power supply issue and operating costs (e.g., for Wi-Fi and 4G payments). Second, the previous works only presented small-sized models that are not close to reality.

In this paper, we present a remote monitoring and control system for canal gates of paddy fields irrigation systems. Unlike previous studies that consider solutions that are suitable mainly for main canal gates, we focus on a system that can be deployed for field canal gates, which are in large quantities. While the main canal gates need to operate in real time, the field canal gates only need to be controlled on demand. However, field canal gates are distributed over a large area and are often not powered from the grid. Thus, we must consider problems related to long-distance communication, power consumption, and operating costs. Different from previous works, the system is built based on LoRaWAN, which is a low-power wide-area wireless network. The proposed design was constructed and practically deployed to several canal gates of the irrigation system in An Trach village, Hoa Tien commune, Hoa Vang district, Da Nang city. Besides, we also built a similar system but based on the MQTT-4G protocol, which has been widely employed by many previous studies for remote canal gate control. Experiments were performed to evaluate the two systems based on different quantitative criteria to show the effectiveness of each system.

The main contributions of this paper are as follows. First, a LoRaWAN-based remote monitoring and control system for canal gates of paddy field irrigation systems is proposed. The system ensures long-distance communication, low power consumption, low operating cost, suitable for deployment to a large number of field canal gates. Second, a real-world system was constructed and deployed in practice for experiments. Experimental results showed the effectiveness of the proposed system.

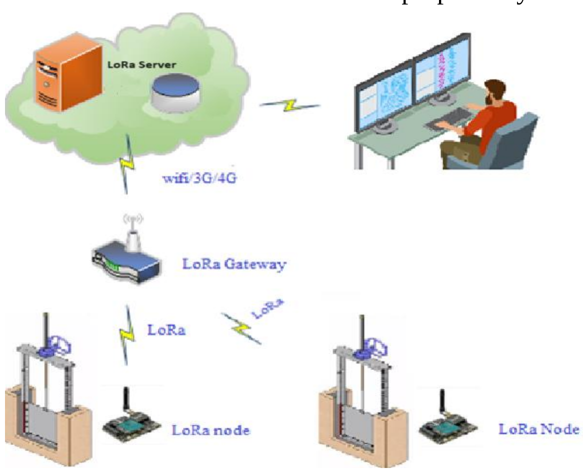


Figure 1. *Remote monitoring and control system for canal gates of paddy field irrigation systems*

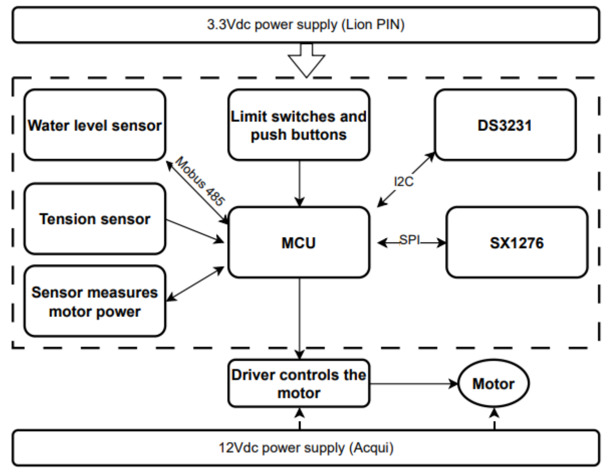
2. Proposed system

2.1. General structure

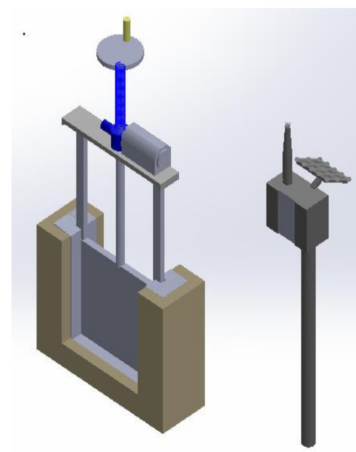
In this section, we present the general structure of the remote monitoring and control system for canal gates. The system is built on a low-power wide-area wireless network LoRaWAN, which allows communication between devices over long distances and consumes low power [8]. The system includes LoRa nodes used to collect water level data and control the canal gates (Figure 1). According to the regulations of the Vietnam Ministry of Information and Communications [9], the transceiver frequency range of LoRa devices is set to $920 - 923MHz$ and the transmission power must be lower than $25mW$. A LoRa gateway is used to transmit and receive data with LoRa nodes. It then converts the LoRa protocol into the IP protocol to transmit data of LoRAWAN devices to the Internet. An application on the website is built for users to remotely monitor and control canal gates via LoRa server.

2.2. Lora node

LoRa nodes receive data from the water level sensors and control the motors to open and close the canal gates. Nodes are capable of transmitting and receiving data with the LoRa gateway according to the LoRa protocol. The block diagram of the LoRa node is depicted in Figure 2a. The mechanical design of a canal gate and a LoRa node is shown in Figure 2b.



(a)



(b)

Figure 2. *(a) Block diagram of a LoRa node; and (b) Mechanical design of a canal gate and a LoRa node*

The LoRa nodes are configured to match Channel 3 of the AS923 frequency diagram according to the regulations of the Vietnam Ministry of Information and Communications [9]. The details of parameter setting are shown in Table 1. The format of packets transmitted from LoRa nodes to the LoRa server are described in Table 2.

Table 1. *Parameter setting of LoRa nodes*

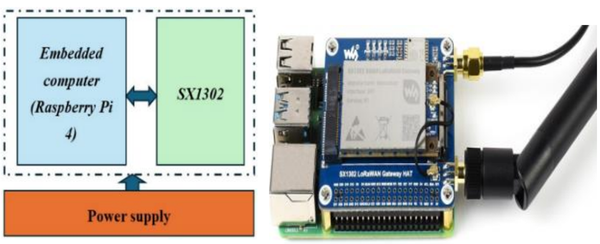
Parameter	Setting
Class	C
Frequency	$921.4Mhz$
SF (Spreading Factor)	SF12
BW (Bandwidth)	$125kHz$
CR (Coding Rate)	$4/5$
Data transmission cycle	$30\ min$
Data reception cycle	Ready

Table 2. *Packet format of LoRa nodes*

Packet frame	**Size**
ID node	1 byte
Water level	2 bytes
Tension level	2 bytes
Power motor	2 bytes
State gate	1 byte
Volage of Battery	2 bytes
Duration of status sending	4 bytes
Duration of repeating packet	4 bytes

2.3. LoRa gateway

The LoRa gateway collects data from LoRa nodes. It is connected to the LoRa server through the Internet using Wi-Fi. The Lora gateway is built on an embedded computer Raspberry Pi 4 and the Semtech's core SX1302 [10] (Figure 3a). The device has many advantages such as scalability, multi-channel, large memory, and long-distance transmission (up to 30km) [10].



(a) *(b)*

Figure 3. *LoRa gateway: (a) Block diagram; and (b) Actual device*

The LoRa gateway is connected to the Internet via Wi-Fi provided by a 4G-to-wifi adapter. The gateway is always connected to the power supply via a 5.1V - 3A adapter. The data transmitted to the gateway is configured to forward to the address http://203.205.43.93:8080/, which is a LoRaWAN cloud built on the LoRa server using ChirpStack [11]. Some libraries and tools used to build the gateway can be accessed at https://github.com/Lora-net/sx1302_hal.git. Figure 3b depicts the actual gateway that has been built.

2.4. LoRa server

The LoRa server receives and stores the data transmitted from LoRa nodes through the LoRa gateway. Besides, the LoRa server also transmits the control and setting data from the user interface to LoRa nodes. The LoRa server, which is based on ChirpStack [9], operates on a computer with Ubuntu 22.02 LTS operating system. The server is able to establish a proactive and private network. ChirpStack itself provides a web interface for managing the gateway and LoRa nodes and establishes data integration with major vendors, databases, and cloud services commonly used to process device data. ChirpStack also provides a gRPC-based API that can be used to integrate or extend ChirpStack.

2.5. Monitoring and control website

A website is designed as a GIS map for users to easily manipulate and monitor. It connects data to the LoRa server via MQTT protocol. The canal gate status, control and setting data are displayed in the website's interface (Figure 4).

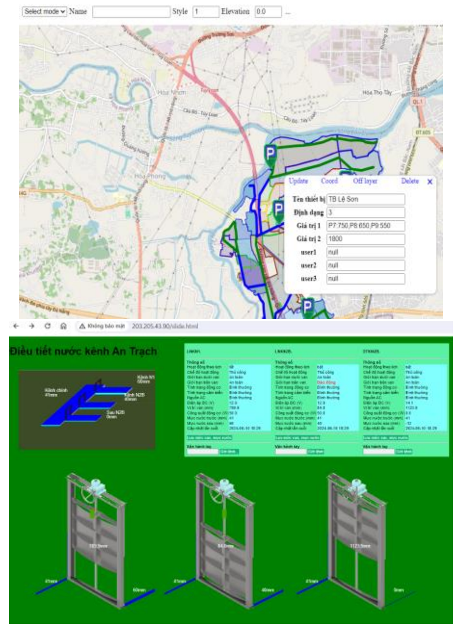
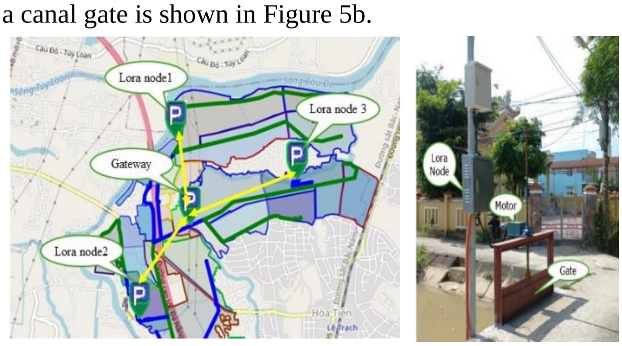


Figure 4. *The interface of the monitoring and control website*

3. Experimental results

3.1. Proposed system evaluation

In this section, we evaluate the proposed system in terms of transmission capability. We deployed a real-world system, which consists of three LoRa nodes and one LoRa gateway, for the irrigation system in An Trach village, Hoa Tien commune, Hoa Vang district, Da Nang city. The LoRa nodes are arranged to ensure the condition of line-of-sight propagation. It means that waves can only travel from the source to the receiver in a direct visual path without obstacles. This condition ensures that the signal loss is mainly due to the distance and antennas. The distances between the Lora nodes and the gateway are $1.3km$, $1.5km$ and $2.1km$. The GIS map showing the deployment location of the LoRa nodes and the LoRa gateway is demonstrated in Figure 5a. The deployed LoRa node with a canal gate is shown in Figure 5b.



(a) *(b)*

Figure 5. *(a) The GIS map showing the deployment locations of three LoRa nodes and one LoRa gateway in An Trach village, Hoa Tien commune, Hoa Vang district, Da Nang city; (b) Deployed LoRa node and canal gate*

To evaluate the system's transmission capability, the following criteria are used: RSSI (Received Signal Strength

Indication), SNR (Signal-to-Noise Ratio), and PDR (Packet Delivery Ratio) [8]. The RSSI index measures the power loss relative to the transmitter source and is calculated based on the delivered power minus the total loss on the transmission line. RSSI is measured in dBm and has negative values. The closer the RSSI value is to 0, the stronger the received signal. The SNR index measures the ratio between the received signal power and the noise power and is expressed in dB. The noise includes unwanted signal sources that cause decoding difficulties at the receiver. If SNR is greater than 0, the received signal will operate above the noise floor. If SNR is less than 0, the received signal will operate below the noise floor. The PDR index measures the ratio of the number of packets successfully received to the total number of packets transmitted [8]. PDR is an important parameter to evaluate network stability.

To measure the above indices, 48 packets were transmitted in a day. Table 3 shows the average RSSI, average SNR, and PDR values for 48 packets transmitted in a day.

According to the datasheet of the Semtech's module [10], for the spreading factor of 12, the minimum SNR for demodulation is $-20dB$. It can be seen from Table 3 that the quality of the signal received at the gateway is guaranteed to be demodulated. This also corresponds to PDR values of 100%. Table 3 also shows that, as the distance increases, the average RSSI and SNR indices both decrease due to distance attenuation. However, these indicators are still good enough to ensure signal demodulation at the gateway.

Table 3. *Average RSSI, average SNR, and PDR for 48 packets transmitted in a day*

LoRa node	Distance (km)	RSSI (dBm)	SNR (dB)	PDR
Node 1	1.3	-94.7	1.52	48/48
Node 2	1.5	-102.3	-2.21	48/48
Node 3	2.1	-135.1	-6.33	48/48

3.2. Comparative study

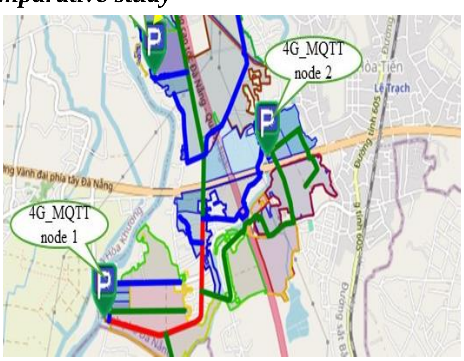


Figure 6. *The GIS map shows the deployment locations of the MQTT-4G nodes*

In this section, we compare the proposed system with the MQTT-4G-based solution, which has been employed by many studies [3-5]. The purpose of this comparative study is to show the advantages and disadvantages of each solution and the feasibility of applying it to a paddy field irrigation system. To this end, we deployed an MQTT-4G-based system which consists of two nodes. Each node has a similar design to the LoRa node but using the MQTT-4G transmission protocol. Besides, the MQTT-4G node uses the module SIM7600CE instead of the module SX1276 like the LoRa node. Two MQTT-4G nodes are arranged independently as shown in Figure 6. The operating parameters of the MQTT-4G nodes are described in Table 4.

Table 4. *Operating parameters of the MQTT-4G nodes*

Parameter	Setting
Frequency	4G ($2500MHz - 2600MHz$)
Uplink	$50Mbps$
Downlink	$150Mbps$
Data transmission cycle	$30\ min$
Data reception cycle	Ready

For the MQTT-4G nodes, the packet format has a type of string data. Thanks to the MQTT protocol, these nodes can exchange data well even in the limited bandwidth condition. The data is transmitted to the server according to topics specified for each node. We measured the signal transmission quality of the MQTT-4G based system to ensure comparative experiments. Test results showed that the signal level during the day is in the range from $-60dBm$ to $-71dBm$, which is within the range of good to very good signal levels as recommended by the network operator [12]. The PDR index reached 100% for 48 packets transmitted in a day.

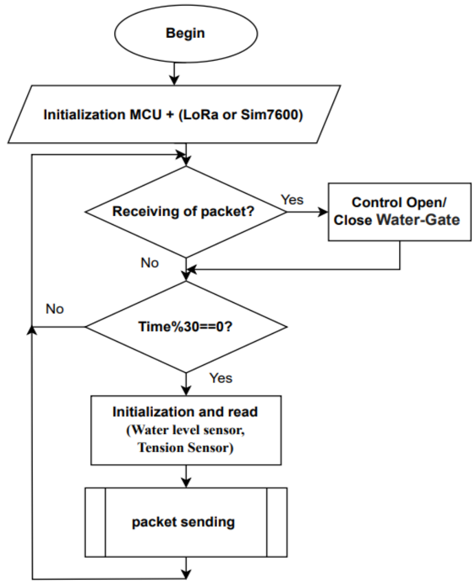


Figure 7. *Flow chart of the algorithm to control the timing of data transmission for both systems*

To ensure fairness in comparison, we used the IC DS3231 real-time clock to simultaneously trigger the data transmission of both systems every 30 minutes. For control data sent from the server, the website transmits randomly to both systems simultaneously. To save energy, the sensors as well as the motors are powered off using MOSFETs and are only awakened to operate for a short period of time before transmitting and receiving control data. The algorithm to control the timing of data transmission for both systems is shown in Figure 7.

The digital multimeter Keysight DMM 34460 [13] was used to measure the power consumption of the two systems. The energy dissipated by sensors, motors, and drivers is ignored because they consume the same power for both systems. Table 5 shows the average current and duration for different tasks of both systems.

Table 5 shows that the initialization process of the MQTT-4G-based system is longer and consumes more energy than the LoRaWAN-based one. The reason is that the initialization of the SIM 7600 module requires a lot of time for SIM card reception and stable network connection [14]. The LoRAWAN-based system takes about 5 times longer than the MQTT-4G solution to transmit and receive a packet. It is due to the fact that the data transfer speed of LoRaWAN with the spreading factor of 12 is only about $250bps$ [15] that is much slower than the uplink speed of $4Mbps$ of the 4G SIM module [14]. To save energy, both systems use the standby state. In this state, the proposed system consumes much less energy than the system using MQTT-4G. Note that the standby state is a task that operates more frequently compared to other tasks.

Table 5. *The average current and duration for different tasks of the LoRaWAN-based and MQTT-4G-based systems*

Task	LoRaWAN		MQTT-4G	
	Average current	*Average duration*	*Average current*	*Average duration*
Initialization	39mA	412ms	198mA	4000ms
Status packet sending	129.5mA	1199ms	125mA	205ms
Packet listening	0.6mA	Always	80mA	Always
Receiving of packet	99.0mA	786 ms (randomly)	108.0mA	146ms (randomly)

In summary, the experimental results showed that the power consumption of the MQTT-4G-based system is much higher than that of the LoRaWAN-based solution. However, the time duration for data transmission and reception of the proposed system is longer, which means that the control signal response is slower than the system using MQTT-4G.

It can be seen that the LoRaWAN-based system is suitable for field canal gates, which are controlled on demand. Besides, the motors and drivers of field canal gates consume little energy so the LoRa node can operate solely on solar energy. Meanwhile, the MQTT-4G solution allows for real-time data packet exchange, compatible with the main canal gates. Additionally, compared with the LoRaWAN-based approach, the MQTT-4G solution has higher operating costs due to the high-cost SIM modules and monthly SIM card payments. Therefore, this solution is not suitable for deployment to a large number of field canal gates.

4. Conclusion

In this paper, we presented the LoRaWAN-based remote monitoring and control system for canal gates of paddy field irrigation systems. Unlike other studies that employed the Wi-Fi and Internet protocols to exchange data, the proposed system uses the LoRa communication technique. The system includes the LoRa nodes that collect data from sensors and communicate with the LoRa gateway. The server is built to store data and communicate with users through the website. While previous studies only implemented small-sized models for experiments, we deployed the real-world system in An Trach village, Hoa Tien commune, Hoa Vang district, Da Nang city. Experiments have been conducted to evaluate the quality of data transmission, and power consumption of the proposed system. We also built a similar system but based on the MQTT-4G protocol to compare with the proposed system. Experimental results show that the LoRaWAN-based system is suitable for monitoring and controlling field canal gates, while the MQTT-4G solution is suited to main canal gates.

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