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Design and Implementation of Wireless Irrigation Valve System Based on LoRa Controlled by Cloud Server

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Abstract: Wireless actuator networks, which control devices by analyzing data collected from sensors, are becoming important in the area of precision open-field agriculture. This paper will present wireless irrigation valve system architecture based on LoRa and controlled by a cloud server for autonomous irrigation in open fields and the design of a non-real-time actuator protocol; this includes the implementation procedure for each node in the system. The results are also presented for the experiment conducted on a lawn that shows the proper operation of irrigation valves that use the protocol proposed in this paper.

Keywords : irrigation, LoRa, actuator node, precision agriculture

I. INTRODUCTION

Information and communication technology has evolved to agriculture applications such as improving crop productivity and quality and reducing labor costs. Precision agriculture (PA) initially focused on environmental data collected on crop growth, but the focus now is migrating toward intelligent autonomous systems technologies comprising the Internet of Things (IoT), big data, artificial intelligence, and cloud technology as well as other disciplines.

In general, PA systems functionality comprises three elements: collecting environmental data on crop growth, using collected information to inform decision-making, and operating the actuators according to the decisions made based on the collected data.

Across wide open fields, wired networks are far more costly to construct than are wired networks, and they have the added drawback of frequent wire breakages. Thus, wireless networks have captured research interest and appreciation. Wireless sensor networks comprise aggregated technologies designed to transport data collected at individual sensor nodes to the other nodes across the networks. These wireless networks in PA collect environmental data related to crop growth such as temperature, humidity, and soil moisture content, and remote-controlled wireless actuator networks manipulate field devices in autonomous systems. In the area of irrigation, irrigation valves controlled with these networks have the following features:

- robust wireless technology against radio interference from crop growth or weather;
- decreased energy consumptions because the actuator nodes operate on batteries;
- low costs for farmers for Internet communication;
- expansive area network coverage; and
- lack of need for real-time actuator node operation because open fields are watered only until the soil is saturated.

The objective of this study was to design and implement a low-cost, LoRa-based, autonomous, non-real-time wireless open-field irrigation valve system controlled by a cloud server. We here present the communication architecture and operation diagram for the open-field irrigation valve system including prototypes of the actuator and gateway nodes. Additionally, we present the non-real-time actuator protocol for the irrigation valves and review the results from applying our proposed system in a testbed. The low-cost communication architecture enabled us to control irrigation in the open fields without requiring real-time control of the actuators, and our design for these actuators along with the protocol for their application in open fields is the main contribution of this paper.

This paper consists of the following sections. In Section 2 we examine existing studies on issues associated with wireless actuator networks. In Section 3 we describe the structure of our data collection system including its individual elements, and in Section 4 we discuss the testbed environment and present the experimental results. Finally, we present the conclusions of this paper in Section 5.

II. RELATED WORK

Wireless actuator networks are among the elementary PA technologies are intended to increase crop production using fewer resources such as water and fertilizer. In this section, we review the extant studies on issues associated with using wireless actuator networks for precise crop irrigation.

Usmonov et al. [1] configured actuator nodes equipped with LoRa (long-range) modules to control the remote valves, the master node comprising the LoRa and WiFi modules, and the control server in the drip irrigation system. The proposed communication architecture was similar to that of the system we present in this paper. However, those authors did not describe the algorithms they used to control their actuators.

Rehman et al. [2] configured sensor, actuator, and sink nodes for crop irrigation and used ZigBee end devices between each node. The sink node was connected to the PC using serial interfaces, and the PC controlled the wireless actuator network.

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Filipe at al. [3] used weather information and data collected through their proposed sensor network to make irrigation decisions in a system configured with wireless sensors, an actuator network, and a cloud server. The network transfers control signals created by servers to actuator nodes that determine irrigation via controlled order. These authors used ZigBee end devices as well as IEEE 802.15.4 for their actuator network and either WiFi or cellular networks to control the gateway and cloud server. Similarly, Senbetu at al. [4] estimated necessary irrigation using sensor data and watered fields with a wireless autonomous irrigation system; these authors used the ESP8266 microcontroller for the wireless network.

Chinnusamy et al. [5] used LoRa and GSM (global system for mobile communications) between the actuator and gateway nodes to control valves and monitor the water distribution network and used a structure connected to a cloud server via Ethernet for the gateway node. Many previous researchers have used ZigBee or WiFi technology for their wireless actuator networks, and more are investigating LoRa technology such as low-power wide-area networks to support long-range irrigation with low electricity consumption.

III. METHODOLOGY

A. Proposed system

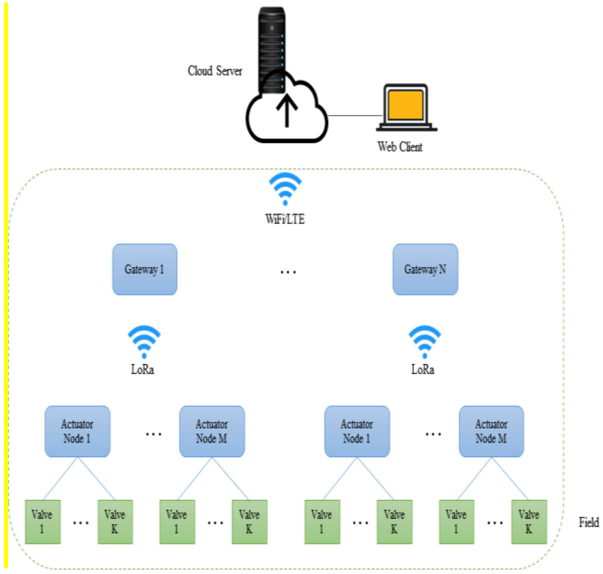
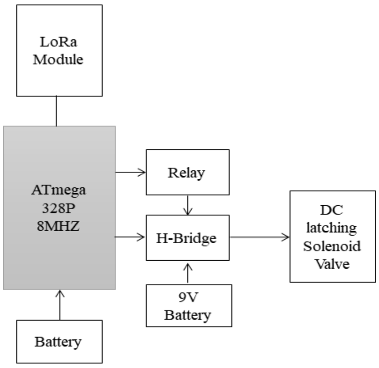
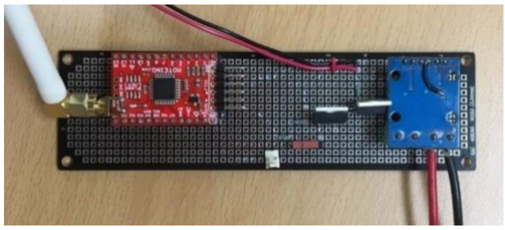


Fig. 1. Architecture of Actuator Network to Control Irrigation Valves in Open Fields.

We designed a low-cost three-tier communication architecture to control wireless irrigation valves in open fields as illustrated in Figure 1. For open fields across a wide area, we used a private LoRa network between the gateway and the actuator nodes to reduce communication expenses for farmers and WiFi technology to connect gateway nodes to servers or cellular networks where WiFi was disabled. A gateway can manage multiple actuator nodes, and one actuator node can connect multiple designated irrigation valves. Figure 2(a) illustrates the block diagram of the actuator node, and Figure 2(b) shows the node prototype.



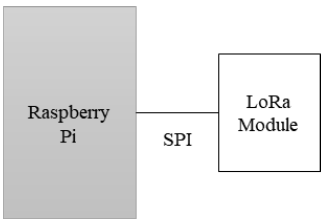
(a)



(b)

Fig. 2. Actuator node: (a) block diagram and (b) prototype.

The LoRa radio frequency module we used was based on the RFM95W LoRa chip designed by Hoperf Electronics and operating in the 922.5MHz frequency band. We selected an Atmega328P with 8MHz microcontroller unit based on its low power consumption, and this unit communicated with the LoRa module through an SPI interface. We used an H-bridge to control the DC latching solenoid that ran with a 9V battery, and the power supply to the bridge was shut off with the relay when the valves were not in use. Figure 3(a) illustrates the gateway node, and Figure 3(b) shows the prototype of the gateway. We connected the RFM95W module to Raspberry Pi using the SPI interface to control the LoRa gateway and controlled the single-channel gateway using the RadioHead library [6].



(a)

(b)

Fig. 3. Gateway node: (a) block diagram and (b) prototype.

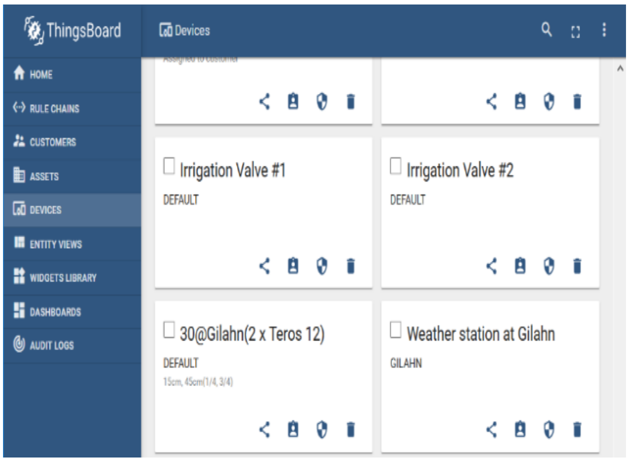


Fig. 4. Cloud server with ThingsBoard platform.

We installed a private server as illustrated in Figure 4 using the ThingsBoard open-source IoT platform [7] and MQTT (Message Queuing Telemetry Transport) to store in the server the actuator statuses and the server's generated valve control commands. The server then transmitted the control commands to the specific gateway.

B. Protocol for non-real-time irrigation control

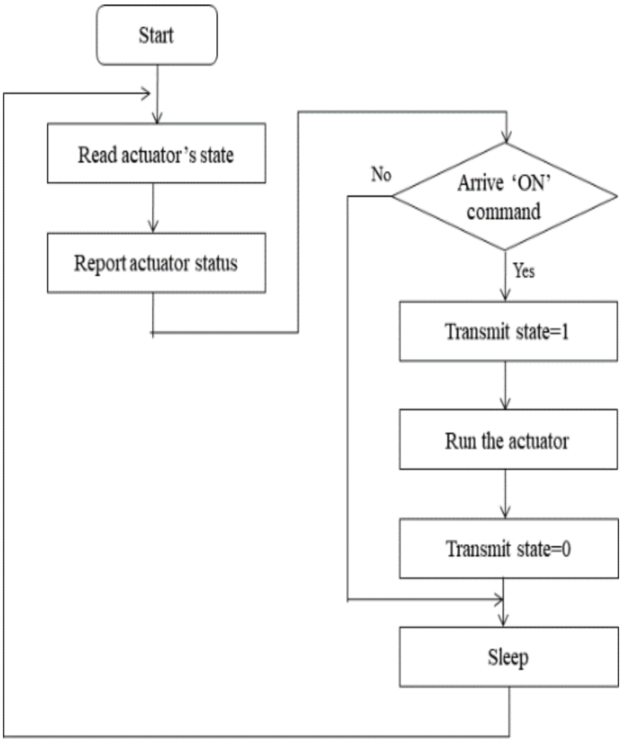


Fig. 5. Flow diagram of actuator node.

Figure 5 illustrates the operation of the actuator node. The node regularly reads the valve status, ON or OFF, and transmits the data to the gateway along with its own data. When the gateway node transmits the ON command, the actuator node transmits a status of 1 to its gateway and runs the valve for the duration that was activated by ON. When the operation expires, then the actuator turns the valve off, immediately transmits a message of 0 to the gateway, and enters sleep mode to reduce battery consumption.

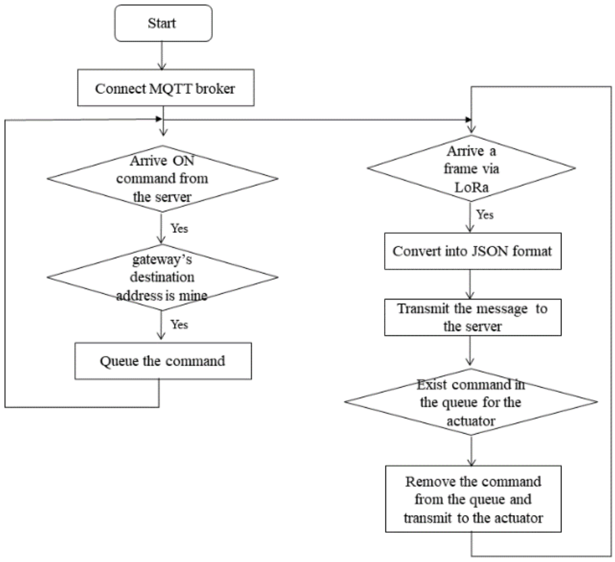


Fig. 6. Flow diagram of gateway node.

Figure 6 illustrates the operation of the gateway. The gateway is connected to a cloud server, the MQTT broker, and when the server, the MQTT publisher, receives the ON command to manipulate the valve, the message is directly stored in the queue. When the actuator receives the status message, the message is converted into JSON (JavaScript Object Notation) format and then retransmitted to the server. Then the gateway examines the message queue to identify any control commands for the actuator; if the control command is present then it is removed, and the command is transmitted to the actuator node.

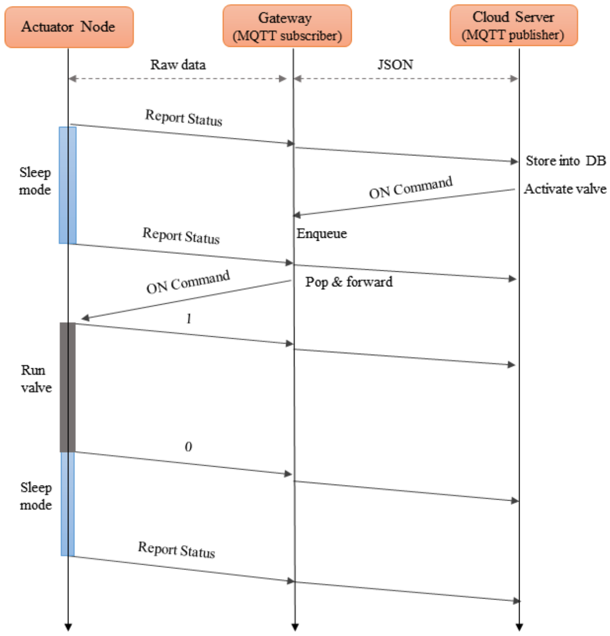


Fig 7. Non-real-time irrigation valve control protocol.

Figure 7 illustrates the protocol for controlling the irrigation valves connected to the actual nodes. MQTT is used between the cloud server and a gateway node to transmit the JSON message, whereas the primitive message is transmitted between the gateway and the actual node due to the low transmission rate of LoRa.

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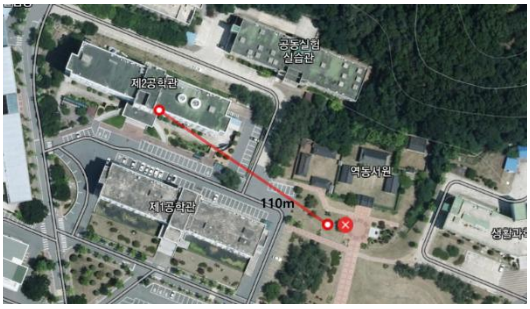
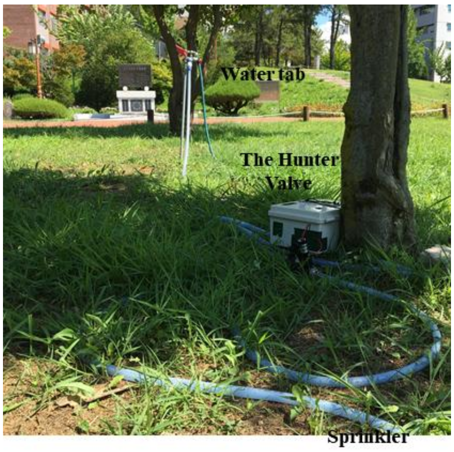
When the irrigation scheduling algorithm makes irrigation decisions, the cloud server sends an ON command with the gateway address, actuator node address, valve identifier, and operation time to the gateway for controlling the valves in that zone of the field. However, if the gateway is in sleep mode, it may not receive the control command messages the server transmits; in these cases, the control command that arrives at the gateway is stored in the queue until the actual nodes are commanded to activate. Similarly, if the actuator node is in sleep mode, it may not receive the control commands the server transmits, and again, the control command is stored in the queue.

When the gateway receives a valve state report message from an actuator node, the gateway finds the command corresponding to that node in the queue because the node is alive, as explained in Figure 7. The found command is removed from the queue, and then the gateway transmits the ON command, comprising the actuator address, valve identifier, and operation time, to the actuator node. The actuator node receives the command and then transmits a 1 to the cloud server to activate the solenoid irrigation valves for a predetermined duration and transmits a 0 to the server when valve operation ceases. Through this process, the server records the times and operation states for each actuator node.

IV. RESULTS AND DISCUSSION



(a)



(b)

Fig. 8. Experimental setup: (a) distance between gateway and actuator node and (b) layout.

We conducted the experiment for this study on a lawn on the campus of Andong National University and used Ethernet to connect the gateway and server. As illustrated in Figure 8(a), the distance between the gateway and the actuator node was approximately 110 m, and we used a water tap, Hunter PGV valve, and sprinkler to irrigate the lawn as illustrated in Figure (b). When the irrigation scheduling algorithm determines that it is time, the server transmits ON to the node to begin irrigation, and the node reports the node's initiation or termination operation state to the server.

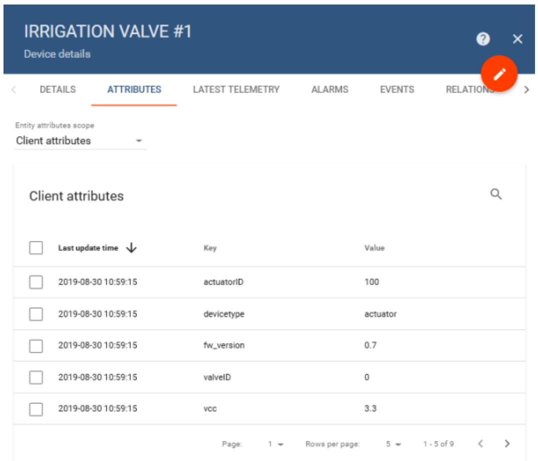


Fig. 9. Sample actuator report.

Figure 9 shows a sample of the state data transmitted from the actuator node: actuator identifier, node type, firmware version, valve identifier, and current node voltage. We designed the node to send status information every hour to “Attribute” in the server and to periodically update these values. The actuator node transmits its own status to “Telemetry” in the server when the valve starts and ends.

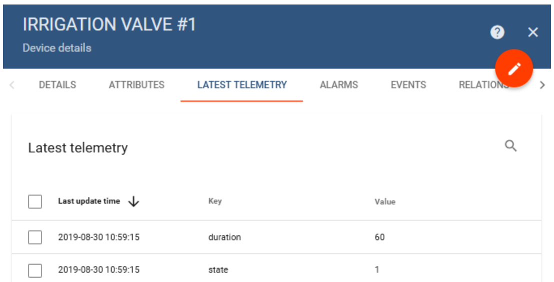


Fig 10. Example of actuator node telemetry

Figure 10 presents a sample valve operation state and duration transmitted to the server before the actuator node activates the irrigation valves; this valve was set to operate for 60 minutes, and when operation terminated, the state of 0 was received and recorded.

The results of this study showed that the low-cost, three-tier, open-field irrigation valve system worked correctly in non-real time.

V. CONCLUSIONS

Attention to wireless actuator technology is gradually increasing in the field of PA. With this paper, we aimed to describe a low-cost LoRa-based wireless irrigation valve system that used a cloud server to autonomously control open-field irrigation valves.

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We designed the hierarchical structure and the non-real-time actuator protocol of the system to reflect characteristics of open fields, and the system exhibited normal valve operation in the experiment. This wireless irrigation valve system precisely controlled watering times and extent for the specific experiment area with an intelligent irrigation scheduling algorithm, and we believe this system can increase productivity while reducing labor costs.

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