

Design and Implementation of an Autonomous Irrigation System using an Open-Source Internet of Things Platform

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Abstract: There is much interest in an autonomous precision irrigation system that can reduce labor and water use and improve productivity in agriculture. This paper explains the design and implementation process of a water pump control for autonomous irrigation by custom scheduling using an open-source Internet of Things platform. Experimental results are presented for demonstrating the proper operation of the automatic irrigation system in an apple orchard.

Keywords : autonomous irrigation, ThingsBoard, Pandas, LoRa, MQTT.

I. INTRODUCTION

Water is central to plant growth, but it is also a finite resource. In Korea, water shortages occur frequently in summer because of irregular rainfall; in fact, Korea could be facing a future water crisis. Furthermore, Korea's agricultural sector is at risk owing to the aging of rural populations, which is diminishing the stock of available farm labor. Therefore, to reduce water and labor needs and improve sustainable agricultural productivity, efficient, autonomous irrigation is necessary [1]. Smart management of irrigation to maintain balanced soil water content is crucial for the health and productivity of farm crops such as apple trees [2], and with smart irrigation, novice farmers can water as efficiently as experienced farmers do. Our objective was to design and implement an autonomous irrigation system based on an open-source Internet of Things (IoT) platform. The system collects soil moisture using a private Long Range (LoRa) network, schedules the irrigation based on the soil moisture data, and automatically controls the water pump in real time using the actuator control technology of the platform. This method has the advantage of reducing the time cost required to build an autonomous irrigation platform and allowing for platform-independent custom irrigation scheduling. We applied our implemented system to an apple orchard and showed that our irrigation system works appropriately. This paper consists of the following sections. In Section 2, we examine existing studies; in Section 3, we describe the network architecture of the autonomous irrigation system, the automatic irrigation control protocol, and the experimental environment; and in Section 4, we present the experimental

results. Finally, we present the conclusions of this paper in Section 5.

II. RELATED WORK

Researchers have used wireless sensor networks to collect weather, soil, and environmental information using soil moisture, temperature, and agro-meteorological sensors and to control a variety of irrigation systems [3 - 5].

Osroosh *et al.* [4] performed automatic irrigation scheduling using the crop water stress index, and Millan *et al.* [6] presented an automated irrigation system using IRRIX, a custom web platform, for a plum orchard. However, investigators have proposed no technology for automatic actuator control.

Ren *et al.* [7] described implementing a system that applied fuzzy control theory for greenhouse irrigation. This system used a local computer to control the actuator valve.

Many researchers have described soil-based, weather-based, or plant-based irrigation scheduling, but it is difficult to find a study about how to run actuators automatically based on a platform.

III. METHODOLOGY

A. Real-time soil moisture measurements and automatic control system

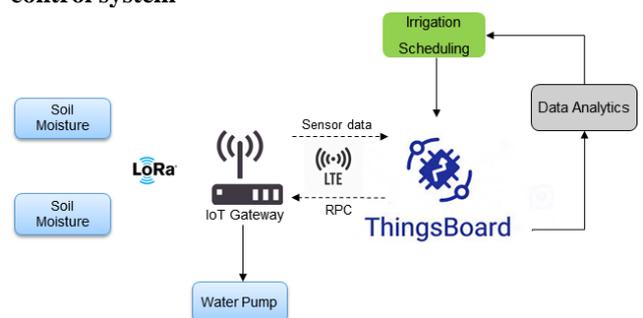


Fig. 1. An Autonomous irrigation system's architecture.

We configured a soil moisture-based autonomous irrigation system using a wireless system network based on private LoRa, as shown in Fig. 1, and constructed a private server using open-source Things Board and PostgreSQL. We constructed the sensor node with Atmega328, RFM95W, and a battery and the gateway with Raspberry Pi, RFM95W, LTE modem, and a relay to control a water pump, as shown in Fig. 2.

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Fig. 2. Prototype: (a) sensor node and (b) gateway node

In computer communication, a sensor node communicates with the IoT gateway using a private LoRa, the gateway communicates with the server using LTE cellular networks, and the messages between the gateway and the server are exchanged using the message queuing telemetry transport (MQTT) protocol [8].

B. Autonomous water pump control protocol

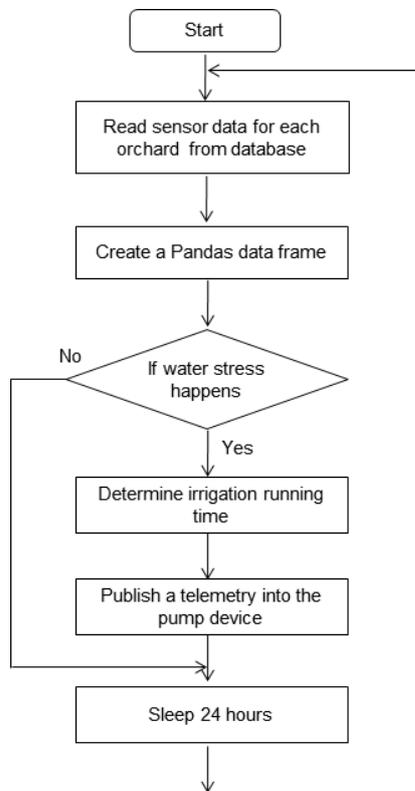


Fig. 3. Flow chart of a simple irrigation schedule.

Fig. 3 shows our simple irrigation schedule. The system reads the data from all the sensors installed in the orchard, and then creates the Pandas data frame. Based on whether or not the crop is under water stress condition, the system decides whether or not to start irrigation. Then, the system determines the duration of irrigation, and publishes the telemetry with irrigation time to the server's water pump device.

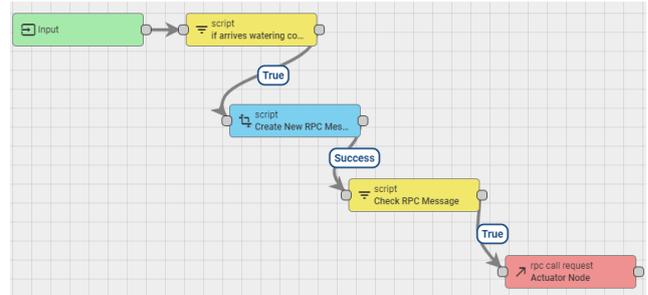


Fig. 4. A rule chain for automatic irrigation.

Fig. 4 shows a rule chain for automatically running a remote water pump using the remote procedure call (RPC) function in Things Board that provides communication among multiple IoT devices. When a piece of telemetry {duration:value} data arrives at a device whose device type is pump, an RPC command is published. Then, the gateway subscribed to this device will receive the published RPC command.

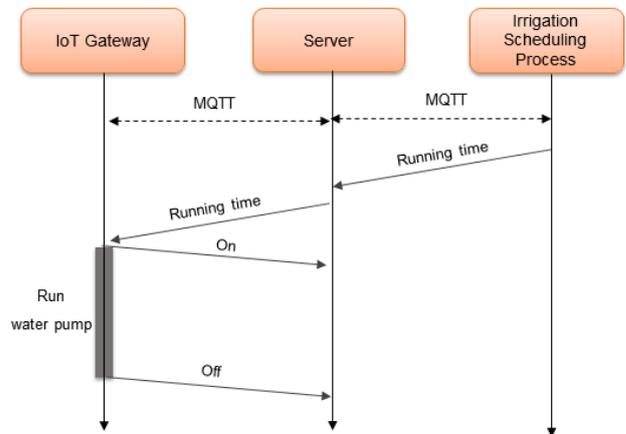


Fig 5. Diagram of an automatic water pump control.

Fig. 5 shows our protocol which operates the water pump automatically with high reliability. When the water pump operation time is transmitted to the ThingsBoard by the irrigation scheduling daemon process, the gateway receives the water pump operation time message, and the gateway uploads an On status message indicating to the server that the water pump is operating. Then, after the water pump has operated for the scheduled time, an Off status message is sent.

C. Experiment Setup



Fig. 6. Experiment setup

We conducted the field experiments in a drip-irrigated Fuji apple orchard near Andong, Gyung-sangbuk-do, at the coordinates of latitude 36.40° N, longitude 128.86° W, and 205 m above sea level, as shown in Fig. 6.

To measure the soil moisture, a TEROS 12 and MPS 6 (Meter Group Inc.) are installed on two plots at a depth of 20 cm. TEROS 12 is for measuring volumetric water content, bulk electrical conductivity and temperature, and MPS 6 is for measuring water potential and temperature. These sensors were read every hour.

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IV. RESULTS AND DISCUSSION

Our custom irrigation algorithm first read the soil moisture data from the database, and the Pandas data frame was created as shown in Fig. 7.

| Plot 0 | | | | | | | |
|---------------------|-------|------|------|------|------|------|--------|
| TEROS12-0 | | | | | | | |
| datetime | ec | temp | vlc | swc | fc | pwp | stress |
| 2020-07-28 05:02:00 | 0.065 | 22.0 | 33.0 | 66.0 | 62.0 | 24.0 | 43.0 |
| 2020-07-28 06:03:00 | 0.065 | 22.0 | 33.0 | 66.0 | 62.0 | 24.0 | 43.0 |
| 2020-07-28 08:05:00 | 0.065 | 22.0 | 33.0 | 66.0 | 62.0 | 24.0 | 43.0 |
| 2020-07-28 09:07:00 | 0.065 | 22.0 | 32.0 | 64.0 | 62.0 | 24.0 | 43.0 |
| 2020-07-28 10:08:00 | 0.065 | 22.0 | 32.0 | 64.0 | 62.0 | 24.0 | 43.0 |

| Plot 1 | | | | | | | |
|---------------------|------|---------|-----|-----|------|--------|--|
| MPS6-0 | | | | | | | |
| datetime | temp | tension | swt | fc | pwp | stress | |
| 2020-07-28 06:24:00 | 22 | -11 | -11 | -10 | -100 | -60 | |
| 2020-07-28 07:25:00 | 22 | -11 | -11 | -10 | -100 | -60 | |
| 2020-07-28 08:26:00 | 22 | -11 | -11 | -10 | -100 | -60 | |
| 2020-07-28 09:27:00 | 22 | -11 | -11 | -10 | -100 | -60 | |
| 2020-07-28 10:28:00 | 22 | -11 | -11 | -10 | -100 | -60 | |

Fig. 7. A Pandas data frame.

The ec, temp, and vlc columns of Plot 0 refer to the bulk electrical conductivity, temperature, and soil volumetric water content(%) of TEROS12; the fc, pwp, and stress columns(unit = mm/m³) refer to field capacity, permanent wilting point, and water stress; and the swc column refers to the current moisture value. The 'swc', 'fc', 'pwp', and 'stress columns' (units = mm/m³) are obtained by multiplying the 'vlc', 'field capacity', 'permanent wilting point', and 'water stress' (units = %) by 'sensor depth', respectively.

Temp and tension in Plot 1 refer to the temperature and water potential (kPa) of MPS 6; the unit for swt, fc, pwp, and stress is kPa; and swt is the value of the tension column.

| Device details | | | |
|--------------------------|---------------------|------------------|--------|
| DETAILS | ATTRIBUTES | LATEST TELEMETRY | ALARMS |
| Latest telemetry | | | |
| <input type="checkbox"/> | Last update time ↓ | Key | Value |
| <input type="checkbox"/> | 2020-08-04 17:05:19 | waterpump | 1 |
| <input type="checkbox"/> | 2020-08-04 17:05:19 | duration | 20 |

(a)

```
2020-08-04 17:05:19,925 INFO {'method': 'setGWPump', 'params': {'duration': 20}}
```

(b)

| Device details | | | |
|--------------------------|---------------------|------------------|--------|
| DETAILS | ATTRIBUTES | LATEST TELEMETRY | ALARMS |
| Latest telemetry | | | |
| <input type="checkbox"/> | Last update time ↓ | Key | Value |
| <input type="checkbox"/> | 2020-08-04 17:25:21 | waterpump | 0 |
| <input type="checkbox"/> | 2020-08-04 17:05:19 | duration | 20 |

(c)

Fig. 8. Irrigation operation process: (a) Start Irrigation, (b) Gateway's log file, and (c) Terminate Irrigation.

When (stress – swc) is negative, irrigate is performed during the irrigation time corresponding to its absolute value. When the irrigation time is determined as 20 minutes, the {duration: 20} telemetry is uploaded to the water pump device in ThingsBoard (Fig. 8(a)); with this data, the RPC command is sent to the gateway according to the ThingsBoard rule chain. Fig. 8(b) shows the RPC command log received by the gateway, in which RPC uses 'method' and 'params' keys. The gateway uploads the water pump operation status, {waterpump : 1}, to the server indicating that the water pump is operating, as shown in the first row of Fig. 5(a), and the water pump operates during the received time value. When the pump operation is terminated, the gateway uploads the water pump stop status, {waterpump : 0}, as shown in the first row of Fig. 8(c). The server can confirm the actual operating time by checking 1 and 0 of the water pump stored in each water pump device.

V. CONCLUSION

With this paper, we aimed to present the design and implementation of an autonomous irrigation system using Things Board, an open-source IoT platform. Using a rule chain function, a mechanism is established in which when a specific type of message arrives to a water pump type device, the RPC command is automatically transmitted to the gateway controlling the water pump.



Applying the implemented system to an apple orchard, we confirmed that the system operated appropriately. We believe this method allows for easy implementation of an autonomous irrigation system.

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Byungsoon Kim is working with Andong National University in South Korea as a professor since 2003. He received his PhD and MS degrees in computer science from Kyungpook National University and Sogang University, South Korea, respectively. His research interests include wireless sensor and actuator networks, and smart farming.

