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SMARTPHONE-OPERATED SMART FARM WATERING SYSTEM USING LONG-RANGE COMMUNICATION TECHNOLOGY

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ABSTRACT

Keeping proper soil moisture is essential in growing good quality and efficient fruit yield. To that effect, soil moisture level must be controlled, to maintain proper watering. A smartphone application was developed to operate a smart farm watering system. It monitors the soil's moisture and launches sprayers to water dried areas. The system's architecture was built in a distributed client-server computing system, in a small computing grid. The grid was built across long range (LoRa) communication networks with the same ID, but different addresses. In terms of integration, the system was built using autonomous microprocessors, which consist of a server and five client microprocessors. A smartphone was used as the server of a central controller, and four moisture detection modules and a water spraying system module were used as autonomous clients. The server was inter-connected with the clients via a star-type topology network in the polling processes. Each client module autonomously analyzes the measured digital voltage of the moisture sensor plugged into the soil. When the server sends queries regarding the status of the moisture level, the client sends the request signal to the server using the LoRa communication technology. The communication between the server and the clients is based on the LoRa communication technology. The LoRa-to-Bluetooth converter is used to connect the Bluetooth and the LoRa signal. The field test was performed in a watermelon field, with an area of approximately 6600 m^2. The water spraying system constructed with LoRa communication technology could successfully manage and control the moisture level in the field test.

Introduction

Due to global warming, which causes extreme weather phenomena worldwide, such as sudden heat waves and unusually dry weather, it is more difficult to cultivate high-quality vegetables and fruits. Monitoring the soil's moisture is crucial to producing good quality and efficient fruit yield. Too wet or too dry soil could damage vegetable roots, so moisture must be checked regularly with moisture sensors (Jabro et al., 2020; Lee, 2018). Depending on the results, water should be supplied into the dried area.

On the other hand, since fields are wide and open, covered with plant leaves and fruits. Manual monitoring the condition of the soil moisture level of the field is a big problem for farmers, as stepping on the plants damages the stems and makes them more vulnerable to viral or bacterial infections. Sometimes, there are poisonous snakes or harmful insects, too. Many methods were suggested to solve this problem by using soil sensors (Placidi et al., 2020; Millán et al., 2020).

For precision farming, a long-range remote controllable automatic water supply system is needed, which can be remotely operated with a smartphone. The dynamic worldwide smartphone penetration rate and the rapid development of IT have enabled development of many smartphone applications for various purposes, including smart farming systems (Lee, 2019; Othman et al., 2021; Sharmrat et al., 2020; Abhiram et al., 2020; Sivabalan et al., 2020; Tagarakis et al., 2021; Lee, 2017) and chemical spraying applications (Lee, 2019).

For a system to gather data from soil moisture sensors, a network must be constructed. The server-oriented distributed computing system in client/server architectures comprises a server and clients. The server divides a task into many parts and assigns them to the clients. Then, each client completes the given task independently. In implementing a small-size grid, the Monadic model is suggested as a centralized data repository model (Hwang et al., 2013).

To collect measured data in an open area, long-distance communication is needed. In building the long-range remote controllable system, the Long Range (LoRa) communication technology could be used to cover a large area, at a lower power consumption (Mah and Kim, 2019). The LoRa technology belongs to the license-free band network technologies of the Lower Power Wide Area Network (LPWAN) and offfers a communication distance of over 16 km.

The LoRa is a proven technology used worldwide in North America, Europe, and Asia. In Seoul, South Korea, it supports the 421 km of the Internet of Things (IoT) infrastructure, and 195 S-Net (Smart Seoul Network) LoRa base stations will be installed by the end of 2021. Further expansion of the network was planned. The said LoRa network was used to monitor the air quality and the hazardous structures and to read the water meters and the electric meters. And the smart street light was built for the safe way. The smartphone monitoring application can make the light be turned on-off and blink. However, when the phone is outside the WiFi boundary, the smart street light cannot be operated even though the phone is still inside the boundary of the LoRa, which is much longer-range communication technology than short-range WiFi. The water spraying system on the smart farm using the LoRa network was suggested to measure the soil's moisture (Lee, 2022a). And there was research on developing a chemical spraying system using LoRa communication technology (Lee, 2022b).

Purpose of work

Due to unusual global weather instability, some areas, such as Europe, suffered severe water shortages this year. Using water efficiently is a critical issue nowadays, and in crop production, the quantity of water should be monitored very carefully.

Over-irrigation may cause the crop's roots to weaken or rot so that the plants can be infected with fungal diseases, downy mildew, various bacteria, and viruses. Furthermore, most importantly, wasting water must be prevented. But, under-irrigation causes the crops to become stressed, so the plants suffer from growth disorders, such as growth delay and not bearing fruit properly. Also, all the leaves may be withered, causing low-quantity and poor-quality fruits. So, precise irrigation based on soil moisture conditions is essential to produce good products and minimize water waste.

Figure 1 shows the watermelon field of approximately 6600 m^2. The field does not have enough space for a person to enter the field to check the soil's status manually, and it is too wide for WiFi or Bluetooth communication when using soil moisture sensing. So, long-distance communication technology is needed to do moisture sensing.

Figure 2 shows the communication distance and the data rate among various communication technologies. As shown in the graph, LoRa is a better choice for long-distance communication than the previous ones.

In this research, an automatic long-distance remote-controlled irrigation system will be built with soil moisture sensors.

Figure 1. The watermelon field of approximately 6600 m^2, with no easy access for watering treatments.

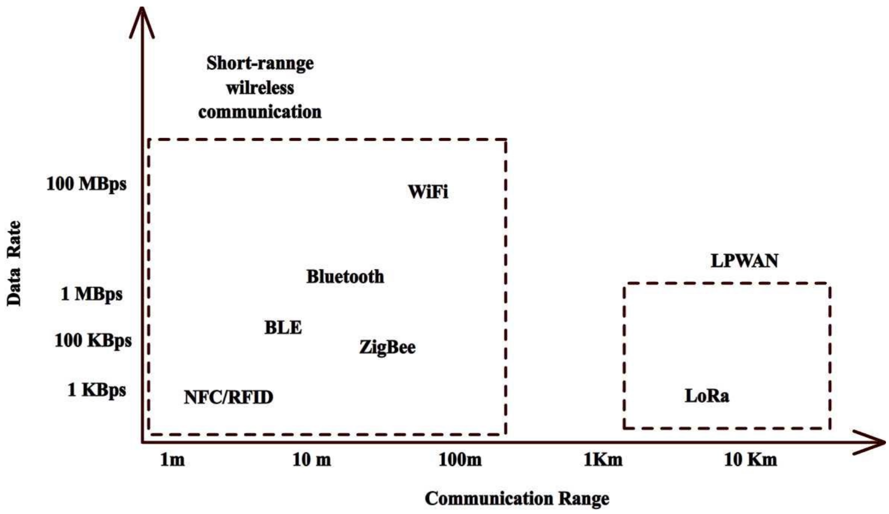

Figure 2. The communication distance and the data rate among various communication technologies.

Scope of work

The main goal of the research is to build a long-distance remote controllable automatic water spraying system by an android smartphone based on the information of four moisture sensing modules on the soil. This system will consist of three different devices: the water control system, soil moisture sensing modules and the remote control device. The water control system will be built to supply water to a selected area by opening the solenoid valve and operating a water pumper. The remote control device will be programmed on a smartphone by developing an android application. Moreover, this water spraying system will be constructed in a distributed computing architecture of the client-server in a small-size computing grid. A LoRa (Long rage) communication network between the client and the server will be constructed.

Finally, the scope of work is to program microprocessors to be clients and an android smartphone to be a server, to construct the network of clients and server, and to develop a converter that can trans-communicate the LoRa and the Bluetooth frames. This converter allows the smartphone to control the end devices within the LoRa communication distance.

In this paper, the watermelon field of approximately 6600 m^2, as shown in Figure 1, will be used as a test bed. In spraying water over the crops, misty nozzles will be used.

Method of work

The water spraying system discussed in this paper was built in a client-server distributed computing architecture on a small computing grid. Figure 3 shows the client/server architecture of the computing and overlay networks.

Clients can be microprocessors or embedded systems. In this research, five microprocessors were used as clients (secondary), and an Android smartphone, Samsung Gallaxy, was used as a server (primary). The dotted lines are wireless connections made using LoRa communication technology. Each distributed microprocessor measured the moisture level and calculated the dryness of the soil independently from the server.

The system grid was built in a LoRa network with the same network ID but different addresses. The network structure of the computing system was classified as the star-type topology at the physical level, in which each client has a dedicated point-to-point link only to a central server, and the bus-type topology at the logical level. The stop-and-wait ARQ (Automatic Repeat Request) method was used to correct communication errors.

The smartphone sever was programmed to collect information from the client-sensor modules, and to send information to the water control system by communicating with all the sensor modules and the control system via a multipoint polling process in which the primary informs to be ready to receive data and the secondary responds with data. The water control system sprayed water over the monitored area when the phone sent the watering request signal for the area.

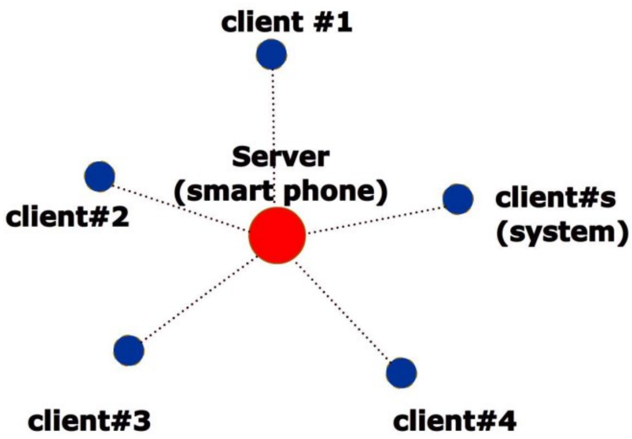

Figure 3. The client/server architecture of computing and overlay networks. The dotted lines are wireless connections based on the LoRa communication technology

Figure 4 shows the configuration of the distributed computing system in which a smartphone server is an information collector from four sensor modules and controls the water spraying device. A distributed microprocessor was embedded in each sensing module and the water control system. The smartphone server sent the task of collecting data to a sensor module and the selected sensor module measured the moisture data. The server sends the task of controlling the water spraying device to the water control system. Each distributed microprocessor performs the task requested by the server. The water spraying system microprocessor also executed the task requested by the server to control the water spraying system.

Each LoRa module of the sensing modules was communicated with the LoRa-to-Bluetooth converter using a 9600 bps LoRa. The converter and the smartphone were in 9600 bps of Bluetooth communication, and the converter translated the Bluetooth signal into the LoRa communication frame and vice versa. The communication between the converter and the water spraying system was also in 9600 bps LoRa communication.

The polling process was performed as follows. First, the server made a connection to the LoRa-to-Bluetooth converter#1 and sent the task of measuring the moisture data to sensor module#1. The selected module performed the task and sent the measured moisture data to the server. Next, the server disconnected converter#1 and connected the LoRa-to-Bluetooth converter#2. This process was repeated until all the data was collected from the module. Then the server made a connection to the LoRa-to-Bluetooth converters and sent the task of requesting water spraying operation to the water control system.

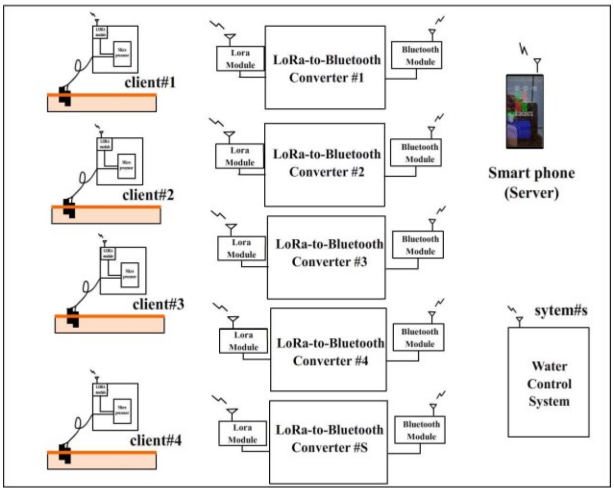

Figure 4. Configuration of the distributed computing system in which a smartphone server is an information collector of four sensor modules and controls the water spraying device. A distributed microprocessor was embedded in each sensing module, and the water control system

Research results

The results of the research were as follows. First, the moisture of the sample soil was measured. Figure 5 shows the soil moisture sensing module with a conductivity sensor connected to the soil in the LAB. The module was equipped with a LoRa module for LoRa communication. When the sensor server requested the moisture data, the module started to measure the digital voltage of the soil and compared it with the preset-reference voltage value, 800, and estimated the water requirement condition as true or false value. Then, the module sent the true or false value to the smartphone.

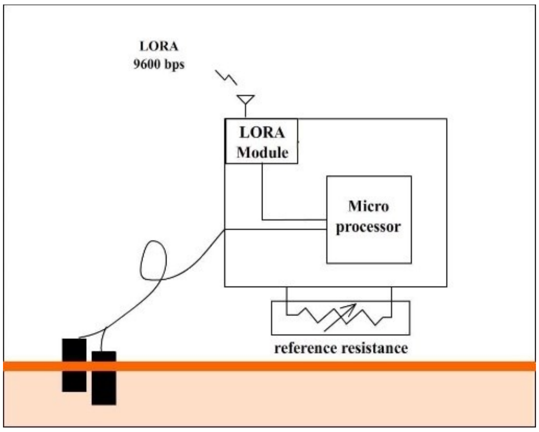

Figure 5. The soil moisture sensing module with a conductivity sensor plugged into measuring soil

Figure 6 shows the measured moisture data of a conductivity sensor plugged into tested soil in the LAB. The vertical axis number was the digital voltage measured in 10 bits binary number scale. The horizontal axis means measured time on a minute scale. The data were measured every minute for eight days. Some peaks on the graph were caused by the cracks created in the dry soil process. The volume of soil will be reduced during the dry process.

The measured analog voltage of the conductivity sensor, V, is as follows:

$$V= Vdigital/1024 \times 5 \text{ (Volt)} \quad (1)$$

and the moisture of the soil in percentage is:

$$M= (Vdigital +1)/1024 \times 100\% \quad (2)$$

Because ten bits were used to express the analog voltage of 5 Volts, 1023 is the maximum number for 5 volts, which is the 100% moisture condition.

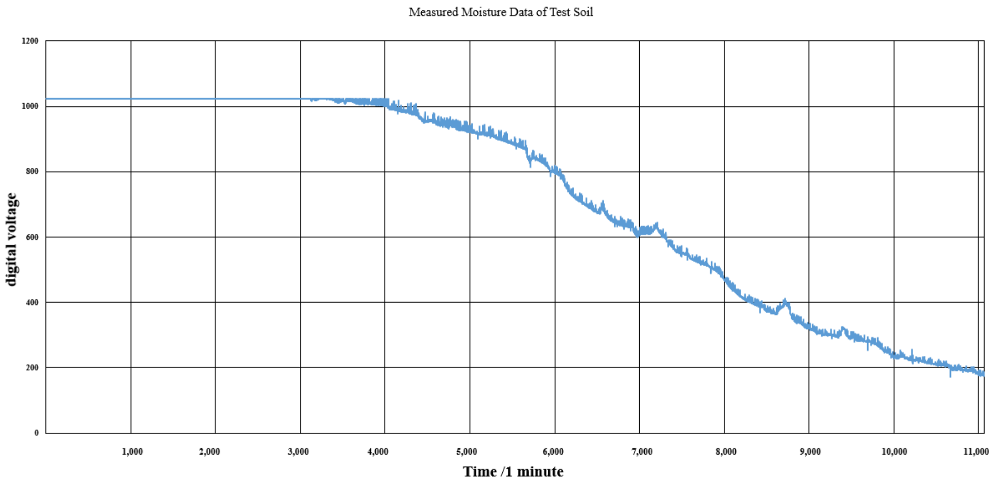

Figure 6. The measured moisture data of a conductivity sensor plugged into tested soil in the LAB. The horizontal axis is a time scale in a minute. The vertical scale is a measured digital voltage in 10 bits binary number scale

To check the accuracy of the moisture sensor data, the soil condition was monitored in follow LAB experiments. Figure 7 shows the wet soil at the 1023 digital voltage. The soil was completely wet. At this condition, the conductivity is almost zero, which is 100% moisturized soil like a rainy day. Figure 8 shows the soil at the 635 digital voltage. The soil was moderately dry. Figure 9 shows the dried soil at the 185 digital voltage. The soil was almost as hard as a during drought, with 0% moisture.

Figure 10 shows the configuration of the water control system. The device control module was equipped with a LoRa communication module, a microprocessor, a water pump, and four solenoid valves. The communication data rate of the LoRa-to-Bluetooth converters and the device control module was in 9600 bps LoRa communication. The smartphone server and the converter communicated in 9600 bps Bluetooth. The device control module was built on an electric circuit board with ATMEGA's 89C51 microcontroller. The device control microprocessor powered up four solenoid valves and a water pump for spraying water over the dried area. The device control center controlled the water spraying time and selected the solenoid valve to spray water over the dried area. Misty nozzles were used to spray water over the field. And the distance between each nozzle was approximately 2 m apart on the same hose, and the separation distance between hoses was approximately 5 m apart. The diameter of the inducing hose was 20 mm. The solenoid valve, the HPW2150 model, was made by the Hyoshin Mechatronics company. The diameter and operating voltage of the valve were 20 mm and 220 Volts each.

Figure 7. The soil at the 1023 digital voltage. The soil was completely wet

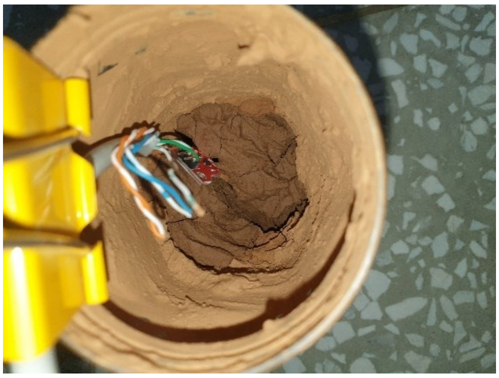

Figure 8. The soil at the 635 digital voltage. The soil was moderately dry

Figure 9. The soil at the 185 digital voltage. The soil was very hard, as during a drought

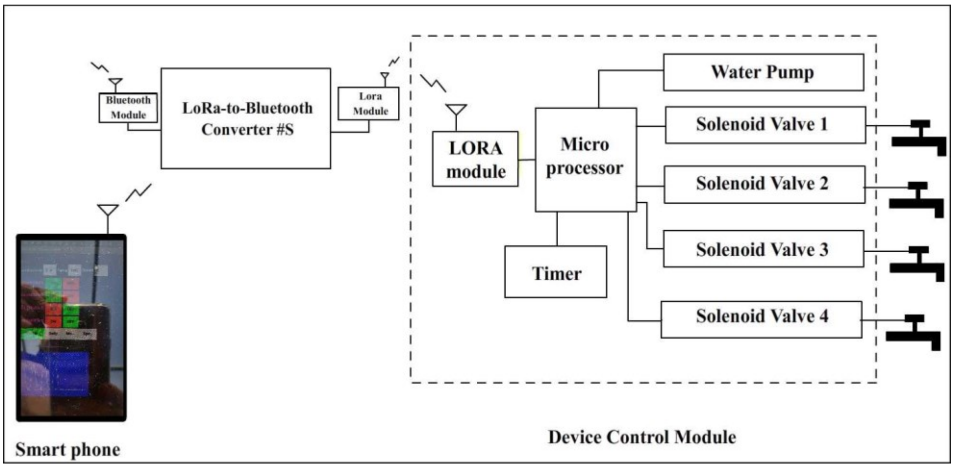

Figure 10. The configuration of the water control system

Figure 11 shows the screenshot of the programmed smartphone. All the Bluetooth modules of the LoRa-to-Bluetooth converters and the spray control module were paired with the phone. When the smartphone application was launched, the phone infinitely repeated to connect and disconnect to/from each of the modules. The phone, as a server, controlled all the sensor module's microprocessors to get the moisture data and the spraying control module's microprocessor to spray water over the dried area in communicating in the polling process.

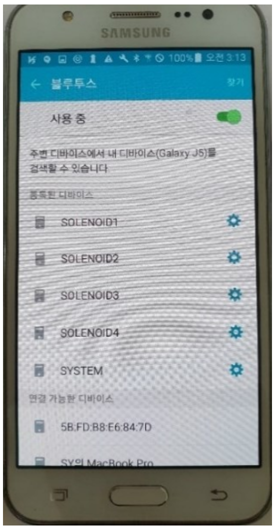

Figure 11. Screenshot of the programmed smartphone. All Bluetooth modules of the LoRa-to-Bluetooth converters and the spraying control module were paired with the phone

Figure 12 shows one of the tested moisture sensing modules inserted into the soil. The sensor module made by Cylewet Co. was the 2Pcs soil moisture sensor soil humidity detection module for Arduino. The sensor size was 6.5 × 2.0 × 0.8 centimeters. Each sensor module was connected to each moisture detection module. The sensing module was built with an Atmel 328P-PU microprocessor. The processor was programmed to check the analog voltage on a digital scale. The digital reference voltage for the water spray condition was set at 800 to simulate the operation of the system. When the voltage was below 800, the processor sent the true value to the server to request water.

Figure 13 shows the locations of the moisture sensor modules connected to the watermelon field. Four sensor modules were numbered #1, #2, #3, and #4 in the field. Each sensor module was plugged into the soil approximately 5 cm deep.

The longest distance between the side edges of the field was approximately 100 meters. Data communication between the LoRa-to-Bluetooth converter and the water spraying device was tested by installing at both edges of the longest side of the field, where the distance between them was approximately 100 m apart, and data communication was found with no data loss. The test result was successful.

Even though the communication distance of the commercial spec of RYLR896, made by RAYAX co, was within 15-20 km.

Figure 12. One of the tested moisture sensor modules inserted into the soil

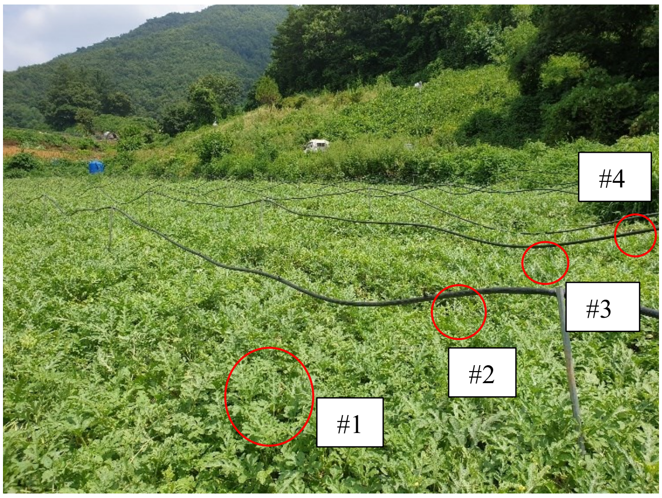

Figure 13. The locations of the moisture sensing modules plugged into the watermelon field. Four sensor modules were numbered #1, #2, #3, and #4

Figure 14 shows the screen of the smartphone as a remote controller. The phone was a Samsung Galaxy 3, model SHV-E210K, with an Android build KitKat, version 4.4.4. On the phone's screen, the water requesting statuses of all four sensor modules were shown. The request statuses of all sensor modules were solenoid valve#1 off, valve#2 off, valve#3 on, and valve#4 on. This means that the moisture conditions of solenoids #3 and #4 were dried out. Then, the phone sent the signal of all the water requests statues to the water spraying center module.

Figure 15 shows the field test of the water spraying system installed in a watermelon field with an area of approximately 6600 m^2. The system successfully measured soil moisture and water sprayed on the field.

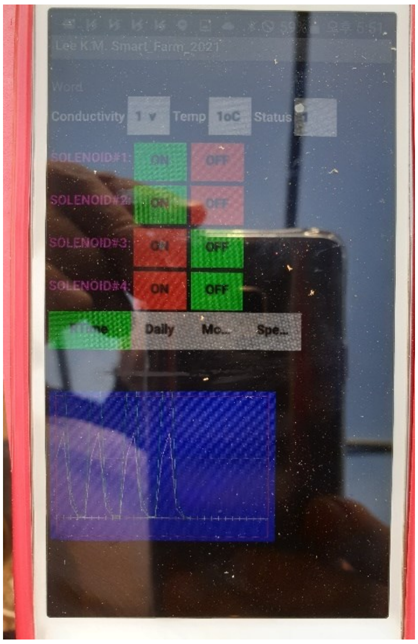

Figure 14. The screen of a smart phone used as a remote controller

Figure 15. The field test of the water spraying system installed in a watermelon field with an area of approximately 6600 m^2.

Conclusions

1. A smartphone was used in a distributed computing system for agricultural water spraying based on a client-server architecture. In building the system, five microprocessors were programmed to be clients and an Android smartphone as a server. The network of this system was built with LoRa wireless communication technology. By the LoRa-to-Bluetooth converter, the smartphone could control the five microprocessors through the LoRa network.
2. Each microprocessor of the sensing modules analyzed the measured digital voltage and independently generated the water request signal. When the server sent queries regarding the status of the moisture level, each client replied with a true or false value to the server. The task handling process between the server and the client was in the polling process. The converter and all modules were in 9600 bps LoRa communication, but the smartphone and the LoRa-to-Bluetooth converter were in 9600 bps Bluetooth communication within approximately 100 meters. After constructing the water spraying system for a watermelon field of approximately 6600 m^2, the system successfully measured the soil's moisture and sprayed water on the dry area.
3. However, further research is required to solve the unstable functionality of the moisture sensing module for an extended period of operation.

Acknowledgments

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SMARTFON JAKO NARZĘDZIE STEROWANIA INTELIGENTNYM SYSTEMEM NAWADNIANIA BAZUJĄCYM NA TECHNOLOGII ŁĄCZNOŚCI DALEKIEGO ZASIĘGU (LORA)

Streszczenie. Utrzymanie odpowiedniej wilgotności gleby jest niezbędne do uzyskania dobrej jakości i wydajnego plonu. W tym celu należy kontrolować poziom wilgotności gleby. Do obsługi inteligentnego systemu nawadniania gospodarstwa opracowano aplikację na smartfona, która monitoruje wilgotność gleby i uruchamia opryskiwacze do podlewania przesuszonych obszarów. Architektura aplikacji została zbudowana w formie rozproszonego systemie obliczeniowego klient-serwer, na bazie małej sieci obliczeniowej dalekiego zasięgu (LoRa) o tym samym ID, ale różnych adresach. Do integracji system wykorzystuje autonomiczne mikroprocesory składające się z serwera i pięciu mikroprocesorów-klientów. Jako serwer centralnego sterownika wykorzystano smartfon, a jako autonomiczne klienty cztery moduły wykrywania wilgoci oraz moduł systemu zraszania wodą połączone z klientami za pomocą sieci o topologii gwiazdy. Każdy moduł kliencki autonomicznie analizuje zmierzone napięcie cyfrowe czujnika wilgotności umieszczonego w glebie. Kiedy serwer odpytuje o poziom wilgotności, klient wysyła sygnał do serwera za pomocą technologii komunikacji dalekiego zasięgu (Low-Range technology, LoRa). Komunikacja pomiędzy serwerem a klientami oparta jest na technologii komunikacyjnej LoRa i zintegrowana z Bluetooth za pomocą konwertera. Eksperyment polowy

przeprowadzono na polu arbuzów o powierzchni około 6600 m^2. System zraszania wodą skonstruowany w technologii komunikacji LoRa z powodzeniem kontrolował poziom wilgotności w teście polowym, i zarządzał nim.

Słowa kluczowe: system nawadniania, aplikacja Android, monitoring z drona, komunikacja LoRa, logistyka, jakość, zaopatrzenie, ocena