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Design of a crop-appropriate irrigation system for digital agriculture during the pandemic, crisis of public health

Seung Jae Kim
Student, Dept. Information & Communication Engineering, Sunchon National University, Korea

Meong Hun Lee
Professor, Department Smart Agriculture major, Sunchon National University, Korea

Hyun Yoe
Professor, Depepartment Information and Communication Engineering, Sunchon National University, Korea

***Abstract*---**A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself. The Abstract should be 100 to 200 words in length. The abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited. The keyword list provides the opportunity to add keywords, used by the indexing and abstracting services, in addition to those already present in the title. Judicious use of keywords may increase the ease with which interested parties can locate our article.

Keywords*---IoT, application, smart farm, precision irrigation system.*

Introduction

Due to the rapid increase in population in recent years, there have been many efforts to increase food production necessary for human survival (Mumtaz et al., 2017). It is urgent to prepare measures for efficient irrigation of crops along with drought caused by climate change caused by such an increase in population

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(Choi et al., 2013; Kim 2013). To solve this problem, precision agriculture, one of the many advanced technologies that increases food productivity for human survival, uses certain sensors and software to maintain crop productivity. As a technology that receives exactly what is needed to optimize the possibility of increasing food production, it is possible to monitor crop conditions simultaneously (Uferah et al., 2019).

Research on the irrigation system for precision agriculture is being conducted in various ways. The irrigation system currently in use has an empirical method of managing the irrigation time and amount using a timer after observing the growth state of a crop, and an automatic irrigation method of controlling the water supply by measuring the moisture state in real time (Sehan et al., 2018; Atijosan et al., 2021; Lee et al., 2013). In addition, to optimally manage the elements necessary for the field crop environment, a system is established to predict the production of the field after big data analysis using IoT such as a soil component collection device (Youm et al., 2018; Kim et al., 2021).

However, irrigation methods that do not fit the characteristics of crops, the state of the soil, and the environment are fatal to crops as well, and can have a significant impact, such as an increase in water consumption due to irregular irrigation methods (Navarro-Hellin et al., 2015). This paper aims to design and propose a precision irrigation system for optimal growth by incorporating welsh onions, one of the crops of field vegetables, into the study while increasing the efficiency of water use according to the characteristics of soil for precise agriculture. The technology used in this paper constitutes three scenarios, installs Internet of Things (IoT) sensors in places where crops are planted (field vegetable gardens, greenhouses, and smart pots), analyzes information through automatic weather stations (AWS), and delivers real-time weather data to the database and mobile WS application server. In addition, two farms were selected to verify the performance of the automatic water system, one maintaining the traditional agricultural method, and the other was introduced to collect water supply data for three months and compare their yields.

The composition of this paper is as follows. Chapter 2 presents the irrigation method according to the cultivation method, Chapter 3 discusses the design of the research system presented in this paper, Chapter 4 discusses the implementation process and its own experimental process through three scenarios, and Chapter 5 discusses the performance verification. Finally, Chapter 6 concludes with a conclusion about the research process.

Cultivation Method and Irrigation

Traditional Cultivation Method

Traditional welsh onion cultivation is mainly produced in field gardens, and germination is induced by sowing seeds from mid-March when the temperature of the ground rises to prevent frost damage or by using medium vegetables that can properly cover soil or induce dark environments such as straw.

Welsh onions that have been germinated are manually irrigated by humans according to temperature, humidity, and soil conditions. Due to the nature of welsh onions, from May to July, the temperature and climate suitable for welsh onions to grow are provided to grow well, but from autumn, the cold comes quickly, and the growth period is shortened.

The traditional welsh onion farming is from February to March, early in the early spring. There is spring cultivation by sowing seeds in May or early June, and autumn cultivation by sowing seeds in late October or early September (https://hae-su.tistory.com/28). In this traditional cultivation method, a lot of information can be found to the extent that guidelines are provided, but one of the problems presented in this paper, global warming is making the timing of sowing or cultivation unstable, and drought occurs, leading to indiscriminate use of agricultural water.

The Cultivation Method Using Information and Communication Technology

On the other hand, in the case of cultivation using information and communication technology (ICT), a technology capable of managing open gardens using mobile devices is presented. In the traditional cultivation method mentioned above, humans manually perform irrigation, while in the cultivation method using ICT, control devices installed in the open garden and mobile devices are operated remotely to provide irrigation function (https://www.farmnmarket.com/news/article.html?no=10267). However, until now, the system for irrigation after accurately grasping the temperature and humidity of the soil is insufficient, resulting in indiscriminate waste of agricultural water. Although it provides convenience that humans do not directly perform irrigation through remote control, there may be problems in that sufficient amount of moisture is not supplied to the welsh onions or too much moisture is supplied to cause soil decay.

Therefore, the system that provides an appropriate amount of irrigation according to the soil condition presented in this paper aims to contribute to solving this problem and leading to optimal welsh onion growth.

Data Collection Procedure and Analysis

In order to conduct this study, two comparative farms were selected, and data collection was conducted to farms using traditional methods and farms that introduced optimal irrigation systems, respectively. Farmers using the traditional method measured the total irrigation volume for a week through a farming journal operated by the farm itself and checked the yield per quarter. On the other hand, farmers who introduced the optimal irrigation system presented in this paper measured the weekly irrigation volume stored through the database operated by the system itself, and the crop yield was measured based on the crop yield written in the farming journal, such as farms using traditional methods. The evaluation index of this study was designed as follows.

A. How much is the difference in irrigation volume?
B. Is there a difference in yield according to the difference in irrigation volume?

Through two evaluation indicators, we will evaluate how good the system presented in this paper.

System Design

This chapter deals with the contents of the system in which the study was conducted to provide precise irrigation according to the soil condition of the crop. First, we deal with the system architecture that designs the research which is divided into physical layers, intermediate layers, and application layers, respectively.

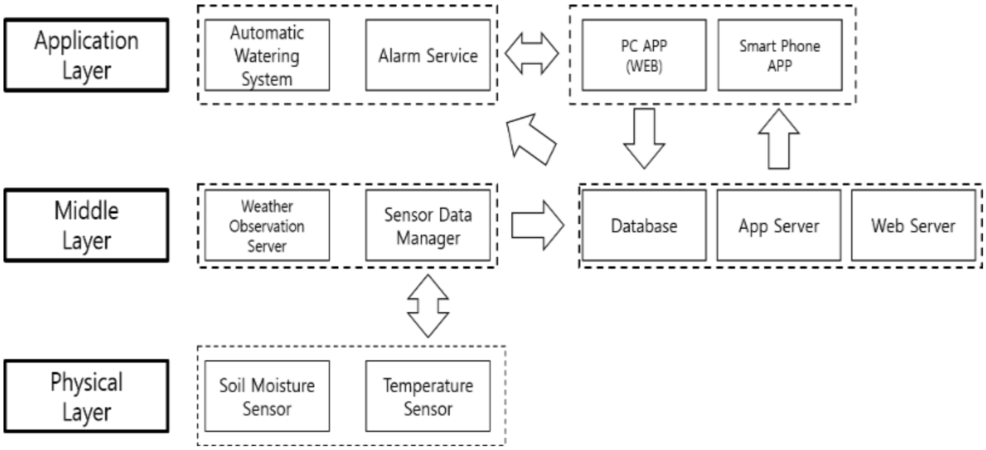
System Architecture

In this paper, the architecture of IoT sensor-based environmental monitoring system, which is necessary to design precision irrigation system according to soil condition of crops, was designed. The composition of the system consists of the physical layer in which the sensor is built, the middle layer in which measured data and the AWS measurement data are relayed and communicated by the Meteorological Administration, and the application layer in which the last analyzed system is provided to the user in an application or web environment (Lee et al., 2018). Figure 1 illustrates the system architecture for these remote precision irrigation systems.

The physical layer consists of soil moisture sensors and temperature sensors for measuring soil environment, and the middle layer consists of sensor data managers store measured sensing data in the database or transmit it to web servers and mobile application servers, and weather observation servers that transmit measured weather data from the Meteorological Administration AWS.

The application layer consists of an automatic irrigation system and an abnormal situation notification service. The results data from the weather data measured at the Meteorological Administration AWS and the database analysis are delivered and operated to the automatic irrigation system, and the operation cycle, real-time sensor measurement data values, and weather station AWS measurement data are provided to the user through mobile app and PC. The data provided is then stored back in the database to derive the best value for the analysis of the data being repeated.

Figure 1. *System architecture for precise irrigation according to soil conditions of crops (Lee et al., 2018)*



System Configuration

Before explaining the composition of the precision irrigation system according to the soil conditions of crops, the current open source IoT-based systems are mostly theoretical and there is a limit to the demonstration of concepts (Kamienski et al., 2019). An example of not introducing advanced functionality in existing platforms and architectures in irrigation functions is the FIGARO project. It aims to increase water quality productivity and improve irrigation methods through the development of precision irrigation platforms, but the IoT is not directly involved (Doron 2017).

Thus, this paper used two kinds of sensors for soil humidity and site temperature measurement to be able to measure soil condition and temperature and collect data in real time by installing environmental IoT sensor on the open field to improve irrigation method and implement precision irrigation according to soil condition while directly involved by the IoT.

To measure the soil environment, a system was designed to realize precision irrigation suitable for the soil environment using soil moisture sensor, which measures soil moisture content suitable for the growth of welsh onion, and temperature sensor, which measures field temperature.

For precision irrigation, the database is built to measure the properties of soil and the information of the target crops from sensors and store them in the database, and at the same time deliver them to the application server and web server. In addition, real time weather conditions are communicated to the automatic water irrigation system in connection with the AWS system of the Meteorological Administration for precision irrigation.

Finally, it consists of services that receive these irrigation data, abnormal situation notification, and remote environment data through PC App or mobile App.

Precision Watering System Flow Chart

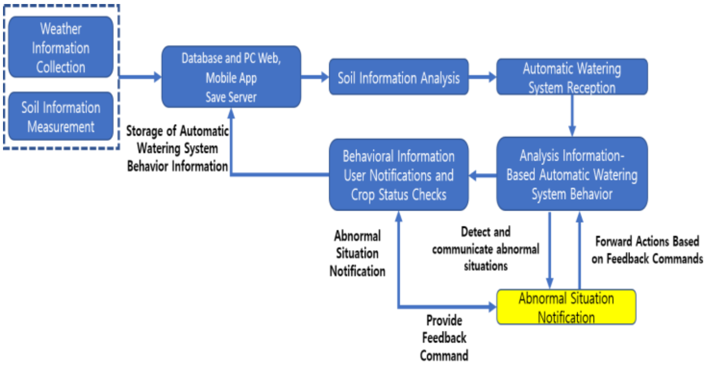


Figure 2. *System Flow Chart for Precise Induced Water Depending on Soil Condition of Crops*

As shown in Figure 2 the flow chart for precise irrigation according to the soil conditions of the crops is stored in the database established after collecting weather information and measuring soil information from the AWS and sensors of the Meteorological Administration, and stored in the PC web or mobile app server, and delivered to the automatic irrigation system based on the analyzed data to carry out irrigation of the crops.

In the process of irrigation, the user is notified of the abnormal situation in the event of an abnormality, and the user is notified to the automatic irrigation system based on the feedback provided to take action.

Users can check the status of crops and check the number of automatic irrigation system operations and frequency of operation through mobile applications or PCs, and this information will be stored in the database again to provide a precision of the crops.

Design for Web or App Interworking

In order to perform precise irrigation according to the soil condition of the crop, this section deals with the process of remote control through interworking between the web or apps, one of the research methods presented in this paper. First, an XAMPP-based web server is built to handle data in a web server. Figure 3 is a code for building a PHP-based web server of XAMPP

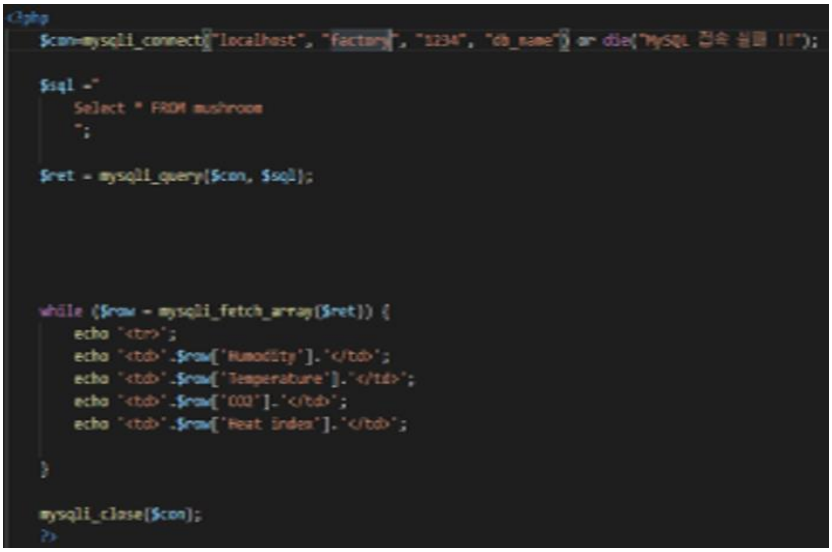


Figure 3. *Web server implementation screen*

The WWW (HTTP) port was applied through the system-config-firewall command to enable access to the web server from the outside. The application was built based on Android studios, and a simple UI was applied to make it easier for users to use the irrigation system. Figure 4 shows the process of designing an Android studio-based application UI

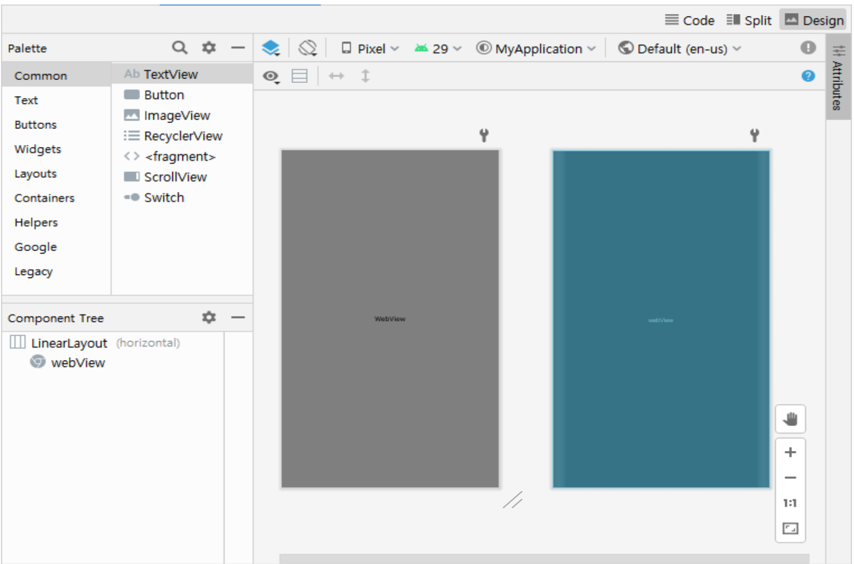


Figure 4. *Application UI design*

Next, local host access should be provided to the application for interworking with the web server built using the PHP of XAMPP. Figure 5 shows the code that provides the local host access function of the application and web server

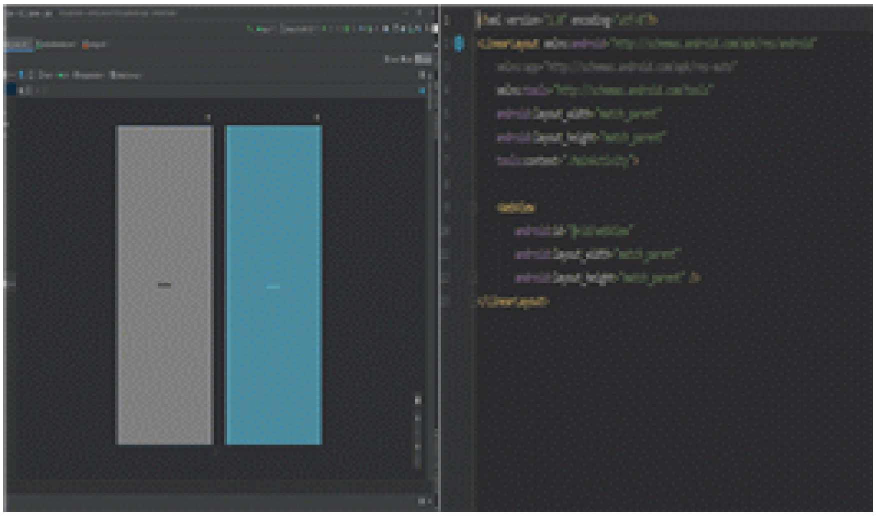


Figure 5. *Link application local host*

In general, Android-based applications adopt a method of communicating with each other through web server interworking, performing remote control functions, and returning the results to the application. Figure 5 is the process of coding an HTTP Client source that makes it simple to use when sending request data to a web server. Through this process, not only it can access the DB within the server, but it also provides a foundation for providing irrigation functions from a remote location

Implementation

Database

The database for designing a precision irrigation system according to the soil condition of the crop was built based on the E-R diagram. As shown in Figure 6, the date, time, and place of the data measured by the environmental sensor are stored in the environmental information table, and the values of the automatic irrigation system (number of operations and operation cycle) and the abnormal situation type are stored in the database.

It is designed to realize precise irrigation according to the soil condition of the crop through analysis from the database storing soil environment data such as temperature and soil humidity, the number and operation cycle of the automatic irrigation system, and abnormal situation data.

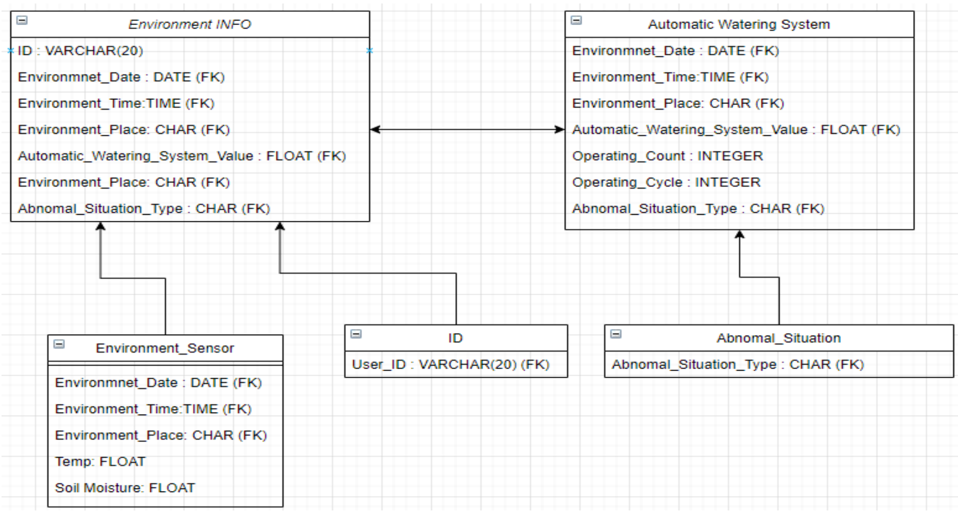


Figure 6. *E-R diagram for database deployment*

Application

In this paper, an application was constructed using an Android studio to design a precision irrigation system according to the soil condition of the crop. Figure 7 is the main screen for the automatic irrigation system information. On this screen, real-time weather conditions can be checked in conjunction with the Korea Meteorological Administration AWS, and temperature and soil humidity values measured from sensors in places where automatic water systems are installed can be checked.

In addition, it is possible to determine the total number of operations and operation cycles of the automatic water system, and when an abnormal situation occurs in the automatic water system, it is delivered through the abnormal situation notification text below.

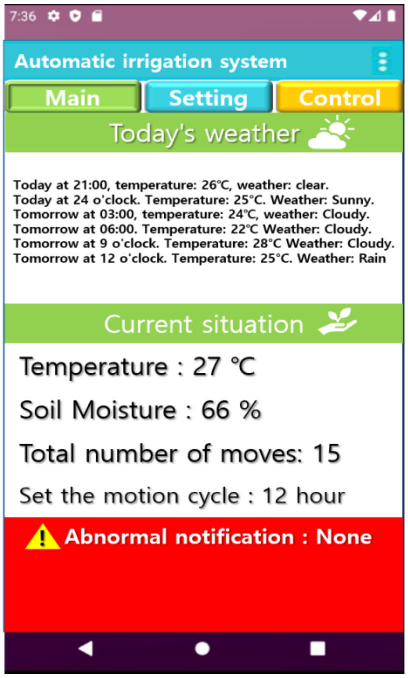


Figure 7. *Automatic irrigation system information application main screen*

Figure 8 shows the application setting screen and is implemented to set the operating cycle of the automatic irrigation system. At the upper end, the operation cycle of the irrigation device can be set from a minimum of 10 minutes to a maximum of 10 days.

The irrigation amount setting part of the lower end may be set from a minimum of 1 liter to a maximum of 500 liters, and a set value is displayed at each central part to provide convenience. Finally, at the bottom, it was implemented to calculate and mark the expected weekly irrigation amount according to the set period and set irrigation quantity.

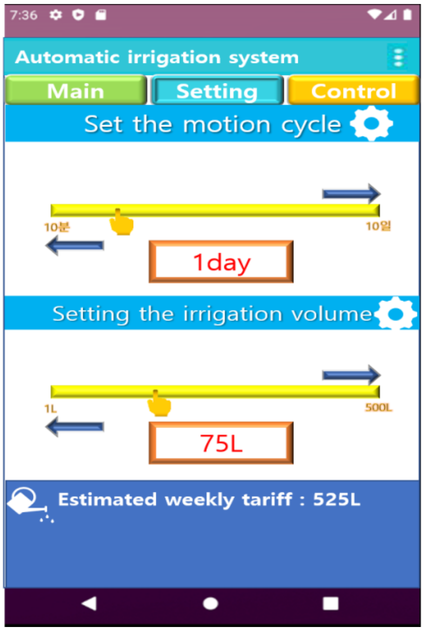


Figure 8. *Application setting screen*

Next, on the control screen of the application, a function capable of remotely controlling the automatic irrigation system when an abnormal situation occurs may be used. As shown in Figure 9, if you select an area corresponding to a notification text with an abnormal situation at the bottom, you can use the reboot and forced operation of the water supply installed in the area, and if the device needs to be repaired manually, it is implemented to identify exactly where the problem occurred.

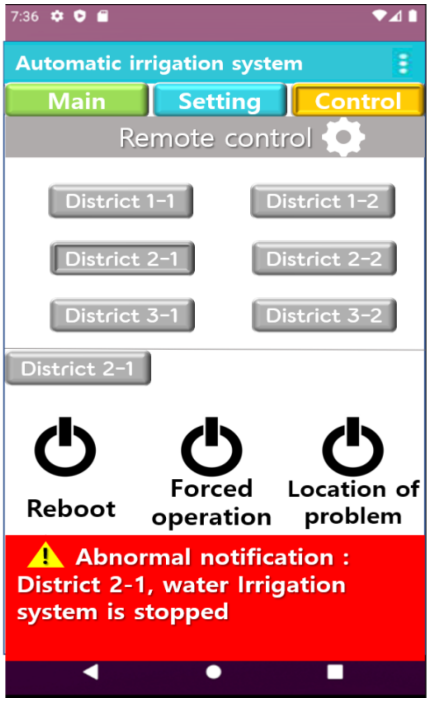


Figure 9. *Application control screen*

Comparison

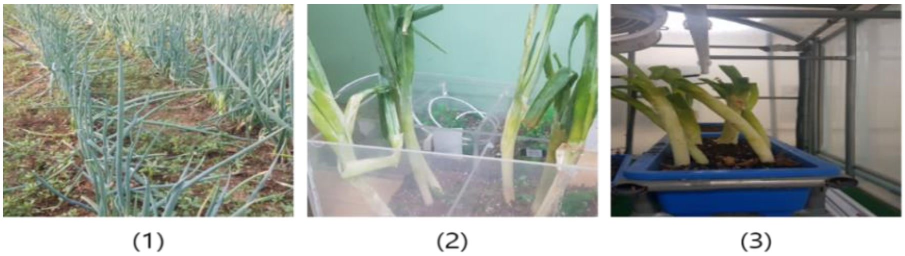


Figure 10. *(1) Open Field, (2) Smart Potted, (3) Smart Greenhouse*

In this paper, three scenarios for the design of precision irrigation systems according to the soil conditions of crops are constructed as shown in Figure 10. The target crops were wrought to the welsh onions, and soil moisture sensors and temperature sensors were installed in the same area, respectively, to collect two weeks of soil humidity information, temperature information and weather agency AWS information from August 10 to August 23, 2020 [16].

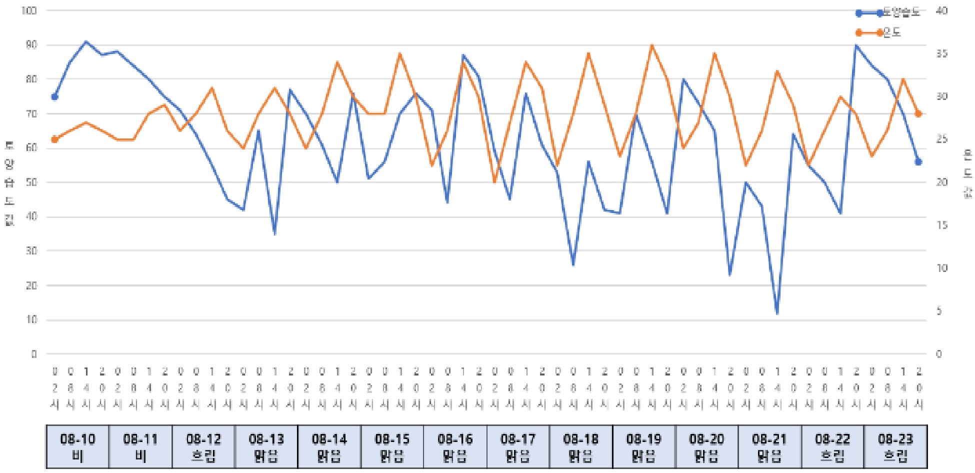


Figure 11. *Open field soil environment information*

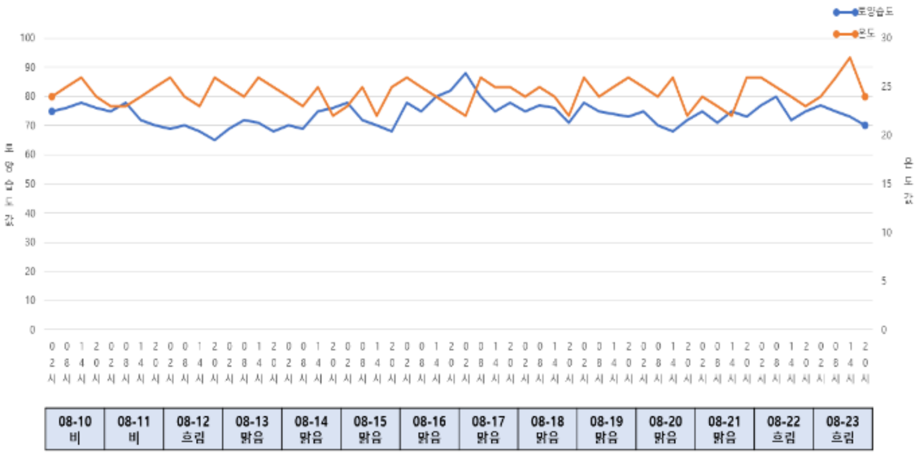


Figure 12. *Smart potted soil environment information*

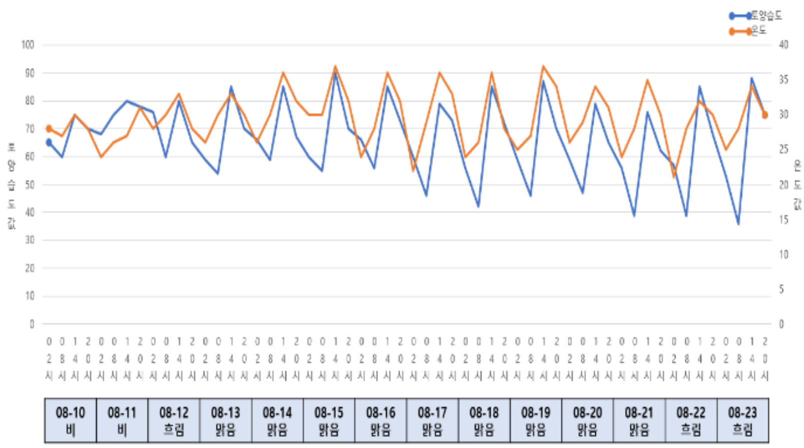


Figure 13. *Smart greenhouses soil environment information*

Analyzing the measured graph through the three scenarios shows that the humidity and temperature values of the soil are different, even if the regions are the same. In Figure 11, soil information in the off-site environment was not significantly different in temperature and soil humidity on rainy days, depending on the weather in the Meteorological Agency AWS shown below the graph, and measured temperature and soil humidity were significantly different on clear days and 12 irrigation sessions were conducted. The results of the analysis in the open field were observed to increase the amount of irrigation due to the significant decrease in soil humidity as the temperature increases.

In Figure 12, the humidity and temperature values of soil measured from sensors installed in smart pots are not affected by the weather compared to the open field environment in Figure 11 and automatically controlled temperature and humidity environments have been established to maintain a stable graph and four irrigation sessions have been conducted. In Figure 13, a relatively stable graph was observed because the smart greenhouse soil environment information was not affected by the weather as shown in Figure 12, and eight irrigation sessions were conducted.

The results of these three scenario comparisons show that for precise irrigation, the optimal environment can be built by using soil conditions and information from the Meteorological Administration's AWS, and that the introduction of this information into the automatic irrigation system is expected to help save water due to regular irrigation methods.

Comparing between Farms

In order to verify the performance of the research system presented in this paper, a comparative analysis was conducted by selecting a traditional farm and a farm using an automatic water supply system, respectively. To carry out the experiment, a welsh onion farm located in Goheung, Jeollanam-do was selected, and the cultivation range of the two farms was 0.5ha, collecting three months of irrigation data from August to October 2021. One farmhouse was required to introduce and operate an irrigation system and the other farmhouse was required to cultivate in a traditional way.

Prior to entering the experiment, a hypothesis was established that the difference in crop yield would occur due to the difference in irrigation volume, and the comparison was conducted after investigating the welsh onion yield twice during the experiment period of each farm. In addition, through the Meteorological Administration AWS presented in Table 1, the current status of precipitation at the experimental site was identified and the appropriateness of the irrigation period was also reviewed.

Table 1
Precipitation statistics by year and month in Goheung-gun
Unit : mm

Year	Aug.	Sep.	Oct.
2021	275.6	96.3	16.5

Figure. 14 is a farm composition diagram using a traditional method, and this farm, located in Goheung, Jeollanam-do, is cultivating welsh onions for about 0.5ha. Water tanks are installed in each area of the garden

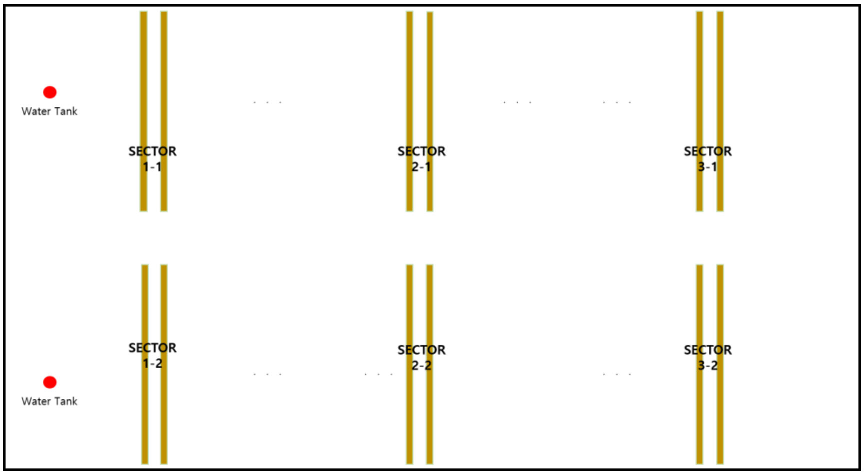


Figure 14. *The composition of the farm using the traditional method*

Figure 15 shows the configuration diagram of a similar farm installed to carry out irrigation according to the soil moisture content and temperature by installing soil moisture sensors and soil temperature sensors in each area.

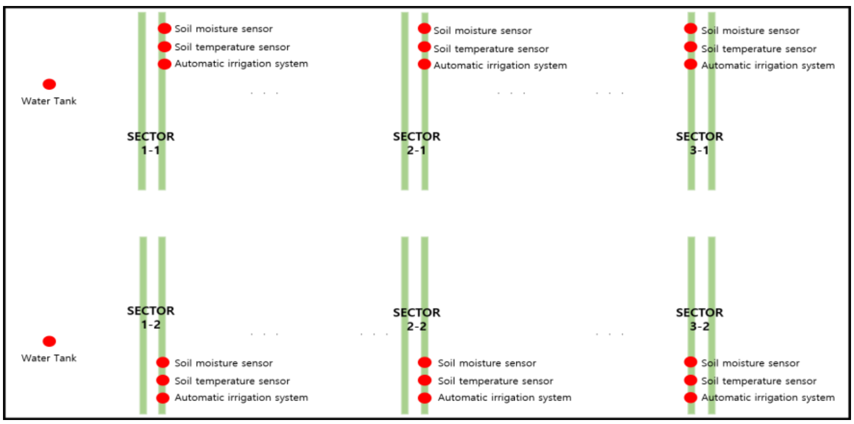


Figure 15. *Farm configuration with automatic irrigation system*

First, the three-month data performed to verify the performance of the automatic irrigation system are shown in Figure 16.

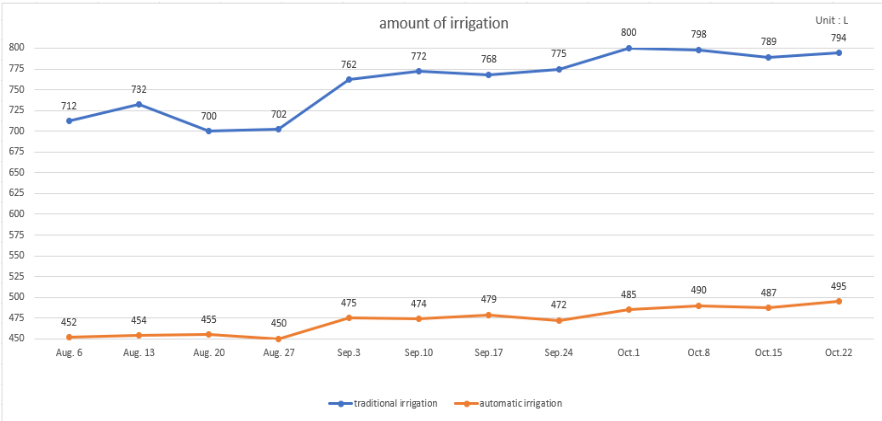


Figure 16. *Comparison of irrigation data*

An average of 758 liters of water per week was used for farms using traditional methods, and an average of 472 liters of water was used for farms that introduced automatic water supply systems. The result data showed that the farm using the traditional method conducted the subjective irrigation of the farm owner regardless of the moisture content of the soil and the AWS data of the Meteorological Administration. On the other hand, in the case of farms that introduced the automatic water system, irrigation was carried out in consideration of the AWS data of the Meteorological Administration and the soil moisture content measured by the sensor, so the irrigation volume was reduced by about 38%.

However, even if the irrigation volume decreases, if the yield decreases, the verification of the system presented in this paper is inferior to the previous one, so the yield was also compared and analyzed. Comparing the yield data presented in Figure 17, the results were analyzed as follows.

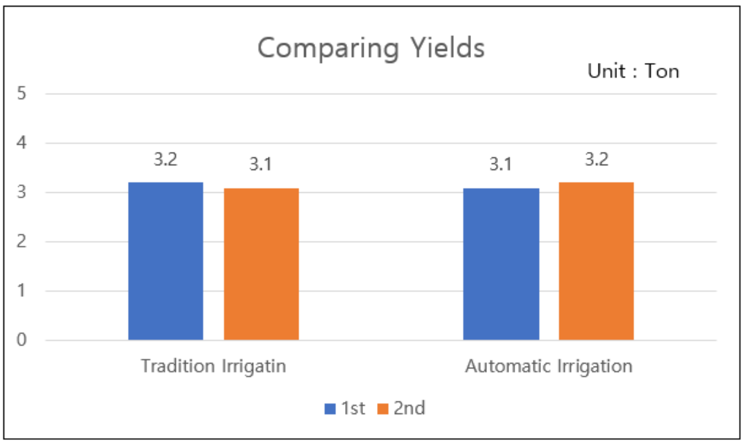


Figure 17. *Comparison of yield data*

The difference in farm yields from August to October 2021 was not significantly different from 3.1 tons to 3.2 tons for both farms using traditional methods and farms using automatic water systems. Therefore, it has been verified that the introduction of the automatic irrigation system presented in this paper can yield the same crop with less irrigation than traditional agriculture.

Conclusion

In this paper, to realize the precise irrigation according to the soil condition of the crop, the target crop was selected as welsh onions and the soil condition of the crop was analyzed through three scenarios. Based on this, a database is established and delivered to the automatic irrigation system based on data linked to weather data from the Korea Meteorological Administration AWS to realize precise irrigation and provide an optimal environment for welsh onions, the target crop, to grow. To verify the study, two farms were selected to verify the traditional irrigation method and the automatic irrigation method, and as a result about 38% of agricultural water was reduced, and the difference in yield was not significantly. This precision irrigation is expected to be effective in saving indiscriminate waste of agricultural water, and provides optimized irrigation system convenience for farmers growing wild vegetables by checking the operation status and real-time weather information through applications, delivering and remotely manipulating these feedbacks to databases. The research system presented in this paper plans to be expanded into research that combines with deep learning technology and agricultural control systems in the future to control crop disease detection.

Acknowledgments

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