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The enhancement of agricultural productivity using the intelligent IoT

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ABSTRACT

The abnormal climatic changes due to global warming causes damage to crops. Uncontrollable factors make it difficult for farmers to use conventional methods for farming. Furthermore, with the aging population and the reluctance of the younger generation to be devoted to farming jobs that require a large amount of physical work, there is a problem of global food shortage. Therefore, several countries have invested in the development of science and technology in agriculture, expecting to promote the overall development of agricultural production through the Agricultural Internet of Things (AIoT). AIoT is a highly integrated and comprehensive application of a new generation of information technology in the agricultural field. In this study, the currently popular Internet of Things (IoT) is used to build a smart greenhouse. To solve the problem of farmers not understanding the operation of the information interface, this study proposes an IoT-based smart voice control architecture, which details the operation of the voice system architecture. It successfully replaces the conventional unfriendly operation interface and is generally recognized by users, which lowers the barrier of entry with respect to of science and technology for those who are willing to devote themselves into the development of scientific agriculture, inspires a wide range of applications, and effectively improves the production efficiency of agriculture.

Keywords: Internet of Things, Aquaponics system, Smart agriculture, Precision agriculture.

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1. INTRODUCTION

Over the recent decades, due to industrial and urban development, humans have caused deforestation during the attempt of obtaining limited land for construction. Moreover, heavy use of petrochemical raw materials and uncontrolled human activity has produced excessive amounts of greenhouse gases, which has greatly aggravated the greenhouse effect (Chiang et al., 2004) and caused the surface temperature of the earth to rise, i.e., the global warming phenomenon. The climate change caused by global warming exacerbated the phenomenon of extreme climate, and weather changes in recent years exhibit great instability and irregularity. As a result, crops frequently suffer from natural phenomena such as wind, rain, drought, and high temperature, which farmers find difficult to handle with conventional planting experience. At the same time, global warming is accompanied by rising temperatures. Although increased temperature is favourable for the growth of crops (Mitchell, 1989), the amount of plant pathogens also increases, which is conductive to the reproduction of pathogenic bacteria and insect pests, destroying the natural ecology and damaging the growth of crops. The global warming causes various changes in environmental factors, which seriously affects the yield and quality of crops (Gandomi and Haider, 2015). Therefore, by transformation or applying science and technology to food production, damages caused by human and environment can be reduced and the problem of labour shortage can be relieved. Smart and non-toxic production will facilitate the development of agriculture, contribute to stable and high-quality output, and provide an effective solution to food shortages in each country.

With the transformation of social population structure and the impact of environment, agriculture is also facing the challenge of transformation (Karl and Trenberth, 2003). Smart agriculture, resource recycling and sharing, however, not only play important roles in agricultural transformation but are also the key solutions promoted by governments in various countries in the face of agricultural transformation. Smart agriculture is a new type of agricultural operation technology that combines big data analysis, science and technological agriculture, IoT, and Machine to Machine (M2M) to adjust cultivation management in a timely and appropriate manner (Jones, 1975; Stojkoska and Trivodaliev, 2017; Yaqoob et. al, 2019). Farmers can remotely obtain temperature, humidity, sunlight, soil moisture, pH, carbon dioxide, and other information through sensors deployed in the field using wireless transmission technology enabling them to make the most accurate decision at the most accurate time to precisely increase the crop yield, use water resources, pesticides, and fertilizers, thereby reducing the wastage of resources. The entire production process of recycled agriculture achieves reduced emissions, with instances of zero emissions and resource reuse as well. The use of non-renewable energy sources such as pesticides, fertilizers, and coal is being significantly reduced, resulting in cleaner production, lower investment, lower consumption, lower emissions, and more efficient production (Li et al., 2015).

To improve the production efficiency of agriculture and to overcome the problems of global warming, climate change, and labour shortage, the IoT-based Smart Greenhouse System (ISGS) and IoT-based Smart Voice Control System (SVCS) are proposed in this study that is pollution-free, energy-saving, carbon-reducing, and recyclable, with controllable environmental factors, owing to scientific agriculture. It solves the problems of unstable production such as severe wind, severe rainfall, drought, and high temperature faced in conventional agriculture. The scientific application of science and technological agriculture and IoT will be able to control environmental growth factors, thereby enabling stable growth of planted crops, so as to greatly increase the productivity and solve labour issues (Gebbers and Adamchuk, 2010; Suma et al., 2017). Aiming at the SVCS, this study proposes an IoT architecture that is suitable for voice control. This architecture can solve the problem of ordinary famers who do not understand the operation of information interface because the proposed architecture can directly perform remote communication and realize a friendly interface operation of remote control and automatic decision control. This study will collect temperature, humidity, sunlight, soil moisture, pH, carbon dioxide, and other environmental parameters and integrate them into big data by using ISGS. Herein, the remote environment is controlled by voice, and notifications are conveyed through audio channels, which help famers grasp the most recent environmental monitoring data and make the most favourable decisions for production. Therefore, the ISGS is implemented and the feasibility of using IoT in agriculture is evaluated in this study.

The rest of this paper is organized as follows. In section 2, a literature review is carried out. The concept of the proposed system and the SVCS are presented in section 3. The design of the ISGS is shown in section 4. Section 5 is the conclusion of this research.

2. LITERATURE REVIEW

In this section, Taiwan's agricultural employment over the past 10 years and AIoT will be discussed respectively.

2.1 Analysis of Agricultural Employment in Taiwan in the Past 10 Years

Over the recent years, the age distribution of Taiwan's population exhibits the following characteristics (National Development Commission. Republic of China Population Estimate, 2018): the proportion of the elderly population (over 65 years old) has been increasing yearly, and the proportion of the younger population (under 14 years old) has been decreasing each year (as shown in Fig. 1). As early as 1993, the proportion of the elderly population already reached 7%. Based on the definition set by the World Health Organization, Taiwan was already an aging society at that time. In 2018, this number reached the 14% threshold, officially making Taiwan an aging society. According to statistics from the National Development Commission (as shown in Fig. 2), it is estimated that Taiwan will become a super-aging society by 2026. Subsequently, with the yearly declining birth rate, the burden on the young and middle-aged population will become increasingly heavier, which will have a major impact on various domestic industries.

Under such a social background, domestic employment also faces the challenge of the aging population (Visualization of Agricultural Statistics, 2020), as shown in Fig. 3. The proportion of agricultural population over 50 years of age is more than 60%, and the proportion of that over 65 is nearly 20%. The aging of the agricultural population has limited the available human resources and

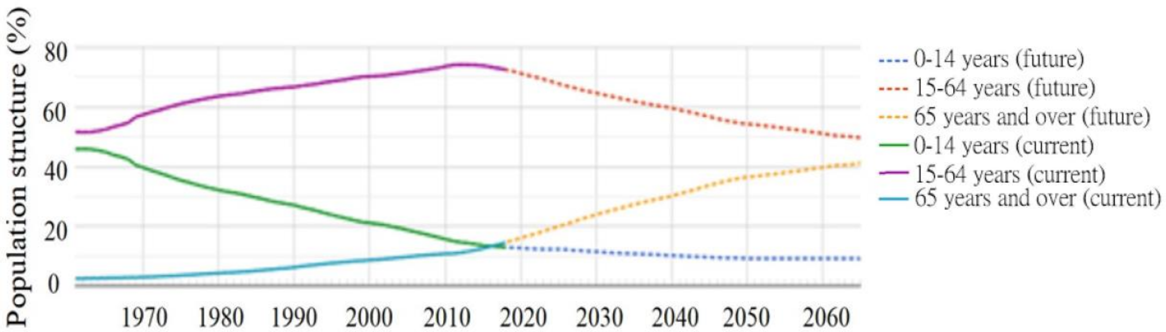

Fig. 1. Population structure of the three-stage age

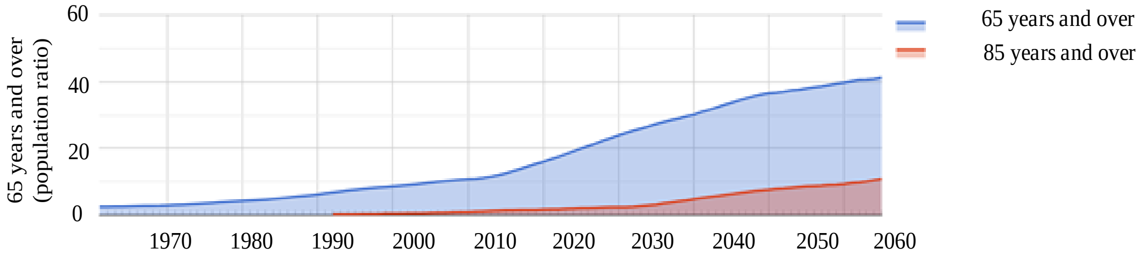

Fig. 2. Aging indicators for the domestic population

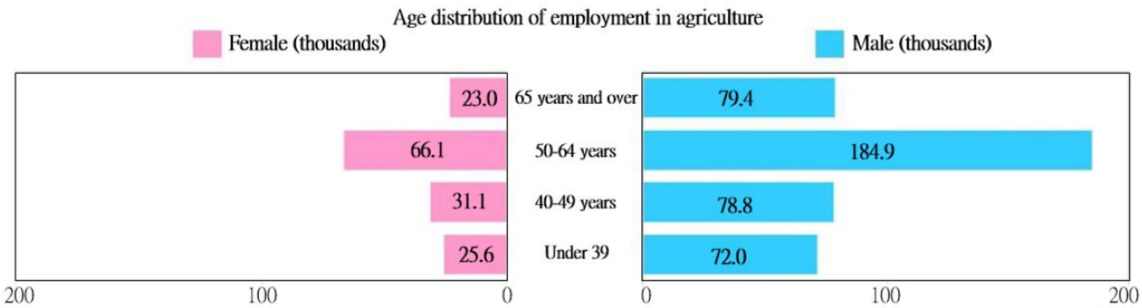

Fig. 3. Age distribution of employment in agriculture over the last 10 years

prevented large-scale cultivation. With the declining birth-rates in recent years and the country's gradual development toward urbanization and industrialization, most of the young and middle-aged population opts to work in cities and are unwilling to engage in laborious agriculture. Based on the statistics in Fig. 3, less than 20% of the population is under the age of 40, which not only exacerbates the impact of labour shortages but also creates a gap in technological inheritance. In the long run, Taiwan will face significant difficulties in food production (Speare et al., 1973).

In addition, according to the Executive Committee of the Agricultural Committee, due to labour resources and high production costs in China, subsequent to Taiwan's accession to the World Trade Organization, it faced the completion of imports of agricultural products from various countries.

2.2 Agricultural Internet of Things (AIoT)

The Agricultural Internet of Things (AIoT) is a highly integrated and comprehensive application of a new generation of information technology in the agricultural field. AIoT plays an important leading role in agricultural informatization in various countries. It has changed the production methods of traditional agriculture, and also promoted the transition from traditional agriculture to intelligent precision agriculture.

For the IoT-based agricultural greenhouse control system, various sensors are set to monitor the growth of various vegetables and fruits (Yang et al., 2019). These sensors include: temperature sensor, humidity sensor, soil moisture sensor, nutrient element sensor and carbon dioxide sensor, etc., used to measure the temperature, relative humidity, soil moisture, soil nutrients, carbon dioxide concentration and other physical parameters of the environment. Through various sensors installed in the agricultural greenhouse control system, the monitored data can be collected, analyzed and processed. When the processed data meets certain conditions, it is regarded as a service request. In this AIoT, there are some devices, such as irrigation machines, fertilizer applicators and pesticide sprayers. And, these devices are regarded as AIoT service providers.

In the research of Liu et al. (2016), the architecture of AIoT consists of five layers, there are data access layer, data transmission layer, application service support platform, application module layer and user application layer. The five-layer AIoT is shown in Fig. 4.

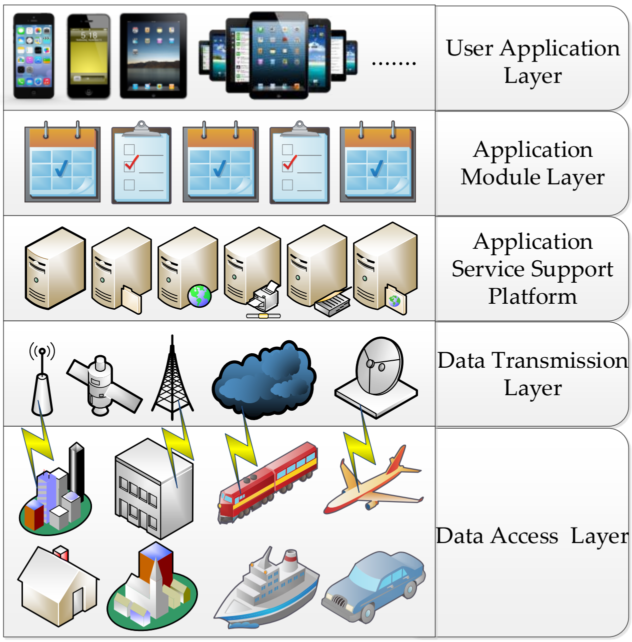

Fig. 4. Five-layer framework of AIoT (Liu et al., 2016)

In data access layer, the data in the full life cycle of agricultural products, including sensor detection data, RFID data, video recording, will be captured and pre-processed in this layer. The full life cycle of agricultural products usually contains farming period, manufacturing period, logistics period, storage period, and sale period. In data transmission layer, the data captured in the data access layer is transferred to the servers in the application service support platform, making use of networking technologies. The application service support platform offers a wide range of engines and services. The application module layer provides a collection of application modules. Users can select one or multiple application modules in order to meet the business requirements in agriculture. In user application layer, the user applications are implemented with application modules for target users.

This study is based on IoT architecture, deploying sensors for IoT-based Smart Greenhouse System (ISGS) and building Smart Voice Control System (SVCS) of the IoT. Wireless transmission technology was used in the study to transmit the sensed data to the back-end host. Then, the data is stored and analyzed. Finally, the real-time production decision is generated for farmers as a reference.

3. THE PROPOSED SYSTEMS

In this section, the concept of the proposed systems and the Smart Voice Control System (SVCS) will be discussed.

3.1 The Concept of the Proposed Systems

In this study, the current mainstream crops in the country are investigated, such as rice, convolvulus, white bamboo shoots, yellow okra, carob, ashitaba, celery, carp, tilapia, grass carp, catfish, and trout, selected the plants suitable for second-season production to be farmed for field visits, learned about the major problems that farmers face when growing and farming these, such as pests and diseases, water pollution, and soil infertility, and the related environmental factors that affect plant growth, such as air temperature, relative humidity, carbon dioxide, water quality, wind speed, wind direction, solar radiation, and atmospheric pressure, to facilitate subsequent environment monitoring using IoT devices. To achieve this purpose in the proposed research, the ISGS is built, and analyzed and compared the conventional agriculture with the IoT-based smart agriculture. The construction of the ISGS prototype and the ISGS have been detailed in the section 4.

In this study, a SVCS of the IoT that can assist farmers to use information technology to overcome environmental factors and labour costs and improve agricultural productivity has been proposed. In addition, the ISGS is proposed to collect the environmental parameters with regard to the growth information in agriculture industry, monitor, store, process, and analyze the relevant environmental parameters of the system, and provide an effective reference for production decisions, which is expected to help farmers in agriculture production. The deployed ISGS can not only be implemented in agriculture, but it also greatly improves production efficiency, reduces human labour, and interests young people who are willing to devote themselves in agriculture, along with jointly promoting the development of the scientific agriculture 4.0 of the country. In addition, this study proposes voice control architecture suitable for the IoT to inspire more diverse applications and lower the barrier of entry to the field of agriculture, laying the foundation for the national agriculture production. The integration of ISGS and SVCS is shown in Fig. 5.

In this study, the main problems encountered by farmers during planting and breeding have been investigated to facilitate subsequent environmental monitoring using IoT devices. These problems affecting plant growth include: plant diseases and insect pests, water pollution, soil sterility, and environmental related factors. Moreover, the environmental factors include: temperature, relative humidity, carbon dioxide, water quality, wind speed, wind direction, solar radiation and atmospheric pressure. To achieve this purpose in the proposed research, the ISGS prototype system and the ISGS will be constructed, and will be discussed in detail in section 4. The SVCS of the IoT will be discussed in section 3.2.

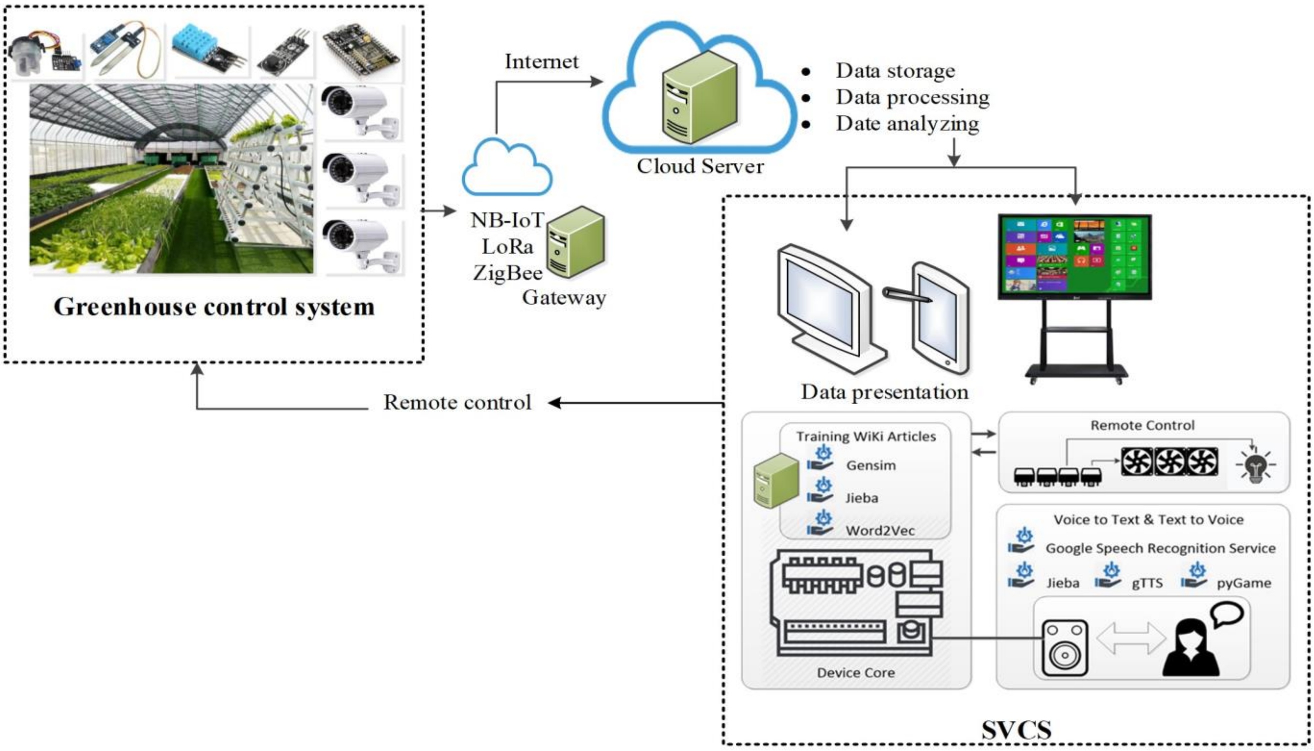

Fig. 5. The integration of ISGS and SVCS

3.2 The Smart Voice Control System (SVCS)

It is difficult for ordinary farmers to use the operation interface of the information system. Despite spending time on education and training, the results are still unsatisfactory, which will lead to psychological resistance to the information system and hinder the processing of agricultural information. Therefore, the SVCS based on the IoT to control the environment required for greenhouse production is used in this research. For farmers who do not understand the information technology system, the control system can greatly solve the problem. Fig. 6 shows the architecture of the SVCS. The system includes the core system of smart voice and semantic analysis module. Since SVCS has been proposed and constructed by Wang et al. (2020), this article only explains conceptually.

The Raspberry Pi Linux-based single-chip computer is used to develop the core system of smart voice. The core program is to train word vectors with a large corpus. After training, users can input keywords for similarity calculation to determine the most similar words. Therefore, the Gensim package is first used to extract the title and content from three million Wiki articles. Then Jieba package is used to hyphenate the organized title and content. In the process of word segmentation, stop words are introduced to filter offensive words. Finally, the Word2Vec package is used to train the word vectors with all the segmented words. After training, a core word vector similarity comparison model can be obtained.

The architecture of the semantic analysis module, which mainly includes two parts, the cloud semantic setting program and the user control program call. Cloud semantic setting program can provide a cloud remote user control platform. Users can implement remote environment control settings with the provided interface. The platform will execute the word segmentation program on the natural sentences, extract feature words to retrieve similar words, and store all feature data in the database. However, the user control program allows the user to communicate with the speaker via voice.

First, the user conducts a dialogue with the voice control device. The device converts the voice into words, extract feature words and filters dirty words, and then sends them to the semantic analysis module for similar vocabulary set analysis, and takes out the user's creation on the cloud semantic setting platform remote control commands, through the cloud MQTT service. Finally, the control commands can be published to the voice control device for execution to achieve the purpose of remote control.

4. THE IOT-BASED SMART GREENHOUSE SYSTEM (ISGS)

In this section, the ISGS prototype system and the construction of ISGS will be discussed in detail.

4.1 Construction of the ISGS

Environmental data is collected based on the selected

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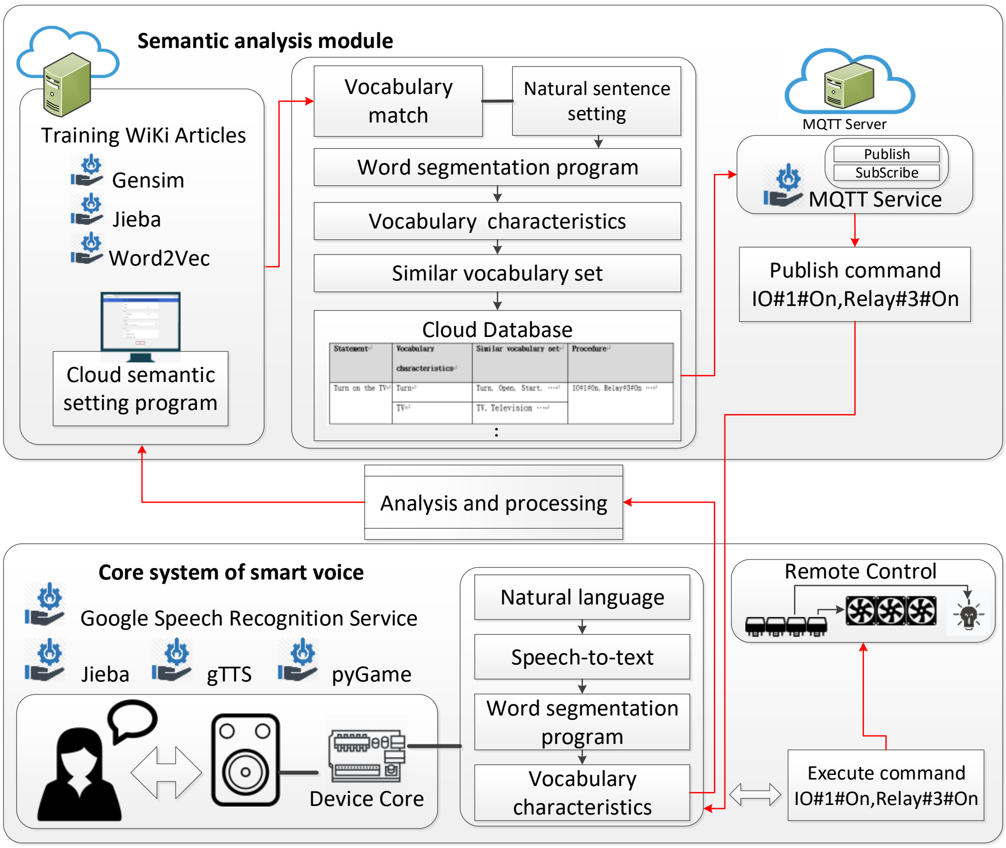

Fig. 6. Diagram of the architecture of the SVCS

mainstream crops, and IoT devices are deployed based on the data to be collected, such as air temperature sensor, relative humidity sensor, air quality PM2.5 sensor, soil temperature and humidity sensor, raindrop sensor, light sensor, water temperature and pH sensor, sensor of nitrite concentration in water, sensor of ammonia concentration in water, sensor of oxygen concentration in water, and hydration sensor, and these IoT sensing devices are installed to the IoT-based smart greenhouse prototype system. In terms of the information system software and hardware, the overall system architecture is planned; data structures and open RESTful API are collected, analyzed, and then displayed in an electronic version for relevant staff to monitor these in real-time, thereby enabling them to make right decisions at the right time.

With a focus on the prototype system, relevant growth information to be collected, and environmental key monitoring items, the software/hardware system architecture (as shown in Fig. 7) is proposed, and a list of IoT sensing devices to be deployed is presented (see Table 1 for details). These software/hardware devices are then integrated into the prototype system. To present real-time data for analysis and decision-making, an electronic information reading board will be arranged to facilitate the tracking of growth and environmental key monitoring items. To more effectively use the collected data, a RESTful API is planned at this stage for an easy access of data at any time.

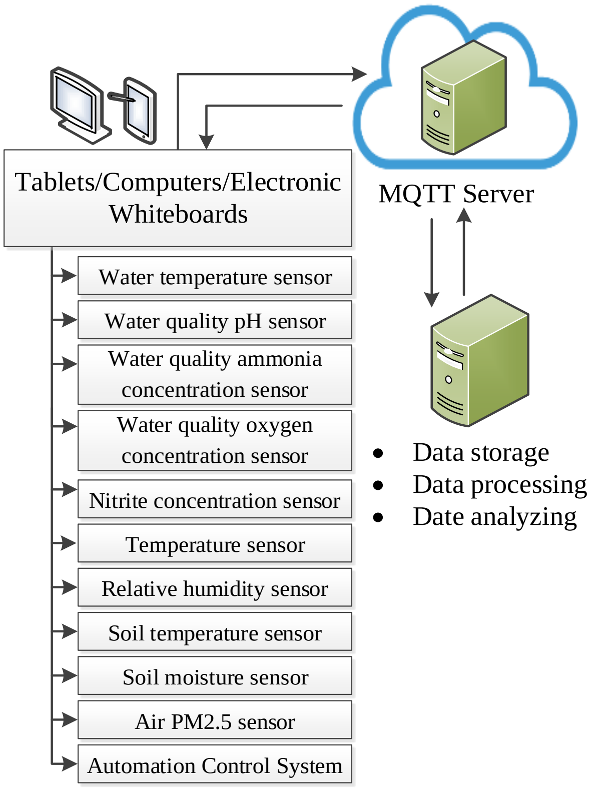

Fig. 7. Software system

Fig. 7 illustrates the main functional architecture of the software system. The functionalities include water quality, air, and soil monitoring, such as water temperature, pH, ammonia concentration, oxygen content, nitrous acid concentration, air temperature, relative humidity, PM2.5, soil temperature and humidity, and remote environmental video information. This information is collected to understand the growth environment factors of the overall breeding and planting, thereby facilitating the storage, processing, and analysis of subsequent data, which provides output production logs. To instantly notify the integration of subsequent systems, in addition to the system functions listed above, a publish–subscribe messaging environment of MQTT is also built in this study, as well as a RESTful API for interface integration purposes.

Fig. 5 illustrates the entire hardware system architecture. In the prototype system proposed in this study, IoT sensing devices and remote monitoring systems are integrated. The data collected by all IoT sensing devices is transmitted to the Gateway Server host using communication methods like Wi-Fi, NB-IoT, LoRa, and ZigBee. Then, the Gateway Server host initially checks and processes the data and sends the data to the cloud host through the Internet. The cloud host will store, process, and analyze the received data, and finally make production decisions for the users' reference. All data are presented on tablets, computers and electronic whiteboards. The software system also integrates functions such as remote environmental video and remote automatic control.

Table 1 lists the requirements for building an IoT sensing device integration prototype system in this study. In addition to the sensing devices used to monitor the environmental factors of agriculture and plant growth, this list also includes remote monitoring systems and automated control systems.

Fig. 8 is the established ISGS prototype system built in this study that is based on the collected environmental factors affecting plant growth. The prototype system includes monitoring water level, air quality PM2.5, air temperature, relative humidity, soil temperature and humidity, raindrop and light sensing, and setting thresholds for all the collected environmental parameters. By analyzing and processing data through the remote host, remote automatic control is realized. For example, the sunroof is automatically closed when it rains; the fan is started when the temperature is too high; the light turns on when the sunlight is insufficient; drip irrigation is started when the soil is dry; the spray turns on when the humidity is low; and refills automatically occur when the water level is low. In addition to eliminating the need for manual operation, the prototype system can maintain the growth of plants according to the settings, which can overcome the problem of labour shortage and abnormal climate interference.

Table 1. List for IoT sensing devices

Name of the IoT sensing device	Name of the IoT sensing device
Water temperature sensor	Water quality pH sensor
Water quality ammonia concentration sensor	Water quality oxygen concentration sensor
Nitrite concentration sensor	Temperature sensor
Relative humidity sensor	Soil temperature sensor
Soil moisture sensor	Air PM2.5 sensor
Water level sensor	Raindrop sensor
Light sensor	CO_2 sensor
Barometric pressure sensor	Single-chip control board
Wind direction sensor	Wind speed sensor
Remote monitoring system	Automation Control System
Air pump	Relay

Fig. 8. ISGS prototype system

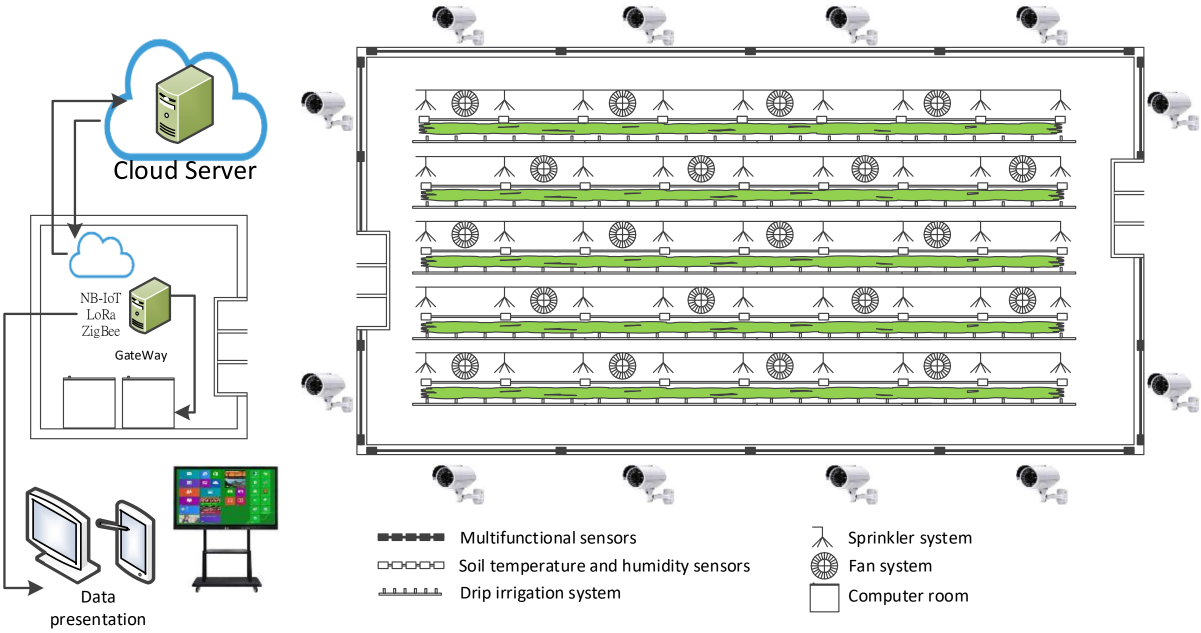

Fig. 9. Illustration of the ISGS architecture

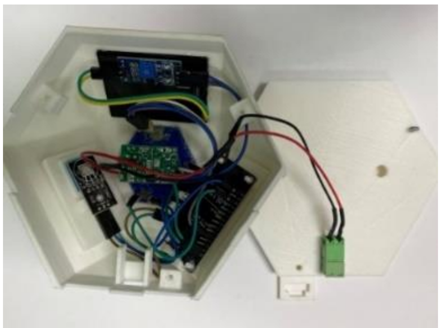
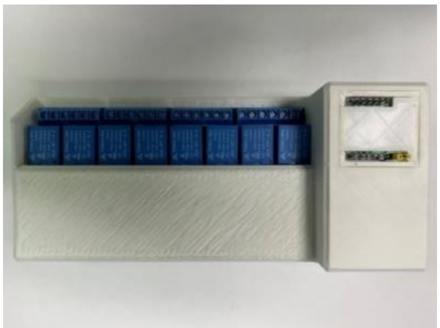

Fig. 10. Multifunctional sensor (left). Relay module (right)

4.2 Establishment of the ISGS

According to the establishment concept of ISGS prototype system, this study devises a plan of the IoT system for an actual greenhouse, and it conducts an overall analysis based on the actual field. Fig. 9 is the system architecture designed in this study. Herein, 18 multifunctional sensors are deployed in the system (as shown in Fig. 10), including raindrop sensor, air temperature sensor, and relative humidity sensor and light sensor, as well as 45 soil temperature and humidity sensors, a drip irrigation system, a sprinkler system, a fan system, and a remote monitoring system. An IoT Gateway host and an IoT relay module are arranged in the computer room (as shown in Fig. 9). The IoT Gateway host is mainly used for collecting all sensor data in the field, analyzing and processing it, and uploading it to the cloud host storage. The IoT relay module is used to allow a single module to connect multiple relay modules in series and control IO of the device. The overall computer room configuration and field plan for this study are shown in Fig. 11.

Fig. 10 illustrates the multifunctional sensor and relay module in this study, which is modularly packaged using 3D printing. The multifunctional sensor is mainly responsible for detecting environmental parameters such as raindrops, temperature, relative humidity, and light. An additional microcontroller (Microcontroller Unit, MCU) is configured for edge computing based on the collected parameters, preventing a large amount of data from being transmitted to the IoT Gateway host, which would cause a load on the host, and in this way the amount of data transmission is reduced. The MCU can directly organize and analyze the data. For example, it can organize the data within five minutes, and then transfer it to the Gateway host and send it to the cloud storage. Furthermore, the MCU can analyze the data when the environmental parameters are collected and notify the Gateway host to perform the control program if environmental control is required. The Gateway host will send the control signal to the MCU in the power distribution box and control the relay module. With edge computing, a lot of time-consuming analysis can be dispersed, which reduces the overall system load and improves the system performance.

Fig. 11. The overall computer room configuration (left) The field plan (right)

Based on the system architecture in Fig. 9, the ISGS is constructed in this study, as shown in Fig. 11. In the ISGS, in addition to multifunctional sensors in the greenhouse, temperature and humidity sensors are also deployed for the soil. The sensors are also equipped with an MCU control board for edge computing and data analysis. When the soil temperature is too high or the humidity is insufficient, the Gateway host is notified to perform an irrigation program, which will notify the MCU in the relay module to perform irrigation or to start the fan operation. To allow farmers to effectively control multiple greenhouses, the system provides a remote monitoring system and integrates the monitored greenhouse images to the electronic boards on the user end. In addition to the control functions, such as remotely opening the sunroof, opening the side roller shutter, starting watering, and starting the fan, farmers can cultivate crops according to cultivation experience, which saves labour time.

The integration of ISGS and SVCS is proposed in this study, which can improve the productivity of agriculture. The proposed system can collect the environmental parameters related to agricultural growth information, and provide monitoring, storage, processing and analysis system related environmental parameters, providing effective reference for agricultural production decision-making. The deployed ISGS can lower the barriers for farmers to use the related technologies. In addition to increasing the yield of crops, it can also reduce manual labour, and interest young people who are willing to devote themselves to agriculture, and jointly promote the development of the scientific agriculture 4.0. In addition, the SVCS used in this research can stimulate more applications and reduce barriers to entering the agricultural field, laying the foundation for national agricultural production.

5. CONCLUSION

Today, the technologies of IoT have been successfully applied to agricultural greenhouse control systems. The feasibility of integrating traditional agriculture with the IoT can greatly reduce the labour required for traditional agriculture. In the research, ISGS and SVCS were proposed. The environmental parameters collected through ISGS will help to provide decision-making in the production process, and improve the production efficiency of crops, and can solve climate change, manpower shortage, arable land restrictions, rotation, and other arable land and other waste resources. The deployed ISGS can not only be implemented in agriculture, but also can greatly improve production efficiency and reduce manual labour. And, SVCS can provide a friendly and intelligent voice operation interface, successfully solve the problem of lack of farmers' information knowledge, resist the process of agricultural informatization, and lower the threshold for system operation.

This research successfully applied IoT to traditional greenhouses. Verifying the feasibility of combining traditional agriculture with the IoT can greatly reduce labour. Conventional agriculture must use a lot of manpower to monitor the cultivation environment, including monitoring soil moisture, climate temperature, water level and oxygen content in the water. This process is based on the farming experience of farmers, which also changes with the climate, which makes the entire farming process difficult to control. Therefore, introducing technology to help farmers and providing real-time environmental monitoring data will help the development of agriculture. Table 2 compares traditional agriculture and IoT-based agriculture. After the technology is introduced into conventional agriculture, labour can be effectively saved. It is better than

Table 2. The comparisons of traditional agriculture and IoT based agriculture

Item	Traditional agriculture	IoT based agriculture
Manpower required	In order to obtain relevant information for monitoring or controlling the environment, relevant personnel must collect data on site.	Through remote monitoring and real-time warnings, labour costs can be saved.
The ability of environmental protection and energy saving	Farmers follow empirical methods to cultivate, and the process of planting is unfounded and consumes more resources.	Refer to the data returned by the actual IoT sensors to ensure accurate farming and effective use of resources.
Growth quality of crops	The crops produced are prone to imbalances in supply and demand, leading to uneven growth.	Farmers use technology to assist in farming, and growing conditions can be easily controlled.
Required cost	The labour and resource cost requirements are huge.	The initial cost of the IoT construction is required; however, manpower and resources can be effectively controlled.
Traceability of the information obtained	N/A	The collected environmental parameters can be stored, and the related data can be traced back.
Capable of remote monitoring	N/A	The ability of remote monitoring is possessed.
Ability to provide instant warning	N/A	Thresholds can be established and provide early warning functions.

conventional methods in terms of energy saving, production quality and cost, and it can also realize scientific and technological agriculture.

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