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To Improve the Production of Agricultural using IoT-based Aquaponics System

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Abstract: Because the aquaponics system does not require soil, uses very little water and land area, it can produce fresh vegetables and fruits under any climatic conditions, and its energy consumption is far less than that of general traditional agriculture. Therefore, the aquaponics system is expected to be one of the priority choices for future sustainable farming systems. In this study, the technology of Internet of Things (IoT) was introduced into science and technology agriculture, and the IoT-based Aquaponics System (IAS) was actually built. In the study, the feasibility of precision technology agriculture was confirmed, and the advantages and disadvantages of the traditional greenhouse planting system and IAS were compared. In addition, in order to solve the problem of farmers lacking the ability to use information interfaces, the Intelligent Voice Control System (IVCS) of the Internet of Things was proposed in this study. The traditional unfriendly operation interface can be successfully replaced by IVCS. Therefore, IVCS can provide partners who are interested in the development of science and technology agriculture with a lower barrier to entry for science and technology, and inspire more diverse applications to effectively improve the production efficiency of agriculture, fishery and planting.

Keywords: Internet of Things; aquaponics system; greenhouse planting system; smart agriculture; precision agriculture.

1. Introduction

Because the aquaponics system does not require soil, uses very little water and land area, it can produce fresh vegetables and fruits under any climatic conditions, and its energy consumption is far less than that of general traditional agriculture [1]. In the aquaponics system, “fish” and “vegetables” can be produced simultaneously, and the aquaponics system is mobile. Therefore, the aquaponics system is expected to be one of the preferential systems for sustainable farming in the future. In addition, the aquaponics system greatly reduces labor compared to traditional agriculture that requires farming on the ground [2].

With the transformation of the social demographic structure and the impact of the environment, agriculture must be transformed to face different challenges. However, smart agriculture, resource recycling and sharing not only play an important role in agricultural transformation, but also a key solution for governments of all countries to promote agricultural transformation. Smart agriculture is a new type of agricultural management technology, which combines big data analysis, scientific and technological agriculture, the Internet of Things (IoT) and machine-to-machine (M2M), which can timely and appropriately adjust agricultural management [3]. Farmers can obtain information such as temperature, humidity, sunlight, soil moisture, pH value, and carbon dioxide through wireless transmission technology over

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long distances. Therefore, farmers can make the most correct decisions at the most precise time to increase crop yields, use water resources, medicines, and fertilizers precisely, and reduce waste of resources. In the entire production process of recycled agriculture, the related wastes can be reduced, and even zero emissions and resource reuse can be achieved. In other words, the use of pesticides can be reduced in large quantities, thereby achieving cleaner production, low investment, low consumption, low emissions and high-efficiency production.

In order to improve the production efficiency of agriculture and to overcome the problems of global warming, climate change and labor shortage, the IoT-based Aquaponics System (IAS) is established by this research. The IAS proposed by this study can solve the problems caused by wind, rain, drought and high temperature in traditional agriculture through the characteristics of pollution-free, energy-saving, carbon-reducing, and recyclable. The growth factors of the environment through scientific application of science and technology agriculture and the IoT will be able to be controlled, so as to achieve stable growth of planted crops, thereby greatly improving the productivity and solving labor problems.

In addition, the Intelligent Voice Control System (IVCS) of the IoT was proposed by this study to solve the problem that farmers generally do not understand the operation of information interfaces. IVCS provides farmers with natural language to communicate directly with IAS through IoT to achieve a friendly operation interface for remote control and automatic decision control.

The rest of this paper is organized as follows. In section 2, the literature review is carried out. The proposed systems are discussed in section 3. The comparisons of conventional agriculture and greenhouse planting system with the proposed IAS are discussed in section 4. Finally, conclusions are presented in section 5.

2. Related Work

In this section, the aquaponics system and the concept of IoT will be discussed.

2.1 Aquaponics System

Aquaponics refers to a new combination of aquaculture and hydroponics [4]. Its principle is to utilize the excreta (ammonia) from the raised aquatic animals, transport the aquaculture water from the submerged motor to the filtration system, and discharge the aquaculture water to the nitrification system via the filtration system [5]. The nitrification system contains a large number of nitrite bacteria, which can decompose and oxidize ammonia. Oxidized nitrate can be converted to nitrate, which is an almost non-toxic substance. In an anaerobic environment, it can be decomposed into nitrogen and oxygen by anaerobic bacteria. Subsequent to the entire nitrification, the aquaculture water is drained into the plant bed. As the plant roots absorb nitrogen fertilizer, the water is simultaneously purified [6]. The purified water is then returned to the breeding barrels for feeding. This continuous cycle does not require significant artificial fertilizers, and there are no dangers of pesticide residues. Just by regularly maintaining the entire aquaculture ecological water system, the symbiotic environment of agriculture, fishery, and aquaculture can be realized [6].

Aquaponics has the following advantages [7]:

(1) Manpower saving and ease in crop rotation: The aquaponics system does not face the issues such as conventional agriculture needing cultivating soil, fallow, and rotation. Therefore, compared with conventional agriculture, it will save manpower and eliminate obstacles to crop rotation. In conventional soil cultivation and crop rotation, soil disinfection is needed, which will inevitably cause pesticide damage to crops.

(2) Environmental protection and water saving: Compared with the conventional agricultural methods used in the past, the aquaculture water in the aquaponics system will not lead to excess waste water, except for absorption by plants and external evaporation. Usually, only refills are required. Therefore, water resources are significantly saved. In addition, the system itself is a concept of an aquaculture water cycle; hence, there is no concern about plant destruction owing to forgetting to water them.

(3) Self-sufficiency: The aquaponics system can be either large or small; furthermore, hydroponic methods or the medium of foamed stone, wood chips, moss, or coconut fiber can replace soil cultivation, which can significantly reduce the source of pollution in the soil. As long as there is a place at home to raise fish, vegetables can be grown at the same time, like a small space on the balcony or the roof can be used, which is ideal for urban residents to grow fruits and vegetables at home.

(4) Non-toxic, safe, and clean: It is not suitable to use pesticides or insecticides in the aquaponics system. If they are used in fish ponds, plant growth may be inhibited. If pesticides are used on vegetables, there is also a great risk of fish death. Therefore, it can be regarded as a non-toxic, pollution-free, and safe breeding system.

(5) Fast growth: Plants can get more space in nutrient water than in the soil. Only half of the energy is required for the root system to grow, and the rest of the energy can be used for growing stems and buds; therefore, plants will have an accelerated growth rate.

(6) Energy saving and carbon reduction: Compared with conventional agriculture, which uses a lot of fuel for crop cultivation, the proposed system uses electric power for water cycle farming. Electricity can be generated using solar, wind, or hydropower. These power generation methods are not only environmentally friendly but also inexpensive and pollution-free.

Today, aquaponics systems using information technology mostly also apply IoT technology and wireless transmission technology, such as the ones demonstrated by case studies in [8] and [9]. Using IoT technology and sensor deployment, the water quality or soil condition of the current system can be detected, and the collected data can be transmitted to the device specified by the user using wireless transmission technology, such as Wi-Fi, ZigBee, or Bluetooth, to allow users to monitor or analyze the collected data. Then, by adjusting the environmental factors based on the results of the analysis, both aquatic animals and crops can grow in ideal conditions.

2.2 Internet of Things

The Internet of Things (IoT) refers to the only identifiable things (objects) and their virtual representations in an Internet-like structure. The main advantage of the IoT concept is that it has a huge impact on many aspects of the potential users' daily lives and behaviors. From the perspective of private users, the most obvious effects of the introduction of IoT will be visible in the work and home fields. Currently, some industrial, standardization and research institutions are participating in the development of solutions to meet outstanding technical requirements [10].

The IoT is a network formed by connecting actual objects (such as vehicles, machines, and household appliances) through APIs or embedded sensors, and is linked by various wireless or wired communication devices to provide communication and dialogue for management and other services [11]. The IoT architecture is mainly divided into four layers, including sensing layer, network layer, IoT application support layer, and application layer [12].

(1) Sensing layer: In the IoT architecture, the sensor layer is responsible for data collection and transmission. At the sensor layer, there are two main technologies, namely sensor technology and recognition technology. Use sensing technology, the sensors are used to make connected objects sense changes in the environment or detect the movement of objects. The identification technology is radio frequency identification, which is a wireless communication technology that can identify a specific target and use radio signals to read and write related data without establishing mechanical or optical contact between the identification system and the specific target.

(2) Network layer: The network layer is responsible for transmitting the information identified or collected in the sensor layer to the application platform or application layer. Therefore, the network layer is regarded as a bridge between the sensing layer and the application layer. There are many key technologies for the network layer, such as Wi-Fi, Bluetooth, ZigBee and TCP/IP.

(3) IoT application support layer: The IoT application support layer is responsible for receiving the data transmitted by the sensing layer of the network layer, and processing and storing data using the cloud or IoT application platform. The IoT application support layer can combine many different analysis technologies to analyze data to provide prediction results or decisions (such as the technology of big data analysis), and transmit the analysis results to the application layer to provide services or management.

(4) Application layer: The application layer is the most important part of the actual implementation of the IoT. The application layer uses all technologies and resources on the sensing layer, network layer, and application support layer to provide various applications and services. Currently, the application layer can be used in many different kind of industries such as medical, transportation, agriculture, industry, culture and food. As the IoT technology matures, it can be expected that the future development of the application layer will become more diverse and make our lives smarter.

This study is based on IoT architecture, deploying sensors for IoT-based Aquaponics Systems (IAS) and building Intelligent Voice Control Systems (IVCS) 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, the IoT-based Aquaponics System (IAS) and the Intelligent Voice Control System (IVCS) of the IoT will be discussed in detail.

3.1 The Concept of the Proposed Systems

In this study, an Intelligent Voice Control System (IVCS) of the IoT that can assist farmers to use information technology to overcome environmental factors and labor costs and improve agricultural productivity has been proposed. In addition, an IoT-based Aquaponics System (IAS) that can collect environmental parameters related to the growth information of agriculture, fisheries, and aquaculture, monitor, store, process and analyze relevant environmental parameters of the system and provide an effective reference for production decisions was also proposed. Through the integration of IAS and IVCS, it is expected to help farmers and fishermen in aquaculture production. The deployment of IAS and IVCS can not only be implemented in agriculture and aquaculture, but also greatly improve production efficiency, reduce manual labor and increase the interest of those willing to invest in agriculture and aquaculture. The integration of IAS and IVCS is shown in Figure 1.

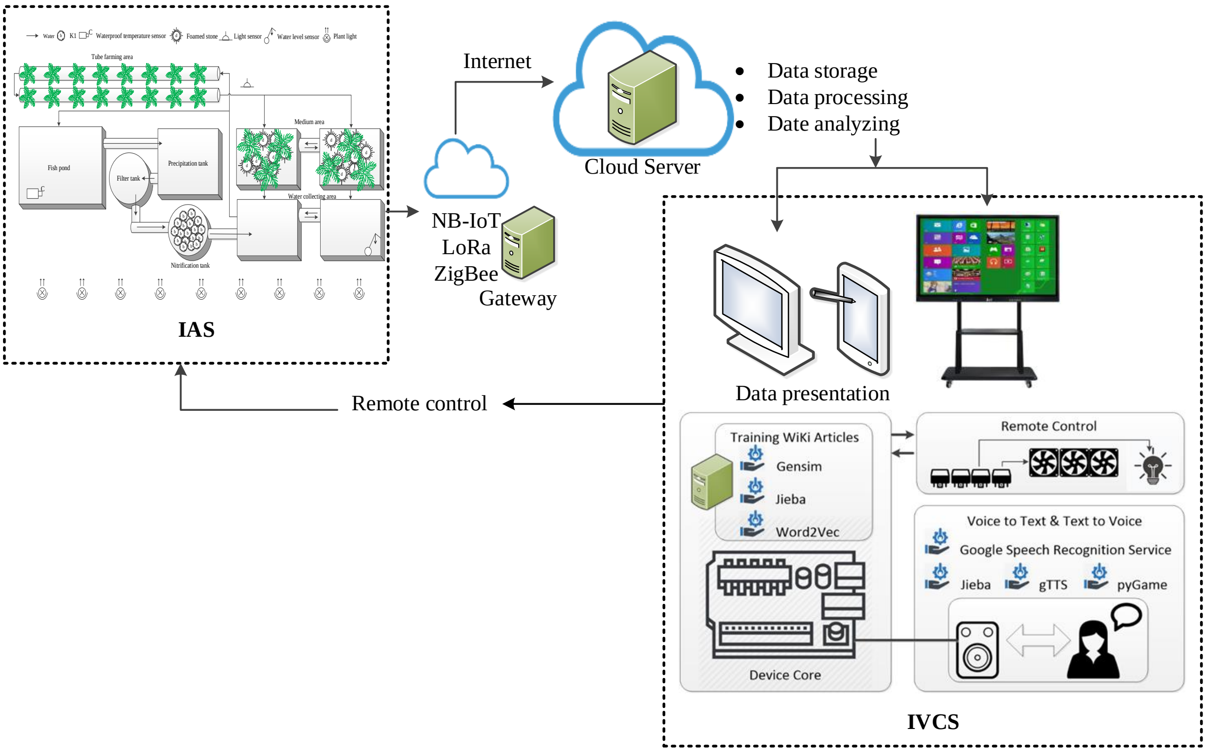

Figure 1. The integration of IAS and IVCS.

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. And, the environmental factors include: temperature, relative humidity, carbon dioxide, water quality, wind speed, wind direction, solar radiation and atmospheric pressure.

To achieve this goal in the proposed study, an IAS with IVCS was constructed in this research. The construction of the IAS and IVCS has been detailed in the following subsections.

3.2 IoT-based Aquaponics System (IAS)

To build an IoT-based Aquaponics System (IAS**)**, the first task is to understand the data collected by the system and clearly know the crops to be planted and the fish species to be selected, which involves the expertise of agriculture and aquaculture. Therefore, in this study, we interviewed farmers in the field who actually farm, to understand the major issues they are facing and how to effectively control and solve them. There are various environmental factors that affect plant growth, and monitoring key ones, such as air temperature and humidity, soil temperature and humidity, and water quality, can effectively help in collecting data for analysis and making useful decisions in the end. Therefore, by field investigation, this study learns about a wide range of key monitoring parameters, such as air temperature sensor, relative humidity sensor, air quality PM2.5 sensor, soil temperature and humidity sensor, water temperature sensor, sensor of pH in water, sensor of nitrite (NO_2) concentration in water, sensor of ammonia concentration in water, sensor of oxygen concentration in water, and automatic watering sensor.

The IAS includes a fish pond, a precipitation tank, a filter tank, a nitrification tank, tube farming area, medium area, and water accumulation area. Aiming at these areas, the system architecture is planned in this study, as shown in Figure 2. In Figure 2, fish ponds are mainly used to raise selected aquatic species, such as Wuguo fish or Nile fish. The precipitation tank is mainly used to precipitate all the aquaculture water returned through the aquaponics system. As the water may contain impurities that cannot be filtered, it will be precipitated during this process, and the aquaculture water will flow through the filter barrel subsequent to precipitation. At this stage, the impurities that are not filtered will be filtered with a finer filter material, and then the aquaculture water will go to the nitration tank, which is used to decompose ammonia in fish excrement or residual feed. As the nitrification system comprises a large number of nitrite bacteria, ammonia can be decomposed and oxidized to nitrate, and it can then be decomposed into nitrogen and oxygen by anaerobic bacteria. Subsequently, the aquaculture water is sent to the tube farming area and the medium area to allow the plants to absorb nitrogen fertilizer, and the entire circulating water aquaponics aquaculture system is completed. Figure 2 illustrates the architecture of the IAS, and the functions of each area are explained below.

(1) **Fish pond.** The main function of the fish pond is to breed aquatic species. In this study, we cultured the Wuguo fish and Nile fish. During the breeding, breeding waste and fish excreta will be generated, which will affect the quality of the aquaculture water and cause ecological disasters for fish and crops. Therefore, the water from the fish pond is pumped into a precipitation tank for the filtration of larger impurities.

(2) **Precipitation tank.** Aquaculture water pumped through the fish pond is stored in the precipitation tank. At this stage, the study uses large brushes to filter the breeding waste and excreta. The small impurities that cannot be filtered are re-filtered using precipitation. At this stage, a large amount of waste that affects water quality will be removed, and the aquaculture water will be sent to a filter tank for fine filtering.

(3) **Filter tank.** This area is mainly used to filter relatively small feeding waste and excreta. Therefore, this study uses filtering cotton and biochemical cotton for filtering. At this stage, a small amount of impurities still remains in the aquaculture water. Therefore, the aquaculture water is sent to the nitrification tank for digestion and decomposition.

(4) **Nitrification tank.** In this study, a large number of nitrating rings and K1 filter materials are deployed in the nitration tank (see Figure 3), and the air is pumped in using an air pump to make the nitrating rings and K1 filter materials roll, during which nitrifying bacteria is cultivated. Nitrifying bacteria can digest and break down tiny impurities in aquaculture water. This process contributes to the growth of the plant. It can increase the oxygen content in the aquaculture water with the help of the air pump, thereby avoiding rotten roots in the plant.

(5) Tube farming area. In this study, a hydroponic tube farming area is created in the system. Tubes can be vertically erected, which can save a lot of space. Subsequent to precipitation, filtration, and nitration, aquaculture water comprises a large amount of nitrogen and oxygen, which facilitates plant-absorbing nutrients and hydroponic cultivation.

(6) Medium area. In this study, a medium area is built for the system, mainly because not all plants are suitable for hydroponics. The medium area can replace the soil with the same effect as the soil without affecting the quality of the aquaculture water. Therefore, this study uses foamed stone (as shown in Figure 3), wood chips, water moss, or coconut fiber for the construction of the medium. Therefore, it is unnecessary to install additional siphon equipment to facilitate plants' breathing and promote plant growth.

(7) Water collecting area. This area is mainly for collecting aquaculture water. Aquaculture water is pooled to this area through the siphon equipment for nitrification tank and medium area. This area can also be used for precipitation and purification, or for replenishing water from this area. Subsequently, aquaculture water is sent to fish ponds and planting areas to form a water circulation system, thereby effectively using water resources.

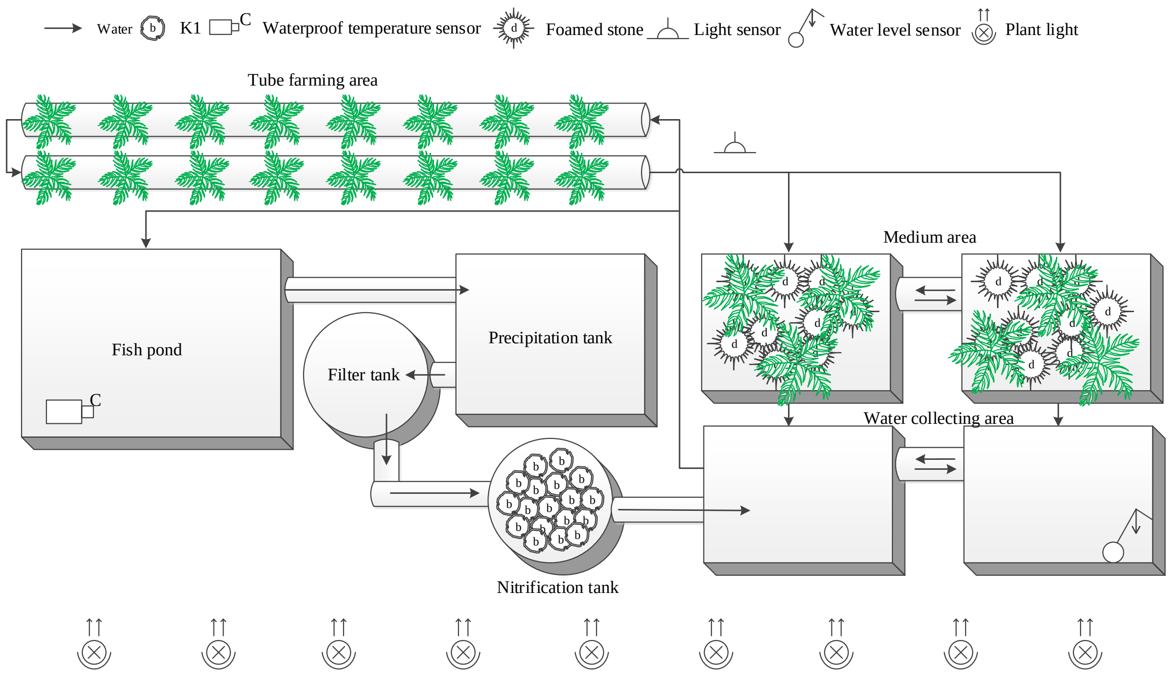

Figure 2. The architecture of IAS.

Figure 3 shows the filter material K1 used in the study for the cultivation of nitrifying bacteria in the nitrification tank. K1 is a lightweight plastic filter material, like a small biochemical ball, with a hollow structure and gear-shaped external appearance. The filter material can be rolled by pumping air, and the nitrifying bacteria will be cultivated during the rolling process. The bacteria can oxidize ammonia in water, which helps in plant growth. The aquaponics system does not use soil as a medium for planting crops because the soil is prone to disease and insects, which will pollute the aquaculture water. Therefore, foamed stone, wood chips, water grass, or coconut fiber are usually used instead. The medium used in this study is foamed stone. Foamed stone, also known as expanded clay aggregate, is fired at 1100°C. Its appearance is reddish-brown, with its interior being porous light gravel with different thicknesses. The surface can absorb moisture, and the interior can retain air, which features water retention and air permeability. It protects the roots of plants from rotting, and furthermore, diseases and insects cannot parasitize foamed stones. They prevent insects and also inhibit the growth of weeds.

Figure 3. K1 and foamed stone.

Figure 4 shows the IAS built based on the architecture designed in this study. The fish pond is a 160-liter square tank, which breeds a total of 40 Nile fish. Watercress and Qingjiang are planted in the tube farming area, and Chaotian pepper, coriander leaves, and ginger are grown in the medium area. The overall water body is approximately 200 liters, and the pH of aquaculture water is maintained at approximately 7. The nitrous acid (NO_2) content in water is maintained at 0.1. The system has worked for more than a year without the requirement to replace water. As the aquaculture water will be lost due to the evapotranspiration of plants and natural evaporation, the system automatically replenishes water through a water level monitor to avoid the death of farmed fish and crops due to labor shortage. To avoid poor growth or excessive growth of plants caused by insufficient light, a light sensor is deployed in the system for monitoring. When the sunlight is insufficient, the plant lights in the balcony are turned on to supplement light. The water body is equipped with a waterproof temperature sensor. When the water temperature is extremely high or low, MCU (Micro Controller Unit) notification will be triggered.

Figure 4. The IAS built based on the architecture designed in this study.

3.3 Intelligent Voice Control System (IVCS)

Because farmers have difficulty in using the operation interface of the information system, the farmers' resistance to the information system is generated, which will hinder the process of scientific and technological agriculture informatization. Therefore, the environmental control required for IAS operation through the Intelligent Voice Control System (IVCS) of the Internet of Things was proposed by this research. IVCS provides farmers with IAS operations, monitor and control in natural language, which can solve the problem that farmers cannot use information technology.

The architecture of the IVCS is shown in Figure 5. The IVCS is divided into four components, namely "intelligent voice module", "semantic analysis module", "parse natural language and text-to-speech module", and "remote environment control module". Next, these four modules will be explained:

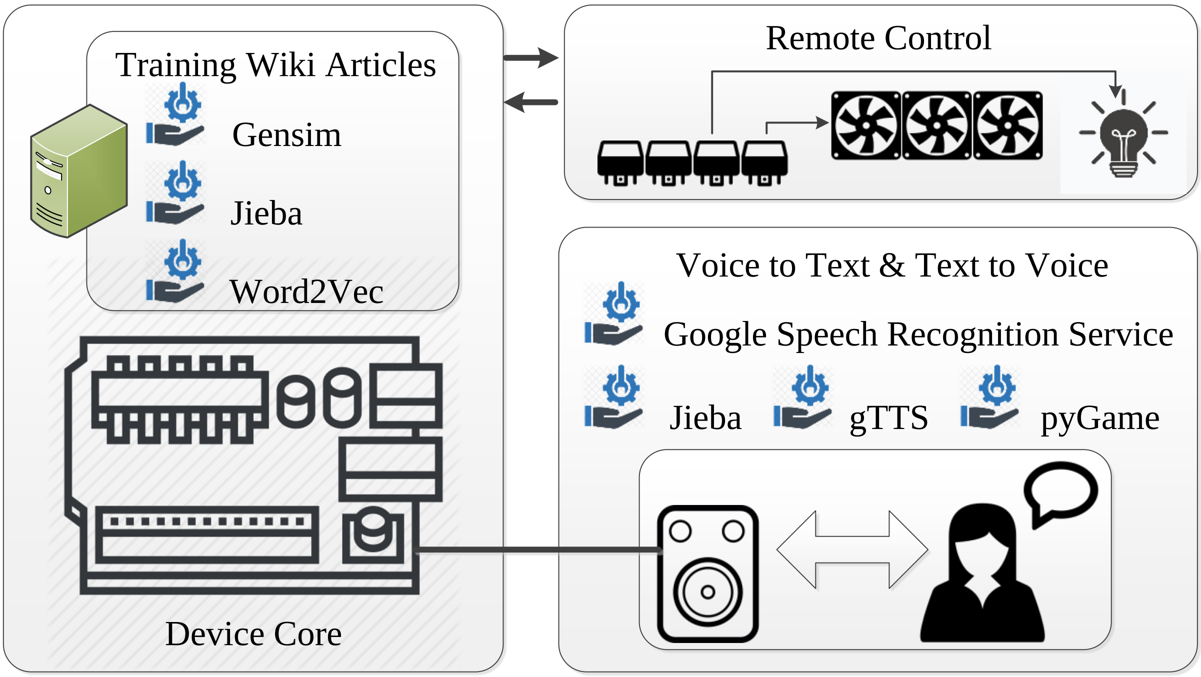

Figure 5. The architecture of the IVCS.

(1) Intelligent voice module: The Raspberry Pi Linux-based single-chip computer is used for semantic program development in the Python programming language. The core program of the intelligent voice module is to train word vectors for a large number of corpora. After training, you can enter keywords to perform similarity calculation to find the closest vocabulary. For example, the keyword "open" corresponding to similar words "open up" or keywords "start" corresponding to similar words "launch". Then, the intelligent voice module can find similar words to help the subsequent vocabulary classification. Therefore, the Gensim package was first adopted to extract the title and content of three million articles in Wiki. After that, the collated titles and contents will be hyphenated through Jieba package. Stop words will be introduced in the process of word segmentation, the purpose is to filter slurred words. Finally, all word vocabularies that have been segmented are used for word vector training through the Word2Vec package. After training, the core word vector similarity comparison model can be obtained. With this model, similar words for keywords will be found. Then, the programming of keywords and similar words will be carried out.

(2) Semantic analysis module. The architecture of the semantic analysis module is shown in Figure 6. The semantic analysis module is divided into two parts: cloud semantic setting procedure and user control procedure call.

- **Cloud semantic setting procedure.** IVCS provides a cloud-based remote user control platform. Users can perform remote environment control settings through the interface provided by the cloud semantic setting procedure. In the process of using the interface, the user uses the Universally Unique Identifier (UUID) of the MCU control board to be controlled, and the MCU IO control pin number or relay module control pin number, and the sentences and keywords to be used for remote control will be set. The intelligent voice module of IVCS will perform a word segmentation program for natural sentences, and extract feature words to find similar words, and then write all feature data to the database. Table 1 is the result of analyzing and processing a sentence. Table 1 describes the feature word corresponding to the sentence, similar vocabulary and the program command to be executed, for example: IO # 1 # On, Relay # 3 # On is a control command, the command states that the first pin of IO should be turned on and start the third pin of the relay module.

Table 1. Sentence feature information.

Statement	Vocabulary characteristics	Similar vocabulary set	Procedure
Turn on the TV	Turn	Turn, Open up, Start, …	IO#1#On, Relay#3#On …
	TV	TV, Television …	

- **User control procedure call.** The farmer communicates with the speaker by speaking. The MCU on the speaker will convert the text according to the voice, and perform word segmentation and extract the characteristic of vocabulary. After that, the characteristic of vocabulary is sent to the cloud for analysis and processing. For example, the sentence "turn on the TV for me", extract the feature words “turn on” and “TV”. The cloud system will compare “turn on” with similar vocabulary in the database to find the data that contains “turn on” (see Table 1). After that, the “TV” vocabulary is compared with similar vocabulary for the found data to determine whether there are similar vocabularies. If a similar vocabulary is found, the execution program is taken out and transmitted. When the program to be executed is received by the speaker’s MCU, the program commands will be parsed and the control commands will be pushed. When the MCU with the same UUID as the command receives the push broadcast command, the control command will be parsed and the remote environment control will be executed to meet the user's needs.

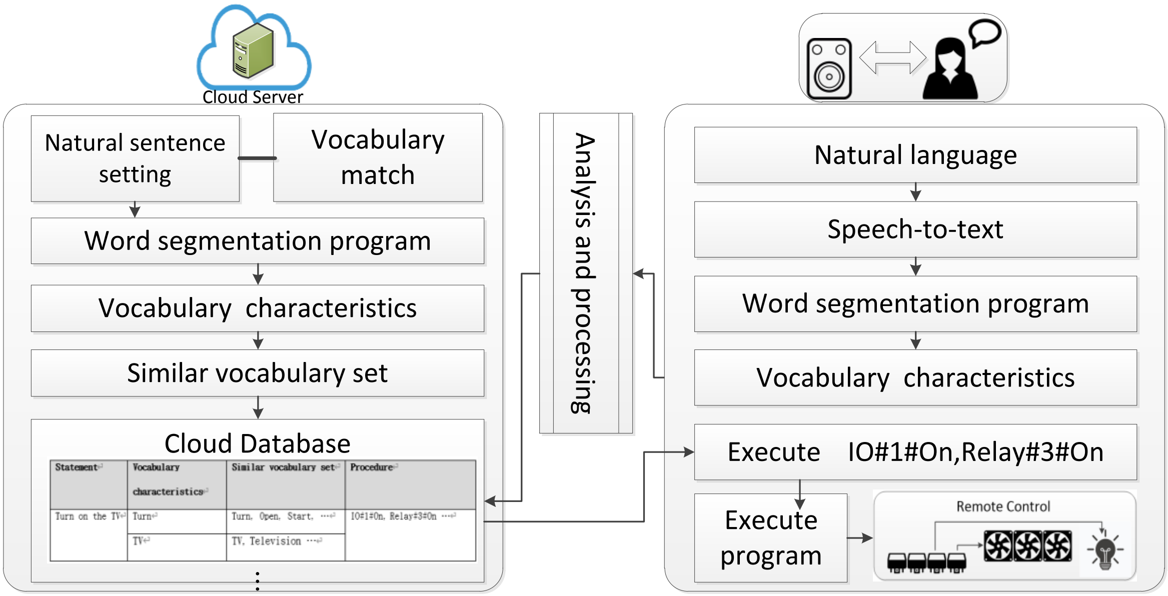

Figure 6. The architecture of the semantic analysis module.

(3) Parse natural language and text-to-speech module. The command of the text can control the information system. Therefore, in order to enable farmers to directly control the environment by speaking, the commands issued by farmers in spoken language must be converted into words. In this study, Google Speech Recognition Service is used to process natural language analysis and convert text to speech. Therefore, the microphone device is configured in the system to record human speech into an audio format through the microphone, and then transmit the audio to the Google Speech Recognition Service server to convert the voice into text. The successfully converted text is a series of sentences, so the Jieba package is used to segment the word. Because the words segmented by Jieba have parts-of-speech. Therefore, unnecessary part-of-speech must be filtered to retain part-of-speech that truly achieves semantic analysis, such as nouns and verbs. In this study, the reserved parts of speech are called feature word. Afterwards, semantic analysis is performed on the feature word to understand what the user wants to express, and an execution control program is executed for this part. When the control program is executed according to the user's words, the message that the program execution is completed or failed will be provided to the user. In order to notify the user of the status of the program execution, the speaker device was installed in the system by this study, and the text was converted to audio for play. The gTTS package is used in this study to convert text to audio files, and audio play is performed through the pyGame package.

(4) Remote environment control module. The remote environment control module will be equipped with an MCU board, and will subscribe to the MQTT (Message Queuing Telemetry Transport) host service according to its UUID when it starts. When the "intelligent voice module" publishes the requirements for executing environmental control commands, MQTT will publish the information and specify the UUID of the receiver. The push notification is received by MCUs with the same UUID. The MCUs with the same UUID parse the control commands carried in the push information and complete the remote control requirements of the user. Then, the MQTT information will be released by the MCU again. The target of the push broadcast notification is the "intelligent voice module". The execution result of the remote control will be played by the voice of the "intelligent voice module" through the speaker to reach the user notification. The architecture of remote environment control module is shown in Figure 7.

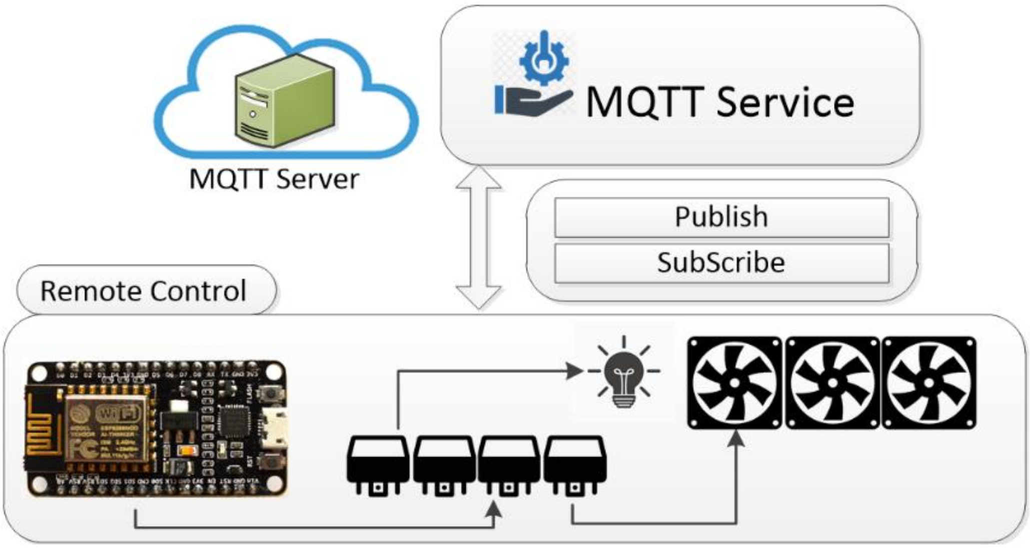

Figure 7. The architecture of the remote environment control module.

The hardware used by IVCS is shown in Figure 8. Among them, the Raspberry Pi is equipped with the intelligent voice module, a microphone array, and a speaker. For the remote environment control module, the MCU is used in this study to receive push broadcast information to achieve the transmission of the environment control command to be executed.

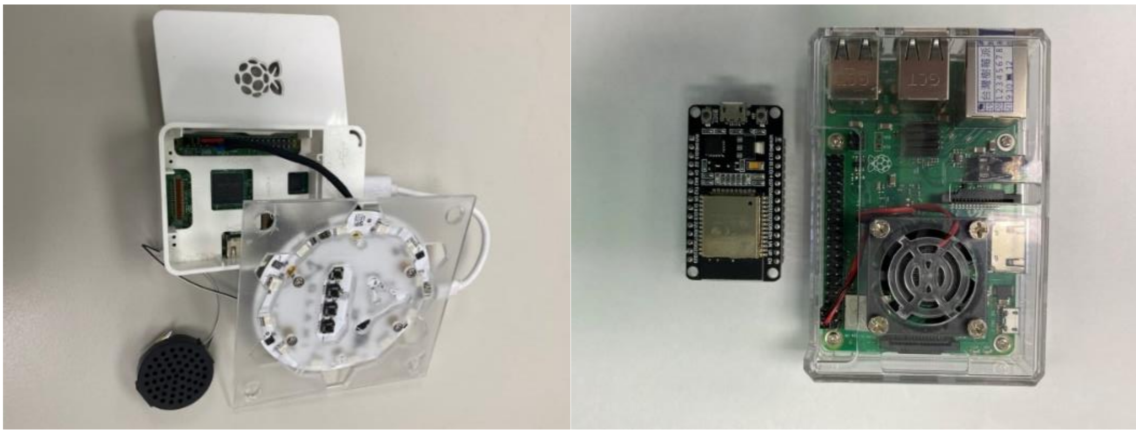

Figure 8. The hardware of IVCS.

4. The Comparisons of Conventional Agriculture and Greenhouse Planting System with the Proposed IAS

Conventional agriculture must monitor the cultivation environment with a large number of manpower, including monitoring of soil humidity, climatic temperature, water level, and oxygen content in the water. The process is based on the cultivation experience of farmers and fishermen, which also changes with the climate, causing the entire farming process difficult to control. Therefore, introducing technology to assist farmers and providing instant environmental monitoring data will help the development of agriculture. The comparisons of the conventional agriculture and the proposed IAS are given in Table 2. When technology is introduced to conventional agriculture, it effectively saves human labor. In terms of energy saving, production quality, and cost, it is better than the conventional method, and it can also achieve science and technological agriculture.

Table 2. Comparison of conventional method with that employing IoT technology.

Method / Factor	Conventional agriculture	The proposed IAS
Human labor	Either monitoring or controlling the environmental situation, the concerned person must be on site.	Introducing remote monitoring and instant warning saves human labor.
Environmental protection and energy saving	Farming following the empirical method, which is less supportive and consumes more resources.	With reference to the data returned by the actual IoT sensor, precise farming is guaranteed, and resources can be effectively used.
Growth quality	Prone to imbalance between supply and demand, causing imbalance in growth.	Leveraging science and technological farming methods, easy to control growth conditions
Cost	Large cost of labor and resources.	Initial IoT construction cost is needed; however, manpower and resources can be effectively controlled.
Traceability	N/A	Environmental parameters can be stored, and data are traceable.
Remote monitoring	N/A	Remote monitoring and control
Instant warning	N/A	Threshold can be established for early warning

In order to increase the productivity of agricultural, in the face of climate change, greenhouse planting system is also one of the most important agricultural techniques [13]. Therefore, the comparison and analysis of the greenhouse planting system and IAS are given in Table 3. From the analysis and comparison in Table 3, it can be known that cultivation through soil cultivation in the greenhouse may cost a lot of resources and money. In terms of food security and production quality, the aquaponics system is more stable. The proposed IAS can create controllable environmental parameters, and it is more productive and cost-effective than conventional methods in terms of energy saving, carbon reduction, food safety, efficient use of space, and reduction of human labor.

Table 3. Analysis and comparison of greenhouse and IAS.

Method / Factor	Greenhouse planting system	The proposed IAS
Energy saving and emission reduction	Conserving soil using organic method can easily result in air pollution and requires large tools to for farming, which wastes large amounts of water.	Relies on a small amount of electricity. Aquaculture with recycled water greatly saves energy.
Food security	Pesticides must be used for pest control.	Nutrients are mainly from fish excrement or feed waste. Pesticides are forbidden.
Land pollution	Organics or chemical drugs are required to conserve soil and water.	Involves off-farm cultivation and uses media instead of soil. No pollution issues.
Human labor	Incapable of self-sufficiency and large labor cost	Self-sufficiency; no requirement of extensive human labor.
Land restrictions	Large area is needed for farming.	The system can be large or small, and it can be adjusted according to the site.
Use of space	Limited land area and farming space	Can cultivate by tube or stack farming, which effectively uses space.
Production quality	Farming in soil is susceptible to pests and diseases; therefore, crops are inevitably contaminated by pests and diseases. In addition, pesticides can render food more unsafe.	Hydroponics or farming in media. Monitoring of water pollution through fish; producing non-toxic organic food
Maintenance cost	Large area of arable land, limited space to use, soil cultivation is restricted by rotation. The soil needs to be reconserved every time, and water resources cannot be effectively used. The overall cost is high.	The site can be large or small; effective use of space; only a small amount of power is required to operate the system; recycling water; self-sufficiency; immune to climate; rotation without limitation; and lower overall cost

5. Conclusion

In this study, IoT technology was successfully applied to the aquaponics system. In the process of research, the feasibility of the integration of traditional agriculture and IoT is determined, and it can greatly reduce human labor. The environmental parameters collected through the IAS constructed in this research will help to provide decision-making during production and improve the efficiency of crop production, and can overcome problems such as climate change, shortage of manpower, restrictions on cultivated land, rotation of cultivated land and waste of resources. In addition, the advantages and disadvantages of conventional agriculture and greenhouse planting system were compared with the proposed IAS. And, in the research, the proposed IVCS provides a friendly and intelligent voice operation interface, which successfully solves the farmers' lack of information knowledge, and the process of resisting agricultural informatization has lowered the threshold for system operation.

Overall, the IAS and IVCS proposed by this study can provide a common reference for partners interested in participating in science and technology agriculture, and inspire more diverse applications. The precision agriculture provided by IAS and IVCS can produce non-toxic and non-polluting food, make food safer, and achieve the purpose of improving the efficiency of agricultural and fishery production.

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