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Greenhouse for Effective Agriculture with Electricity Generation and Water Collection Systems

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Global warming and pollution have increased concerns about the agricultural industry and are regarded as contributing to the decrease in global crop production. Therefore, advanced agricultural methods have been researched and applied in farming. Using improved sensors and communication technology, we designed a greenhouse that can generate electricity from renewable energy sources and collect water from precipitation, which does not need additional energy and water resources. Solar panels and a wind turbine were employed to generate electricity to operate the sensors and devices of the greenhouse, while a rainwater collection and storage system was developed to supply water to grow plants. Building on sustainable green energy and water resources, an advanced plant cultivation system operates within a greenhouse. It adjusts key environmental parameters, including soil moisture, air temperature, humidity, and illumination, through the use of sensors and actuators such as mist sprayers, ventilators, heating bulbs, water sprayers, and sun-shading devices. To enable real-time monitoring of the aforementioned environmental parameters, sensor data and monitoring results were sent to a server installed in a personal computer and on the cloud and were used to control heaters, cooling fans, LEDs, water sprayers, water pumps, and others for automated farming. Since farming is often carried out in remote areas where Internet connectivity may be unavailable or weak, a long-range technology that operates independently of Internet networks is proposed. The developed greenhouse can be controlled remotely using the long-range technology. The greenhouse can be implemented in remote areas where resources and access to the Internet are limited. A prototype was created for testing but it needs to be tested on a real scale to evaluate its operation.

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1. Introduction

In farming, temperature, air humidity, illuminance, and soil moisture considerably affect the growth of plants.(1) However, owing to global climate change and environmental pollution, it has been difficult to maintain the expected products of crops, which has led to the development of innovative agricultural methods such as precision farming, vertical farming, and automated farming. For such new methods, sensors and devices including heaters, cooling fans, LEDs, or water sprayers are used, being powered by solar photovoltaics(2,3) and integrated with advanced technologies including IoT.(4,5) The new agricultural methods with advanced sensors and devices also prevent damage caused by wild animals(6) and pesticides and repellents.(7–10) They can also be used to avoid theft using heat and motion sensors.(11)

Even with such methods and technologies, water cannot be produced for agriculture. Usually, groundwater is used as a water resource,(12) but environmental changes have significantly impacted the hydrology and water reservoir underground.(13,14) For sustainable agriculture, it is essential to develop the technology for water management to solve the problem of water shortage in the future.(15) Increased evaporation rates and changed precipitation patterns make it difficult to manage water resources effectively and cause a rapid decrease in surface water and underground water reservoirs by 10–14%.(16) The overuse of groundwater also leads to the shrinkage of the land area for agriculture.(17)

To address the problems in using devices and water supply in advanced agriculture, we designed and prototyped a greenhouse to increase the quality and yield of agricultural products. For the greenhouse, we included an automated rainwater collection and storage system(18) and an electricity generation and storage system using solar and wind energy. Global climate change(19,20) and the anticipated depletion of fossil fuels have facilitated the adoption of solar energy.(21,22) Solar energy has become more widely used owing to its improved efficiency in generating electricity on the basis of the development of related technologies and their adoption.(23,24) The efficiency of electricity generation with solar panels has increased to 32% when using sun-tracking devices.(25,26) The two-axis sun-tracking system increased its efficiency to 40%.(27–29) Kazem *et al.* reported a 45% efficiency of electricity generation using flat photoelectric panels and a two-axis sun-tracking electricity generation system.(30) Recently, Chiu and co-workers. have developed a semicircular spherical sun-tracking system on multiple axes with an automated monitoring system.(31,32) To avoid the lack of electricity generation, a wind turbine was also included in the system. To overcome the possible unstable network in the rural farming field, a long-range (LoRa) radio module was proposed in this study for remote control and monitoring.(33) To mitigate the impact of extreme climate conditions on plants, a greenhouse device in the study is employed for cultivation. To maintain an optimal environment including air temperature, air humidity, soil moisture, and illumination, a microcontroller-based control system equipped with various sensors and actuators is implemented within the greenhouse. To ensure a reliable supply of electricity and water, the system integrates a solar panel, a fan generator, and a rainwater collection system. For the real-time monitoring of environmental parameters, sensor data and monitoring results are transmitted from the greenhouse to a remote center via the LoRa network. The developed system can be controlled and monitored remotely using the LoRa technology with an antitheft module to prevent the invasion of animals and humans. Agricultural damage in traditional farming is often caused by wild animals, pesticide use, irrigation challenges, and extreme temperatures, making greenhouse systems increasingly important. Additionally, providing adequate care for plants typically requires significant manpower. To address these challenges, our plant cultivation system leverages reliable electrical power and abundant water resources to enhance crop productivity while minimizing labor. By incorporating automated cultivation techniques and a remote monitoring platform powered by LoRa technology, the system ensures efficient plant care and streamlined management.

2. Methodology

In the developed greenhouse in this study, a microcontroller, environmental sensors (air temperature, air humidity, illumination, soil moisture, and rain sensors), and security sensors (ultrasonic, infrared, and image detection) are used. An actuator is used to control the sprayers, sprinklers, fans, heating bulbs, and electricity generators of the system based on the real-time data collected by the sensors. The security sensors are used to detect intrusion. In the event of intrusion, the actuator activates alarms and warning lights, and a message is sent to the control room. The sensor data and monitoring results are uploaded to a personal computer (PC) and the cloud servers via the LoRa module, and transmitted to the registered mobile phone of the manager (Fig. 1).

Figure 2 shows the rainwater collection and storage system. The system comprises water tanks, water pumps, water level sensors (float switches, ultrasonic level sensors, and capacitance and level sensors), and a water collection device installed on the roof of a separate building. The wings of the system can be controlled depending on the amount of precipitation. Considering the

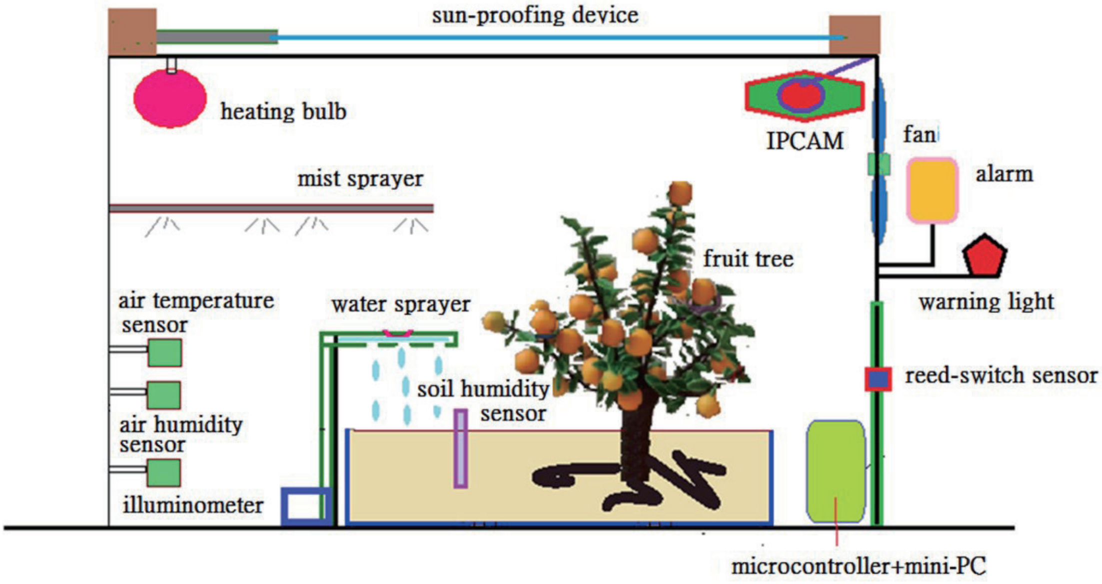


Fig. 1. (Color online) Structure of developed indoor farming system.

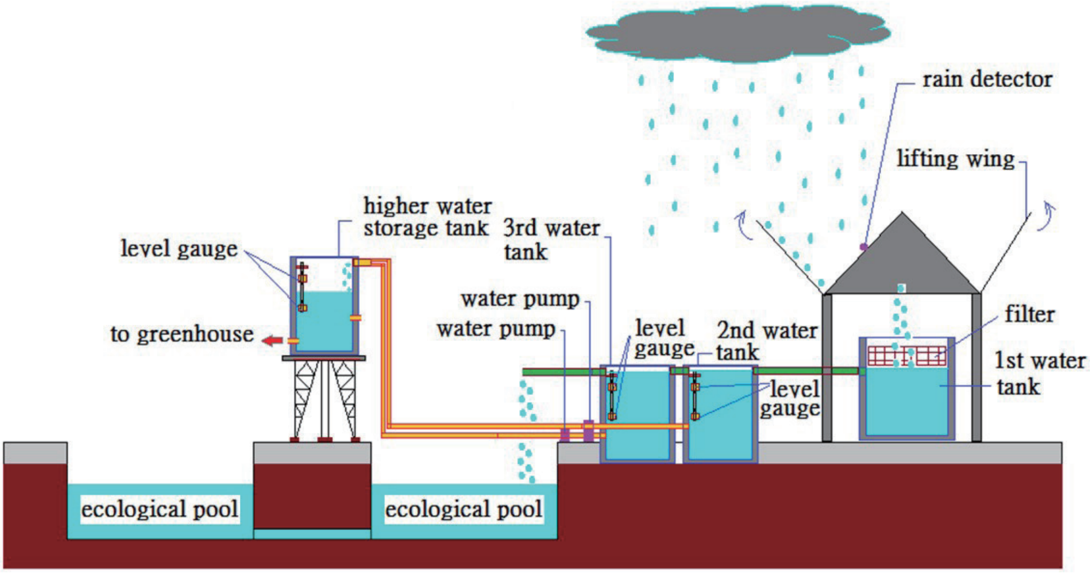


Fig. 2. (Color online) Automatic rainwater collection and storage system.

weather in Taiwan, where the greenhouse is implemented, we placed four water tanks with pools around the fourth water tank.

We developed electricity generation systems using solar panels and a wind turbine, which are controlled using Arduino (Fig. 3). Electricity is generated using solar panels and a wind turbine and is used to charge a 12-volt battery. The charged electricity is monitored using a voltage-detecting sensor attached to the battery and is also sent to the server. The wind turbine generates electricity in alternating current, while the solar panels produce electricity in direct current. The resulting alternating current is converted to direct current via the Wheatstone Bridge in order to charge the battery.

The overall system architecture is shown in Fig. 4. The sensors detect air temperature, air humidity, illumination, and soil moisture, and control these parameters by driving the related actuators to operate devices including heating bulbs, fans, sprinklers, sprayers, wind blinds, and others. According to the sensed data, the devices are operated automatically or a designated operator can control them. To monitor the status of plant growth, images are captured by a camera connected to the LoRa network. For any intrusion of animals and humans, warning lights and alarms are also triggered with sensed signals. The fill level of the water tank is continuously monitored using water level sensors. The sensor data are transmitted to the servers to operate water valves (Fig. 5). The water pump is operated to control the level of stored water. All data and images are sent to the PC and cloud server, according to which devices are operated automatically on the basis of preset threshold values. A LoRa module is used for data transmission and networking. LoRa communication is enabled up to 10 km. The circuit of the control panel of the greenhouse is shown in Fig. 6.

(a) (b)

Fig. 3. (Color online) Solar panel and wind turbine of electricity generation systems of developed greenhouse: (a) solar panel and (b) wind turbine.

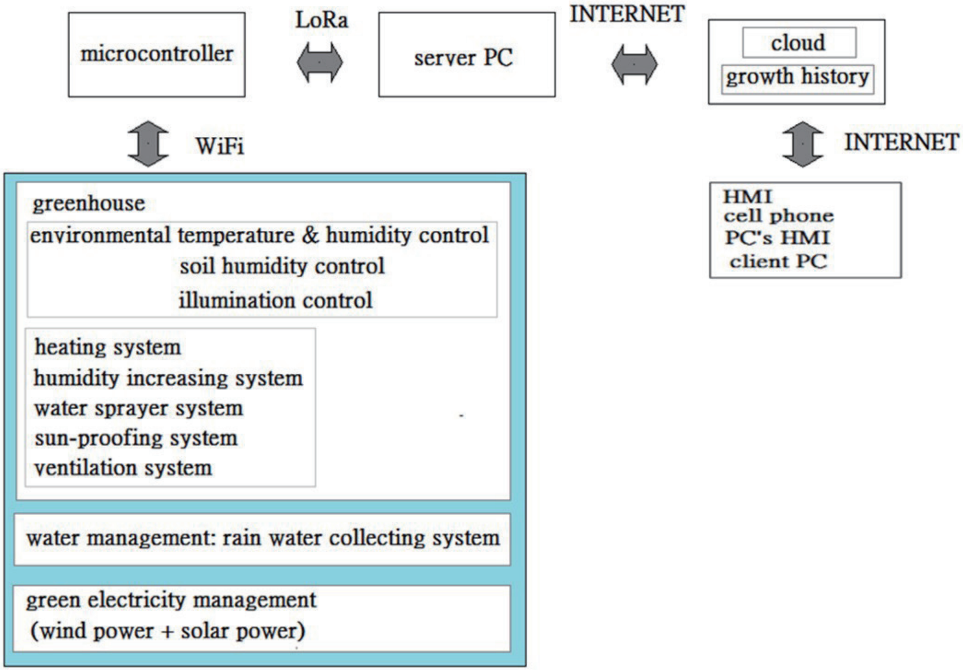


Fig. 4. (Color online) LoRa-based remote monitoring/controlling effective agriculture system.

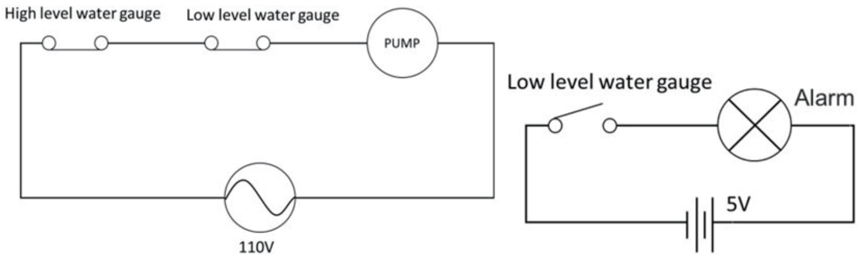


Fig. 5. Diagram of water level control.

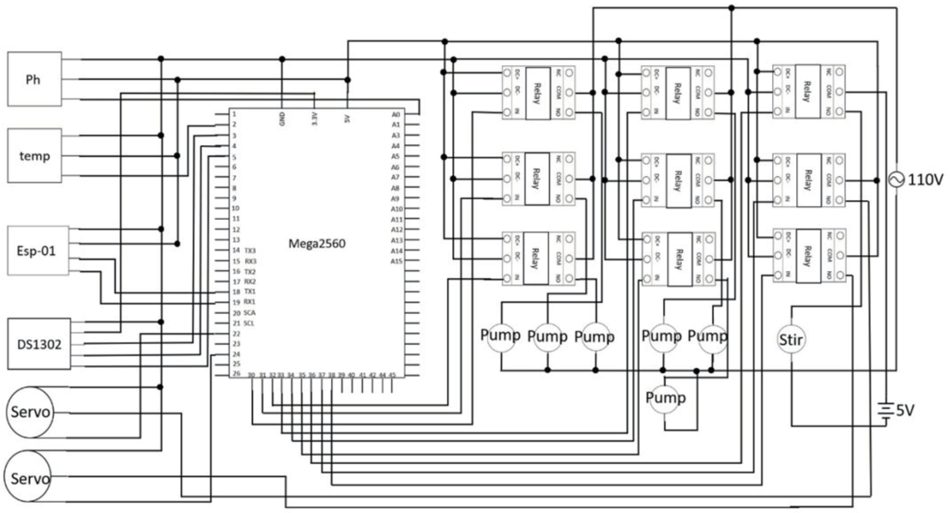


Fig. 6. Circuit of control panel of greenhouse.

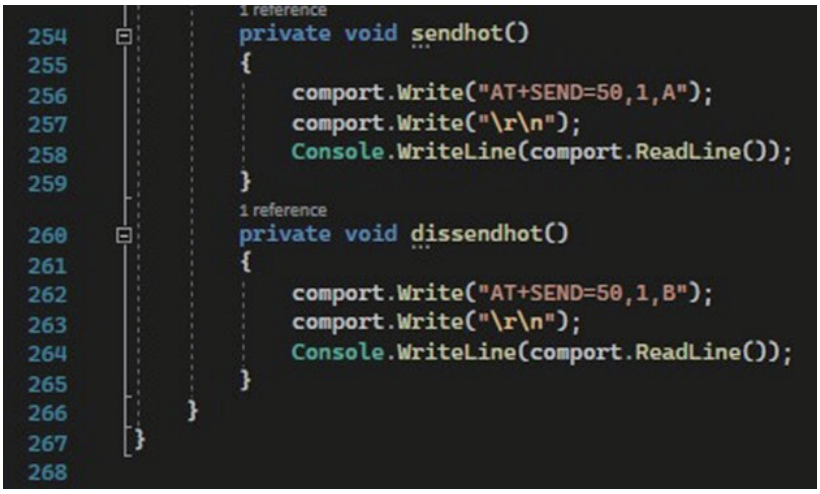
3. Results and Discussion

We designed and prototyped a greenhouse with a rainwater collection and storage system and an electricity generation system. The greenhouse is controlled remotely by a PC or a mobile device. All sensor data and monitoring results are stored in the PC and the cloud server. For the control, we created a C# program, as shown in Fig. 7, and the interface for remote control is shown in Fig. 8.

The prototype of the greenhouse is shown in Fig. 9. It consists of solar panels on the roof, the control panel, actuators, and sensors. Figure 10 shows the prototype of a rainwater collection and storage system. There are three water tanks outside of a box and a rainwater sensor and wings on the roof. Water tanks are connected with water tubes to control the water level. Sensors are placed in the water tanks.

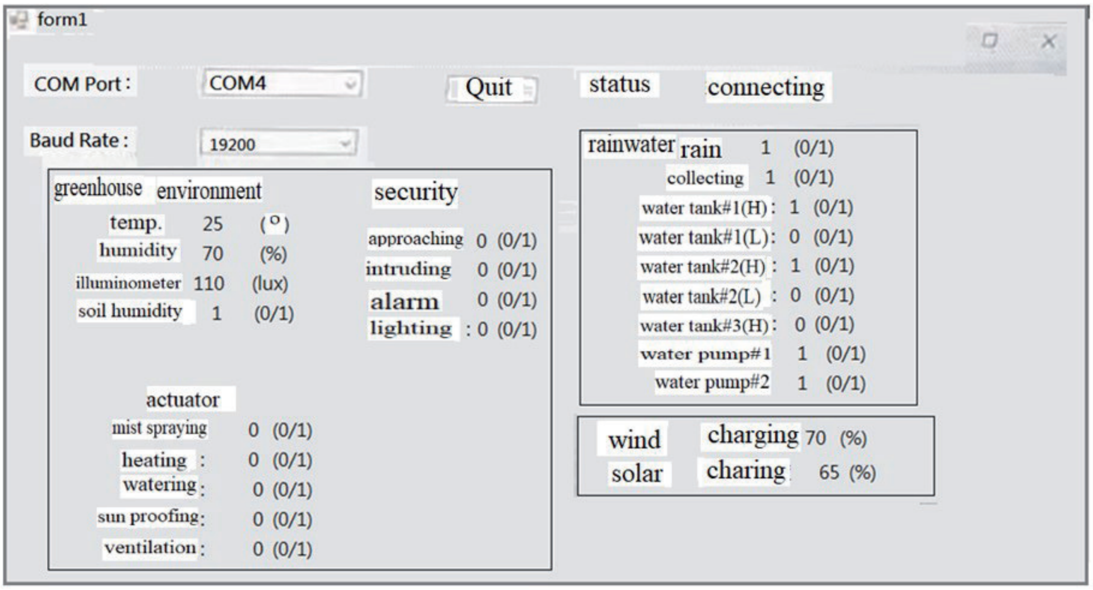
Figure 11 shows the control unit for using and charging the battery. The unit was designed to save electricity as much as possible to manage the electricity generation system and the battery.

In the performance test of the prototype automated effective agriculture system, we set environmental control targets at the near end (equipment end) with greenhouse temperature,



```
        1 reference
        private void sendhot()
        {
            comport.Write("AT+SEND=50,1,A");
            comport.Write("\r\n");
            Console.WriteLine(comport.ReadLine());
        }
        1 reference
        private void dissendhot()
        {
            comport.Write("AT+SEND=50,1,B");
            comport.Write("\r\n");
            Console.WriteLine(comport.ReadLine());
        }
    }
}
```

Fig. 7. (Color online) Part of C# program in human–machine interface of control system of developed greenhouse.



form1

COM Port : COM4

Baud Rate : 19200

Quit

status connecting

greenhouse environment

temp. 25 (°)

humidity 70 (%)

illuminometer 110 (lux)

soil humidity 1 (0/1)

security

approaching 0 (0/1)

intruding 0 (0/1)

alarm 0 (0/1)

lighting : 0 (0/1)

actuator

mist spraying 0 (0/1)

heating : 0 (0/1)

watering : 0 (0/1)

sun proofing : 0 (0/1)

ventilation : 0 (0/1)

rainwater rain 1 (0/1)

collecting 1 (0/1)

water tank#1(H) : 1 (0/1)

water tank#1(L) : 0 (0/1)

water tank#2(H) : 1 (0/1)

water tank#2(L) : 0 (0/1)

water tank#3(H) : 0 (0/1)

water pump#1 1 (0/1)

water pump#2 1 (0/1)

wind charging 70 (%)

solar charing 65 (%)

Fig. 8. (Color online) Interface for remote control on PC.

humidity, illuminance, and soil moisture threshold values of 27 °C, 50%, 110 lux, and 1, respectively. Additionally, we conducted a raindrop detection test. The results showed that when artificial rain conditions were applied, the microcontrol system could detect the raindrops and raise the rain collection panel to gather the rainfall. The collected rainwater could be stored in the rainwater collection tank, and any excess rainwater would be diverted to the ecological pond system.

Additionally, when the system is subjected to artificial heating (brief heating within the greenhouse) reaching 30 °C, the greenhouse system will automatically activate the fan until the

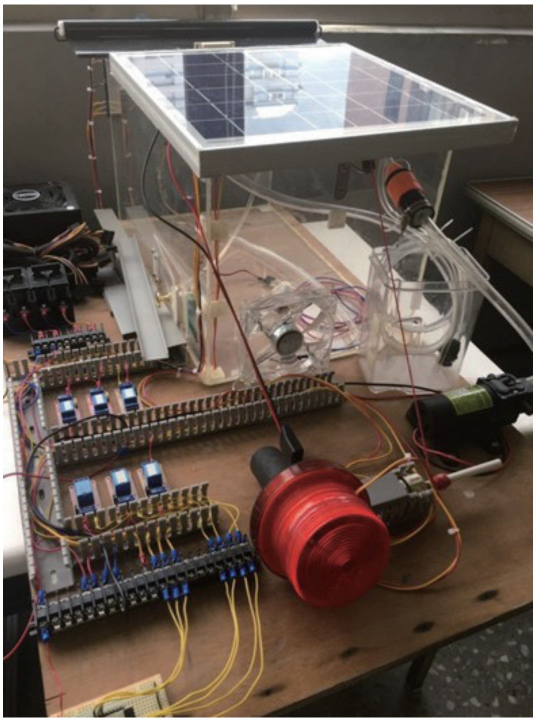


Fig. 9. (Color online) Prototype of greenhouse.

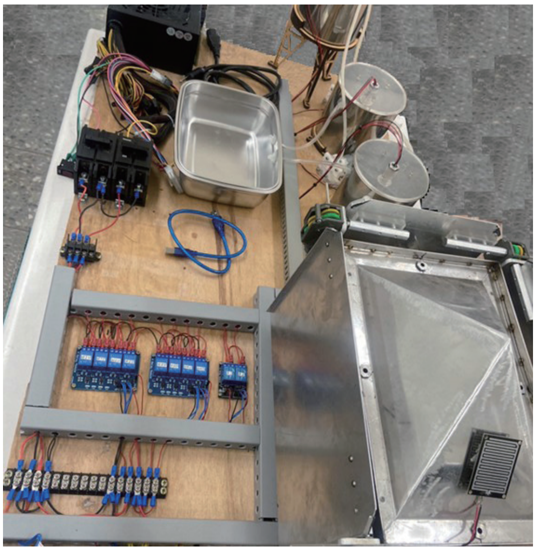


Fig. 10. (Color online) Prototype of rainwater collection and storage system.

Fig. 11. (Color online) Control unit of using and charging battery.

indoor temperature drops to 27 °C, at which point the fan will stop. Similarly, when the humidity is artificially increased (brief humidification within the greenhouse) to 76%, the system will activate the heater and fan until the humidity drops to 50%, then it will stop. Furthermore, when strong artificial light is briefly applied to the top of the greenhouse, upon reaching 155 lux, the shading device above the greenhouse will activate to block the light. When dry soil is placed in the planting area, the microcontrol system will detect it via the soil moisture sensor and activate the irrigation pump until the soil moisture threshold reaches 1, at which point watering will stop. Additionally, when an external object approaches the greenhouse, the ultrasonic sensor will immediately activate the alarm and floodlight.

The sensor values mentioned above (raindrop detection, temperature, humidity, water tower level, illuminance, soil moisture, and intrusion alert) and the status of the actuators (fan, sprinkler, humidifier, shading device, heater, alarm, and floodlight) activated by monitoring will be transmitted via LoRa to the remote (control room) PC's human machine interface (HMI) in the absence of a network. Additionally, the wind turbine and solar panels at the equipment end can both generate electricity normally and store the generated green power in batteries. Therefore, the performance test of this system indeed meets the preset goals of the system design.

Considering the impact of the greenhouse effect, which reduces plant productivity owing to extreme temperatures, an advanced plant cultivation system that minimizes manpower while utilizing sustainable energy and water resources is essential. The system proposed in this study integrates solar energy, a fan generator, and a rainwater collection system. Plants are cultivated within a greenhouse where optimal growth conditions are maintained using automation technologies. This approach not only reduces labor requirements but also ensures consistent monitoring and control of growth conditions through LoRa communication technologies. The LoRa system is particularly suitable for remote planting areas lacking internet connectivity, enabling effective management and oversight.

4. Conclusions

Innovative agricultural methods such as automated farming have been widely used owing to the increasing concern about unpredictable weather, pollution, and damage by wild animals. Such methods are also used to maintain constant crop production or to increase it. For the new methods, advanced technologies of sensors, devices, and communication are actively introduced. Taking into account the electrical power and water resources required for plant cultivation, we designed a greenhouse with an automated rainwater collection and storage system and an electricity generation and storage system using solar panels and a wind turbine. With the aging rural population in Taiwan, automated farming in greenhouses has become essential. The developed greenhouse can also be controlled and monitored remotely using LoRa technology, which increases the applicability of the greenhouse in remote areas where access to the Internet may be limited. The greenhouse proposed in this study can be integrated into most farming facilities, enabling water collection and electricity generation for farming without the need for additional external water or power sources. Consequently, the prototype needs to be scaled up for the farming test, which requires the improvement and adjustment of the greenhouse.

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