Design and Implementation of Greenhouse Environment Monitoring System Based on NB-IoT

Chuan-Wang Chang [1*], Chung-Jen Kuo [2], Yu-Jhe Lin[2]

ABSTRACT

With the development of the Internet of Things (IoT) technology, the traditional farming methods have shifted towards smart agriculture. The main benefit is that we can improve overall agricultural management through the use of various sensors. In this paper, we present an innovative, highly scalable and power efficient greenhouse environment monitoring system based on narrow-band Internet of Things (NB-IoT). We combine a microcontroller with NB-IoT modules and various sensors to collect and transmit data, including ambient temperature and humidity, dew point temperature, ambient light, soil pH, CO2, etc. The data are transmitted to the server via the cell site of the 4G cellular network for further analysis and decision-making. The proposed monitoring system then sends control signals to control remote devices in the greenhouses, including pumps, fans, lights, etc. We also develop an APP with the following functions: real-time monitoring, historical records, message push, alarm settings, and remote device control.

Keywords: NB-IoT, smart agriculture, greenhouse environment monitoring system, environmental sensor

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I. INTRODUCTION

The technology of Internet of Things (IoT) is widely used in several areas, such as smart-home [1], smart city [2, 3], smart car [4], smart agriculture [5, 6], health care [7], smart hospital [8] and other domains.

With the surge in the global population, coupled with the diminishing natural resources, particularly limited availability of arable land, and the increase in unpredictable weather conditions, food security has become a major concern for most countries. Recent statistics reveal that the global population is about to reach 9.6 billion by 2050. And to feed this massive population, the agriculture industry is bounded to adopt the Internet of Things. Amongst the challenges like extreme weather conditions, climatic changes, environmental impact, IoT is eradicating these challenges and helping us to meet the demand for more food [6].

In Taiwan and several countries, they also face the problems of aging farmers and insufficient labor in countryside. This has forced people to move towards smart agriculture to save labor and improve productivity. It is considered a good solution to use Internet of Things (IoT) technology for farm monitoring and management due to the use of interoperable, pervasive, scalable and open technologies. The application of IoT in agriculture is designed to provide farmers with decision tools and automation technologies that can integrate products, knowledge and services to increase productivity, quality and profit.

Elijah et al. [6] presented the IoT ecosystem and how the combination of IoT and data analytics had enabling smart agriculture. Nagaraju *et al.* [9] pointed various benefits in the IoT based applications in agriculture like community farming, fraud prevention and safety control, competitive advantage, and increased operational efficiency. Tzounis *et al.* [10] surveyed recent IoT technologies, including their current penetration in the agricultural sector, their potential value to farmers in the future, and the challenges that the IoT faces in the agricultural sector.

In the past, many wireless communication transmission solutions have been proposed, such as WiFi, Bluetooth, Zigbee and so on. However, in agricultural applications, greenhouses in remote areas often lack Internet facilities, so the aforementioned wireless communication technologies are less suitable for this area. In particular, it is expensive to deploy network devices in remote areas. Therefore, greenhouses in remote areas often cannot perform remote monitoring of the Internet of Things, which has also affected the development of smart agriculture.

Narrowband Internet of Things (NB-IoT) [11, 12] is a low power wide area wireless protocol that works virtually anywhere [13]. NB-IoT has the advantages of low cost and low power consumption [14, 15], which provides a new way for connecting devices that require small amounts of data, over long periods, in hard to reach places and has been used in intelligent parking, intelligent meter reading and other domains. Davcev *et al.* [16] presented a model of IoT agricultural system that utilizes LoRaWAN protocol for data transmission from the sensor nodes to cloud services.

In this paper, we design and implement a greenhouse environment monitoring system which use the NB-IoT communication technology for packet transmission, and transmits various sensing values back to the back-end server via the 4G base station network. It can also transmit control signals for remote device control through this system. The communication quality and security of this approach are highly guaranteed, and the cost of setting up the network and deploying network devices is reduced.

The main contributions of this paper are summarized as follows.

(1) We formalize an architecture based on NB-IoT to connect intelligent things in the smart agriculture, which takes the advantages of the wider coverage, lower power consumption, higher capacity, and lower cost of NB-IoT.
(2) As a case study, we design a greenhouse environment monitoring system based on NB-IoT.
(3) We give the challenges, future directions, and opportunities for the proposed greenhouse environment monitoring system.

The rest of this paper is organized as follows. Section II introduces our proposed architecture for smart agriculture. In Section III, we develop a greenhouse environment monitoring system using NB-IoT as a case study. Section IV presents the results of system design and implementation. Finally, in Section V, we conclude this paper and present some challenges and future directions.

II. PROPOSED ARCHITECTURE FOR SMART AGRICULTURE

NB-IoT is an emerging technology of the Internet of Things. It is built on a cellular network and consumes only about 180KHz bandwidth. It can be directly deployed on GSM, UMTS, or LTE networks to reduce deployment costs. There are several advantages of using NB-IoT in smart agriculture.

(1) Real-time Monitoring: The data returned by various environmental sensors can monitor the condition of the farm in real time in order to take reasonable actions.
(2) Higher Capacity: NB-IoT can provide billions of connections, which can meet the connection requirements of smart agricultural devices.
(3) Lower Power Consumption: The lower power consumption with a battery life over ten years, which is

very suitable for a variety of small size environmental sensors, such as temperature and humidity, CO2, and pH sensors, etc.

(4) Lower Cost: The cost of each module is less than 5 US$, which can significantly reduce the cost of deploying sensors.

Because the user does not need to set up a base station by himself, constructing smart agriculture with NB-IoT can make the operation of the overall system not limited by geographical location, and can complete system planning, design, and testing in the shortest time according to the needs of agricultural application systems.

Figure 1 shows an architecture of smart agriculture based on NB-IoT. In this architecture, the terminal devices/sensors in the sensing layer collect and send data to the base station. In the cloud computing layer, the cloud platform stores and processes sensing data, and controls the overall situation with data analysis, criterion setting, and machine learning. The task and function for each layer in the architecture are shown in Figure 2.

(1) *Sensing Layer*: In this layer, there are a large number of terminal devices/ sensors integrated with NB-IoT modules. These devices have the functions of data collection and processing. In addition, the scheme of energy consumption and security should also be considered to deal with the energy supply and security of terminal devices. In smart agriculture, we need to collect many kinds of data. For example, we can use temperature and humidity sensors to observe temperature and humidity data of the environment. We can also use pH sensors to measure the pH of soil and water.

(2) *Base Station Layer*: In this layer, a large number of NB-IoT base stations are deployed, which need mechanisms of routing, congestion control, traffic scheduling, and security to ensure the integrate and secure transmission of data. In the application of smart agriculture, because the data returned by the environment sensor is relatively simple, and the amount of data is small, data transmission methods such as routing, congestion control, and traffic scheduling can directly use the state-of-the-arts protocols, such as TCP/IP.

(3) *Cloud Computing Layer*: In the cloud computing layer, the cloud center can use big data analysis, machine learning, and data fusion techniques to conduct comprehensive data processing of the entire system. In addition, expert knowledge can be applied to take appropriate action on various environmental conditions. Furthermore, access control, security auditing and data backup can be introduced at this layer to ensure data security.

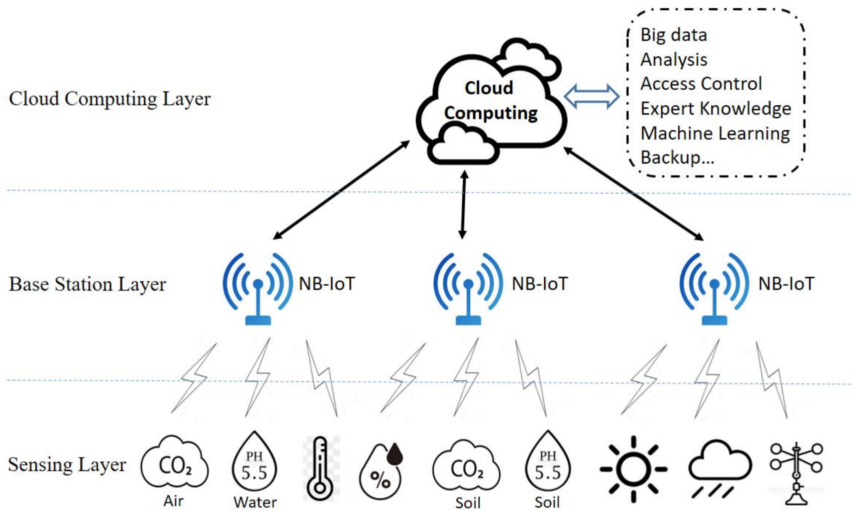


Figure 1. The architecture for connecting intelligent sensors in smart agriculture.

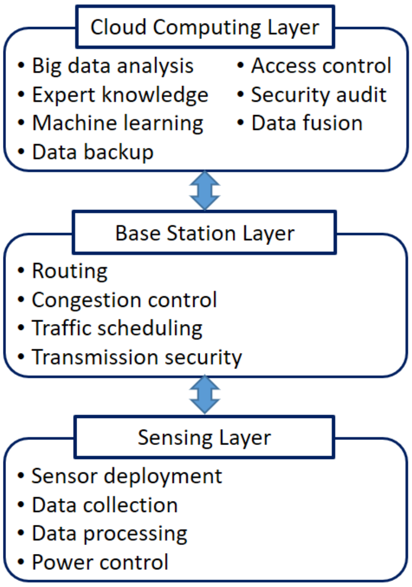


Figure 2. Main function and design requirements for each layer in the proposed architecture.

III. PROPOSED GREENHOUSE ENVIRONMENT MONITORING SYSTEM

Agriculture combined with NB-IoT technology has the advantages of stability, accuracy, low cost, low power consumption, easy deployment, and easy maintenance, which is very suitable for the development of smart agriculture.

The application scenario of this paper, as shown in Figure 3, is a greenhouse monitoring system in a remote area. We use NB-IoT to achieve remote monitoring. In this work, we combined NB-IoT devices with microcontrollers and various sensors for data collection and transmission, including environmental temperature and humidity, dew point temperature, ambient light, soil pH, CO2 and other sensing data. The sensing data are transmitted to the cloud server through the 4G base station network. After analysis, the monitoring system transmits control signals for remote device control, including pumps, fans, lights, and general electromechanical devices. We also developed a monitoring APP that includes the following functions: real-time monitoring, historical charts, message push, alarm settings, and remote device control/settings.

A. Microcontroller and NB-IoT module

The NB-IoT hardware of the proposed system uses the SIMCOM 7000E module [17], with the SIM card of Taiwan Far EasTone Telecommunications (FET), and uses the NB-IoT communication service provided by the FET.

The SIM7000E, manufactured by SIMCOM Wireless Solutions, is Tri-Band LTE-FDD and Dual-Band GPRS/EDGE module solution in a SMT type which supports LTE CAT-M1(eMTC) and NB-IoT up to 375kbps data transfer. It has strong extension capability with rich interfaces including UART, USB2.0, GPIO etc.

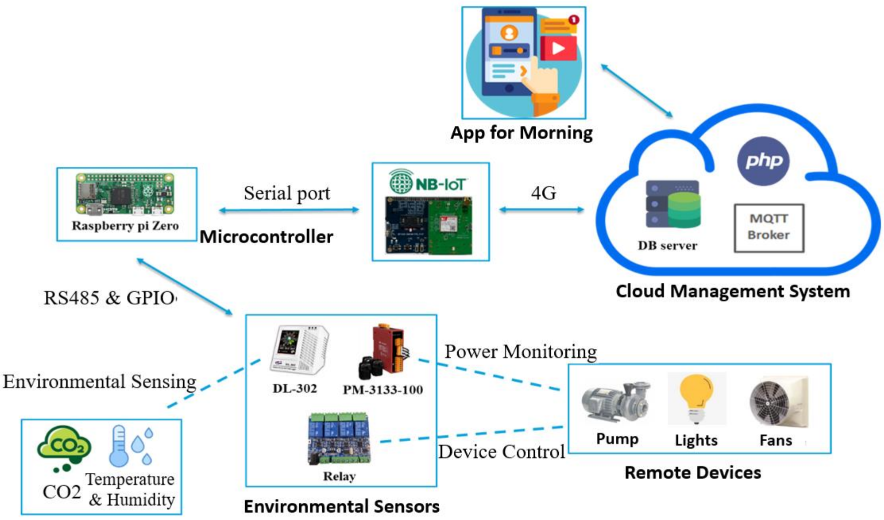


Figure 3. The architecture of the proposed greenhouse environment monitoring system.

(a) (b)

Figure 4. (a)ICP DAS DL-302 and (b)ICP DAS PM-3133-100

The module provides much flexibility and ease of integration for customer's application.

Since the SIM7000E module does not have a built-in microcontroller (MCU), we use Raspberry pi Zero to connect the SIMCOM 7000E module for data transmission and reception through the Universal Asynchronous Receiver / Transmitter (UART) port. And the collected sensing data is transmitted to the cloud server using TCP / IP protocol through 4G communication technology.

We use SIM7000E module to send short message (SMS), MMS, GPRS data packets using the existing GSM network. All communication is achieved by sending AT Commands through UART. AT Commands set [18], also known as Hayes commands set, was originally a command set developed for Hayes Smart 300 modem. These command sets are long commands composed of many short strings, which are used to represent actions such as dialing, hanging up, sending messages, and changing communication parameters. Most data communication devices adopt the rules made by the AT Commands set.

B. Environmental sensors and devices

Because water, air, light, temperature and soil are the key factors affecting plant growth. The greenhouse monitoring system will focus on the monitoring of these environmental factors. Different plants have different requirements for water, air, temperature, light, and soil pH. If the environment can be controlled under conditions suitable for plant growth, it will help plant growth and increase productivity.

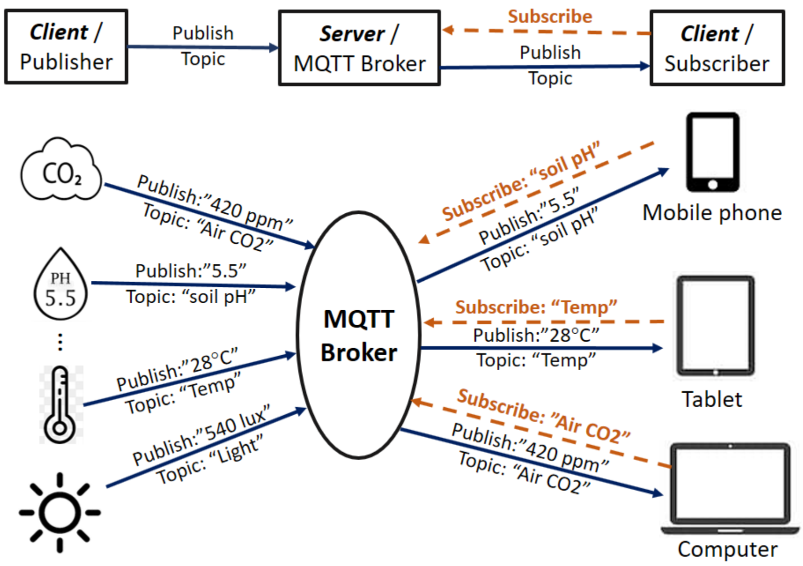


Figure 5. Architecture of publishers and subscribers with sensors and MQTT broker.

The proposed system includes the following devices: environmental sensors, smart meters, and relays.

The main environmental sensor is DL-302, as shown in Figure 4(a), which is an industrial-grade sensing device manufactured by ICP DAS [19], which can detect CO2 concentration, temperature, humidity and dew point temperature in a greenhouse. Farmers can make appropriate decisions based on real-time environmental data.

The ICP DAS PM-3133-100, as shown in Figure 4(b), is a smart power meter that can capture accurate energy consumption data in the greenhouse. Farmers can effectively control and manage the equipment in the greenhouse based on the energy data.

The relay module can perform multi-stage scheduling control and switch control of the pumps, fans, lights, and electromechanical device in the greenhouse according to the change of environmental sensing data.

C. Cloud Management System

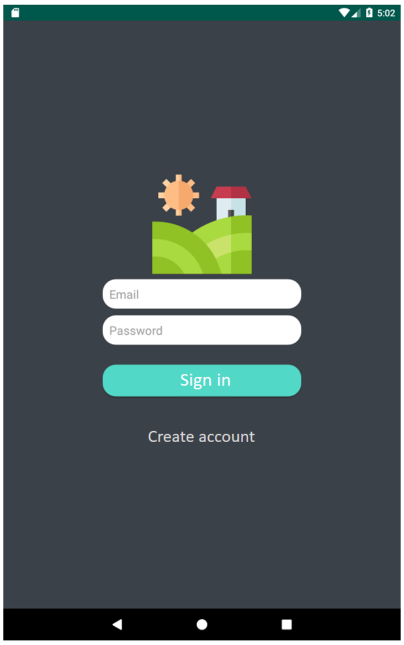
The cloud management system is mainly a database server, which can store various sensing data, the status of various devices, related information of control commands, and user registration data.

For real-time monitoring, we can send data request packets to the database server through the APP on the mobile device, and the database server returns the values of various sensors to the APP through the PHP API. We can also use the APP to transfer the packet containing the device control signals to the database server through the GET operation, and then perform remote device control through the NB-IoT TCP / IP protocol.

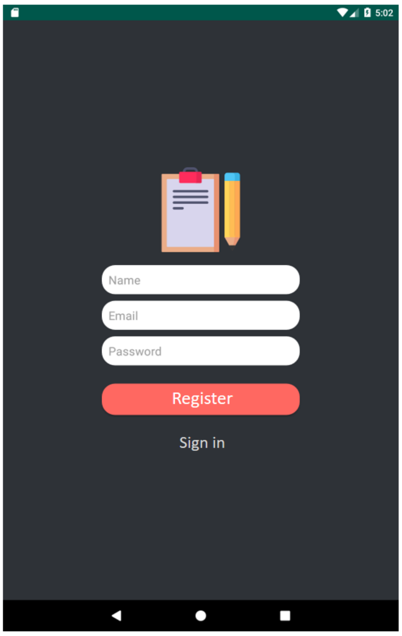
MQTT (MQ Telemetry Transport) [20] is a machine-to-machine (M2M)/ "Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium. It is also ideal for mobile applications because of its small size, low power usage, minimized data packets, and efficient distribution of information to one or many receivers. In this work, we use the function of publish / subscribe to push messages through MQTT broker, as shown in Figure 5. The broker is primarily responsible for receiving all messages, filtering the messages, decide who is interested in them and then publishing the message to all subscribed clients.

As shown in the system architecture of Figure 3, the environmental sensors send sensor data to NB-IoT module. Further the NB-IoT module connect to the server in the cloud by 4G telecommunications network. After connecting to the server, the NB-IoT module send complete sensor data received from environmental sensors to the server using MQTT protocol. The NB-IoT module publishs (publish) the sensor data to the server and server subscribes (subscribe) the data from the NB-IoT module. All sensor data from NB-IoT module is stored into server database. Users/farmer can use mobile devices to get data returned by environmental sensors and stored in cloud database.

The user also can set the upper and lower limits of the alarm on the graphical control interface of the APP on PC/mobile device. The set value of the alarm will be stored in the database and compared with the current environmental monitoring value to achieve the functions of multi-stage scheduling, automatic operation/adjustment of remote devices, and the function of decision-making and pushing messages.



(a)



(b)

Figure 6. **(a)The login interface and (b) the registration interface of the APP.**

D. The User Interface

For remote monitoring, we have developed an APP on the Android platform that can monitor the greenhouse environment based on the Android platform. In order to improve the security of the system, we have added a user authentication mechanism. The login data must be sent to the remote database for user authentication. Once the login data is verified, the user can enter the monitoring system to perform various operations. The greenhouse environmental monitoring APP (will show in Section IV) includes functions such as real-time monitoring, historical charts, message push, alarm settings, and remote device control.

IV. IMPLEMENTATION AND RESULTS OF PROPOSED SYSTEM

In this chapter, we will show the developed APP of greenhouse environment monitoring system.

When users want to use the APP of greenhouse environmental monitoring system, they must register or log in. The system identifies users by user account, e-mail address, and password. Registered users can enter the system for various operations after login verification, as shown in Figure 6.

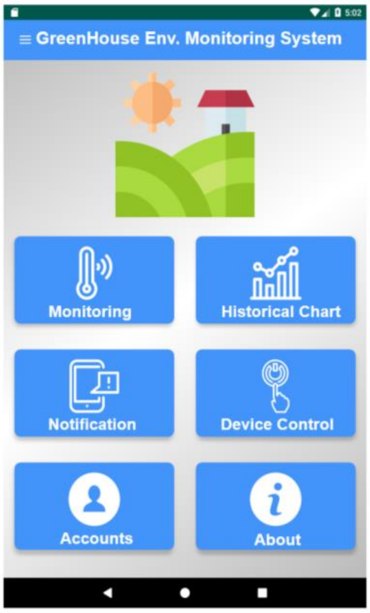
After the user successfully logs in, the user will enter the main control interface of the system, as shown in Figure 7. The main control interface displays various functions, including real-time monitoring, historical charts, message push, remote device control, and user information, etc.

The function of "Monitoring" is a real-time monitoring function that can instantly monitor various environmental data of the greenhouse, as shown in Figure 8. These data are returned by various sensors and smart power meters, including temperature, humidity, CO_2 concentration, dew point temperature and power consumption.

The function of "*Historical Chart*" is to visualize the environmental data of the past period of time. We can choose the dates of interest, and we can choose to display various environmental data in real time or in hours, days, or months. This function helps users understand the relationship between changes in environmental factors of the greenhouse and plant growth. Figure 9 shows the temperature and humidity in the greenhouse on a specific day.

The function of "*Device Control*" can check the current power consumption and total power consumption of various remote devices, and can also directly control various remote devices, such as turning on or off, as shown in Figure 10.

"*Notification*" combines the function of message pushing. The system will send a warning message to the user according to the upper and lower limits of each environmental sensing data set by the user. This function is achieved by the MQTT mechanism. This function allows the user to not need to check the various environmental sensing values of the greenhouse at any time. When receiving a warning message, the user can directly issue control commands to specific remote devices through the APP in response to specific environmental conditions. Figure 11(a) shows the interface for pushing messages, and Figure 11(b) shows the interface for setting the upper and lower limits of the environmental sensing value.



igure 7. The main interface of the APP.

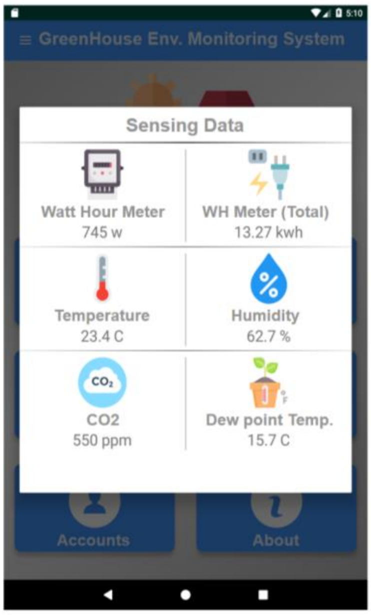


Figure 8. Function of Monitoring.

Figure 9. Function of Historical Chart.

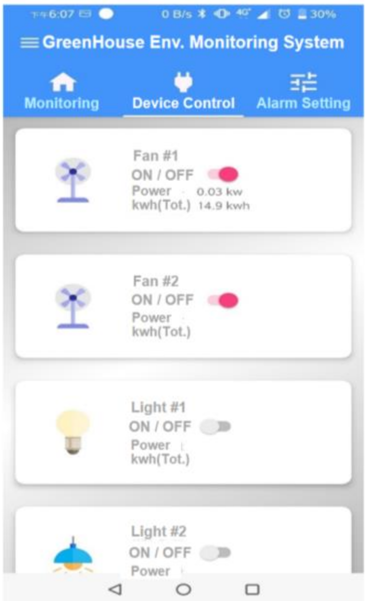
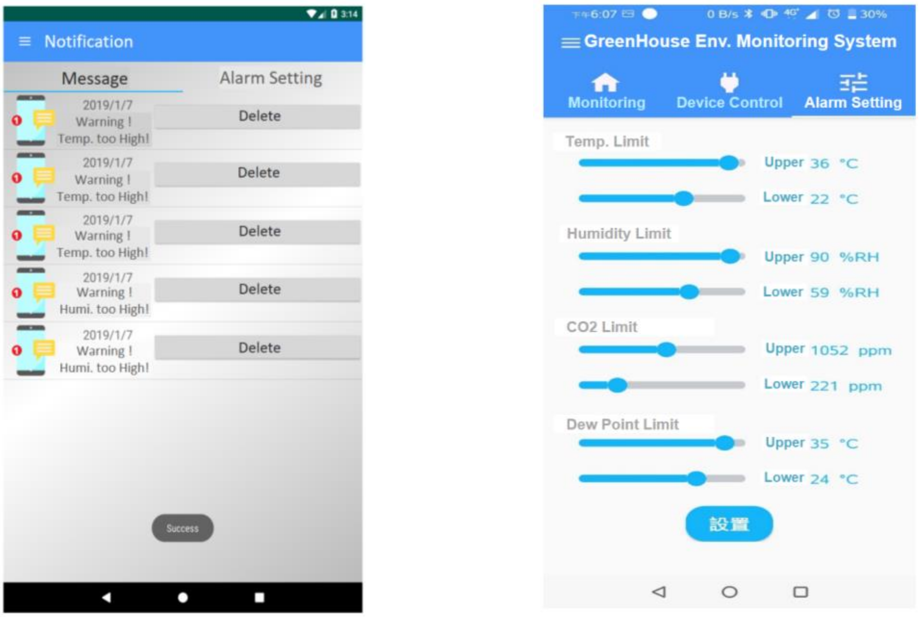


Figure 10. Function of Devices Control.

V. Conclusion and Future Work

In this article, we have designed and implemented a greenhouse environmental monitoring system based on NB-IoT technology. Compared with the traditional communication technology, the system using NB-IoT has improved the problem of expensive network deployment and low signal strength in remote areas. Moreover, it effectively improves the communication quality and reduces the cost. We have also developed an environmental monitoring APP to provide users/farmers with many functions required for greenhouse agriculture. In this way, users/farmers can grasp the environmental conditions of the greenhouse at any time, any place and make appropriate decisions according to the sensor data.



(a) (b)

Fig. 11. (a)The interface for pushing messages, and (b) the interface for setting the upper and lower limits of the environmental sensing value.

In the future, we will definitely enter a new era of AI. To truly achieve digital agricultural production, the Internet of Things is definitely the first step in implementation. Through various sensors and various wired and wireless communication technologies, all information in the physical world is connected to the cloud. Then, by combining expert knowledge, big data analysis, and AI technology, real smart agriculture can be achieved, and the goal of increasing crop yield can be achieved in a more economical and efficient manner.

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