An IOT-based Multi-sensor Ecological Shared Farmland Management System

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Abstract—With the wide adoption of a shared economy, the term “share” has become closely linked with people’s daily life. To improve the economic output per unit area of farmland and allow urban residents to experience the fun of cultivating, an IOT-based multi-sensor ecological shared farmland management system is presented and designed in this paper. Furthermore, the system also presents an agricultural economy model that shares planting and gains by remote control. This system consists of multiple sensors for data collection, automatically controlled equipment, a transport module (with a ZigBee module and a WiFi module), an app-based smart monitoring and control module and a WeChat public platform. Various monitoring data, including air temperature and humidity, soil humidity, illuminance, CO2 concentration, pH, real-time video and images, are collected for users to ensure an optimal crop growing environment via remote control and by sharing agricultural products in harvesting seasons. Sharing functions such as picking, leasing and transferring are implemented via the WeChat public platform. Not only is detailed information on vegetables growing in rented farmland available remotely via RFID electronic tags and multiple sensors, but the real-time growing state of the planted crops is also available via camera. Control of functions such as irrigating, fertilizing and shading is also supported. The test shows that in this system, the data collected via multiple sensors are accurate; real-time information is transmitted and managed smoothly.

Keywords—share, multi-sensor, RFID, ZigBee, farmland

1 Introduction

Precision agriculture is an important means of attaining sustainable agriculture. Constituting a new mode of agricultural farming [1-2], precision agriculture optimizes the utilization of pesticides, and reduces environmental hazards. Precision agriculture precisely controls the pesticide, water and chemical fertilizer utilization based on such conditions as the farming unit disaster level and the soil nutrient variation, which saves agricultural resources significantly, reduces investment, protects the environment and improves economic efficiency.

With the wide adoption of a shared economy, the term “share” has become a zeitgeist. In a shared economy that emphasizes the right of use, experience is another way of owning value. Bicycle share, automobile share, apartment share and office share emerge in cities and around us. Many idle resources are utilized [3-4]. In rural areas outside of cities, vast high-quality farmlands are idle and require labor for their maintenance. Most farmers are too occupied with agricultural work to become migrant workers and rely purely on income from farmland for a living. Simultaneously, the demand of urban families for ecological agricultural products cannot be fulfilled; urban families expect a “harvest paradise” but find it nowhere. Additionally, due to the pressures of life and work, urban families cannot spend a long time managing farmland. Therefore, a “shared kitchen garden” with smart control emerges. Precision agriculture is combined with a shared economy, and an IOT-based multi-sensor ecological shared farmland management system is formed.

The development of electronics and communication technology has been accompanied by a new generation of information technologies, such as the 3S technologies (GIS, GPS and RS) [5-6], the Internet of Things [7], cloud computing [8] and big data [9], that are widely adopted in agriculture and catalyzed agricultural modernization. Farmland information collection, transmission, storage and processing are the foundation of modern agriculture. Chen et al. [10] developed a real-time agricultural information collection system based on the Android and iOS mobile platforms. Bailey et al. [11] deployed a mesh wireless network in a container nursery garden that provided a comprehensive monitoring and calculation of irrigation time and irrigation amount. Du et al. [12] designed a solution that integrated “point”-based monitoring data from the Internet of Things and “plane”-based space data from WebGIS and implemented an agricultural environmental monitoring system that integrated monitoring data from the Internet of Things (point) and space data from WebGIS (plane). Hirofumi [13] applied advanced information technology in crop cultivation and designed a real-time control system to supply solution for the hydroponic cultivation of tomato. Zhang et al. [14] developed a farmland information collection system consisting of a portable information collection device based on STM32 technology, a remote server and a mobile app. This system monitors such parameters as the crop leaf chlorophyll content, air temperature and humidity, illuminance and geographical location. However, these researches focus on remote monitoring and control, which are short of data storage separately and labeling farmland renting information. It could be solved by combining radio frequency identification (RFID) technology in the system.

The RFID technology is an automatic recognition technology that leverages a wireless radio signal to achieve contactless information transfer via spatial coupling. The transmitted data are used for target recognition and data exchange. This technology possesses not only such advantages as a large data storage capacity, contactless transfer, a high reading rate, a resistance to environmental interference and a long operational life but also an anti-collision mechanism and the ability to process multiple tags simultaneously [15]. The RFID technology is widely deployed in cultural relic management [16], smart parking [17] and communication security [18]. Yao and Zhou

[19] designed a RFID-based farmland information collection system. In that system, a WSP430F5438, single-chip microcomputer is used as a master control unit to collect and process data that includes soil temperature and humidity, illuminance and CO2 concentration; a GPS module and CC1101 radio frequency transceiver chip provide functions that include electronic tag positioning, timing and communication with a read/write device. Guo et al. [20] implemented a ZigBee-protocol-based network system for farmland environmental monitoring that consisted of three major modules, including an ARM + Linux module, a ZigBee wireless sensor network and a remote information management system. However, fixed-point measurement has deficiencies, such as low practicality, an excessive operational and maintenance load and low flexibility. Moreover, these studies only focus on the remote monitoring and planting management technology. The progress of improving practical application and agricultural economy model is rarely involved.

To improve the economic output per unit area of farmland and application in remote control system, an IOT-based, green shared farmland management system is designed to collect various parameters, including the air temperature and humidity, soil moisture, illuminance, CO2 concentration and pH value. Therefore, to address the aforementioned problems and further improve the economic income and output of each unit of land area, a model based on a shared economy is presented in this system. Additionally, RFID and ZigBee technologies are integrated to implement remote crop planting, management and sharing. Videos of farmland are transmitted and displayed in real-time via camera; information is provided to the user via WeChat or a mobile app-based sharing platform to support remote control and adjustment of the crop growing conditions by the user. Functions such as fruit picking and sharing, farm leasing and transferring are implemented via the sharing platform. The influence of a shared economy and the Internet of Things on the development of precision agriculture is introduced in the first section of this paper. Next, the architecture and design of an RFID-based, multi-sensor, green shared farmland management system are elaborated in the second section. The third section covers related experiments and an analysis of the results.

2 Design of the shared farmland model and management system

An IOT-based multi-sensor ecological shared farmland management system measures and records various parameters characterizing the farmland environment in real time. In this section, the architecture, design and implementation of the ecological shared farmland management system are elaborated.

2.1 Overview of the shared farmland model and management system

The internal layout of an IOT-based multi-sensor ecological shared farmland management system is shown in Figure 1. The farmland is divided into multiple blocks according to a predefined standard. In front of each farmland block, a dedicated ultra-high-frequency RFID electronic tag is positioned. The tag is scanned to provide detailed information on the tenant(s) and planted vegetable(s) in that block: the name of the tenant(s), the lease date, the name of the planted vegetable(s), and the vegetable planting time and growth status. The system administrator can update the electronic tag information as required. This information facilitates the farmland management by the administrator and the information exchange between users. An IOT-based multi-sensor ecological shared farmland management system includes cameras and various sensors that provide comprehensive monitoring and recording from the initial moment of sowing or transplanting. This system also includes an irrigation scheme as well as a ventilator, roller shutter, lighting facility, thermostat and fire alarm. The control room monitors the operational states of all the devices on the farmland. The sensors are deployed at a specific position in the system (e.g., the soil moisture sensor is deployed in the soil, and the CO2, temperature and humidity sensors are deployed in the air) and are responsible for sensing the environmental status of the system. The measured data are transmitted to the single-chip microcomputer master control unit via the ZigBee module. The master control unit stores and analyses the received data so that the system environment is monitored efficiently in real time. Note that various sensors are deployed at different positions in the system to monitor multiple environmental variables. In this way, ubiquitous information collection and reading occur, and more comprehensive and effective data become available.

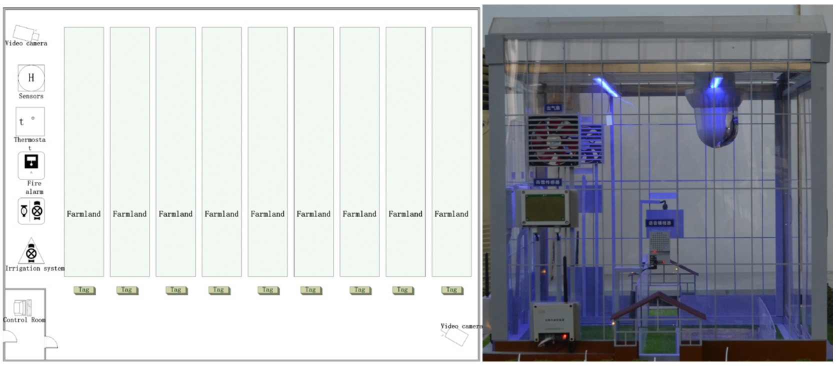


Fig. 1. Layout of the Shared farmland management system

Shared model: The farmland is divided into multiple blocks according to predefined criteria. Each farmland block is shared by multiple tenants who manage the farmland together and share its products when the crops mature. Additionally, tenants of different farmland areas can exchange products to maximize farmland resource utilization.

2.2 Overall design of the shared farmland management system

This system consists of three components: an information-aware layer, a wireless network transport layer and an application service layer. The information-aware layer is responsible for monitoring the environmental parameters and for collecting data via the sensors. The wireless network transport layer consists of a WiFi module and the ZigBee module and is responsible for transmitting the data collected by the information-aware layer to the application service layer. The application service layer consists of a mobile terminal app and the WeChat public platform, which queries these data and makes decisions. These components complement each other and constitute an IOT-based multi-sensor ecological shared farmland management system. Figure 2 shows the architecture of this system.

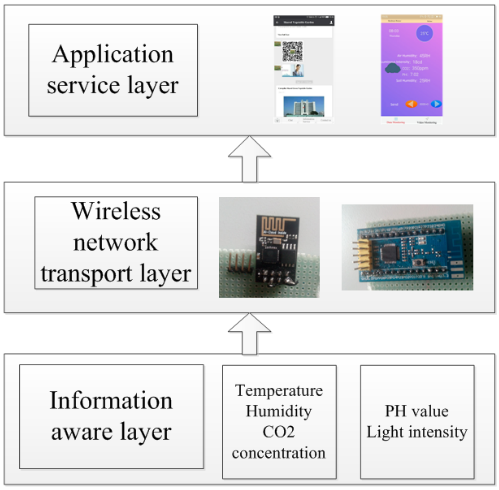


Fig. 2. Architecture of the proposed system

2.3 Software platform design

The workflow of an IOT-based multi-sensor ecological shared farmland management system is shown in Figure 3. This system transmits the greenhouse parameters collected by the sensor nodes via ZigBee to the single-chip microcomputer master control unit; next, the information is transmitted to the mobile app via the WiFi module. As the collection points are deployed in a wide area, multiple sensors are required. ZigBee has a superior networking capability (ZigBee supports up to 65,000 nodes, and all the nodes can communicate with each other), which solves such problems as transmission distance limitations and wiring challenges. WiFi shows a fast data transmission rate and is suitable for information transmission to an external device. The network nodes operate in two modes: a conventional mode and a smart mobile device connection mode. In the conventional mode, the nodes read sensor data, collect information via the ZigBee module and collect device status data before transmitting the data to the single-chip microcomputer master control system. In the smart mobile device connection mode, the nodes respond to a query and a control request from the smart mobile device; based on user instructions, the app in a smart mobile device interacts with the nodes by exchanging data and instructions.

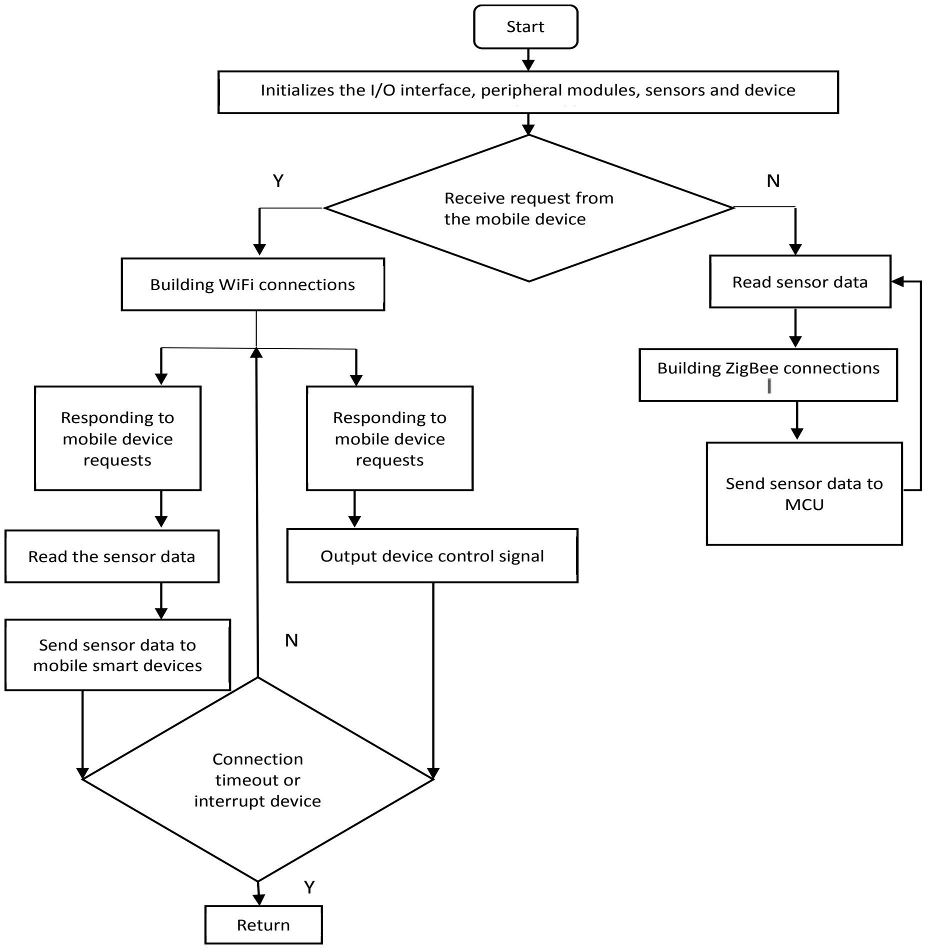


Fig. 3. Workflow diagram of the system

2.4 Sensor-based data collection module

Temperature and humidity are important factors that directly affect crop growth. The environmental temperature drives plant growth, and the proper temperature accelerates plant growth. Humidity refers to the water content in air. Improper humidity is unfavorable for plant growth because plants cannot satisfy their requirements for photosynthesis. Illuminance directly affects plant photosynthesis and subsequently affects plant growth. The CO2 concentration is an important factor for plant growth that directly affects plant photosynthesis. Low CO2 concentrations reduce the plant photosynthetic rate and affect plant growth. An excessively high CO2 concentration causes a partial or even complete closure of plant stomata, which affects plant photosynthesis. Therefore, only a proper CO2 concentration is favorable for plant growth.

An IOT-based multi-sensor ecological shared farmland management system requires sensors for the real-time monitoring of various data. In this system, the sensors collect data such as the air temperature, air humidity, soil moisture, illuminance, CO2 concentration and pH value. The collections are based for the air temperature and humidity on a DHT22 module, for illuminance on a GY-30 module, for the soil moisture on a module that monitors soil moisture, for the CO2 concentration on an MG-811 module and for pH on a pH detection module.

1. The air temperature and humidity DHT22 sensor module uses single-row, four-pin packaging and has an embedded, calibrated temperature and humidity composite collection component. Digital module collection technology and integrated temperature and humidity sensor technology ensure superior reliability and long-term stability. Additionally, the DHT22 module supports digital communication and includes a temperature sensor that is based on a component that measures the negative temperature coefficient (NTC) and a humidity sensor that is based on a capacitor humidity measurement component. An embedded, high-performance, eight-bit, single-chip microcomputer is responsible for data collection and transmission. Therefore, this module has advantages that include a low power consumption, quick response and superior anti-interference capability.
2. The illuminance data collection unit is based on a GY-30 module. The master control chip (BH1750FVI) is a high-sensitivity, integrated circuit that is capable of detecting variations in illuminance over a wide range (1 to 65,535 lx). The sensor has five pins: an I2C serial data (SDA) pin as well as a serial clock (SCL) pin, reference voltage (DVI), power supply port (VCC), common ground (GND) and address definition port (ADDR).
3. The soil moisture detection module is based on an LM393 chip, which has two detection poles that each has a special electrical coating. Two detection poles planted under topsoil generate different electric potentials, which are processed by a voltage comparator as an analogue voltage. In this design, the analogue voltage is collected by an application control terminal via an internal, integrated, analogue-digital (AD) convertor module and then quantified as the corresponding humidity.
4. The CO2 sensor is based on the MG-811 module from Zhengzhou Winsen Electronics Technology Co., Ltd. MG811 is a solid electrolytic sensor that is highly sensitive to CO2 and insensitive to temperature and humidity variation. This module has superior stability and repeatability and is suitable for air quality control systems, the control of a fermentation process and the detection of greenhouse CO2 concentrations.
5. The pH detection module is a liquid electrolyte sensor consisting of an E-201-C pH composite electrode and transport module made by Rex. The electrode consists of a glass tube with a bulbous end and a pH-sensitive glass membrane. During operation, the interior of the tube is filled with an aqueous electrolyte solution.

A detailed diagram of the sensor data collection subsystem is shown in Figure 4.

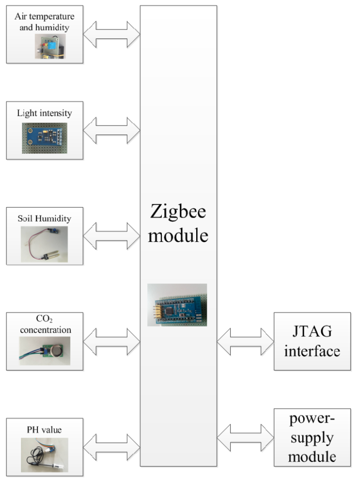


Fig. 4. Hardware structure diagram of the system

2.5 Remote control equipment in the system

In modern agriculture, constant ventilation is beneficial to crop growth because ventilation increases the oxygen concentration in the plant growth environment. A thermal insulating device (roller shutter) is installed in the system to maintain a warm environment for crop growth, especially at night or during the winter when the temperature drops. Additionally, a drip irrigation device is installed in the system to provide functions such as automatic irrigation based on soil humidity data and manual irrigation by remote control. As these devices require automatic control, a means of controlling a terminal actuator via the network becomes a critical issue. In the present system, a relay is used for this control. Ventilation, drip irrigation and roller shutter control commands from a remote controller are received by the ZigBee communication module. Then, the module sends an on/off signal to the relay to control the actuator on/off state. The relays used in this system include a high-level and a low-level triggering type. The high-level triggering type is based on the NPN triode J3Y; the low-level triggering type is based on the PNP triode 2TY. The relay that was designed based on this scheme can control a circuit with a 250-V voltage and a 7-A current under a bias of +5 V.

2.6 System transport module

This system includes two transport modes: one is the ZigBee-module-based wireless transport for sensors inside the system; the other is the WiFi-module-based wireless transport between the system internal sensors and the external mobile apps. These two modules are described in the following sections.

1. The ZigBee module includes numerous sensor nodes. ZigBee has advantages that include a superior networking capability (supporting up to 65,000 nodes, and all

the nodes can communicate with each other), a high transmission rate, low energy consumption and a simple network protocol, which fulfils the requirement of system internal wireless network communication. The ZigBee nodes in the system are deployed in a collection area to gather farmland environmental data and effectively transmit data via internode routing. In this way, the gateway node acquires relevant data.

2. The WiFi module has the major advantage of wireless functionality. This module is not constrained by a wiring requirement and is suitable for both a mobile office user and a mobile user. In addition, the WiFi module has advantages that include the following: a wide range of radio wave coverage, an extremely fast transmission rate up to 11 mbps and a long operational range. WiFi is suitable for wireless communication between the system internal sensors and the external mobile app.

3 System test and experimental results

3.1 Test conditions

To test this farmland management system, a real scenario identical to an application system is deployed at an experimental farm on the west campus of the Agricultural University of Hebei (Baoding, China). In each test area, two real-time monitoring cameras are installed. Each farmland has been assigned an ultra-high-frequency RFID electronic tag to identify the surrounding sensors that detect and store the real-time environmental data. An active RFID read/write device is deployed in the control room and connected to a computer. A farmland tenant periodically communicates with the ultra-high-frequency RFID tag assigned to the rented farmland via wireless communication to obtain growth information on the planted crops.

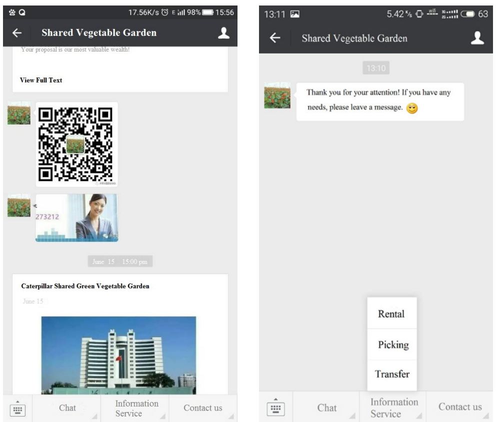
3.2 Software platform test

This section mainly covers two management system components: an app smart monitoring/control unit and the WeChat public platform.

Figure 5 shows the app smart monitoring/control component. This component supplies a mobile app for monitoring and control that is essential for enabling the system administrator and the tenant to check the growth of planted crops in real time. The app user interface supports four functions that include environmental monitoring, remote control, the management of all devices and video monitoring. Environmental monitoring provides visibility to the greenhouse interior environmental parameters (such as the illuminance, CO2 concentration and pH value); remote control means using the app to control the on/off status of a water pump, the ascent/descent of the roller shutter and the open/shut status of a ventilation window; the management of all devices means the organization of all the smart devices in the greenhouse; and video monitoring means viewing the greenhouse in real time. The app supports remote monitoring and control, which makes information publicly available and improves the user experience.

Fig. 5. Interface of mobile phone APP

Figure 6 shows the WeChat public platform component. The WeChat platform facilitates the communication between the tenant and system administrator and implements functions such as lease and transfer. WeChat provides such basic functions as message reply and menu customization, which supports the system. The tenant only needs to follow "xxx" (subscription name) to receive a daily group message (including a pure text message, graphic message, voice message, video message and text and graphic message) or click the content in the customized menu to obtain the required information (such as transfer, fruit and vegetable ripening and harvesting). Tenants can also leave messages to the system administrator specifying suggestions and requirements so that the administrator is best able to try to satisfy the tenants.



(a) (b)

Fig. 6. WeChat public platform. (a) Contact the system manager. (b) The services provided by the system include leasing, picking and transferring.

3.3 Sensor test and results

RFID electronic tag writing speed. Other automatic recognition technologies, such as those using a barcode, magnetic card, or an integrated circuit (IC) card, require tags within a line of sight and a sequential reading order. By comparison, the ultra-high-frequency RFID cards have a reading distance of up to 10 m and permit multiple electronic tags to be identified simultaneously, which is more convenient and efficient compared with any other automatic recognition method. In this experiment, 60 electronic tags are used to record in detail the time required for different data volumes to be written to different ultra-high-frequency RFID tags (128, 256, 512 and 1,024 bytes). These times are shown in Figure 7, after selecting and displaying only 20 sets of data to facilitate diagram plotting.

Figure 7 is a box plot representing six data nodes. The data points in each data group are arranged in descending order from upper edge, upper quartile, median, and lower quartile to lower edge; and an abnormal value is calculated. Figure 7 shows that the writing time for the RFID electronic tag data is very short, ranging from 2.25 to 15.97 s, which is suitable for the multi-sensor, green shared farmland management system.

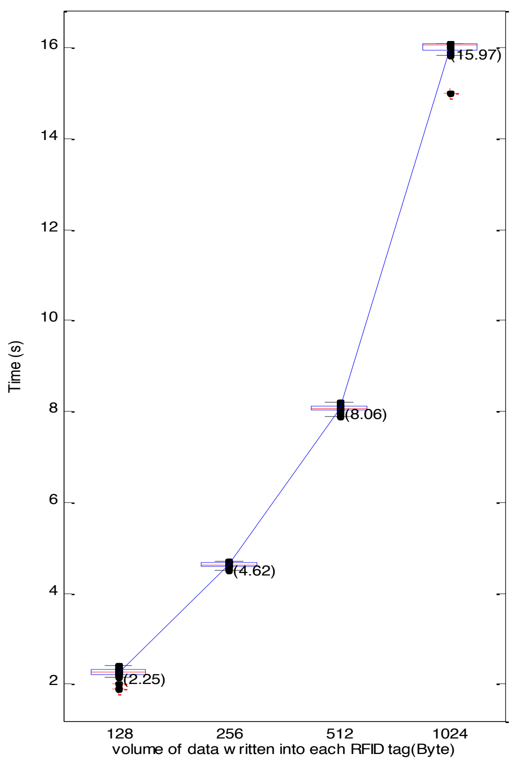
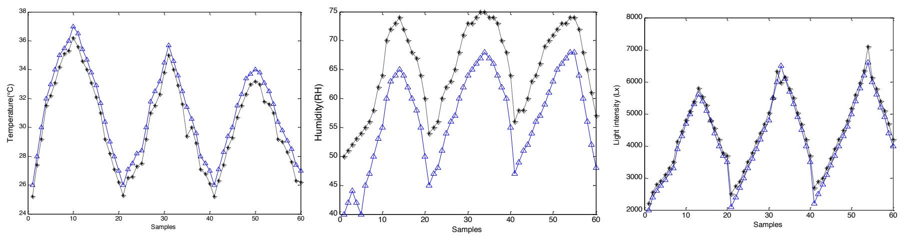


Fig. 7. The Time for writing different volumes of data

Test and evaluation of system accuracy. To demonstrate system accuracy, the sensors in this system are compared with similar sensors. In a laboratory environment, the system is operated continuously for more than 72 hours, the test result is measured and recorded every 30 minutes, and 60 groups of test results are selected and compared. These environmental temperature and humidity results are compared with the results from an AS817 handheld temperature and humidity metre (Smart Sensor, Hong Kong, China), whose temperature detection range is -10 to 50°C (measurement error ± 1.5°C) and humidity range is 5 to 98% RH (measurement error ± 4%). The system illuminance data are compared with the measurements obtained using an HT1300 digital handheld illuminometer (with a measurement range of 0 to 100,000 lx and a precision of ± 3%) manufactured by HCJYET (Guangzhou, Guangdong, China).

The test results are shown in Figs. 8(a), (b) and (c). In Figures 8(a) and (b), the temperature and humidity test data obtained via the DHT22 module are represented by the Δ symbol and those obtained via the AS817 metre are represented by the * symbol. In Fig. 8(c), the illuminance test data obtained via the GY-30 module are represented by the Δ symbol and those obtained via the HT1300 illuminometer are represented by the * symbol. The environmental temperature and humidity measurement results in the present test system are compared with the results from the AS817 handheld temperature and humidity metre. The absolute and relative temperature errors of this metre are 1.5°C, and 4.96%, respectively, and these values are mainly affected by air pressure and wind variation. The absolute and relative errors of this metre for humidity are 7.5% RH and 11.5%, respectively, and these values are mainly affected by air temperature, pressure and wind variation. The illuminance measurement result in the present test system is compared with the result from the HT1300 digital handheld illuminometer. The absolute error is 158.25 lx, and the relative error is 3.6%, values that essentially meet the design requirements. Future research to achieve increased measurement accuracy will improve the IOT-based multi-sensor ecological shared farmland management system



(a) (b) (c)

Fig. 8. The experimental results by the two instruments. (a) Temperature results; (b) Humidity results; (c) Light intensity(Lx) results.

4 Conclusions

To improve the economic output per unit area of farmland and allow urban residents to experience the fun of cultivating, an IOT-based multi-sensor ecological shared farmland management system records and collects various parameters of farmland-planted crops in real time. This system provides integrated services, including data collection, smart control and information sharing, and replaces conventional kitchen garden planting. The system features are summarized as follows:

1. The concept of sharing is applied in this system, reasonably and effectively using idle farmland and fulfilling the demand of urban families for ecological and green agricultural products. To improve the economic return per unit area of farmland, farmland blocks are marked by ultra-high-frequency RFID electronic tags that have advantages such as a high data storage capacity and superior environmental adaptability. Various types of information, such as tenant name(s), lease date, the name(s) of planted vegetable(s), the date of vegetable planting and the vegetable growth status, are recorded in real time. This information facilitates farmland management by tenants. When a tenant transfers farmland, the next tenant can obtain the real-time growth status of the farmland crops.
2. RFID and ZigBee technologies are applied in this system. The RFID read/write device not only shows a high read/write rate and a long reading distance but also effectively improves agricultural modernization. The test results show that ZigBee guarantees fast data transfer from each sensor. Compared with measurements made via handheld sensors, it shows that the relative errors in the temperature, humidity and illuminance data collected by multiple sensors in this system are only 4.96%, 11.5% and 3.6%, respectively. This means that the measurements are accurate.
3. A mobile app smart monitoring/control system and the WeChat public platform system are developed. The monitoring and control supplied by the app are essential to the system, enabling the system, the administrator and the tenants to check the growth of planted crops in real time. Remote management is based on the collected information, and the farmland is monitored by a camera in real-time. In this way, green and ecological crop cultivation is guaranteed. The WeChat public platform facilitates communication between the tenants and the system administrator and provides functions such as harvesting, leasing, transferring and sharing.

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