Prototype Implementation of Actuator Sensor Network for Agricultural Usages

Takuya Wada and Katsuhiro Naito

Abstract Information technology (IT) agricultural systems for field observation and environmental control have attracted considerable attention. Recently, various kinds of dedicated devices for IT agricultural systems have been released for large-scale farmers. It is well known that introducing IT agricultural systems can enhance agricultural production. On the contrary, an initial cost of the system is quite expensive even if typical dedicated devices are introduced. Therefore, reducing an initial cost of the system is a big challenge to disseminate the IT agricultural systems among small and medium-sized farmers. This paper proposes a prototype of IT agricultural systems that can measure an environment and can control the environment according to the measured information. To mitigate the initial cost of the system, our prototype uses Arduino compatible boards that are one of well-known micro-computer boards for general purposes. Therefore, it has a flexibility for designing a hardware and a capability of software development on the Arduino integrated development environment. The proposed system consists of sensing and control devices, a gateway device, and a web service. The sensing and control devices have some sensors such as a temperature, humidity, and soil moisture sensors, and a control function of a water sprinkling. The web service provides a user interface to manage the information in the database system. Experimental results show that the developed prototype system can realize a periodic environmental monitoring and environmental control according to the measured information. Additionally, users can observe the environment visually through the web service.

Keywords IT Agriculture systems · Environmental measurement · Controlling environment · Arduino · Sensor networks

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1 Introduction

Recent agriculture has serious issues due to various kinds of problems such as a shortage of water, diseases of plants etc. [1, 2]. Information technology (IT) has focused to solve these issues because detail information can support farmers to enhance agricultural productivity [3–7]. Recent IT agriculture systems can measure a field environment, growing conditions of plants by using some environmental sensors. Wireless sensor networks have been also focused to collect measured information in a field because a multi-hop communication technology is suitable to extend communication area [8–10].

Typical wireless sensor networks make up of a lot of sensor devices, a gateway device, and a data management system. The sensor devices have some sensors and a wireless communication module. Therefore, they can measure an environment by sensors and transmit measured information to the gateway device. The gateway device has a wireless communication module and a network interface module because its function is a relaying of measured information to the data management system. The data management system has a data base function and a data receiving function from the gateway device. Since sensor networks require a routing protocol for multi-hop communication, various routing protocols have been proposed [9, 11]. Additionally, due to a difficulty of using a commercial power supply in a field, a low-power operation is also an important function in sensor networks. As a result, a low-power micro-computer is required to develop sensor networks.

Commercial IT agriculture systems have been released recently in practical agricultural fields. With these systems, agricultural workers can monitor an environment of fields remotely. Therefore, they can estimate diseases of plants and to enhance agricultural productivity when they can obtain dense information at many positions. On the contrary, an installation fee of these systems is quite expensive. For example, a smart plastic greenhouse employing sensors is two or three times as expensive as a conventional one. Additionally, the approximate amount of the conventional system is more than $10,000 even if the system includes only some sensors, a communication function, and a data management function [12, 13]. Therefore, it is difficult for almost all farmers to install a useful IT agriculture systems.

This paper develops a prototype IT agriculture system that employs a general microcomputer board. The developed system consists of sensing and control devices, a gateway device and a web service. The sensing and control device has some sensors such as temperature, humidity, brightness and soil moisture sensors and IEEE 802.15.4 based wireless module. They employ an Arduino compatible board as a hardware. The gateway device also employs the same microcomputer board as a hardware and implements an ethernet interface and IEEE 802.15.4 based wireless module. Therefore, it can forward a data message from IEEE 802.15.4 network to an IP network. The web service has two main function: a database system and a web application The database system can store measured information and management information of the sensor network. The web application has two interfaces: a data upload interface and a user interface. The data upload interface is used to receive a data message from the gateway device. The user interface provides management views of the sensor network and measurement data for users.

In the experimental evaluation, we have developed the prototype system. The prototype system employs an ATmega2560 low-power Atmel 8-bit AVR RISC-based micro-controller to realize a low-power operation. Additionally, we have employed Xbee Series 1 as IEEE 802.15.4 based wireless module. The experimental results demonstrate that the prototype can measure an environment of a field periodically and can upload the measurement data to the web service through the gateway device. In addition, we have confirmed that the sensing and control device can control the environment of the field depending on the measurement data. Finally, the prototype can be developed with a general Arduino board that is a quite reasonable price comparing to a special hardware for agricultural use. Therefore, the cost of each sensor device and gateway device is lower than $100. Then, our prototype can be a candidate system to promote a reasonable IT agricultural system.

2 Actuator Sensor Network for Agricultural Usages

2.1 System Model

Figure 1 shows the system model of the development system. The development system is composed of sensing and control devices, a gateway device, and a Web service. The sensing and control devices are installed in agricultural fields to measure an environment. They measure temperature, humidity, brightness and soil moisture by external sensors, and control the growing condition by water sprinkling. Additionally, they also transmit the measurement data to the gateway device, that is placed in an office, by using the wireless communication module based on IEEE 802.15.4. The gateway device receives the measurement data and uploads them to the web service by the HTTP communication. The Web service can store the uploaded data into the database. In addition, the Web service also provides a user interface to handle the system and confirm the stored data for users.

2.2 Hardware

The development system uses Arduino based micro-controller for general purposes. The development system employs an original Arduino compatible board called Comduino. Since Comduino is designed as Arduino-compatible board using ATmega2560, an integrated development environment of the Arduino (IDE) is available. Figure 2 shows the overview of the board. The board supports a solar battery, a Li-Po battery, two Xbee radio interfaces, and connectors for general Arduino shields.

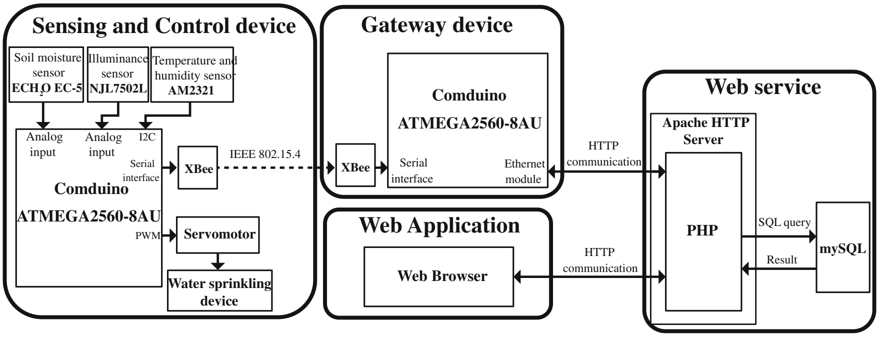

Fig. 1 System model

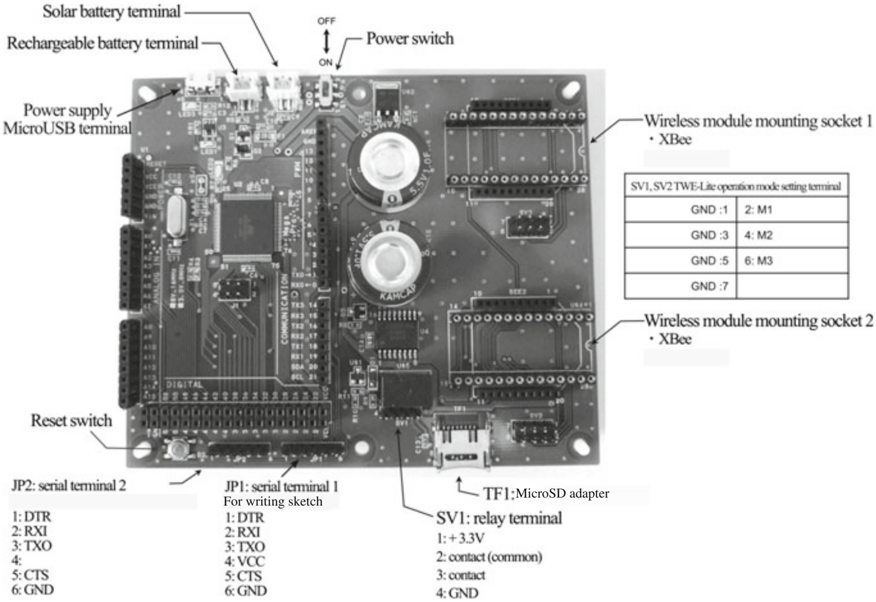

Fig. 2 Overview of Comduino

Table 1 shows the comparison of the well-known microcomputer board and Comduino. We can find that the microcomputer board of Arduino-based including Comduino have a limited hardware resource: small size of memories, a low clock CPU comparing to Raspberry Pi and BeagleBone. On the other hand, their consumed power is quite low because they use a resource constrained hardware and have a sleep mode. Low-power operation is quite important function in practical sensor networks due to a limitation of a battery. Therefore, Arduino-based microcomputer is suitable hardware for sensor networks.

Table 1 Specification of microcomputer boards

Name	Arduino Uno R3	Comduino	Raspberry Pi (Model B+)	BeagleBone Black
Processor	Atmega328	Atmega2560	ARM11	AM3358
Clock speed	16 MHz	8 MHz	700 MHz	1 GHz
RAM	2 KB	8 KB	512 MB	512 MB
Flash	32 KB	256 KB	MicroSDCard	4 GB (8 bit eMMC)
EEPROM	1 KB	4 KB		
Power	51 mA	21 mA	250 mA	210–460 mA
Sleep	40.9 mA	8.15 mA	n/a	n/a
Digital GPIO	14	54	40	65
Analog input	6	16	n/a	7
PWM	6	14		8

2.3 Sensing and Control Device

The circuit diagram of a sensing and control device is shown in Fig. 3. The modules for sensing and control devices are shown as Table 2.

The prototype device employs various kinds of interfaces for sensors. The soil moisture and illuminance sensors use an analog input interface. The temperature and humidity sensor uses an I2C interface. The servo motor is controlled by a PWM interface. Since the servo motor requires 5 V DC source, we have implemented a 5 V regulator. Therefore we have confirmed that various sensors can be attached to our prototype board. Xbee is a well known wireless module for a low-power operation. The prototype has two connectors for Xbee modules. Therefore, we can design a wireless network flexibly. In the prototype implementation, we utilize Xbee Series 1 that is an IEEE 802.15.4 based module.

Figure 5 shows the flowchart of the prototype device. The prototype implements a sleep operation by a watch-dog timer. Owing to the limitation of the hardware specification, the prototype wakes up every 8 s. It also measures an environment by using the sensors every predefined interval period. In addition, it also evaluates the measurement data of the soil moisture sensor to control the water sprinkling system. The water sprinkling system is activated when the measurement data are lower than a predefined threshold value.

2.4 Gateway Device

Figure 4 shows the circuit diagram of the gateway device, and Table 3 shows the additional module for the gateway device. The function of the gateway device is relaying a measurement data from sensing and control devices to the Web service. There-

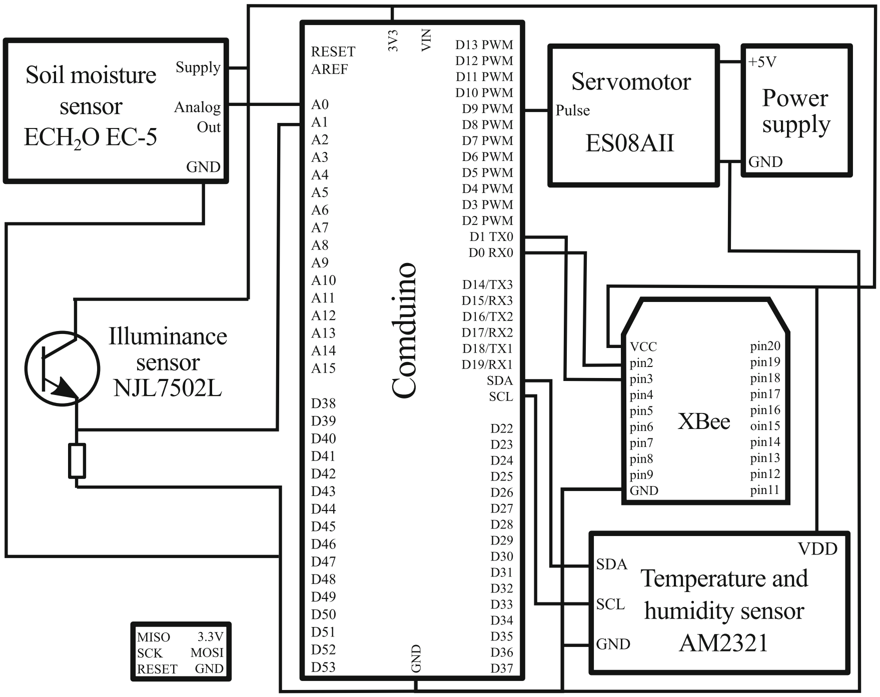

Fig. 3 Circuit diagram of sensing and control device

Table 2 Modules for the sensing and control device

Name	Type
Soil moisture sensor	ECH_2O EC-5
Illuminance sensor	NJL7502L
Temperature and humidity sensor	AM2321
Control servo for water sprinkling system	ES08AII
Wireless communication module based on IEEE 802.15.4.	XBee Series 1

fore, the gateway device receives measurement data through Xbee module that is an IEEE 802.15.4 based wireless module, and transmits the measurement data through the Ethernet module. It also employs HTTP communication to the web service.

Figure 6 shows the flowchart of the software in the gateway device. Since the Xbee module is connected through a serial interface, the serial interface is initialized for the Xbee module in the initialization process. Additionally, a Serial Peripheral Interface (SPI) is also initialized for the Ethernet module. As accurate time is important in sensor network systems, it also obtains accurate time by Network Time Protocol

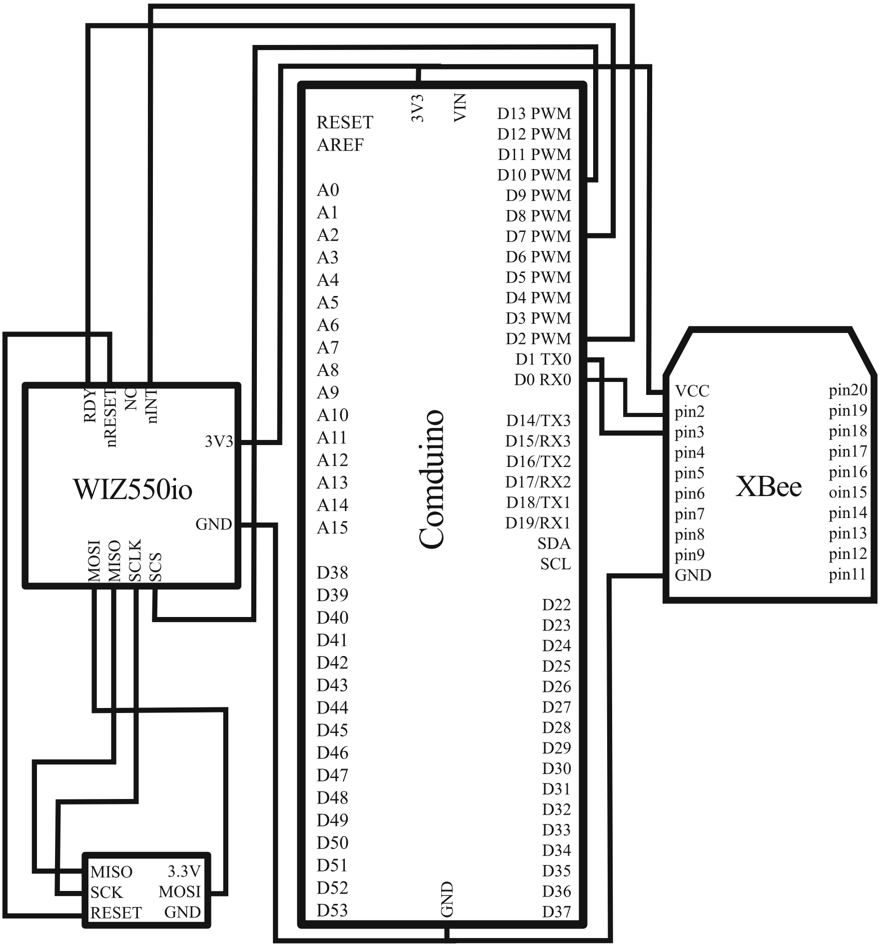

Fig. 4 Circuit diagram of gateway device

(NTP). In the normal operation, it receives a message from the Xbee module when the receive queue of the Xbee module has a message. Then, it also relays the message to the web service every 15 min. The message is transmitted by HTTP with POST format. Further, it sends a time request message to a NTP server every hour to adjust the local time.

2.5 *Web Service*

The web service has a database function and a web application function. The web application has two web interfaces for a gateway device and users. The gateway

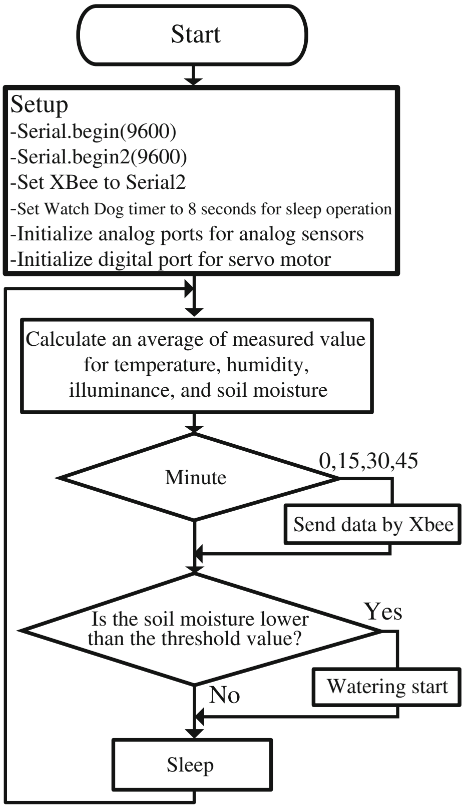

Fig. 5 Flowchart of sensing and control device

Table 3 Modules for the gateway device

Name	Type
Ethernet module	WIZ550io
Wireless communication module based on IEEE 802.15.4.	XBee Series 1

device uses a data upload interface to post a measurement data by HTTP. Users use a user interface to manage the system and to check the measurement data.

Figure 7 shows the communication sequence of the data upload interface. The sensing and control device transmits a measurement data to the gateway device. The gateway device transmits the measurement data to the data upload interface on the Web service by HTTP. The Web service stores the received data in the database. The prototype system employs PHP and MySQL to implement the software. Table 4 shows the database table in the prototype system.

Fig. 6 Flowchart of gateway device

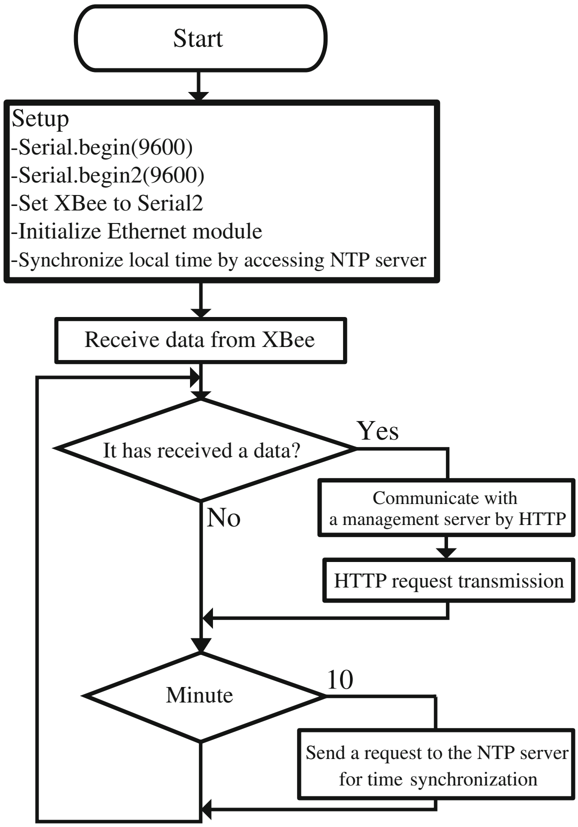

Figure 8 shows the communication sequence of the user interface. The web application can create a visual image of the measurement data by JQuery. In the HTTP communication, the web browser sends an HTTP request to the software on the web service by asynchronous communication. We use a JSON format to transfer the measurement data from the Web service. Finally, the Web browser can draw some graph according to the received JSON data.

3 Experimental Results

We have implemented the proposed system on the Arduino compatible board and cloud server. The sensing and control device is installed at a pot for tomato in an indoor environment. Since the cloud server is installed on our local server, the gateway device is connected to the Web service through a local network.

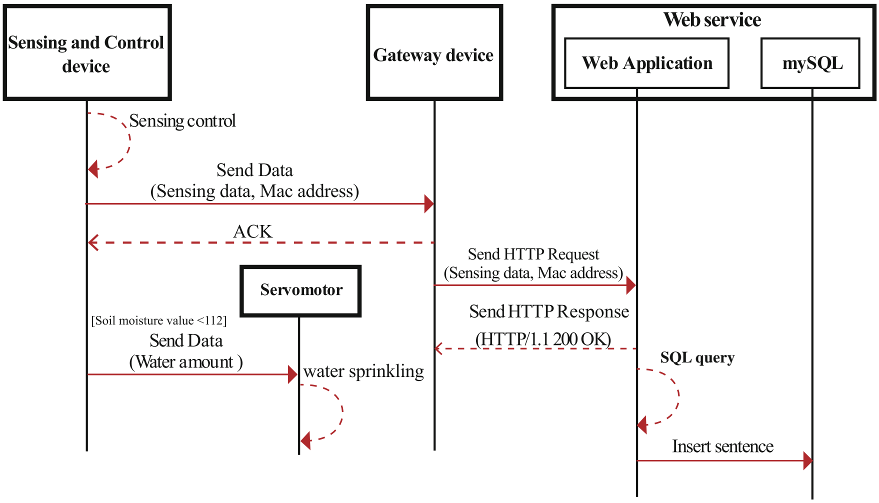

Fig. 7 Communication sequence of data upload interface

Table 4 Management table of observation information

Name	Type	Collation	Attributes	Null	Default	Extra action
id	int		No	None	AUTO_INCREMENT	Primary
date	datetime		No	None		
mac_address	char		No	None		
tmep	float		No	None		
humi	float		No	None		
illu	int		No	None		
water	int		No	None		

The experimental results show that the developed system can measure the environment by temperature, humidity, illuminance and soil moisture sensors, and can inform the measurement data to the Web service every 15 min. The sensing and control device can also control the water sprinkling function according to the measurement value by the soil moisture sensor. Additionally, the developed Web service can provide a visualization of the measurement data. Figure 9 shows the example of the graph of the measurement data.

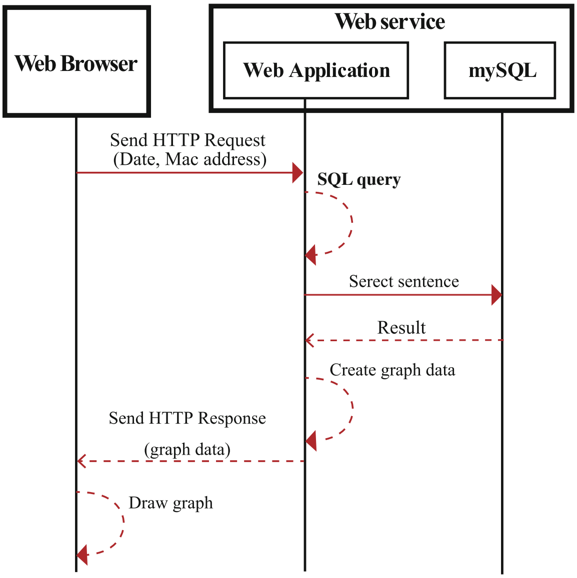

Fig. 8 Communication sequence of user interface

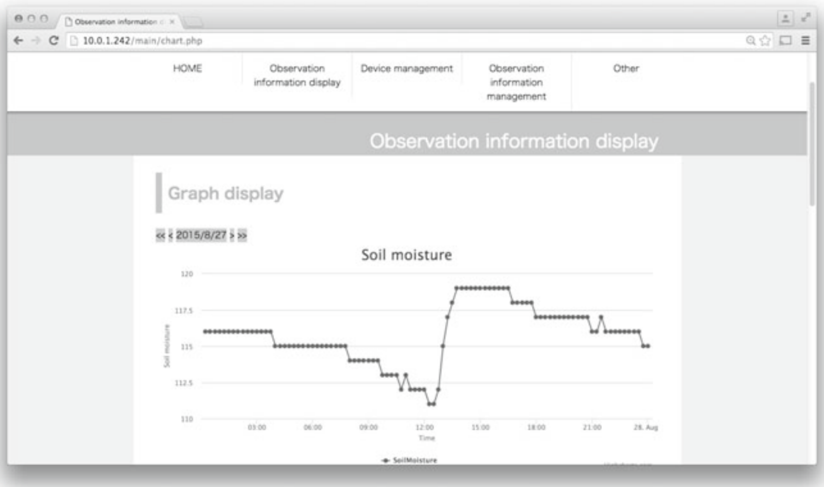

Fig. 9 Example view of Web service

4 Conclusion

This paper has developed a prototype IT agriculture system that employs a general microcomputer board. The developed system consists of sensing and control devices, a gateway device and a web service. The sensing and control device has some sensors such as temperature, humidity, brightness and soil moisture sensors and IEEE 802.15.4 based wireless module. The gateway device implements an ethernet interface and IEEE 802.15.4 based wireless module. Therefore, it can forward a data message from IEEE 802.15.4 network to an IP network. The web service can provide a visual interface for checking a measurement data for users, and a management function of a measurement data.

In the experimental evaluation, we have developed the prototype system. The prototype system employs an ATmega2560 low-power Atmel 8-bit AVR RISC-based micro-controller to realize a low-power operation. Additionally, we have employed Xbee Series 1 as IEEE 802.15.4 based wireless module. The experimental results demonstrate that the prototype can measure an environment of a field periodically and can upload the measurement data to the cloud server through the gateway device. In addition, we have confirmed that the sensing and control device can control the environment of the field depending on the measurement data. Finally, the prototype can be developed with a general Arduino board that is a quite reasonable price comparing to a special hardware for agricultural use.

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