Design and Implementation of a Connected Farm for Smart Farming System

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***Abstract*—Agriculture has been one of the most important industries in human history since it provides humans with absolutely indispensable resources such as food, fiber, and energy. The agriculture industry could be further developed by employing new technologies, in particular, the Internet of Things (IoT). In this paper, we present a connected farm based on IoT systems, which aims to provide smart farming systems for end users. A detailed design and implementation for connected farms are illustrated, and its advantages are explained with service scenarios compared to previous smart farms. We hope this work will show the power of IoT as a disruptive technology helping across multi industries including agriculture.**

I. Introduction

In human history, the agriculture has been one of the most important industries for humans' living since it is responsible for producing indispensable resources such as food, medicine, energy, fiber. Thus, even after the industrial revolution, most countries (even developed ones) have been emphasizing the essential roles of the agriculture industry and related technologies affecting agricultural production. For example, heavy equipments and agricultural planes deployed were able to increase the work efficiency in agriculture (while saving human resources), dramatically increasing agricultural productivity.

As with advances in other industries, the agriculture industry has been also accelerating to develop by deeply employing information and communication technologies (ICT). In particular, automated farm systems, built with diverse wireless sensor devices and actuators, are able to monitor the environmental conditions and control the deployed devices according to the collected data through wireline and wireless access networks. Lin and Liu presents a remotely controlled farm farmers can monitor and control using smartphones or tablets without visiting [1]. Akshay *et. al* also introduced a similar work [2]. Lee and Yeo proposed a pig farm monitoring system, which can effectively manage the farm by monitoring the environmental data using temperature/humidity sensors and video cameras, and accordingly control farm facilities such as humidifiers and air conditioners [3]. Kaewmard *et. al* introduced an automation system based on wireless sensor network techniques, designed to monitor the agriculture environment [4]. They also developed an irrigation system to collect environmental data and support remote control of the operation via mobile devices.

At present, we are on the verge of a technological revolution, called the Internet of Things (IoT). The IoT term was coined by Ashton in 1999 [5], and represents the future of computing and communication, where all the objects in the world will be able to be 'connected' one another, and share their status and surroundings, finally providing new innovative services to humans (even without human intervention) [6]. This is mainly due to the advances in ICT such as identification systems (RFID), short-range wireless communication (ZigBee [7], Bluetooth, WiFi), and cellular networks [8] and widespread use of smartphones.

Recently, Techworld pointed out the promise of growing agricultural productivity by adopting IoT-related technologies [9]. With the literature survey and our experience on developing IoT systems, previously existing smart farming systems can be enhanced by employing IoT systems in two aspects: 1) make it easy to extend systems by allowing new type of devices to be efficiently and effectively integrated into smart farms; 2) facilitate horizontal smart farm platforms, which enables all smart farms to be connected and take advantage of experts' (i.e., experienced farmers) farming knowledge.

The smart farm, embedded with IoT systems, could be called a connected farm, which can support a wide range of devices from diverse agricultural device manufacturers. Also, connected farms could provide more intelligent agricultural services based on shared expert knowledge. For example, people having even little experience on farming could grow plants or crops for profits. Infectious disease prevention could also be another benefit of developing the connected farms by detecting influenza virus in a specific pig farm, and proactively isolating that one from others.

In this paper, we demonstrate a connected farm, which aims to provide suitable environment for growing crops based on the IoT systems developed in the previous research project [10]. All sensors and actuators for monitoring and growing crops are connected with a gateway installed with a device software platform for IoT systems, called *&Cube*. The gateway is in turn communicated with an IoT service server, called *Mobius*. Accordingly, the Mobius not only monitors the environmental condition of the connected farm by communicating with the gateway installed into the connected farm, but also talks with expert farming knowledge systems and controls actuators in order to make the farm suitable to grow crops.

The rest of this paper is organized as follows. The design of connected farms is introduced in Section 2. Section 3 illustrates implementation of our proposed connected farm, and Section 4 describes the possible service scenarios using the connected farm. Finally we conclude our remarks in Section 5.

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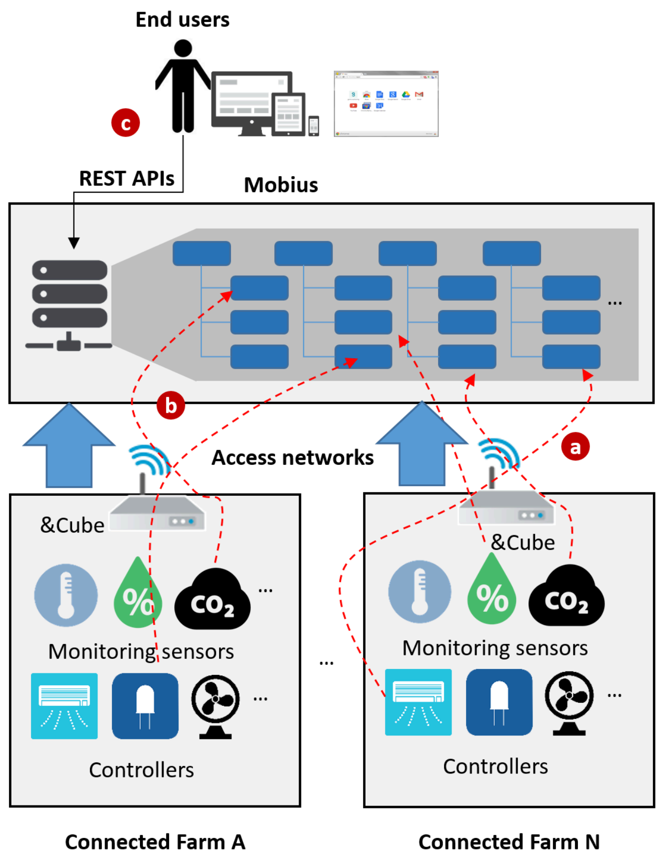


Fig. 1. Design of connected farms based on IoT systems, (a) register devices as virtual representations in the Mobius, (b) transmit data collected from the registered devices via &Cubes, (c) monitor and control the connected farm through REST API-based IoT applications.

II. Design of Connected Farms

The connected farm is a new type of automated farming system developed using IoT infrastructure. As shown in Figure 1, the connected farm system has three main components, i.e., connected IoT devices including monitoring sensors and controllers, IoT gateway (called &Cube), and IoT service platform (called Mobius). In connected farms, there are physical sensors (e.g., temperature, humidity, CO_2, illumination) and controllers (e.g., sprinkler, LED lights, air conditioner, heater) for monitoring and controlling the environmental conditions of the farm. All the sensors and controllers are connected with the IoT gateways in turn connected with the IoT service platform. End users (i.e., farmers) can interact with the connected farm for monitoring its environmental conditions or triggering some farming utilities.

The overall operational procedure is as follows. First, each device (i.e., sensors and controllers) deployed in the connected farm has to be registered into the Mobius using &Cube, as shown in Figure 1a. Once registered with the Mobius successfully, every IoT device can have its virtual representation in the Mobius in the form of a resource type. When running the connected farm, sensors for monitoring the farm send collected environmental data from monitored areas to the &Cube, and then the &Cube transmits the data to the Mobius, as shown in Figure 1b. Finally, end users can monitor and control their connected farm using IoT applications on their smartphones or tablets by accessing virtual representation of the devices resided in the Mobius, as shown Figure 1c.

Here, it should be noted that all interfaces provided by the Mobius are representational state transfer (REST) application programming interfaces (APIs). That is, the interfaces between the Mobius and &Cubes could be standardized and thus easily extended by integrating with other IoT gateways installed with the &Cube, regardless of the type of devices connected into the gateways and access networks. Also, from the point of view of IoT application developers, they can implement their applications using REST APIs provided by the Mobius in order to offer their specialized farming services to customers, even though they have little knowledge about the devices of the connected farm. As a conclusion, our proposed design for connected farms enables seamless deployment of IoT devices into connected farms, but also fosters third party developers to develop their innovative farming services and applications using REST APIs of the Mobius platforms.

III. Implementation

In this section, we introduce our connected farm implementation including its three main components, Mobius, &Cube, and physical devices.

A. Mobius

The Mobius is an IoT service platform complying with oneM2M standards, which supports to create virtual representations of physical IoT devices. The oneM2M initiative is an international partnership project established in 2012, and its aim is to standardize machine-to-machine (M2M) and IoT service layer specifications for globally-applicable and access-independent M2M/IoT services [11]. The Mobius is designed to comply with the oneM2M specifications, and supports common M2M/IoT service functions, including device registration, data repository and management, subscription and notification, security, etc. Thus, the Mobius can support virtual representations of the data collected from physical devices installed into the connected farms. Furthermore, as mentioned in Section 2, the Mobius provides REST APIs to access data resources resided in the Mobius, and control IoT devices.

B. &Cube

The &Cube is a device software platform (i.e., a middleware), which can be installed into IoT gateways. As in the Mobius, the &Cube is also designed to comply with the oneM2M standards, and thus send the collected data from physical devices to the Mobius via standardized REST APIs. The &Cube has been implemented as a Java program so that it could be easily ported on any type of embedded machines installed with the Java virtual machine (JVM). In addition, the &Cube supports various protocol bindings including HTTP, MQTT, and CoAP. For our connected farm, we have installed the &Cube in a Raspberry-Pi, which is a single-board Linux-installed computer.

Fig. 2. Our connected farm implementation.

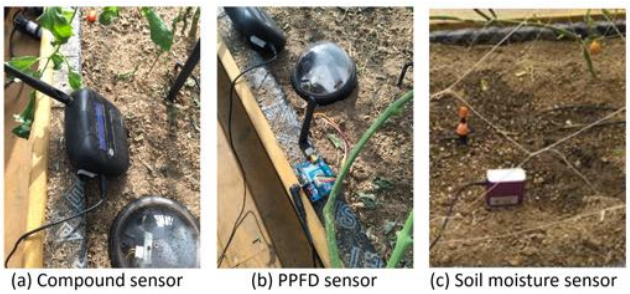


Fig. 3. Three types of sensors to monitor internal environment of the connected farm, (a) a compound sensor for monitoring temperature, humidity, CO_2, (b) PPFD sensor, (c) soil moisture sensor.

Fig. 4. Six types of controllers to control the environmental conditions of the connected farm.

C. Implementation of the Connected Farm

Our connected farm is built in the rooftop of one building in the Korea Electronic Technology Institute. Figure 2 shows the photo of the implemented connected farm.

We deployed three types of sensors in our connected farm in order to monitor the environmental conditions, including a compound sensor (i.e., temperature, humidity, and CO_2), a photosynthetic photon flux density (PPFD) sensor, and a soil moisture sensor, as shown in Figure 3. All sensors are wirelessly connected with the Raspberry-Pi installed with the &Cube through a ZigBee-based network, and the virtual representations of the physical devices are created as a corresponding resource type stored in the Mobius. Each sensor uploads the data collected from its surrounding environment to the Mobius through the &Cube at a 20-second time interval.

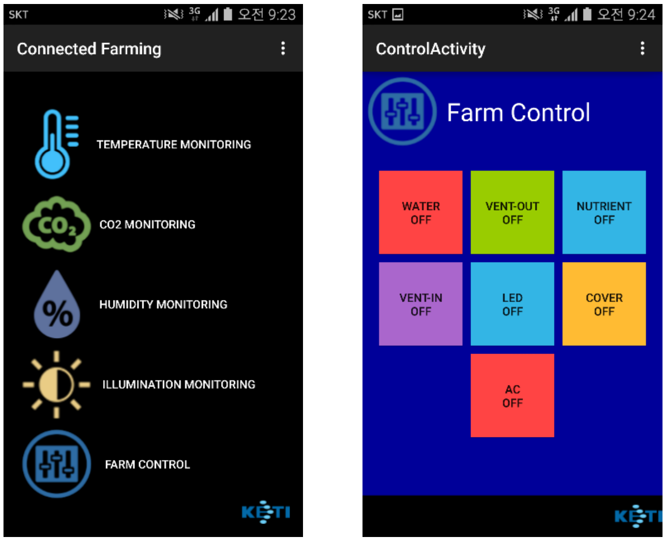
In order to build an automatic connected farming system, we deployed six types of controllers in our connected farm, as shown Figure 4. The controllers include intake and exhaust fans (a-b), an air conditioner with heating and cooling (c), six sprinklers (d), LED lights (e), a cover controller for preventing the light from reaching the plants in the connected farm (f), an irrigation and nutrient management system (g). As with sensors, all the controllers are connected with the Raspberry-Pi installed with the &Cube. Each controller can be operated remotely through the &Cube and Mobius, that is, IoT applications developed with REST APIs provided by the Mobius.

D. Mobile Application

We have developed a smartphone application to enable users to remotely monitor and control the connected farm, as shown in Figure 5. Currently, the application is developed for the Android-based smartphones. End users can monitor environmental conditions of the connected farm and control the controller deployed in the connected farm in real-time.

For smart farming services, the application provides two main menu. Figure 5a shows the monitoring menu. The monitoring menu allows end users to check the environmental conditions of the connected farm including temperature, humidity, CO_2, and illumination. All the environmental variables collected at a 20-second interval can be retrieved from the Mobius, and plotted in a graph. Figure 5b shows the control menu. By pushing buttons in the control menu, end users can remotely control the controller deployed in the connected farm.

As described in Section 2, all the interfaces used in the smartphone application are REST APIs provided the Mobius. This implies that any application developers who are familiar with the REST APIs can develop more user-friendly, easy-to-use GUI applications than our prototype one, which explains exactly our design principle for IoT-based connected farms.



(a) (b)

Fig. 5. Smartphone application to monitor and control the connected farm, (a) monitoring menu, (b) control menu.

IV. SERVICE SCENARIO USING THE CONNECTED FARM

Our service scenario can be described as follows:

1) All IoT devices including sensors and controllers have to be connected with the &Cube, and then the &Cube could register them into the Mobius through the REST APIs.

2) A farm knowledge base (like IBM Watson) will be able to be built, which aims at providing farm knowledge on behalf of experts (i.e., experienced farmers) by sharing the optimal growth conditions for diverse crops and plants. Thus, the knowledge base will provide rich guidance for farmers to control their connected farm effectively and efficiently.

3) After all IoT devices are successfully registered into the Mobius, farmers can remotely monitor and control the IoT devices to make their connected farm appropriate for their crops and plants. For example, if the soil moisture sensor uploads a particular value less than a threshold suggested by the knowledge base, farmer receives an alert message, and triggers the irrigation system immediately.

4) Farmers can create their own connected farm control policy, which will automate the monitoring and control procedure we described above.

5) Finally, farmers can share their knowledge and experience for growing their crops and plants to make the farm knowledge base smarter.

The service scenario described above demonstrates the advantages of our connected farm-based smart farming systems. The connected farm allows end users not only to remotely monitor and control the physical devices deployed via mobile applications, but also to share their knowledge and experience on farming, and finally build a farm knowledge expert system that enables farmers with little experience to start a farm.

V. CONCLUSION

In this paper, we have presented a connected farm based on IoT systems for smart farming systems. To provide Internet connectivity for the sensors and controllers of the connected farm, we have deployed the &Cube, a standardized (i.e., complying with oneM2M specifications) device software platform for IoT devices. Also, we have used the Mobius, an IoT service platform (also oneM2M-compliant) that provides REST APIs with which the data collected from sensors (e.g., CO_2 sensor) can be retrieved, but also the control commands can be sent to controllers (e.g., air conditioner). We have also implemented a smartphone application that allows end users to remotely monitor and control their connected farm, e.g., turn on air conditioner by pushing a button on the smartphone. Our service scenario with the connected farm shows a promise of building a farm knowledge expert system that encourages people to work in the agricultural industry.

ACKNOWLEDGMENT

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