Computers and Electronics in Agriculture 124 (2016) 325–339

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Development of a remote environmental monitoring and control framework for tropical horticulture and verification of its validity under unstable network connection in rural area

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ARTICLE INFO

Article history:
Received 24 November 2015
Received in revised form 16 April 2016
Accepted 25 April 2016

Keywords:
Tropical agriculture
Field-monitoring system
Monitoring and control
Cloud system
Unstable network condition

ABSTRACT

This study focuses on the development and evaluation of a remote field environmental monitoring and control framework, implementing a local-global management strategy to overcome the unstable network connection in the rural area. The framework consists of environmental monitoring and control node as the local management subsystem (LMS), and the web data providing and system management as the global management subsystem (GMS) to establish a simple and flexible remote environmental monitoring and control based on a cloud platform. The supporting features are online and offline environmental monitoring, synchronization of system configuration, actuation, and offline management. Two field tests were conducted to verify its performances and functionalities, (1) environmental monitoring on tropical horticulture cultivation in Yogyakarta, Indonesia, and (2) implementation of the monitoring and control for automatic drip irrigation control based on soil moisture content for tomato. As the result of the first test, the developed framework could help to maintain the sustainability of environmental monitoring under unstable network connection over 80% availability of the data with local offline measurement up to 24% of the total entries. From the second test result, the framework could support the real-time monitoring and control of soil moisture content as well as increase the system flexibility in the adjustment of the system configuration remotely. The control system has 0.78% error (E) and 99.2% in-range soil moisture content ($L < x_t < U$) measurement during the 10-days observation. We concluded that the proposed framework might become a useful tool for a simple remote environmental monitoring and control under unstable network connection in the rural area. The framework has the potential to be adopted in cloud-based tropical horticulture supporting system, aimed for long-term environmental monitoring and controlling local facilities.

1. Introduction

Horticulture is one of the important sectors in the Indonesian agriculture. As reported by the Center for Agricultural Data and Information System Ministry of Agriculture Republic of Indonesia (2014), there are about 2.9-million (8.41%) horticulture farmers. Horticulture sector consists of fruits, vegetables, herbal crops, and ornamental plants. It has real economic value because of its roles in increasing farmer's income and welfare, as well as improving people nutritional status (Dimyati et al., 2012). According to the Indonesian Agency for Agricultural Research and Development (2014), the increase of demands for the horticulture commodities at both domestic and global markets along with a wide distribution of harvested area are some opportunities at the current status of Indonesian horticulture. On the other hand, some weaknesses that must be faced such as inconsistency of quality, low competitiveness of horticultural product, and climate changes. Hence, to sufficient the supplies as well as be able to compete in the markets, it is necessary to improve the horticulture production system in establishing continuity, consistency of supply, and sustainability.

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http://dx.doi.org/10.1016/j.compag.2016.04.025

So as to improve the production system in tropical agriculture, the environmental factor should be well considered. The climatic variable that affects the growth of plants includes the solar radiation, temperature, precipitation, wind speed, and atmospheric humidity (Azam Ali et al., 2002). In open-field cultivation, the climatic variable is an uncontrollable component and what farmers usually do is selecting suitable crop variety and doing operation management to minimize the impact of an unsuitable environment. To enhance the farming management with regard climatic factors, we have considered that it is necessary to have an on-farm data collection to support the decision-making process. Utilization of data-science on decision-making process might help the selection of appropriate management operation as well as improving the farmer experience.

Currently, the demands of environmental field monitoring are shifting from offline data collection system to online data collection based on cloud system architecture. The online control strategy has been established to improve the performance of monitoring systems for agricultural applications with various technologies and approaches, e.g. a distributed data acquisition with a local controller and management (Serôdio et al., 2001; Kaloxylos et al., 2012, 2014), field server type monitoring systems (Fukatsu and Masayuki, 2004; Fukatsu and Hirafuji, 2005; Fukatsu et al., 2011, 2006a,b, 2007), Wireless Sensor Networks (Gonda and Cugnasca, 2006; López Riquelme et al., 2009; Song et al., 2011; Dumitrascu et al., 2013; Gaddam and Esmael, 2014), a web-based monitoring system (Du et al., 2008; Beccali et al., 2008), field router type systems (Mizoguchi et al., 2011; Manzano et al., 2011; Arif et al., 2014), and authors' previous works on a cloud-based information agriculture support system (Okayasu et al., 2010) with an actuation framework (Nugroho et al., 2013). Table 1 shows the comparison between the existing systems.

Realizing the current condition and motivation on the adaptation of on-farm environmental monitoring and control in tropical horticulture in Indonesia, we could formulate the potential and challenges. The potentials are the availability of the internet service, the widespread use of the smartphone, the young horticultural farmer mostly familiar with the internet application (web pages' browsing and social network services). However, the availability and stability of network at the field located in rural area, electricity sources, and low capital are some challenges. Hence, to support the implementation of cloud-based horticulture supporting system, it is necessary to have a robust framework with features to deal with unstable network condition, simple on maintenance, and flexible access.

In order to develop the framework for remote environmental monitoring and control under unstable network condition, we have considered the adoption of suitable hardware, software, method, and algorithm as well as its compatibility with the existing systems. We preferred open source hardware and software as a fundamental opinion to develop the system having the cost affordability and flexibility. As the data transmission, 3G/GSM communications with HTTP protocols are commonly used for the remote connection (Jiang et al., 2011). Local and global management strategy would be adopted to establish a robust remote monitoring and control in the rural area.

The objective of this paper is to present the development of a remote environmental monitoring and control framework having a local–global management strategy in order to overcome unstable network connection. To evaluate the performance, we have conducted two field experiment tests. In the first test, we mainly focused on implementation of environmental monitoring on open field tropical horticulture farming in Yogyakarta, Indonesia. The second test focused on monitoring and control features, implemented on the automatic drip irrigation based on soil moisture content.

2. System development

The remote environmental monitoring and control framework is designed by client–server architecture as shown in Fig. 1. It is composed of an environmental monitoring node as a local management subsystem (LMS), a web application as a global management subsystem (GMS), and the internet to facilitate the communication and the data transmission. The internet also supports flexible information dissemination to users/administrator and data sharing to another web server.

2.1. Local management subsystem (LMS)

The LMS works as an "on-field" operation, which is able to work as both client and local manager depending on the availability of the internet connection. The LMS's components are a CPU, analog/digital inputs for environmental sensors, digital outputs for actuators, additional modules such as a micro SD card, a real-time clock (RTC), and a watchdog timer to ensure the system always running in case of system malfunction during operation. In order to simplify the system development and expandability on implementation in the actual field, an open source prototyping platform, "Arduino Ethernet" board (https://www.arduino.cc/) was selected as the main board. The GSM router (HUAWEI B970b, Huawei Technologies Co., Ltd.) equipped with an SIM card from 3 Indonesia (internet provider company) is used to establish the internet connection. The micro SD card is used to store the initial system configuration and the temporary offline measurement data as a file.

Fig. 2 shows the custom designed sensor shield and LMS hardware setup. The shield (Logical Product Co., Ltd.) aimed to facilitate simple sensor and actuator installation. It equipped with six analogs and two digital I/O connectors, a pairs of LED indicators for power and system activity, a fan connector, a jumper for working voltage operation selector (3.3 or 5.5 V), and a real-time clock module (SparkFun DS3234). The shield attached to the Arduino Ethernet board and set into a waterproof box protector. A circulation fan (Model: 2004KL-04W-B50, 12VDC/0.14A, 5×5 cm, Mineba Matsushita Co.) was installed inside the sensor house where the digital temperature and humidity sensor placed. Table 2 shows the technical specifications of the installed environmental monitoring sensors.

2.2. Global management subsystem (GMS)

The GMS is mainly used to manage the whole system through the internet. The hardware for hosting server has an Intel(R) Core (TM) 2 Quad CPU @ 2.66 GHz CPU with 2 GB RAM, running Debian Linux Squeeze 6.0, Linux kernel 2.6.32-5-amd64 with Apache server 2.2.16, PHP 5.3.3 and MySQL database version 5.1.49. We developed all components on the GMS using the open source software, i.e. web application based on PHP combined with Fat-free Framework 3.2.2, Bootstrap v3.3.2 CSS framework, the *JavaScript*, and *Highcharts* v4.1.4 module for data visualization. For the interaction between the LMS and GMS, two API (Application Programming Interface) were created based on the HTTP (The Hypertext Transfer Protocol), the API for measurements and the API for checking the configuration. The LMS actively sends an *HTTP GET* request, safe method for requests a representation of the specified resource, and the GMS responses with a message contain valuable information related to system configuration.

The system configuration is an important component in the implementation of cloud-based environmental monitoring and control. The configuration of the LMS is synchronized with the configuration stored in the GMS by specified time interval. In the LMS,