Design and Implementation of a Cloud-based IoT Scheme for Precision Agriculture

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Abstract—**The Internet of Things (IoT) technology is currently shaping different aspects of human life. Precision agriculture is one of the paradigms which can use the IoT advantages to optimize the production efficiency and uniformity across the agriculture fields, optimize the quality of the crops, and minimize the negative environmental impact. In this paper, we present an IoT architecture customized for precision agriculture applications. The proposed three-layer architecture collects the needed data and relays it to a cloud-based back-end where it is processed and analyzed. Feedback actions based on the analyzed data can be sent back to the front-end nodes. We built a prototype of the proposed architecture to demonstrate its performance advantages.**

Keywords—Internet of Things (IoT); precision agriculture; sensor networks; platform implementation; cloud computing

I. INTRODUCTION

Precision agriculture emerged in the late 1980's with the matching of grid-based sampling of soil chemical properties with the newly developed variable-rate application equipment for fertilizers [1]. Since then, it became the main farming management practice worldwide. Precision agricultural services provide the means to (1) fight epidemic diseases by applying the appropriate types and amounts of fungicides, pesticides and organic fertilizers at the right times, (2) achieve efficient water consumption by watering the plants with only the needed amount of water and the right time, (3) reduce the harm to the environment since knowing when to spray a pesticide does not only lead to effectively killing harmful pests but also reduces the use of the pesticide, and (4) produce high-value agriculture productions by growing non-toxic, safe, and healthy crops.

The use of Wireless Sensor Networks (WSNs) in precision agriculture increases the efficiency, productivity and profitability of many agricultural production systems [2]-[11]. Real-time environmental information can be remotely gathered from the agricultural fields and transferred to where it can be processed to discover problems, store data, and/or take needed actions. This contrasts with the traditional agricultural approaches in which decisions are taken based on some hypothetical average condition, which may not reflect reality.

WSNs are key components the Internet of Things (IoT) in which different pieces of information gathered from almost anywhere and anything in the world are accessible through the Internet. The integration of WSNs with IoT resulted in a plethora of applications such as smart-cities, remote healthcare, energy and water control, precision agriculture, wildlife monitoring, structural and ancient building monitoring, etc.

In this paper, we propose a cloud-based IoT architecture that is applicable in different precision agriculture applications. The proposed architecture is composed of three layers: a front-end layer that collects the environmental information and applies the needed agriculture actions; a gateway layer that connects the front-end layer to the Internet, and a back-end layer in which the data storage and processing take place. A prototype of the proposed architecture is built and tested to illustrate its performance.

The remainder of the paper is organized as follows. In Section II, we review the related literature. The proposed IoT architecture is presented in Section III. A preliminary set of results of a prototype of this architecture is presented in Section IV. The paper is concluded in Section V.

II. RELATED WORK

A. High-Level IoT Architectures

This category represents the related IoT architectures that were proposed in the literature. A classification of generic IoT platforms is presented in [2], which also develops a top-level generic IoT architecture suited for smart city applications including precision agriculture. Likewise, [3] presents a functional view of an integrated architecture of data acquisition and intelligent control system that can be used in agricultural facilities such as greenhouse. In [4], the authors present a functional architecture that aims at promoting the development of facility habitat intelligence monitoring platforms. The authors of [5] integrate the recently developed Open IoT platform that is applicable in a number of use cases with the Digital Agriculture (Phenonet) to develop a semantically enhanced agriculture ontology. However, all such related works lack actual implementations.

B. Crop Monitoring Platforms

Several IoT systems have been developed for monitoring purposes in precision agriculture application [6]-[8]. With the goal of increasing the crop production, a crop monitoring system was developed to collect the crop data and use production system through correlation analysis between the crop statistical information and agricultural environment information [9]. The platforms presented in [10] and [11] and control functionalities based on the monitored data.

C. *Irrigation Control Platforms*

Several IoT platforms have been recently developed to control the water consumption in irrigation. Examples include the simple system developed in [12]. More advanced systems such as the system presented in [13] which allow users to control the irrigation process via cellular technologies. Likewise, the system presented in [14] uses cellular technologies to transfer the sensors' data to a database system. The platform proposed in [15] directs the data to a cloud service through HTTP.

III. PROPOSED CLOUD -BASED AGRICULTURAL IOT ARCHITECTURE

The proposed cloud-based IoT architecture for agricultural applications depicted in Fig. 1 is composed of 3 layers: front-end, gateway, and cloud back-end. In this section, we discuss these three layers and their implementation in detail.

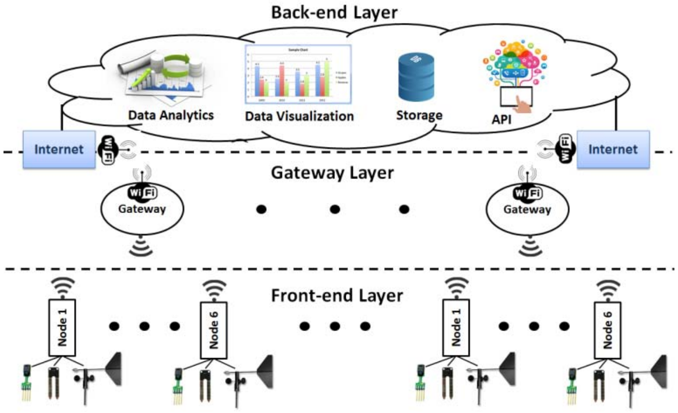

Fig. 1. Proposed cloud-based IoT architecture for agricultural applications.

A. *Front-end Layer*

The front-end layer is the physical hardware or the sensing nodes that are composed of 4 modules: a microcontroller, the environmental sensors and actuators, interfacing circuits, and a wireless communication module as shown in Fig. 2.

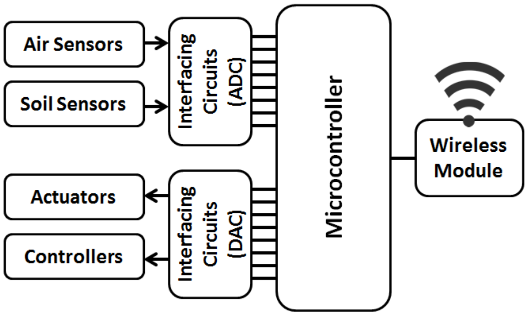

Fig. 2. Front-end node architecture.

Microcontroller: The microcontroller is responsible for collecting the data of the different sensors attached to it and communicating such data to the next layer of the architecture. Depending on the application, the microcontroller can be either battery-powered, self-powered using solar panels, or self-power with backup batteries. We use the Raspberry Pi 2 single-board microcontroller that is powered through a 3.7 V Li-Ion battery in our front-end nodes.

Sensors and Actuators: Different aboveground and underground sensors are used in precision agriculture to measure the different environmental attributes needed by a target application. Examples includes sensors that measure air temperature, air humidity, soil temperature, soil volumetric water content, wind speed, wind direction, rain meter, solar radiation (infrared, visible, and ultraviolet), and leaf wetness. These sensors collect the physical information to be communicated to the back-end server. Table I lists the sensors used in our node prototype. Based on the sensed information, the system is capable of taking the appropriate action such as spraying chemicals or fertilizers, watering the plants, etc. This is implemented through a set of actuators and mechanical controllers that are used to control pumps and sprayers. All communications between the microcontroller and the sensors/actuators are done using the I2C protocol.

TABLE I. USED SENSORS

Sensor	**Model**
Air Temperature	SHT11
Air Humidity	HTU21D
Soil Moisture Sensor	SEN0114
Leaf Wetness	FC-37
Wind Speed/Direction	SEN-08942
Rain Volume	SEN-08942

Interfacing Circuits: The different sensors convert the sensed phenomena (e.g., temperature) into an equivalent electric voltage or current. However, such electric voltage or current is still in the analog format. A sensor interfacing circuitry is needed to convert such analog signals coming from the sensors into the corresponding digital format and perform any further signal conditioning functionality to ensure compatibility with the used microcontroller. Analog-to-Digital Converters (ADC) are the core component of such interfacing circuits. We use the 6-bit CA3306 CMOS parallel ADC designed for low-power applications. On the other hand, the actuators and mechanical controllers use analog signals as inputs. Therefore, interfacing circuits that convert the digital outputs of the microcontroller to the needed analog control signals are needed. Digital-to-Analog Converter (DAC) interfacing circuits are used for that purpose such as the low-power MCP4725 DAC used in our system.

Wireless Communication Module: The purpose of this module is to provide the sensor nodes with the means to communicate the data to the nearest gateway. Unlike the vast majority of related works which use the high power Bluetooth or cellular technologies, we use the nRF24L01 ultra-low-power transceiver operating on the 2.4 GHz ISM band which significantly reduces the power consumption of our design.

B. *Gateway Layer*

The different front-end nodes deployed in the agricultural field collect the sensor data and relay it to a gateway. The gateway then relays the collected data (possibly after manipulating it) to the cloud servers in the back-end for storage and extensive data analysis. The gateway layer also forwards requests from the back-end to the actuators in the nodes. Each gateway can be connected to up to 6 front-end nodes through nRF24L01 transceivers such as those used in the front-end nodes. The gateway is also implemented using Raspberry Pi 2 microcontroller. Being equipped with a 900 MHz quad-core ARM cortex-A7 CPU and 1 GB RAM, such a microcontroller provides the needed processing power and storage that ensure that all the capture sensor data is relayed to the cloud server for analysis. A miniature IEEE 802.11b/g/n (WiFi) module is used to connect the gateway to the remote back-end. The used module is interfaced to the microcontroller using a standard TCP/IP interface. The data rate of this module is 150 Mbps.

C. Back-end Layer

The back-end is responsible for facilitating the end-users' ability of accessing the sensed data. This is achieved by implementing several services including, but not limited to, data storage, data analytics, and data visualization in addition to providing an appropriate application program interface (API) and software tools through which the end-user can access the data. In our proposed architecture, we implement the back-end layer via the cloud-based server shown in Fig. 3.

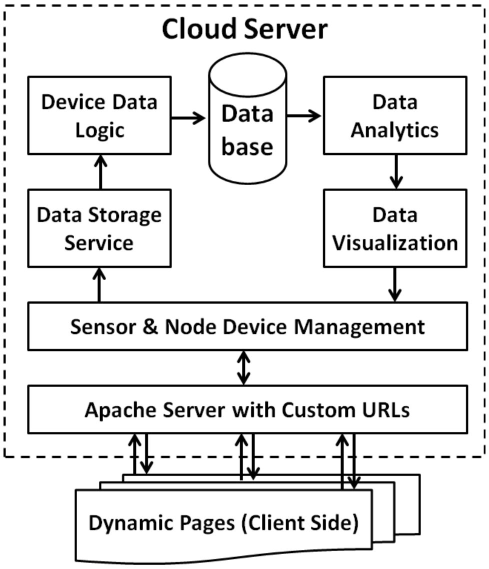

Fig. 3. Cloud server architecture.

The back-end cloud server has a large database at its core that can accommodate huge amount of data relayed through the gateway layer from the front-end node. The database is interfaced to a wide set of data analysis algorithms and APIs such as Google Sheets for data visualization. Data can be accessed through the Internet using dynamic webpages as shown in Fig. 3.

In our implementation of the cloud server, both Apache and MySQL run on the same virtual machine (VM) running Ubuntu 14.04. This VM is just one of the many VMs that constitute a larger VSphere implementation. The VSphere control panel is used to increase the resource allocation of the VM (such as memory and disk space) with a minimal downtime and without data corruption. It is worth noting that if the agriculture system requirement exceeds the available hardware resources, the implemented VM can be easily moved to a dedicated cloud hosting platform such as an EC2 instance on Amazon Web Services (AWS).

IV. PROTOTYPE PERFORMANCE EVALUATION

A prototype of the proposed architecture for IoT precision agriculture applications has been implemented for a proof of concept to evaluate the proposed IoT transducer framework. Three front-end nodes equipped with sensors listed in Table I were used. These three front-end nodes are deployed outdoors in the Central Michigan University (CMU) campus. The nodes connect to a single gateway using nRF24L01 wireless interfaces. The gateway connects to the Internet, and hence to the back-end cloud server, using the WiFi technology. The gateway collects data from the three front-end nodes and performs abstract data analysis for immediate feedback (if necessary), and transmits the raw data to the cloud for detailed data analytics. The back-end cloud server receives and stores the data received from the cloud server, performs data analytics, and creates visual illustrations for easier data interpretation.

A. Wind Speed and Dirction

First, we collect the wind speed and direction data. For the wind speed data, the rotation of the sensor is converted into velocity measured in Miles Per Hour (MPH). The used SEN-08942 sensor gives different voltage values for different directions. The sensor used in the prototype gives up to 16 different directions. Fig. 4 depicts the wind speed collected over a 200 minutes window. This figure shows the variations of the wind speed by the minute over the observation window. Different granularities can be obtained using our cloud server. We omit the wind direction results for space considerations.

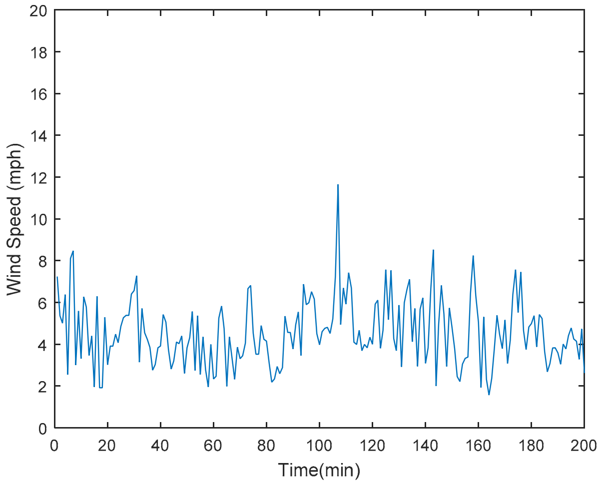

Fig. 4. Wind speed recorderd over a 200-minute window.

B. Rain Volum

Next, we present the results of the rain meter and the moisture sensors. We show such data in Fig. 5 for a 200 minutes window in which the rain existed only in the first 23 minutes. Fig. 5 shows the gradual decrease in the rain volume before it stops. Meanwhile, the moisture slightly increased after the rain stopped. Such data can be used in predicting the evolution of plan diseases.

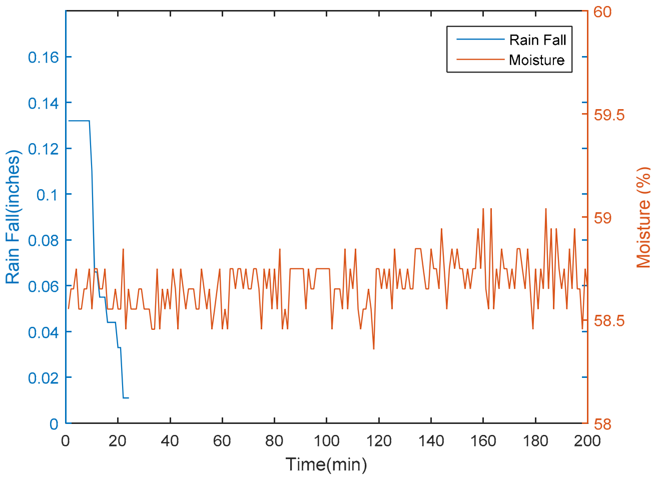

Fig. 5. Rain volume recorderd over a 30-minute window.

C. *Air Temprature and Humidity Results*

Another important environmental data for agricultural IoT applications is the air temperature and humidity. Fig. 6 depicts an example of the recorded air temperature and humidity results.

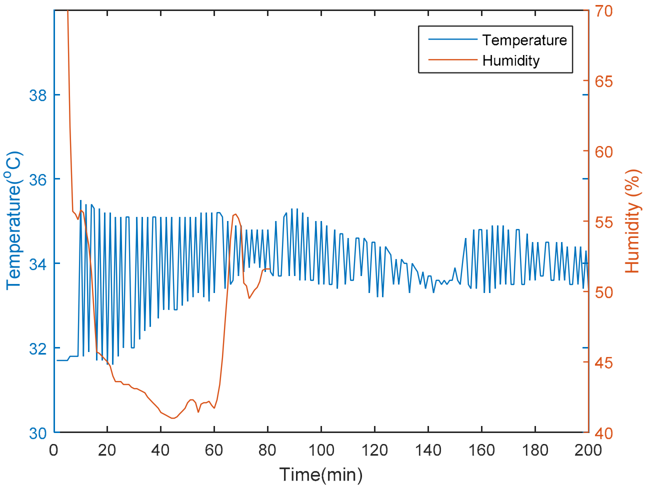

Fig. 6. Temprature and humidity data reports.

The results presented in this section demonstrate the ability of the proposed cloud-based IoT system to efficiently collect, store, process, and visualize the environmental data needed for different precision agriculture applications.

V. CONCULSIONS

In this paper, we have presented a cloud-based architecture for IoT precision agricultural applications. We have outlined the three layers of the proposed architecture and explained their implementation details. We have built a prototype to illustrate the different performance aspects of the proposed architecture. The preliminary performance evaluation results have demonstrated the efficiency of the proposed architecture – despite its simplicity. This makes the proposed architecture a good candidate for implementing a wide set of precision agriculture systems. Our future work will include how to secure the access of the data and will develop a mobile application that allows access of the data on handheld devices.

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