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Interoperable agro-meteorological observation and analysis platform for precision agriculture: A case study in citrus crop water requirement estimation

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ABSTRACT

Advances in Internet of Things (IoT) based sensing systems have improved capabilities to precisely monitor environmental conditions. Plants are sessile organisms and are affected by biotic and abiotic stresses caused due to surrounding environmental conditions such as soil water content, pest/disease infestation, and soil health. High-resolution sensing (Wireless Sensor Networks (WSN) Systems) of agro-meteorological parameters helps to solve critical issues about the crop-weather-soil continuum. Currently, many WSN systems are deployed all over the World for precision agriculture purposes. Although there have been many improvements in the communication aspects of the WSN's, the data dissemination and near real-time analysis components for taking dynamic decision, particularly in agriculture domain has not matured. The current WSN systems do not have a standardized way of data discovery, access, and sharing, which impedes the integration of data across various distributed sensor networks. This study addresses above issues through the adaptation of a framework based on Open Geospatial Consortium (OGC) standards for Sensor Web Enablement (SWE). For precision agriculture applications a cost-effective, standardized sensing system (hardware and software) has been developed, which includes functionalities such as sensors plug-n-play, remote monitoring, tools for crop water requirement estimation, pest, disease monitoring, and nutrient management. Also, the modeling techniques were integrated with the interoperable web-enabled sensing system for addressing water management problems of horticultural crops in semi-arid areas.

1. Introduction

Agriculture is an important sector which drives the economy and food security of many nations. Various kinds of sensing systems are emerging in the area of precision agriculture in which the current trend is towards the design and development of cost-effective, energy efficient and fault tolerant Wireless Sensor Networks (WSNs) for various monitoring and management applications. The focus of recent research is on improving and sustaining the productivity of different crops. Current advances in Information Communication and Dissemination Technologies (ICDT's) have well proven their ability in information and knowledge dissemination. Globally, the ICDT initiatives in the field of agriculture have shown that with accurate monitoring and analysis of crop/weather parameters, it is possible to judiciously allocate available resources in agriculture (Nash et al., 2009; Lee et al., 2010; Prabhakar et al., 2010; Li et al., 2011). Several WSNs are being deployed in many countries, and have a wide range of applications in agriculture, such as:

- Crop/pest disease monitoring (Riquelme et al., 2009; Tripathy et al., 2011).
- Crop water management (Panchard et al., 2006, 2007; uAgri C-DAC, 2013; Sudharsan et al., 2012; Ojha et al., 2015).
- Crop yield prediction (Honda et al., 2009; Sudharsan et al., 2011).
- Weather based advisory services (IMD, 2016; ISRO, 2015; mKRISHI, 2016).

In general, several dissemination systems are currently being deployed, which enables the discovery, access and retrieval of various meteorological, biophysical, ocean and coastal water quality parameters. This kind of systems can be divided into two types:

(1) Stovepipe or standalone systems which provide sensor details (i.e. metadata, observations and measurements) in their own formats (Panchard et al., 2006, 2007; Riquelme

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et al., 2009; Sudharsan et al., 2011, 2012; Tripathy et al., 2011; Ojha et al., 2015).

(2) Interoperable systems and platforms which implement commonly agreed standards for sensor metadata, observation and measurement representation (Korduan et al., 2004; Murakami et al., 2007; Mizoguchi et al., 2008; Nash et al., 2009; Durbha et al., 2010; Nikkilä et al., 2010; Bröring et al., 2011a,b; Patil et al., 2012; Sawant et al., 2012; Jazayeri et al., 2012; Liang and Huang, 2013; Chen et al., 2015; Du et al., 2016; Geipel et al., 2016).

However, there is a paucity of standards driven, interoperable systems in the Agriculture domain that severely impedes the discovery and access of data across Agri-WSN's. For example, to answer a question such as "*What is the crop water requirement during a particular crop growth stage?,* there is a need for weather parameters such as air temperature, relative humidity, solar radiation, wind speed, and rainfall. from weather station and crop growth stage information from field/cultivation practice. It's hard for users from diverse areas of study to understand the exact lineage of the collected data i.e. how the measurement is transformed into an observation. It is possible that the measurement has gone through various transformations (e.g. application calibration curves), which can also give rise to heterogeneous data formats (Comma Separated Values (CSV), Tab Separated Values (TSV), EXtensible Markup Language (XML), etc.). With this ever increasing spread of WSNs, there is a need for standard sets of specifications (both syntactic and semantic) and encodings to bring multiple sensor networks on a common platform (Durbha et al., 2010; Bröring et al., 2011a; Patil et al., 2012; Liang and Huang, 2013). Which enables the development of geographically distributed systems that are standardized at the semantic (Folmer and Verhoosel, 2011; Compton et al., 2012) and Syntactic (Bröring et al., 2011b) level for regional agricultural practices planning (i.e. irrigation, pest/disease management, etc.).

The initiatives such as, FOODIE: Farm-Oriented Open Data in Europe (Esbri et al., 2014), GeoCENS: Geospatial Cyberinfrastructure for the World-Wide Sensor Web (Liang and Huang, 2013), Sensor Asia (Mizoguchi et al., 2008) and Service Oriented Architecture for sensor data discovery in agriculture (Patil et al., 2012; Sawant et al., 2012; Chen et al., 2015), are some of the attempts towards facilitating the interoperability and sensor data discovery. These studies have shown the utility of Open Geospatial Consortium (OGC) specified Sensor Observation Service (SOS) standards for sensor data access from geographically distributed sensing systems (OGC, 2016; Bröring et al., 2012, 2011a).

Keeping in view of the requirement of a sensing and analysis platform in the ever increasing precision agriculture area, the specific objectives of this paper are:

- to design a sensor platform (hardware) with integrated SWE architecture for precision agro-meteorological monitoring
- to integrate the OGC's Sensor Web Enablement (SWE) standards to achieve interoperability and scalability of heterogeneous sensing systems
- to demonstrate the utility of such interoperable sensing systems for agro-meteorological monitoring and potential evapotranspiration estimation.

This paper is organized into various sections: Section 2 describes the design of sensor platform (hardware) and integration of sensor web architecture (software) for agriculture monitoring. A case study on the application of interoperable sensor system for crop water requirement analysis is described in Section 3. Section 4 presents results and discussions on the integrated sensor web system and its utility for crop water requirement analysis. Section 5 concludes with a comparison between current SWE initiatives for precision agriculture and a description of the future work.

2. Materials and methods

The sensor web enablement framework of the agro-meteorological observation and analysis platform consists of three layers: (1) Sensing systems, (2) Sensor Web Enablement (middleware) and (3) Web based visualization layer (Fig. 1). Below is a description of each component of the framework shown in Fig. 1.

2.1. Sensing systems

The sensing systems layer comprise of the network of geographically distributed heterogeneous sensing systems (i.e. a set of standalone and interoperable sensing platforms).

2.1.1. Development of an interoperable sensing platform

An interoperable wireless sensing system (henceforth called as SenseTube) has been designed using low powered System on Chip (SoC) single board computer (i.e. Raspberry Pi/R-Pi, Raspberry Pi (2016)) as a data collection and dissemination platform (Fig. 2a) (Sawant et al., 2015). Multiple sensor nodes (child nodes) can be interfaced with the SenseTube base station.

Field level node to node communication has been established using Wi-Fi (i.e. IEEE 108.11) communication protocol (Fig. 2b) (Sawant et al., 2015). The General Purpose Input Output (GPIO) pins of SoC hardware are utilized to connect the Analog to Digital Converter (ADC), and through Serial Peripheral Interface (SPI) the data is collected. The ADC has eight analog channels for connecting external sensors. The resolution of ADC is 10 bit thereby facilitating to interface analog sensors such as temperature, and humidity. The digital (raw) voltage observations collected from ADC are converted into physical measurements and stored onboard. The sensor sampling and polling frequency can be adjusted through the configuration interface. The default sampling interval has been set to fifteen minutes and polling frequency to one hour. The sensing system comprises of sensor node collecting observations at fixed interval. The sensing system can be configured as a base station and child node. When set as base station sensor node receive observations and measurements from distributed child nodes and transmit over remote address/service. The child node configuration provides a capability to receive and locally transfer sensor observations and measurements to the base station. Table 1 lists sensing system configurations for interoperable sensing system (SenseTube).

Existing infrastructure of Internet Service Providers (ISP's) has been utilized in the present study for internet connectivity. Normally, the ISP's dynamically assign Internet Protocol (IP) address to the field based sensing system, this configuration brings out two cost-effective approaches to communicate with the data processing layer: (1) through Virtual Private Network (VPN) server configured on fixed IP addressed remote/cloud service platform (Liu, 2000), (2) using cost-effective cloud service (e.g. ownCloud, Dropbox, etc.) which is easily accessible to both the field based sensing system and remote/cloud based data processing server (ownCloud, 2016; Dropbox, 2016). Direct reliable and secure access to SWE sensing platform facilitate the on-board data processing (i.e. estimate reference evapotranspiration, daily minimum/maximum temperature, humidity, etc.). The remote/cloud based data processing server can access the field nodes using SWE requests such as GetCapabilities, DescribeSensor, and GetObservation detailed information about communication between field based interoperable sensing systems, and sensor