Sensor Based Context-Aware System Architecture for Improving Yields in Agriculture

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Abstract

For countries like Ethiopia, agriculture is a backbone. The country's most economic activities depend on agriculture. Agricultural commodities account for half of the Gross Domestic Product (GDP). However, factors like poor infrastructure, traditional techniques used for farming, periodic drought, and soil degradation have been the main obstacles for not projecting the export income, and also for not supporting and sustaining people needing food assistance. On the other hand, globally Information Communication Technology (ICT) is growing in an alarming rate and developing countries like Ethiopia are doing their level best to mainstream ICT solutions in all sectors of the economy. The agricultural sector is one of the areas in which ICT can be of paramount importance.

In this work, we have designed and developed sensor based Context-Aware System Architecture (CASA) for improving yield in agriculture. The work in CASA has focused on modelling and creating system architecture that merges two well known technological domains namely context-aware computing and Wireless Sensor Network (WSN) for the benefit of improving agricultural products. The architecture would present generic solution to solve many problems like crop irrigation, fertilization, pesticide spraying, and early detection of various crop specific issues. The work has mainly focused on one of the problems, crop irrigation.

One of the technologies used is Context-Aware Computing, which involves sensing the context via sensors. Our work involves sensors of different kinds deployed throughout the desired area which are sensing the environmental parameters like temperature, humidity, soil moisture, etc. Then the data would pass through a middleware, which has some components like application interface, sensor network interface, and database controller. The aggregated data would be processed and analyzed to create context model, then an action command would be sent to the respective application.

Implementation of sensor based context-aware solutions in agriculture can be considered as an extension of Precision Agriculture. The proposed work would transform the traditional agricultural practices, would be low cost, would ensure proper monitoring of the fields, would require less involvement of human, would be instantaneous, and would bring about accurate decision making.

Keywords: Precision Agriculture; Context Aware; WSN; CASA

1. Introduction

In many countries, agriculture is one of the most important areas on which human life is very much dependent. Ethiopia's economy is based on agriculture. This domain currently uses traditional methods for producing crops. In the country, this domain would have improved yield production if it had used a different technology which has become an inseparable part for different disciplines. The research will focus on creating system architecture merging two well known technological domains namely context-aware computing and Wireless Sensor Network (WSN).

Context-aware applications adapt according to their location of use, the collection of nearby people and objects, as well as the changes to those objects over time [1]. Context-aware computing involves sensing the context via sensors. Wireless sensor network technology is one of the important technologies for implementing a ubiquitous society, and it is applied into various fields such as distribution, logistics, construction, transportation, agriculture, defence, medicine, etc. [2]. One area where context-aware and wireless sensor network technologies would be highly beneficial is agriculture.

Agriculture should benefit from real-time data transfer and high resolution of sensor data that shows variations. Sensor technology has the potential to provide added value for agriculture e.g., for improving yield quality or for decreasing costs or risks in production. Currently sensor technology has been most commonly applied in real-time weather monitoring for support of management practices and in precision agriculture [3].

2. Background

In Ethiopia, agriculture is heavily reliant on rainfall; productivity and production are strongly influenced by climatic and hydrological variability that are reflected as dry spells and droughts [4]. The agriculture domain currently uses traditional methods for producing crops. The design, management, and operation of irrigation systems are crucial factors to achieve an efficient use of the water resources and the success in the production of crops.

Globally ICT is growing in alarming rate and developing countries like Ethiopia are doing their level best to mainstream ICT solutions in all sectors of the economy. The agricultural sector is one of the areas in which ICT can be of paramount importance. To accomplish this, the use of pervasive computing technology would be the best strategy. It is widely known that pervasive computing introduces a radically new set of design challenges. In particular, pervasive computing demands applications that are capable of operating in highly dynamic environments and adapting to changing contexts. Context-aware applications adapt according to their location of use, the collection of nearby people and objects, as well as the changes to those objects over time [1]. Context-aware computing involves sensing the context via sensors.

WSN presented itself as an essential part of all systems that require physical and environmental attribute measurement [5]. Wireless Sensor and Actuator Networks (WSAN) emerged as a new generation of WSN that offer both sensing and control. One area where context-aware and wireless sensor network technologies would be highly beneficial is agriculture.

As presented in [6], both irrigated and rainfed agriculture are important in the Ethiopian economy. Most food crops in Ethiopia come from rainfed agriculture with the irrigation sub-sector accounting for only about three percent of the food crops. Better operation and management of irrigation water leads to significant savings and to a more sustainable use of water resources, as well as enhanced soil productivity. To achieve this, systematic monitoring is required for the soil water content in the root zone, as well as for other relevant parameters (soil temperature, salt content of the groundwater, climatic parameters, etc.). As the sensor devices are not biased, they would give us the exact values of the environmental parameters on the basis of which it would be decided that which of the areas is having a deficiency of water, then as per the need of the crop, the water would be supplied. This is the motivation to design a sensor based context-aware system. The system helps agricultural organizations and also local farmers to produce a better crop yield.

3. The Proposed Solution

The proposed system architecture is shown in Figure 1. It is named Context Aware System Architecture (CASA). CASA has three sections, each composed of different components: Sensor Network Manager, Middleware, and CASA Application.

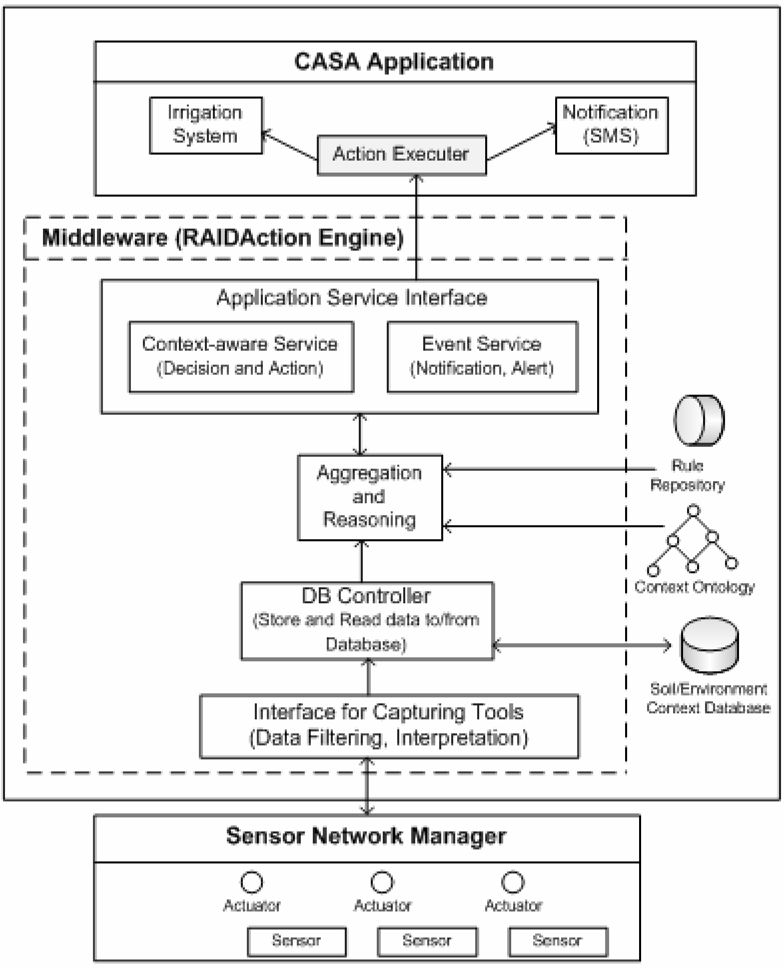

Figure 1: Architecture of the system

3.1 Sensor Network Manager

This is the physical layer where the sensor devices collect soil and environmental data in the field. In the proposed system, we have used a number of sensor devices for data collection. These sensors measure soil and environmental parameters like temperature, humidity, pH, climatic conditions, etc. Sensors convert temperature, moisture, humidity, and pH values in the soil into digital electrical signals.

3.2 Middleware (RAID Action Engine)

In this work this component performs reasoning, aggregation, interpretation, and decision. It reasons over the context information, ontology and user defined rules. After all the reasoning and interpretation is completed, the next step is to decide on which action to execute. It is also responsible to interpret the captured low level context to high level meaningful context. When new contexts are received from the soil/environment, this component loads the ontology and user defined rules for processing. Then SPARQL query would be applied to extract the necessary information. For example, we can query the value where soil moisture is below the optimum value. Another example is SMS message to be sent by the system for critical situations in the farm land.

3.3 CASA Application

This component is where the new system will reside in. The application will be put on the server and it will be accessed remotely via Intranet/Internet. The Administrator would control the system by entering the necessary range values for each parameter. The User would be able to monitor the data collected from the sensor devices periodically. The farmer who owns the farm land sometimes may get SMS message sent from the application on critical parameter values from the soil and the environment.

3.4 Context Ontology

In this work, we have developed an ontology indicating concepts specific to irrigation system for agriculture. These are Person, Soil, Environment, Parameter, Device, Location, and SoilTreatment. These ontology classes have object and data type properties.

3.5 Rule Repository

One of the key benefits of building an ontology-based application is using a reasoner to derive additional truths about the concepts. During reasoning over context ontologies, reasoners use different rules to derive additional knowledge assertion from existing RDF/OWL statements. There are ontology rules which are implicitly defined and user defined rules that are explicitly defined and associated with the reasoner. In the proposed work we have used different user defined rules associated with the Jena reasoner, in addition to the ontology driven rules. Below is a user defined rule which is used by the system.

If a Soil s has a water content value less than some thresh hold value, then apply water to s.

Rule representation using generic rule syntax:

[SoilMoisture_Rule:(?sensor CASA:locatedIn CASA:Location)

(?sensor CASA:detectParameter ?param)

(?soil CASA:hasSoilParameter CASA:soilMoisture)

(?param CASA:hasMinValue ?pmin)

(?param CASA:hasMaxValue ?pmax)

(?param CASA:hasValue ?smv)

LessThan(?smv,?pmin)

-> (?actuator CASA:applySoilTreatment CASA:WaterTreatment)]

4. Prototype

In this section, we have developed simulation system to evaluate the proposed work. The simulation system has generator method which generates similar soil and environmental parameter values as the real sensor devices. These low level parameter values are processed to get high level context data. Then decisions are made to perform an action whether to initialize the Irrigation system or not. The processing (reasoning) and the decision are implemented using Java class.

The system has also an interface which displays generated soil and environment parameter values based on time interval. The average results of each parameter values are also displayed. There are other interfaces to set optimum range values for each parameter and also to add mobile phone number of the farmer. The system uses the mobile phone number to send SMS message to the farmer on critical situations which affect the normal growth of the crops.

The sensor devices send real-time data to the server through the gateway using wireless communication. The gateway can be connected to the server using wireless communication or cable. The data collected from the sensor devices is stored in the database for processing.

The CASA application, for this case simulation of Irrigation Control System, is deployed in the server so that it could be accessed in the local network or remotely. It is implemented using Eclipse thread which periodically generates valid values of soil and environmental parameters. This depends on range of values pre-configured in the application. For example, pH value should be between 1 and 14. The application has a user interface which the user monitors the data collected from the sensor devices periodically. The Context Reasoner component gives final a reasoning based on predefined rules. It is implemented as Java class which intensively uses the Jena API.

In this section, we will demonstrate the implementation of the prototype. The demonstration is prepared based on a scenario taken from Gensis Farm plc.

For this scenario we will take only Soil moisture as a parameter and examine how the reasoner component derives decision based on the user defined rules. The Soil moisture parameter reading shows DRY after calculating the average collected data. This parameter reading is not good for vegetable. Therefore, the system will take an action by initializing the Irrigation system to make the soil wet enough for the vegetable. Table 1 shows the final context output. Figure 2 shows the data collected from the sensor devices and calculated average values.

Table 1: Soil moisture final context

Parameter	*Status context*	*Final decision (after reasoning)*	*Action*
Soil moisture	Soil moisture is DRY	The soil moisture is DRY and is not good for the vegetable.	Initialize Irrigation System

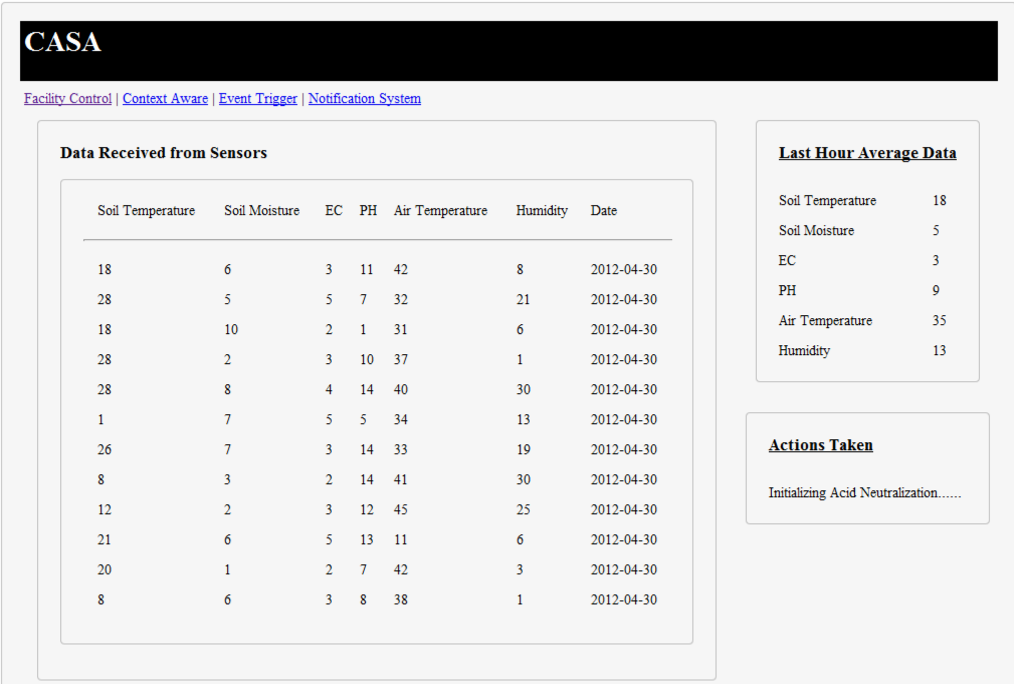

Figure 2: Data collected from sensor devices

5. Related Work

This section discusses some related works in the area of context-aware computing and wireless sensor networks f agriculture. Agriculture is one of the best suited for dynamic situation having highly variable environment. This concept is utilized by different researchers toward this domain.

The authors in [7] reported the use of sensor networks for integrated management of a vineyard. Their work was motivated by the primary importance of temperature in the development of grapes to ensure wine quality. Field work was conducted, 48 nodes were deployed over a period of more than 6 months in an Oregon vineyard, reporting temperature every five minutes. The results were logged in a centralized way and could be displayed on a map and retrieved on a per-sensor basis. Moreover, alarms were sent when the temperature decreased below 0, indicating a risk of frost. The history of temperature variations throughout a cropping season is especially critical.

The work in [8] explores the potential of wireless sensor networks for nationwide cattle monitoring. Each wireless sensor acts as an extended RFID ribbon storing the identity and health status of the animal, which can be tracked at different locations, such as pasture or farm buildings. Each location is equipped with a base station opportunistically recording the information from the ribbons as the animals come into its range. The system was evaluated through extensive rounds of simulations.

Tim Wark *et al.* [9] deployed soil moisture nodes which use commercially available ECH_2O capacitance based sensors that measure the surrounding soil's volumetric water content. These sensors generally don't require calibration and have an error of +/– 2 percent. The network automatically takes readings, typically at one-minute intervals, from each node and sends them back. Data is aggregated at the base to give an up-to-date moisture profile for the whole field.

Jadoon *et al.* [10] proposed a machine based (IT Based) irrigation control system that could deal with the proper monitoring and distribution of water in Pakistan. The country's economy is based on agriculture. Due to mismanagement, the country faces immense problem of water shortage. The researchers proposed solution which uses WSN for Irrigation Control.

6. Conclusion

Implementation of sensor based context-aware solutions in agriculture can be considered as an extension of Precision Agriculture. By monitoring soil, crop, and climate in a field and providing a decision-support system, it is possible to deliver treatments, such as irrigation, fertilizer, and pesticide application for specific parts of a field in real time. We have presented in this paper an ontology-driven architecture for developing precision agriculture application. The proposed work would transform the traditional agricultural practices, would be low cost, would ensure proper monitoring of the fields, would require less involvement of human, would be instantaneous and would bring about accurate decision making. Thus, it is believed to contribute towards improving yields in agriculture.

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