A Cloud-Based Application for Smart Irrigation Management System

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***Abstract*—Agriculture is one of the most important sectors in the Palestinian economy and it is the main consumer of freshwater. Several factors have a major impact on agricultural activities including water availability, soil type, climate condition, fertilizers, and diseases. In this paper, we provide a cloud-based software application that is combined with the Internet of Things (IoT) devices that can automate the irrigation schedule based on information obtained from agricultural experts and environmental data collected from the field using sensors technology. The application can easily be extended to automate fertilization as well as provide recommendations for weed and pest control.**

Keywords—wireless sensor network, smart agriculture, water management, database schema, cloud application

I. INTRODUCTION

Demands on water resources are constantly increasing due to natural growth in population. It is predicted that world population will double in the next 50 years. In response, greater yields must be extracted from the current agricultural areas and more marginal lands should be prepared. Generally, and particularly in Palestine region, agriculture is the largest consumer of fresh water accounting for more than 50% of water consumption [1]. A pressing challenge facing the agriculture sector is how to boost production with less land, less water, and without damage to the environment.

To meet these requirements, there is a strong need to create new unconventional agricultural techniques with the focus on productivity and better management of the available resources--productive farming. The focus of these techniques is to maximize the agricultural productivity [2] by increasing the yield and minimizing the cost and losses. One main component in productive farming is the employment of Information and Communication Technologies (ICT) [3] into agricultural management systems. These systems are called Smart Farming systems [4]. In smart farming, multiple recent emerging technologies such as Internet of things (IoT) [5], Wireless Sensors Network [6], and Cloud Computing [7][8], combined with machine learning techniques are integrated to create an environment that advance productivity in farming practice. Smart farming is expected to have a major impact on the advancement of this development in the near future. This paper describes the design and implementation of the software component of a smart farming system with the focus on the management of water use in agriculture, irrigation. The work in this paper is based on the Masters' thesis of the first author [9].

Irrigation is one of the main consuming factors of agricultural resources. To get an optimal irrigation schedule, it is necessary to deliver to the plant the required quantity of water taking into consideration other parameters, such as the environment condition, the texture of the soil, the kinds of crop and its growth stage. In Palestine, the irrigation schedule is mainly conventional based on the farmer experience. This conventional approach causes inefficient use of water and over or under irrigation. This can reduce the crops' yield and increase wasted fresh water due to non-beneficial evaporation, drainage, leaching, or ineffective water delivery. Furthermore, a loss in fertilizers which are delivered through water is likely to happen. Even though, there is a significant effort in establishing additional surface water resources, saving water and improving operational skills can have a major impact on agricultural productivity [10].

One challenge facing farmers to practice productive farming is the lack of knowledge about the state-of-the-art productive farming techniques. Inexperienced farmers need better knowledge of the texture of the soil, the characteristics of the field, and the development of the crops. One goal of the application described in this paper is to gather this knowledge from agricultural experts and the environment's condition. This knowledge together with a decision-support system will allow inexperienced farmers practice best farming in a semi-automated manner. In this system, the farmer only needs to decide what he want to plant, and the date of planting, then the smart farming process will lead him to practice productive farming that minimizes consumption of resources and maximizes the yield.

The main contributions of this paper are: 1) a cloud-based application that controls automatic irrigation in the field, and 2) a database schema that integrates the sensors' data with information gathered from agricultural experts and information gathered from the farmer about the characteristics of the field.

II. RELATED WORK

The integration of Wireless Sensor Networks with Cloud Computing has received attention in multiple domains [11]-[15]. This includes smart hospital [16] and patient monitoring [17]. The need and challenges of this integration and how they are approached are discussed as well [18].

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In agriculture, Anisi et. al [19] presented a survey of wireless sensor network approaches and their energy consumption for monitoring farm fields in Precision Agriculture. The potential of WSN on sugarcane crop is explored in [20]. The optimal topology of the WSN in agriculture for improving the network lifetime is explored in [21]. However, these systems did not consider cloud computing and data management. The work in [22] gathers information from experts and made them available to the farmer through a cloud application. A review on big data and using it in smart farming is discussed in [23]. The development of smart farming technologies and their application in Brazil [24] show the impact of these technologies on production system and the environment.

The SWAMP project [25] develops an IoT-based smart water management platform for precision irrigation in agriculture with the focus on replicability and scalability. However, the focus of our work is on the data management using database schema to manage the automation process in smart farming.

III. Method and Material

A. Root Zone Management

Irrigation can be defined as the proper application of water to the plant root zone at the proper time. To get an optimal irrigation schedule, it is necessary to deliver to the plant the required quantity of water, taking into consideration several factors include.

- The kind of plant..
- The stage of growth of a plant, plants require more water as they grow.
- The texture of the soil, the fraction of sand, silt and clay in the soil mix. Different soil textures have different water holding capacity.

In addition to its own need for the plant, water acts as a delivery medium for transporting the necessary nutrients and treatments to the root through irrigation. Therefore, optimal water management can help achieve optimal nutrients and medicines management. A plant available water must be in the root zone in sufficient quantity for optimal growth. In addition to water and nutrients, plants need sufficient air concentration in the soil. Field Capacity refers to a moisture level where all excess water is drained out due to the force of gravity. At this level small pores space of soil are full of water while large pores are full of air. This is the ideal condition for plant growth. It is easy for a plant to pull water and nutrition from the soil and air is available as well. Lack of air in the soil "may be" due to excess water in the root zone, a condition called waterlogging or saturation, where soil pores are filled with water. If this condition happened for a long period of time, it can cause harm to the plant due to the lack of Oxygen (plant air stress) and causes a reduction in the yield [26]. Plant air stress will limit the growth of the root and makes plants more susceptible to diseases and other deficiencies. Further, it causes losses in water, fertilizers, and labor.

As shown in Fig. 1, when the moisture level in the root zone drops below a threshold value called wilting point, where the plant cannot pull water from the soil, it causes a condition called plant water stress. Under this condition, water is strongly bounded by capillary "action" to the soil particles and it is hard to be extracted by the plant. If this happens for a long period of time, the plant will wilt and possibly die.

Field capacity [27] and the wilting point [28] depend on the soil texture and the kind of crops. For optimal growth to maximize the yield and to reduce wasting resources, water content should be maintained in the available water range. At this level, it is easy for the plant to absorb water and air is available in the soil as well. Fig. 1 shows these cases.

In summary, maintaining soil moisture at optimal level in the root zone can enhance farming productivity. Too much moisture can cause root diseases and wasted water. While too little moisture can cause yield loss and plant death.

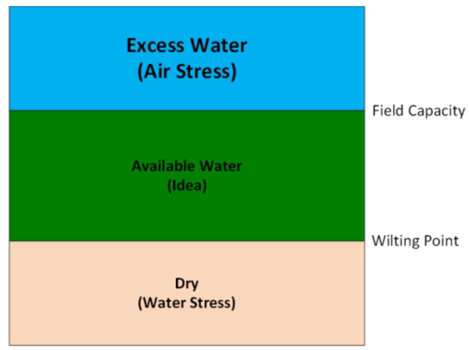

Fig. 1. Field Capacity and Wilting Point.

In conventional farming, there are several challenges to achieve optimal irrigation schedule include, when to irrigate ? and how much? The required amount of irrigation must, at least, meet the crop water loss through evapotranspiration. Both timing of irrigation and the amount of irrigation has a major impact on productive farming. However, timing of irrigation has a significant influence on crop yield and quality. In some growth stage, delayed irrigation can reduce the potential yield and quality significantly.

The application described in this paper provides the software component of an automation technique to manage the root zone moisture. The goal is to control the water and air concentration in the root zone to their optimal level for a given crop and soil texture. Application of such a system will help increase the productivity of farming by increasing the yield and decreases losses in resources such as water, nutrient and human labor. The application uses recent emerging technologies which are described in the following subsections.

B. Gathering Data and Triggering Action

Recent advances in computing power, storage, and network communications have enabled Machine-to-Machine communication and shifted the roll of computing devices from passive devices to proactive devices. Based on these technology advancements, new systems are emerging including Wireless Sensor Networks (WSN) [29]. The main components of these systems are small and cheap sensing elements and actuators linked together through wireless connections to perform sensing and actuation tasks. Sensor nodes can collect information about the physical environment around them and communicate this information wirelessly to a base station. Based on this information, a decision-support system application running on the base station can be used to trigger events that execute actuation responses in the environment. Accessing devices such as GPS, soil moisture sensors have become cost effective and widely available to be deployed in the field in a large scale. By gathering data from the field using these devices, the use of agricultural resources such as fertilizer and water can be more effective. Furthermore, controlling the delivery of these resources to the plant will keep them at optimal level which results in increasing the yield and the quality. The basic elements of a WSN are: sensor nodes, a gateway, and a base station described below.

- Sensor nodes: A wireless sensor node contains sensing and computing devices, radio transceiver and power components. It gathers environmental properties through attached sensors, translates them into digital form and sends them wirelessly to a base station possibly through other nodes. Actuators can be connected to a wireless node to trigger actions in the environment (e.g. turning a pump or valve on or off)
- A base station: A base station is a computer that interfaces between users and the wireless sensor network. It executes applications that are responsible for receiving and processing data collected by the sensor nodes. It is responsible for triggering actions in the environment by sending control messages to actuators connected to wireless sensor nodes. Typically, the amount of data collected by the sensors and the amount of necessary computation is large. Therefore, it is more practical that the base station is connected to a cloud-based server through web services where the data can be shared and processed.
- A gateway: A gateway is a networking device that interconnects two different networks running different communication protocols. The gateway in the WSN is necessary to interconnect the communication between a WSN using Zigbee protocol [30] and the IP-based network.

C. Cloud Computing

The amount of data generated by WSN systems is significantly large and requires high storage and processing power, which is beyond the capability of a personal computer. Further, more information from domain experts in the targeted application is needed, and feedback to the decision-support system is useful in improving the future decisions based on previous experience through the application of machine learning techniques. Typically, those experts are not available on site and their remote access to the system is essential to include their experience. Therefore, leveraging the recently emerging Cloud Computing Paradigm provides an effective solution to these issues. First, Cloud Computing provides a scalable computing and storage resource as needed by the system. Second, Cloud Computing provides most of its resources as services which allows sharing of data and information [31].

The goal of this project is to design a Cloud-based application which manages the data coming from the sensors in a WSN for smart farming and water management systems. Using Web Services [32]-[34] interface, the application will gather data collected by the sensors in the field, which includes environmental conditions (e.g. soil moisture and temperature). Furthermore, the application will gather data through a web interface from agricultural experts about best agricultural practice which includes: 1) knowledge about the amount of water needed for a particular kind of crops as a function of age of the plant and the nature of the soil, and 2) the kind of fertilizers needed for each kind of plant at different age, and 3) the different types of soil and their specifications. This knowledge will be saved in a database.

IV. System Architecture

In this section we describe the architectural design of a cloud-based application which manages the data coming from the sensors in a WSN for smart farming and water management system. The application gathers the data collected by the sensors in the farm, such as, soil moisture and temperature. Also, through a web interface, it gathers from agricultural experts' information about best agricultural practice which includes information about the amount of water required for a particular kind of plant as a function of age of the plant and the type of the soil. This information and the sensors data are saved in a database. Based on this information, the application determines an irrigation schedule for the plants that needs it, and communicates this schedule to the base station in the field. Consequently, the base station triggers irrigation events in the field. The application, not only, schedules irrigation but also helps the farmer make decisions about some of these factors in order to automate the decision-making process.

The architecture of the management system as shown in Fig. 2 consists of two main components, the hardware component and the software components. The hardware component consists of sensing devices distributed in the field. These devices gather data from the environment through sensors and communicate this data to a base station using wireless sensor network in the field. Other devices (actuators) are connected to a wireless node to trigger action in the field such as open and close water valves.

The software component consists of two applications, the *farm application*, and the *cloud application*. The farm application is executed on a computer in the farm. It has two main tasks, 1) It gathers the data from WSN and puts it in a specific format and communicates this data to the cloud application through a web service interface and 2) It receives decision from the cloud application in a timely manner about each valve whether it should be open for irrigation or closed. The cloud application is a web application that runs on a cloud server. It saves the data obtained from the farm application and from agricultural experts in a database. Also, it has a decision support system that determines when to irrigate each zone of the farm based on sensors data and the information provided by agricultural experts. The focus of this paper is only the cloud application.

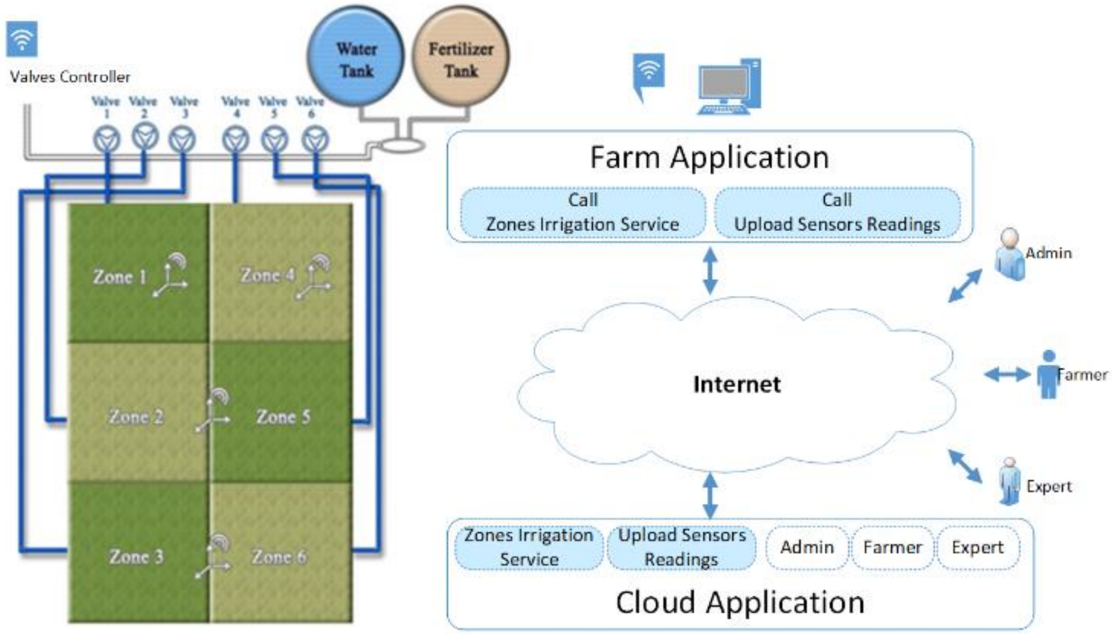

Fig. 2. System Architecture.

The rest of the section is organized as follow. Subsection A gives a brief review about web services. Subsection B describes how the land is partitioned and the placement of sensors in the field. Subsection C give a brief description about the farm application. Subsection D provides the design of the smart farming web application and the database schema.

A. Web Services

The communication between the cloud-based framework and the base station in the field is based on web services. A web service is a piece of software that is available remotely over the Internet. Web services are not tied to any operating system or any programming language which makes them loosely coupled. They provide a reliable way for publishing data and applications over the Internet for sharing.

There are two types of web services, the Simple Object Access Protocol (SOAP) [35] and the Representational State Transfer (REST) [36]. SOAP is a standard-based protocol that has been developed earlier than REST. It depends on XML for messaging services and from the beginning it is designed to be extendible. SOAP is not tied to any particular transport protocol. Unfortunately, the XML-based communication can become very complex in some programming languages.

Unlike SOAP, REST [37], the successor of SOAP, is not a protocol. It is a network-based architectural style developed to simplify the access to web services. It provides a lighter way approach. REST web services are built to work best on the web. Instead of using XML, REST uses URL for messaging services and uses the HTTP1.1 verbs (GET, POST, PUT, and DELETE) to perform its tasks. REST web services doesn't have to use XML for messaging. It can communicate the data in Comma Separated Value (CSV), JavaScript Object Notation (JSON), XML, and Really Simple Syndication (RSS)[38]. These features free the programmer to choose the data format that suites the used programming language. Both SOAP and REST has their own advantages and disadvantages based on the requirement of the application. We chose the REST web services over the SOAP mainly because it is easier to use and develop

B. Sensors Placement

As shown in Fig. 2, the field is divided into several irrigation zones. A zone can be considered as an irrigation management unit that has semi-uniform characteristics, such as topography, type of soil, kind and age of the growing crops. Each zone corresponds to an area for irrigation. A zone can be irrigated by turning on and off an electric valve controlled by the farm application. In each zone, several sensors can be placed to get the value of different parameters necessary for optimal growth of the plant, such as, moisture levels. For optimal irrigation [39], soil moisture level in the root zone must be maintained between the field capacity and the wilting point as discussed in Section II. Since the size of the root zone increases as the plant grow, moisture sensors are placed at different locations and at different depth in the field. Each sensor is connected to a wireless node and identified by its zone and to which wireless nodes it is connected.

The data gathered by the wireless nodes are transmitted through an RF antenna to a gateway node, where it receives all different kind of sensed data in a timely manner. This data will be passed from the gateway to a computer in the field where it then can be transmitted to the cloud application.

C. Farm Application

The farm application is a software that runs on a computer in the field. The main tasks of the farm application are:

- In a timely manner the application reads the sensor data from the sensor nodes deployed in the field. Then, it puts the data in a specific format and communicates this data to the cloud application by invoking the web service `uploadSensorsReading` provided by the cloud application.

- In a timely manner the farm application invokes the web service `zonesIrrigation` provided by the cloud application to get the list of zones' ids and which valves to turn on and which ones to turn off.
- Based on the data received from the cloud application, it sends a message to the wireless node that controls the water valves to turn each water valve on or off.

D. Cloud Application

The cloud application is a software run on the cloud. It gathers sensors data from the field through the web service interface, knowledge about the soil and plant characteristics through a web form interface, the arrangement of zones and sensors through a farmer web form. The cloud application based on this information starts/stops irrigation based on this data through the irrigation service.

The software architecture of the cloud application is shown in Fig. 3. There are three different users of the web application, admin user, expert user, and farmer user, in addition to two web services for programs to access. All users have different privileges to access the backend database.

- Farmers interface: Farmer interface provides a web form, where the farmer can select the crop he wants to plant and the cultivation date. Also, through this interface, the farmer sets zones identifiers, different kind of sensors identifiers and to which wireless node each sensor is connected and in what zone.
- Admin interface: The admin user has full privileges on all tables of the database. He can create, modify, and delete any user he wants.
- Domain expert interface: This interface allows agricultural expert to add, modify, and delete information about different kinds of plants and soil characteristics. This information is saved in the irrigation optimal values table with the appropriate data for different kind of plants and different types of soil.
- Save sensors data web service: This web service is used to upload the readings of the sensors in the field and saves it in the backend database. The farm application gathers the sensors data from the field. Then it puts this data in a JSON object and invokes the service with the JSON object as a parameter. The interface of this service is `uploadSesnorsReading(JASON)`.
- Irrigation web service: The function of the second web service is to return to the caller a list of zones that require their irrigation status be changed to start or stop. This web service invokes the Irrigation decision support system described below to get this information and return it to the caller.
- Irrigation decision support system: The decision support system decides whether a zone is to be irrigated or not based on zones' moisture level, the type of soil, and the kind and age of the plant. The moisture level of a zone is calculated by taking the weighted average of all sensors' readings in the zone. Weights based on the age of the plant can be used to give lower weights for deep sensors when the plant is young and increase the weights for these sensors as the plant grows. However, we didn't implement this approach in this paper. We just calculated the average moisture of all sensors in the zone and call it zone moisture. Once the zone moisture level is calculated for each zone, it is compared with the threshold data stored in the database for each crop and soil type. If the moisture value exceeds the upper threshold, the irrigation is set off for that zone. If the moisture level is below the lower threshold value, the irrigation is set to on. Otherwise, when the moisture level is in the optimal range, the irrigation status stays as it is and no action needs to be taken.

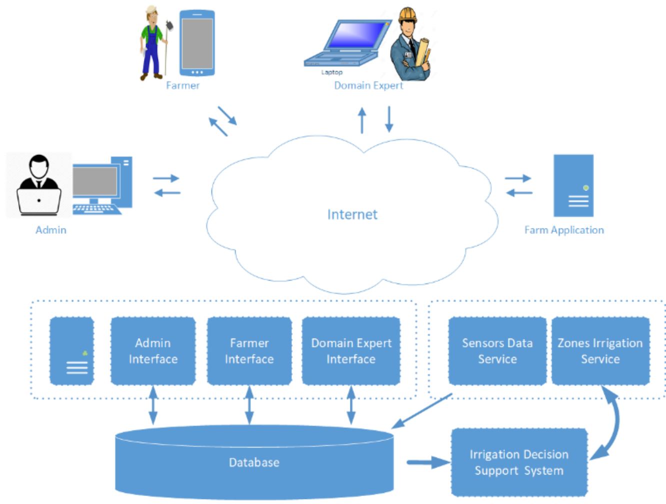

Fig. 3. Software architecture of the cloud application.

E. Database

The cloud application uses a backend database to manage the data gathered from the sensors in the field, the data gathered from agricultural experts, and the data from the farmer. A cultivation cycle consists of one or more zones. Each zone can be irrigated using an electric valve and it contains multiple different sensors. These sensors are connected to wireless nodes to communicate the data to the base station. The relational database schema as shown in Fig. 4 consists of the following entities.

- Cultivation entity: Each cultivation cycle consists of one or more zones and one kind of plant. Each cultivation cycle has its own id, and date of planting. The age of the plant can be calculated from the cultivation date.
- Sensor entity. Several kinds of sensors that measure different quantities can be used in this system. Each sensor has attributes: id, name, type, and unit. The type attribute of a sensor is the physical quantity that it measures, such as moisture, temperature, humidity, etc. The unit attribute is the unit of the measured data. For example, degree Celsius for temperature. Data collected by the sensors in the system is saved in the Sensors Reading table. Since each physical sensor is connected

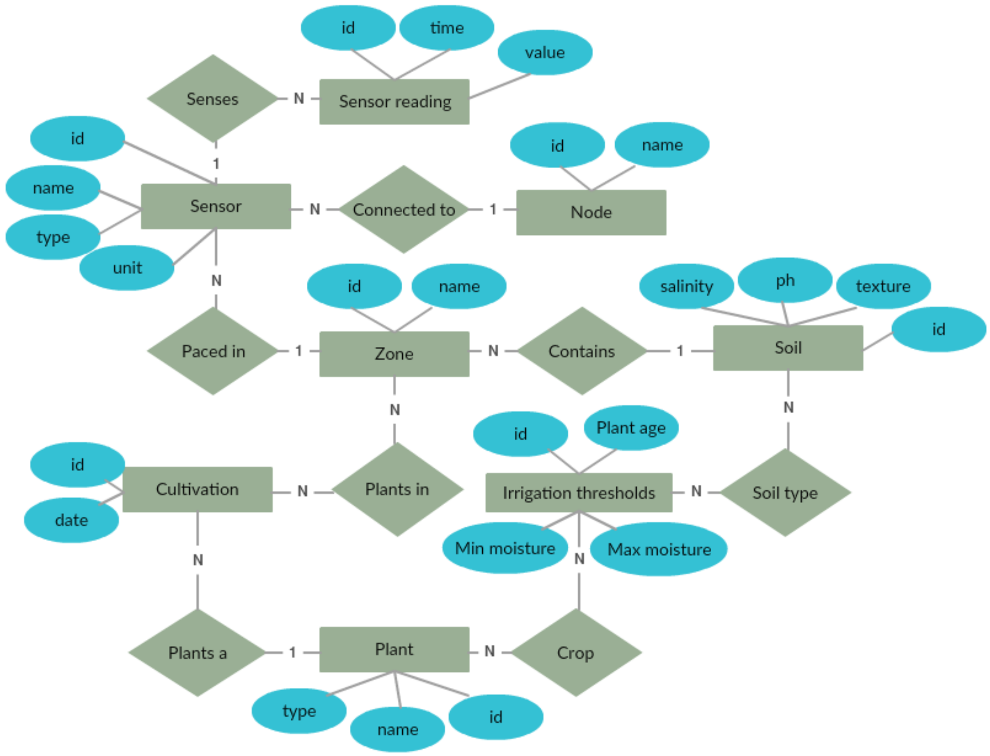

Fig. 4. Data model for the smart irrigation system.

to a wireless sensor node in the field. The sensor entity is connected to the node entity as shown in the schema. The relationship is many-to-one, since many sensors can be connected to a particular node. But a particular sensor can only be connected to one particular node. Also, since sensors are placed in zones in the field. The sensor entity is related to the zone entity by a many-to-one relationship since multiple sensors are placed in a zone, while a particular sensor can only be in one zone.

- Node entity. A node entity corresponds to a physical wireless node in the Wireless Sensor Network in the field. Each node has the attributes: name and id. These attributes should match labels on the nodes in the field. The node entity is useful to allow the system communicate with actuator, or detect failure.

- Zone entity. The cultivation farm is divided into zones. The system treats each zone as it has uniform characteristics such as topography, soil texture, soil salinity, etc. Each zone has the attributes: **name** and **id**. The zone entity is related to the sensor entity by one-to-many relationship. Since a particular zone can have many sensors, but a sensor can be in a particular zone. Also, the zone entity is related to the cultivation entity by many-to-many relationship.

- Soil entity. The soil entity contains information about the characteristics of the soil and its specifications such as water holding capacity and salinity. The attributes of soil entity are: **id**, **name**, **texture**, and **salinity**. Other attributes regarding soil characteristics can be added. Soil entity is related to zone entity by a many-to-one relationship since each zone has one particular type of soil, but several zones can have same soil types.

- Irrigation thresholds. This entity holds values of the upper and lower moisture level thresholds for a particular plant and soil type. In this paper, agricultural expert provides these values through a web interface. This entity has the attributes: **id**, **plant age**, **minimum moisture level**, and **maximum moisture level**. Other thresholds can be included as well such as minimum temperature, maximum temperature, etc. This entity is related to plant entity by many-to-many relationship and to the soil entity by many-to-many.

- Plant entity. The plant entity holds information about different kinds of plants. This entity is related to the irrigation threshold entity and the cultivation entity. The attributes of this entity are: **id**, **name**, and **type**.

V. Results

Several software technologies can be used to implement the system. Our choice was the Java environment and the state of the-art-oracle technologies. We chose this environment mainly because of our familiarity. We used Oracle SQL developer [40], Oracle Database Expression Edition [41], and Oracle database XE for the database development and management. For web server, we used Oracle Web Logic Server [42]. To implement our application which includes the web services interface, accessing the database, the web forms, and login pages we used the IDE Jdeveloper [43]. In this paper we used Jersy RESTful web service framework to develop RESTFul web service in java that provides support for JAX-RS API.

For developing the graphical user interfaces, we used the Model, View, and Controller (MVC) architecture . Fig. 5 shows the home page of the system which appears after the login of administrator user. Adding or modifying sensors and nodes can be accomplished through the administrator interface. The connectivity of each sensor to which node, and the placement of each sensor in which zone, can be set using this interface as well. As an illustration example, by clicking on the sensors icon, a list of sensors readings that is stored by the web service in the database will be displayed as shown in Fig. 6. This table shows the zone, node, sensors, sensors-readings, readings-time, and description.

Fig. 5. Home page of the administrator.

In the farmer form, the farmer decides what he wants to plant using the add cultivation icon where the farmer can select from a list of plant kinds. Also, he decides in which zone he wanted to plant and the date of planting.

The agriculture expert form allows the expert to add plant by clicking on add plant icon, and to add soil types using the add soil icon. Also, he can set the irrigation and other threshold values such as temperature as a function of the age of the plants and the plant type. The system provides a dashboard that allows monitoring the execution of the system.

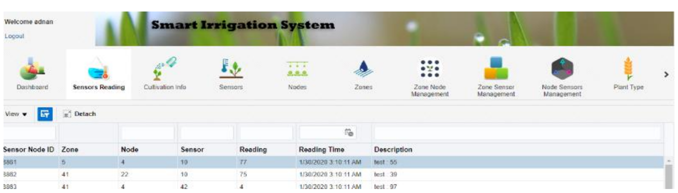

Fig. 6. Sensors readings.

To evaluate the system we used a simulated data of the moisture level in a simulated farm of 4 zones. In this simulation we set the moisture level to drop linearly with time. Fig. 7 shows the dynamic of the simulated moisture level in a particular zone.

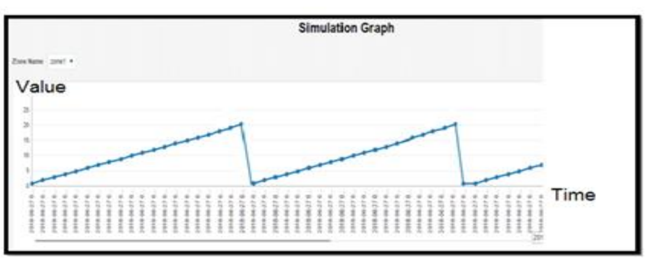

Fig. 7. Simulated moisture values as a function of time for a particular zone.

VI. Conclusion

In this paper we provided the design and implementation of cloud-based application that manages the data coming from the sensors in a Wireless Sensor Network located in the field, and information supplied by agricultural experts in order to create smart farming and water management system. The system provides communication interfaces to trigger irrigation schedule in the field. This application enables building a decision-support system that allow inexperienced farmer to practice productive farming in a semi-automated manner.

We are currently integrating this system with a wireless sensor network that we have developed. Several issues are being addressed in this implementation which includes system security and a more sophisticated decision support system that considers a weighted average of the sensors' readings.

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