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An Integrated Framework to Develop Context-Aware Sensor Grid for Agriculture

[1]Aqeel-ur-Rehman, [2]Zubair A. Shaikh, [3]Noor A. Shaikh and [1]Noman Islam

[1]Ph.D. Student, Department of Computer Science, National University of Computer and Emerging Sciences, Karachi, Pakistan
[2]Professor & Director, National University of Computer and Emerging Sciences, Karachi, Pakistan
[3]Assistant Professor, Shah Abdul Latif University, Khairpur, Sindh, Pakistan

Abstract: Context-Aware Computing involves sensing the context via sensors and other input channels, taking smart decisions, reflecting back the decisions and feedback tracking from the context. Agriculture is one of the key disciplines where context plays a vital role. Implementation of context-aware solutions in agriculture can be considered as an extension of Precision Agriculture. Very little work has been done in Context-Aware Agriculture. This involves transforming key agricultural concerns which follow traditional approaches to a context model governed via an I/O channel of sensors and actuators. The context model is a semantic model of the traditional practice. One novel approach to create context model is through building Ontology, use of wireless sensor and computing grids. In this paper, a context aware model of a typical watering process in agricultural fields have been developed and tested against the traditional practices. The results spanning over a large period of crop indicates that the context model clearly saves the scarce water resource and may have long term impact on improved decision making for agriculturists and other soil properties, directly affecting improving yield over a long period. As a cross disciplinary research, we have identified several technological issues and directions that make this novel approach viable under certain constraints, providing a pragmatic generic solution to solve many other problems like fertilization, pesticide spraying and early detection of various crop specific issues through the generic context-aware layer provided in our framework.

Key words: Wireless Sensor Network, Context-Awareness, Context-Aware Agriculture, Technology Integration, Context Model.

INTRODUCTION

Involvement of electronics and information technology in the domain of agriculture are providing encouraging results in form of enhanced productivity and better quality of production by offering autonomous and proactive solutions having the support of prediction power. Better management of scarce resources like water is also getting possible due to the involvement of technology. Advanced technologies like satellite navigation technology, wireless sensor and actuator networks (WSAN) (Wang *et al.*, 2006), grid computing (Foster and Kesselman, 2003), ubiquitous/pervasive computing (Weiser, 1991) and context-aware computing (Schilit *et al.*, 1994) are benefiting the domain in many aspects.

The first contribution of this paper is to provide the concept for automation of agriculture process by integrating context-aware computing, grid computing and sensor/ actuator network. Second contribution is to present the extended work on context-aware sensor grid framework (Aqeel and Shaikh, 2008) to show the implementation requirements on crop irrigation problem as well as its extensibility to different problems of agriculture. This shows that the presented integrated framework is well suited for agriculture domain due to its context rich environment.

The rest of this paper is organized as follows: It starts by presenting about technology integration and new emerging technologies as a result of integration. Then literature review is provided about technologies' utilization in the domain of agriculture. A framework that is developed specifically for agriculture domain is highlighted next with prototype development and implementation to show the technical requirements for the realization of the system. Finally, we offer our conclusions and future work followed by the discussion on results.

Corresponding Author: Aqeel-ur-Rehman, Ph.D. Student, Department of Computer Science, National University of Computer and Emerging Sciences, Karachi, Pakistan
E-mail: aqeel.rehman@nu.edu.pk

Technology Integration:

Integration of technologies always has been a keen interest of researchers to get additive benefits of the technologies. Technology integration poses many challenges that need to be tackled very carefully. In this section, we present the integration of three technologies and their resultant new concepts (see figure 1).

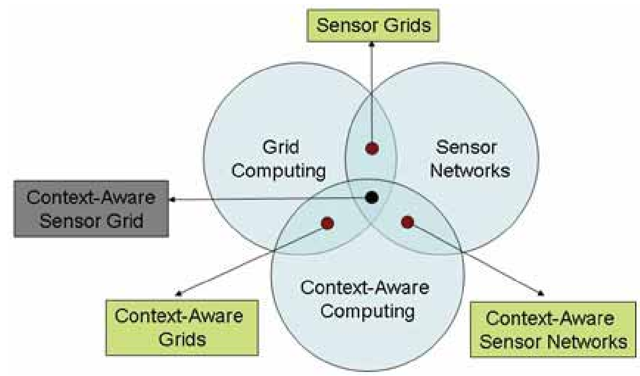

Fig. 1: Technology Integration. (Aqeel and Shaikh, 2009)

Sensor Grid:

The integration of grid and sensor network brings the concept of sensor grid. Sensor Grid (Lim *et al.,* 2005; Tham and Buyya, 2005) also termed as 'Pervasive Grid' that was coined in 2003 (Hingne *et al.,* 2003). Many of the researches (Lim *et al.,* 2005; Tham and Buyya, 2005; Parashar and Pierson, 2007; Coulson, 2006) define Pervasive Grid as the combination or merger of sensor networks with the computationally intensive wired grid in a seamless manner to provide a common framework. In (Hingne *et al.,* 2003), author defines it as a combination of pervasive devices (i.e. mobile and embedded devices) and the wired grid infrastructure. Several advantages of sensor grid has been reported in (Lim *et al.,* 2005) that include the availability of processing, analyzing and storage power of grid facility to sensor network, efficient sharing of sensors to different users and applications and additive processing power to the embedded processor of sensors.

Context-Aware Grid:

It is defined (Deroure *et al.*, 2005) as the extension of the current grid having context-aware decision support to provide right contents to intended user at the right time, format and location (device). In (Deroure *et al.*, 2005) described context-aware grid as Semantic Grid. Kerry Jean *et al.* (Jean e*t al.*, 2004) in support of Context-aware Grid presented the concept of context-aware grid services by extending Virtual Organization (VO) concept to Grid Context.

The main theme behind context-aware grid concept is to achieve seamless and easy-to-use automation for flexible collaboration and computation on global scale.

Context-Aware Sensor Network:

Bringing Context-awareness in sensor network is helpful in making the network energy efficient (Huaifeng and Xingshe, 2005; Wood e*t al.,*2008; Ahn and Kim, 2006). Context-awareness enables sensor to adjust sampling and communication rate to reduce energy consumption based on activity patterns and behavior of neighboring sensors. Sungjin Ahn and Daeyoung Kim (Ahn and Kim, 2006) also used context-awareness feature to provide distributed decision making capability to sensors that avoided the base-station node requirement from sensor network and provided benefits over centralized mechanism like reduced average power consumption, avoiding congestion at base-station node etc.

Context-Aware Sensor Grid:

Context-Aware Sensor Grid holds advantages of all three areas that are context-aware computing, grid computing and WSAN. We define context-aware sensor grid (Aqeel and Shaikh, 2008) as "*a distributed computing environment that has shareable resources having the power to sense the physical world with the capability of high computing power on low price. It is adjustable to the environment autonomously on the basis of collected information.*" The context-awareness makes it suitable for the environments that are context rich e.g. agriculture, health-care, smart spaces etc, while the availability of grid computing facility provide the global and transparent access of computing resources.

Related Work:

Use of technologies in different domains is a challenging task. Several researchers are proposing many different solutions in this regard. Every domain has its own features and attributes that are exploited using different technologies to get more and more out of that domain.

Several researches were completed in the domain of agriculture that provided the way to collect the plant and field status for monitoring purpose that latter supported the users to make decision for the required treatment. Sensor networks were used to sense the physical attributes of the surroundings for variations and current situation in the area of irrigation, plant disease monitoring, cattle monitoring etc (Zhang *et al.,*2004) utilized sensor network to monitor air temperature, humidity, ambient light, soil moisture and temperature that helped them in analyzing the current state of plant nursery. Such network may also help in finding the plant diseases. Aline Baggio (Baggio, 2005) exploited sensor network to deal with potato crop disease develops due to increase in humidity contents. Sensors were used to measure humidity and temperature that helped him to reduce the disease. Specially designed sensors and their network also contributed towards animal behavior monitoring for grazing, sleeping, ruminating etc. (Wark *et al.*, 2007).

A step forward to the above is the use of wireless sensor and actuator network (WSAN) that played a vital role in providing control in addition to the monitoring. Exploiting these properties of WSAN, irrigation control systems were developed (Basu *et al.*, 2006; Kim *et al.*, 2008) to support the concept of maximize productivity while saving water. Context-awareness is used to know about the current situation of an entity, person, place etc. This concept is useful in those circumstances where the situation is highly dynamic. Agriculture domain is one of the best suited for this situation having highly variable environment. This concept is utilized by different researchers toward this domain. Kristian Ellebaek Kjaer (Kjær, 2008) presented the requirement of a middleware for context-awareness in agriculture that will support in gathering context from different heterogeneous sources and environments found at agricultural land as well as context reasoning facility. In continuation to provide context-awareness to farms, Christos Goumopoulos *et al.* (Goumopoulos *et al,* 2007; Goumopoulos *et al,* 2009) presented the concept of 'Proactive Agriculture' and developed system architecture for precision agriculture applications. Using ontology as an aid, they developed hardware and software components that could provide seamless interaction among plants and other artifacts available in different scenarios like domestic plant care and precision agriculture.

Agricultural land is graphically distributed in nature and to monitor and control there is a need of resource sharing distributed all over the place. This requirement makes Grid computing the best candidate. As real world data is the basic requirement of all agricultural problems, so the grid should be sensor grid (Lim *et al.,* 2005; Tham and Buyya, 2005). (KnowledgeGRID Malaysia, 2009) is one of the efforts that is offering the weather database and genetic simulations for seed research.

Above mentioned researches clearly showing that multiple systems were developed for monitoring and getting the status of crop and field to provide some decision-support to the users for required treatment. In contrast to such systems, some researchers proposed the solution that emphasized the use of collected information for context modeling (Kjær, 2008; Goumopoulos *et al,* 2007; Goumopoulos *et al,* 2009) to make the system proactive. Such proposed systems are able to react on the situation to cope up with the arising problem. The distributed nature of agriculture field and the real time requirement of context collection and decision making limit the performance and ability of such systems. Keeping these facts in mind, we emphasized the need of using the combination of grid computing with sensor/actuator network and context-aware facility that overcome the limitation of real time data collection, decision making for the distributed agriculture lands (Aqeel and Shaikh, 2008).

Context-Aware Sensor Grid Framework for Agriculture:

Context-aware sensor grid framework for agriculture (Aqeel and Shaikh, 2008) was proposed in consideration to produce solutions for many different problems exist in this domain like crop irrigation, pesticide spraying, land and crop monitoring etc. The system developed using this framework will be able to deal with variety of problems, weather conditions and soil attributes due to the ontology based context modeling and reasoning. In addition to that grid computing will facilitate the system for real time context collection and decision making for globally distributed agriculture fields.

The Framework (see figure 2) is based on three layer architecture having Context-aware application layer, Grid computing layer and the Sensor/Actuator network layer.

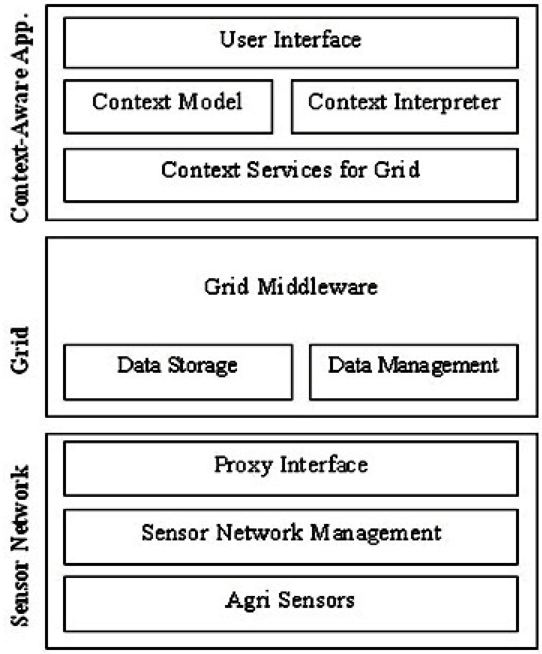

Fig. 2: Context-Aware Sensor Grid Framework for Agriculture. (Aqeel and Shaikh, 2008)

Sensor Network Layer:

This layer deals with the sensors, actuators and their network. Sensor data acquisition, data representation, aggregation, clustering are some of the duties of this specific layer. Different sensors and actuators may have different interfaces. Sensor network layer is also responsible to deal with such variety of interfaces.

Grid Computing Layer:

Grid computing layer is responsible to provide seamless interaction and resource sharing of computing devices. It provides the additive computing power of the contributing devices as well as the shared and distributed data storage facility. It also makes available the global access to the system for monitoring purpose.

Context-aware Application Layer:

Context-awareness is the main crust of this framework. Addition of this layer enables the system to deal with the changing requirements and technical capabilities of users as well as the change in situation, environment and devices' status. This layer is responsible for context modeling, context interpretation and reasoning from low level sensors' data. Knowing the current context helps in modeling arising problems and taking proactive decisions.

Scenario Details for the Prototype:

The prototype was developed for irrigation control to show proof of the concept. The scenario for context-aware agriculture is as follows:

- Sensors placed over piece of green land of university will keep on providing weather and soil moisture attributes of two similar zones adjacent to each other. The rate of sampling is defined as per soil condition and crop under consideration.
- The sink mote will provide the facility to gather all the broadcast based samples and store those samples at base-station node that will be one of the desktop grid nodes.
- All conversions from raw samples, aggregation and data storage facilities will be provided by desktop grid nodes.
- Context-aware sensor grid application will be using these converted and aggregated samples for context modeling and interpretation to know about the current situation for irrigation requirements.
- Based on condition, decision will be taken for actuation of respective sprinklers for misting or for irrigation.

Prototype Implementation:

The prototype was developed to deal with crop irrigation problem. University garden area was selected for implementation of the system and the context-aware sensor grid was deployed on selected piece of land. The area was divided into two similar zones to show decision support capability for multiple zones. Both the zones were monitored for local weather (temperature, ambient light and humidity) and soil moisture. The acquired values were used for modeling the context for irrigation requirement. The basic theme behind crop irrigation control was to provide water in required quantity to only those areas where it is needed.

Figure 3 shows the architecture of the prototype and the distribution of sensor and actuator motes.

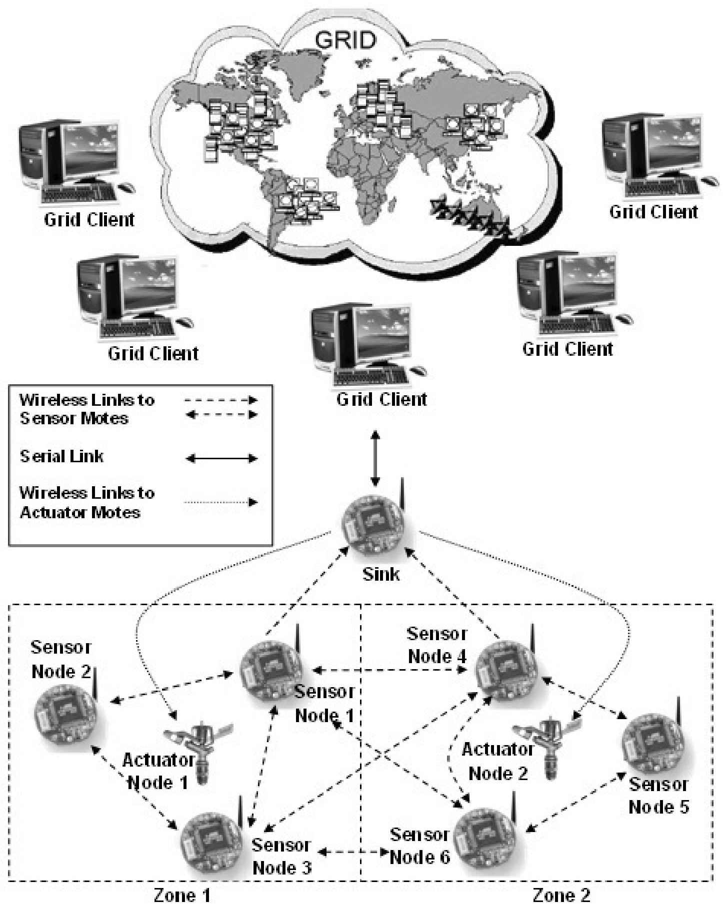

Fig. 3: Context-Aware Sensor Grid Prototype Architecture.

The Hardware:

Following hardware was utilized in the development of context-aware sensor grid prototype:

1. TelosB sensor motes (7 in numbers)
2. Ech2o-20 Soil moisture probes (6 in numbers)
3. Sprinkler with digital actuator (2 in numbers)
4. Desktop Personal Computers (3 in numbers)

Three sensor motes were placed having built-in temperature, ambient light and humidity sensors in each zone. Soil moisture probe was attached to every mote via external port provided on TelosB sensor mote. One TelosB was used as a sink mote to gather the sensed data (refer figure 3). The sink mote was connected to base-station PC node via serial interface. Actuator nodes containing sprinkler were placed in each zone having wireless connectivity via Zigbee communication module with the base-station.

Desktop PCs were used to develop grid computing environment having wired and wireless connectivity. One of the grid nodes was dedicated as base-station node connected with the sink mote of WSAN.

The sample rate for each sensor mote was kept 5 minutes to better utilize the battery power. While each zone average (i.e. average of 3 sensor motes) was calculated after every 40 minutes. Specified sampling rate was taken as default although it could be varied based on soil type and weather condition. The zone values were checked for the specified threshold values of specific crop under consideration.

The Software:

Several different software tools and languages were used to develop prototype context-aware application, WSAN and grid computing environment. nesC for TinyOS was used to built broadcast based WSAN modules for sensor motes. Alchemi toolkit provided facility to develop grid computing environment while SQL server was utilized for getting database facility. Protégé, Jena, SWRL and SQWRL were involved in producing context modeling, interpretation, reasoning and rule engine facilities. All the interfaces, GUIs and decision support system were programmed in C# .net language.

RESULTS AND DISCUSSION

Results are obtained from the system developed for above mentioned scenario. Rabi and Kharif are two major crop seasons. To cover both types of crops, data of weather and soil attributes are collected throughout the year but to show the proactive nature of system only two but quite different day data is selected. Based on the rules defined (see sample rules in table 1) and context situations different treatments were performed to properly irrigate the area under consideration. Threshold levels for irrigation and misting were defined based on the plant under consideration. Below mentioned threshold levels are used to initiate actuation of sprinklers and other alarms depending on the context situation. Figure 4 presents the graphical representation of climate and soil moisture data of a cool day of January 2009 having hazy sun conditions and system response where sprinkler is actuated at a point when average soil moisture drops down the minimum threshold level to cope up with water stress condition.

Table 1: Example Application Rules

Rule	Details
Water Stress	IF AvgSoilMoisture < 30% THEN WaterStress ← TRUE ELSE WaterStress ← FALSE
Heat Stress	IF WaterStress AND AvgTemperature > 40°C AND AvgRelativeHumidity ≥ 60% THEN HeatStress ← TRUE ELSE HeatStress ← FALSE
Need Irrigation	IF WaterStress AND NOT HeatStress THEN NeedIrrigation ← TRUE ELSE NeedIrrigation ← FALSE
Need Misting	IF HeatStress AND WaterStress THEN NeedMisting ← TRUE ELSE NeedMisting ← FALSE

The sprinkler of the required area remains open as per the pre-specified timings that depend on the plant specifications. Figure 5 represents data of a very hot and dry day of June 2009 having bright sun condition. These conditions may engender heat stress on plant. To overcome this heat stress, sprinkler was switched on for misting. Figure 5 shows the condition of heat stress when average temperature and average humidity increases above the maximum threshold level in addition with the water stress condition.

Average water utilization to irrigate 100 square feet grassy land is collected for 2 different traditional ways of irrigation and after implementing our context-aware system. The results are then compared for all the applied methods to check for the water conservation. The data for traditional methods was collected through interviewing of several farmers and gardeners.

The first method considered is the furrow irrigation for which 1x1 feet channel is used in which water was provided with 1ft/sec velocity. That gives the discharge value of 1 cubic feet/sec (as Q=AxV=1x1x1=1cu-ft/sec, where A=Area and V=Velocity). One cubic feet could contain 28 liters of water that provides water discharge of (Q=1x28) 28 lit/sec. It takes around 30 min to irrigate 1 kanal of land using furrow irrigation method that provides around 1125 liters of water requirement for 100 square feet of land which lasts for average of 5 days. Second traditional method used to irrigate garden areas is through water pipes. The water is supplied on a particular piece of land until it is like flooded. This method requires around 5 liter/sq-ft water. So, around 500 liters are needed for 100 sq-ft of land that lasts on average of 3 days.

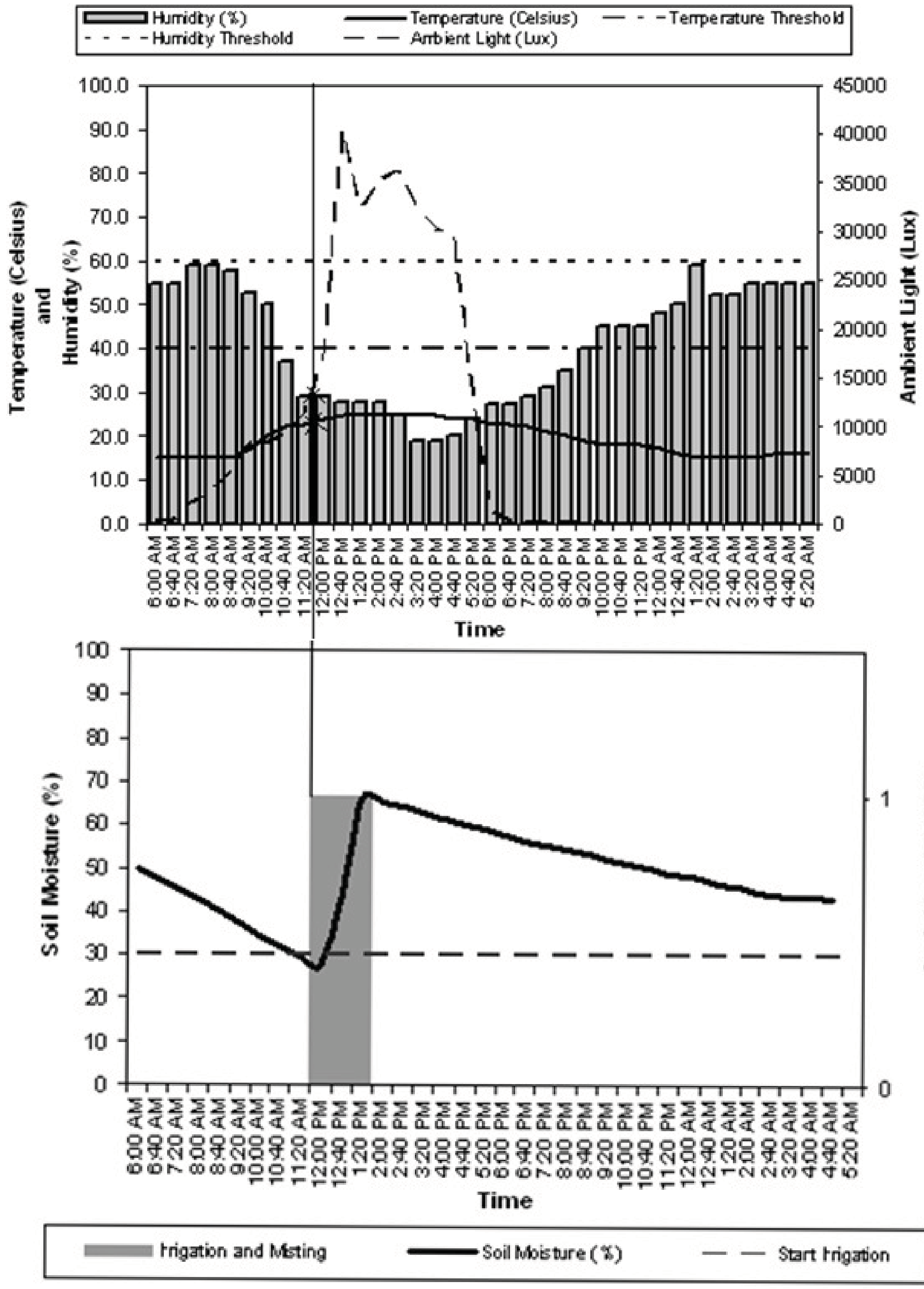

Fig. 4: Graph Showing System Behavior on Sensed Values of Cool and Hazy Day.

In our system, we applied 0.75in/hr application rate rotor head sprinkler to irrigate the same piece of land. To properly irrigate lawn area to the depth of 4-6 inches around 1.0 inch water is needed. To fulfill the requirement, sprinkler was kept switched ON for 80 minutes (refer figure 5 and 6), when the irrigation is needed (i.e. water stress), that provided 236 liters of water (calculated based on the discharge rate of sprinkler). Such amount of water lasts for around 2 days.

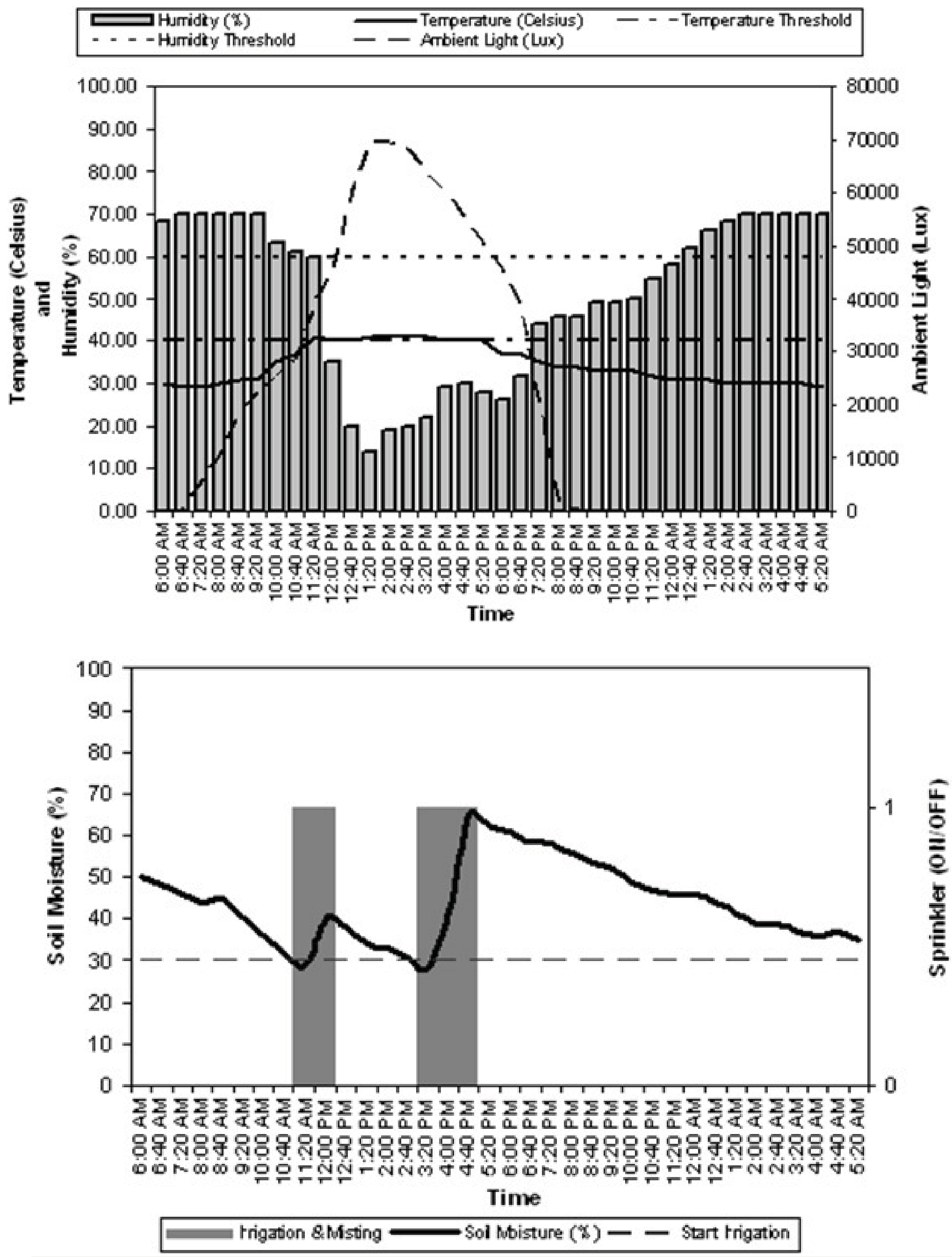

Fig. 5: Graph Showing System Behavior on Sensed Values of Hot and Bright Day.

Based on the above mentioned calculations, first method utilized on average 6750 liters water per month while second method utilized on average 5000 liters of water that conserves water of around 26%. On the other hand, our system utilized on average 3540 liters of water to irrigate the same 100 sq-ft lawn that clearly saves 47.6% from first method while 29.5% from the second method.

The results presented in figures 4 and 5 are substantiating proactive nature of the system while figure 6 clearly showing that our system is providing conservation of water that is badly needed nowadays as water reserves are shorting down.

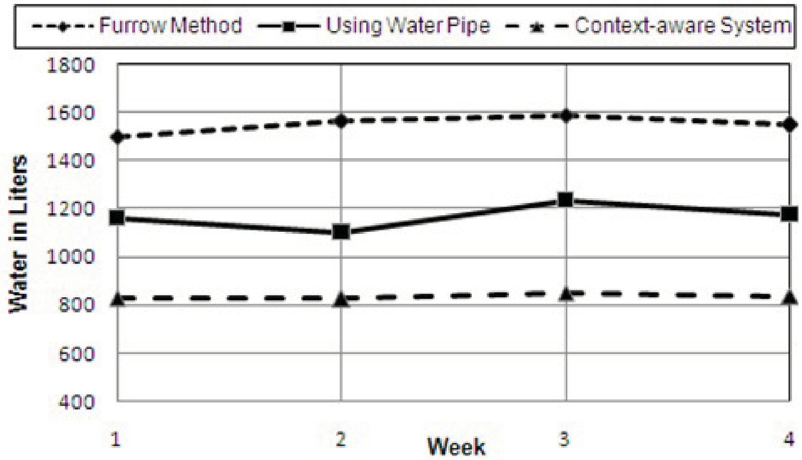

Fig. 6: Graph Showing Water Utilization by Different Methods.

The above mentioned results are for the irrigation of garden area of the University. The context modeling provided in our system supports several threshold levels for different stress conditions that could be defined for many types of plants and crops. Similarly water quantity to irrigate and mist could also be varied as per the requirement.

Agriculture domain possesses variety of attributes that generates highly rich context environment and makes it most suitable for context-aware systems like context-aware sensor grid. The results are also corroborating the above mentioned claim.

Conclusion and Future Work:

Advancement of technologies and emergence of new technologies are benefiting all areas of life in several aspects. Agriculture is one of the domains that are blessed through technology. In this paper, we presented a context-aware model of a typical watering system in agricultural fields that is developed through the integration of technologies namely context-aware computing, grid computing and sensor/ actuator network. Results show that context-aware systems are highly appropriate for agriculture due to the availability of variety of context information. Comparison of results with the traditional practices clearly show that the novel approach of the developed system saves the scarce water resource.

In future, we are planning to test the ability of this novel approach for variety of problems to show that it is viable under certain constraints, in providing a pragmatic generic solution not only for agriculture related problems but also for other context rich domains. Ontology modeling will be extended for different domains to enrich the generic context layer of our framework.

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