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# A review of wireless sensors and networks' applications in agriculture

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ABSTRACT

Due to advancement in technologies and reduction in size, sensors are becoming involved in almost every field of life. Agriculture is one of such domains where sensors and their networks are successfully used to get numerous benefits. Selection of sensors and their effective utilization to solve agricultural domain problems has been an arduous task for novice users due to unavailability of conglomerated information in literature. The aim of this paper is to review the need of wireless sensors in Agriculture, WSN technology and their applications in different aspects of agriculture and to report existing system frameworks in agriculture domain.



## 1. Introduction

Agriculture has played a key role in the development of human civilization. Due to the increased demand of food, people are trying to put extra efforts and special techniques to multiply the food production. Use of different technologies towards agriculture is one of such efforts. Apart from use of scientific technologies in agriculture, information technology is now being heavily exercised in this area. Technologies like satellite navigation, sensor network, grid computing, ubiquitous computing and the context-aware computing are supporting the said domain for improved monitoring and decision making capabilities [1].

Use of sensors and their networks is supporting agriculture practices in a very positive direction [2,3]. For sensor based agriculture, varieties of terminologies are now in use like Precision Agriculture (PA), Smart Agriculture, Variable Rate Technology (VRT), Precision Farming, Global Positioning System (GPS) Agriculture, Farming by Inch, Information-Intensive Agriculture, Site Specific Crop Management etc. [4] but the underlying concept in all of them is same.

Advancements of technologies reduced the size of sensors to such extent that enabled them to be utilized in variety of the domains of human life. Due to the significance of sensor technology, several issues related to sensors and their networks are in research. Energy constraint, limited computing power, small memory and data security are some of the substantial issues of sensor networks for which researchers proposed several solutions [5–7].

The aim of this paper is to review the need of wireless sensors in different aspects of agriculture. The remainder of this paper is organized as follows: In next section, we will present the importance of sensors in agriculture. In Section 3, sensor technology and their networks will be introduced. Wireless sensor and actuator networks application in agriculture will be discussed in Section 4. Section 5 will discuss the available system framework proposed for agriculture domain followed by conclusions in the last section.

## 2. Why sensors in agriculture?

Sensors are used for collecting information about physical and environmental attributes whereas actuators are employed to react on the feedback to have control over the situations. The sensors' accumulated information that characterizes the object or environment and used to identify people, location, objects and their states is known as context [8,9]. The context acquisition provides a valuable contribution in modeling situations of domains that have variety of time variant attributes. Agriculture is one such domain.

Agriculture domain poses several requirements that are following:

1- Collection of weather, crop and soil information
2- Monitoring of distributed land
3- Multiple crops on single piece of land
4- Different fertilizer and water requirement to different pieces of uneven land
5- Diverse requirements of crops for different weather and soil conditions
6- Proactive solutions rather than reactive solutions.

Above requirements entail parallel and distributed application and processing. In addition, wireless sensors and actuators are required to collect the requisite information and to react on different situations. Decision support imposes the requirement to have processed information rather than raw sensor data.

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To cope-up with such requirements, wireless sensors, actuators and their networks present themselves as a strong candidate for development of system for context acquisition, presenting acquired data to remote decision support systems and thus providing a controlled environment based on decision. Several sensors that are used for agricultural related attributes' acquisition are presented in Table 1.

## 3. Wireless sensor technology and networks

Utilization of sensors is becoming possible in almost every field of life due to the advancement of technology and size reduction. Sensor is a device that has capabilities to measure physical attributes and convert them into signals for the observer. Sensors are the part of

**Table 1**
Sensors used in Agriculture Domain.

| S. no. | Sensors | Soil | | | | | | | References |
|---|---|---|---|---|---|---|---|---|---|
| | | Temperature | Moisture | Dielectric permittivity | Rain/ water flow | Water level | Conductivity | Salinity | |
| 1 | Hydra probe II soil sensor | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | www.stevenswater.com |
| 2 | Pogo portable soil sensor | ✓ | ✓ | ✓ | ✓ | – | ✓ | – | www.stevenswater.com |
| 3 | MP406 Soil moisture sensor | ✓ | ✓ | ✓ | – | – | – | – | www.ictinternational.com.au |
| 4 | ECH2O soil moisture sensor | ✓ | ✓ | ✓ | – | ✓ | ✓ | – | www.ictinternational.com.au |
| 5 | EC sensor (EC250) | ✓ | ✓ | – | ✓ | – | ✓ | ✓ | www.stevenswater.com/catalog/products/ water_quality_sensors/manual |
| 6 | ECRN-50 low-REC rain gauge | – | – | – | ✓ | – | – | – | http://www.decagon.com |
| 7 | ECRN-100 high-REC rain gauge | – | – | – | ✓ | – | – | – | http://www.decagon.com |
| 8 | Tipping buket rain gage | – | – | – | ✓ | – | – | – | www.stevenswater.com |
| 9 | 107-L temperature Sensor (BetaTherm 100K6A1B Thermistor) | ✓ | – | – | – | – | – | – | http://www.campbellsci.com/107-l |

| S. no. | Sensors | Leave/plant | | | | | | References |
|---|---|---|---|---|---|---|---|---|
| | | Photosynthesis | Moisture | Hydrogen | Wetness | $CO_2$ | Temperature | |
| 1 | 237 leaf wetness sensor | – | ✓ | – | ✓ | – | ✓ | http://www.campbellsci.com |
| 2 | LW100, leaf wetness sensor | – | ✓ | – | ✓ | – | ✓ | http://www.globalw.com LW100B.pdf |
| 3 | SenseH2™ hydrogen sensor | – | – | ✓ | ✓ | ✓ | ✓ | http://www.NTMSENSORS.com |
| 4 | Leaf wetness sensor | – | ✓ | – | – | – | – | http://www.decagon.com |
| 5 | YSI 6025 chlorophyll sensor | ✓ | – | – | – | – | – | http://www.ysi.com ysi_6025.pdf |
| 6 | Field scout CM1000TM | ✓ | – | – | – | – | – | http://www.specmeters.com/pdf/ 2950FS.pdf |
| 7 | TT4 multi-sensor thermocouple | – | ✓ | – | – | – | ✓ | www.ictinternational.com.au/ thermocouple.htm |
| 8 | LT-2 M (leaf temperature sensor) | – | – | – | – | – | ✓ | http://www.solfranc.com LT-2 M Leaflet SOLFRANC.pdf |
| 9 | TPS-2 portable photosynthesis | ✓ | ✓ | – | ✓ | ✓ | ✓ | www.ppsystems.com/Literature/ EDSTPS2_System.pdf |
| 10 | PTM-48A photosynthesis monitor | ✓ | ✓ | – | ✓ | ✓ | ✓ | http://phyto-sensor.com/PTM-48A |
| 11 | CI-340 hand-held photosynthesis | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | http://www.solfranc.com CI-340_hand- held_photosynthesis_solfranc_ENG.pdf |
| 12 | 107-L temperature Sensor (BetaTherm 100K6A1B thermistor) | ✓ | – | – | – | – | – | http://www.campbellsci.com/107-l |

| S. no. | Sensors | Weather | | | | | References |
|---|---|---|---|---|---|---|---|
| | | Temperature | Humidity | Atmospheric pressure | Wind speed | Wind direction | |
| 1 | CM-100 compact Weather sensor | ✓ | ✓ | ✓ | ✓ | ✓ | www.stevenswater.com |
| 2 | Met station one (MSO) | ✓ | ✓ | ✓ | ✓ | ✓ | www.stevenswater.com |
| 3 | XFAM-115KPASR | ✓ | ✓ | ✓ | – | – | http://www.pewatron.com 100-31-102-006-EH-0110.pdf |
| 4 | HMP45C (Vaisala's HUMICAP® H-chip) | ✓ | ✓ | ✓ | – | – | http://www.campbellsci.com HMP45C Temperature and Relative Humidity Probe |
| 5 | SHT71 (Humidity and temperature sensor) | ✓ | ✓ | ✓ | – | – | http://www.sensirion.com/humidity |
| 6 | SHT75 (Humidity and temperature sensor) | ✓ | ✓ | ✓ | – | – | http://www.sensirion.com/humidity |
| 7 | CI-340 hand-held photosynthesis | ✓ | ✓ | – | – | – | http://www.solfranc.com CI-340_hand- held_photosynthesis_solfranc_ENG.pdf |
| 8 | 107-L temperature Sensor (BetaTherm 100K6A1B thermistor) | ✓ | – | – | – | – | http://www.campbellsci.com/107-l |

nature and many of the sensing capabilities are available in living organism in the form of bio-sensors.

Wireless Sensor Network (WSN) comprises over several components called 'nodes' (refer to Fig. 1). The nodes are smart devices that are used to collect the application oriented data requirements. A sensor network performs three basic functions: (i) Sensing (ii) Communication and (iii) Computation by using hardware, software and algorithm. The nodes perform several roles. The distributed nodes that collect the information are called source node while the node that gathers the information from all source node is called the sink node and sometime the gateway node. The sink node could have relatively high computing power. A source node also works as a routing node due to the requirement of multi hop routing.

Wireless Sensor and Actuator Network (WSAN) is a variant of WSN that has one additional type of component that is an actuator. Inclusion of actuator increases the capability of WSN from monitoring to the control.

### 3.1. Communication technologies

Wireless communication technologies like ZigBee, Bluetooth, Wibree and WiFi are part of several sensor network based research works. These technologies have different capabilities and properties on which they are complemented. A brief comparison is given in Table 2.

ZigBee wireless communication technology (IEEE 802.15.4) is preferred over other technologies for the development of wireless sensor network due to its low cost and low power consumption property. It was introduced in May 2003 and operates on Industrial, Scientific and Medical (ISM) band i.e. 2.4 GHz globally. There are 16 ZigBee channels of 5 MHz bandwidth each in 2.4 GHz band.

### 3.2. Wireless sensor node architecture

Wireless sensor node is a basic unit of wireless sensor network. It comprises of 4 basic modules including Sensor/Actuator module, Communication module, Processing/computation module and Power module (refer to Fig. 2). External memory is an optional module that could be needed in case of data storage requirement for local decision making. Its design requires many considerations like energy conservation, scalability, size, housing etc.

Sensor/Actuator module provides interfaces to transducers and actuators. Following are some of the available sensor motes in the market (Table 3).

Selection of sensor mote is carried out considering the major requirements of application domain, problem and distribution pattern. The processor/microcontroller, memory, working frequency band, available compatible sensors, transmission range and size are some of the major attributes of a sensor node that make it preferable over others. Table 3 depicts that majority of sensor nodes comprise over ATmega128L microcontroller, ZigBee (CC2420) or RF (CC1000) transceivers working on ISM band and weather related embedded sensors. It is due to the microcontroller specialized attributes, licensing free ISM band and close relationship of weather attributes to majority of domain problems. Microcontroller plays a vital role as it provides computing power for local decision making and data aggregation, energy management through sleep/awake modes etc. ATmega128L is the most common microcontroller due to its low power requirement, several sleeping modes, flash memory, efficient byte oriented storage and compatibility with virtually all TinyOS code. Agriculture domain engenders some specialized requirements that are presented in the next section. Due to such special requirements, sensor nodes are also especially designed keeping the ruggedness, housing, alternative battery source support etc. e.g. Lofar node and SPWAS [11–13].

**Table 2**
Comparison of communication technologies [10].

| | ZigBee | Bluetooth | Wibree | WiFi |
|---|---|---|---|---|
| Frequency band | 2.4 GHz | 2.4 GHz | 2.4 GHz | 2.4 GHz |
| Range | 30 m–1.6 km | 30–300 ft | Up to 10 ft | 100–150 ft |
| Data rate | 250 kbps | 1 Mbps | 1 Mbps | 11–54 Mbps |
| Power consumption | Low | Medium | Low | High |
| Cost | Low | Low | Low | High |
| Modulation/protocol | DSSS, CSMA/CA | FHSS | FHSS | DSSS/CCK, OFDM |
| Security | 128 bit | 64 or 128 bit | 128 bit | 128 bit |

### 3.3. Issues in wireless sensor networks

Based on flexible and autonomous concept of wireless sensor networks, opportunities have been created for exciting application areas requiring remote sensing and actuation for optimized results. However, wireless sensor network technology poses many issues that need to be handled for long term viability of developed systems. Issues like energy consumption for autonomous operation of sensor nodes, dictate design and development issues including communication, protocols and deployment. Issues in wireless sensor networks have been outlined in existing literature [7,14] and been addressed by others [15,16] for different solutions to the issues. However, in the context of our survey we describe issues that are critical for application of WSN in agriculture

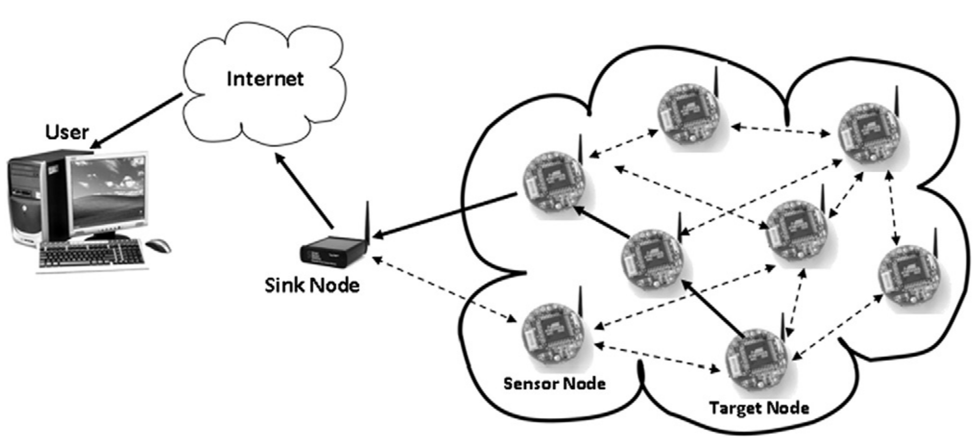


**Fig. 1.** Wireless Sensor Network (WSN).

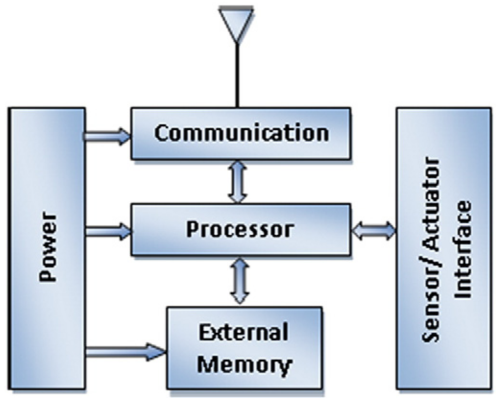


**Fig. 2.** Wireless sensor node architecture.

domain. In many cases, farming is carried out on farms as large as several hundreds of acres and may involve different nature of land, resources and microclimates. The sensor nodes being placed in open, uncontrolled environment pose several design and implementation issues, some key of them as below:

#### *3.3.1. Energy consumption*

Each sensor node placed in a wireless sensor networks has the responsibility of event detection, data processing and transmission. In case of multi-hop network, a node has the additional responsibility of data routing also. Each of the above actions requires energy to be consumed. A node is usually equipped with a limited and finite energy source e.g. alkaline batteries or lithium cells. Therefore, a sensor node life time greatly depends upon battery life time. By applying proper energy management strategy in hardware and software, battery life may be extended to several more months. Alternatively, the use of renewable energy sources such as solar power or kinetic energy could be adopted where a slight expensive solution could be traded off in favor of longer life of sensor nodes. Moreover, in case of agriculture lands, these sensors could be periodically repowered by battery change as their placement and access is usually well-defined.

#### *3.3.2. Data acquisition, sampling and transmission*

With each data sampled, processed and transmitted, energy is spent. An efficient and optimized data collection and sample rate is needed to be programmed so as not only the relevant and useful data

**Table 3**
Comparison of some available sensor nodes.

| Feature | MICAz | MICA2DOT | MICA2 | Imote2 | TelosB | IRIS | Cricket |
|---|---|---|---|---|---|---|---|
| Microcontroller | ATmega128L | ATmega128L | ATmega128L | Marvell/ XScalePXA271 | TIMSP430 | ATmega128L | ATmega128L |
| Clock Speed (MHz) | 7.373 | 4.0 | 7.373 | 13–416 | 6.717 | 7.373 | 4.0 |
| Bus Size (bits) | 8 | 8 | 8 | 32 | 16 | 8 | 8 |
| Memory (bytes) | EEPROM:4 K | EEPROM:4 K | EEPROM:4 K | SRAM:256 K<br>SDRAM:32 M | RAM:10 K<br>EEPROM: 16 K | EEPROM: 4 K<br>RAM:8 K | EEPROM:4 K |
| Memory(flash) (bytes) | Program: 128 K | Program: 128 K | Program: 128 K | Programmable | Program: 48 K | Program: 128 K | Program: 128 K |
| | Serial: 512 K | Serial: 512 K | Serial: 512 K | Flash: 32 M | Serial: 1024 K | Serial: 512 K | Serial: 512 K |
| Size (mm) | 58×32×7 | 58×32×7 | 58×32×7 | 36×48×9 | 65×31×6 | 58×32×7 | 58×32×7 |
| Weight (gm)* | 18 | 18 | 18 | 12 | 23 | 18 | 18 |
| Battery | 2×AA | 3 V Coin cell CR2354 | 2×AA | 3×AA | 2×AA | 2×AA | 2×AA |
| External power | 2.7 V–3.3 V | 3 V | 2.7 V–3.3 V | 3.2 V–4.5 V | 2.7 V–3.3 V | 2.7 V–3.3 V | 2.7 V–3.3 V |
| Active mode power (mW) consumption | 24@3 V | 15@3 V | 24@3 V | 44@13 MHz<br>570@416 MHz | 10@3 V | 24@3 V | 24@3 V |
| Sleep mode power (μW) consumption | 75 | 75 | 75 | 100 | 8 | 24 | 75 |
| Available sensors | Light, temperature, humidity, barometric pressure, accelerometer, GPS, RH, acoustic, video sensor, microphone, sounder, magnetometer | Light, Temperature, Accelerometer | Light, temperature, humidity, barometric pressure, accelerometer, GPS, RH, acoustic, video sensor, microphone, sounder, magnetometer | Light, Temperature, Humidity, Accelerometer | Light, temperature, humidity | Light, temperature, RH, barometric pressure, acceleration/ seismic, acoustic, magnetic and video | Light, temperature, humidity, barometric pressure, accelerometer, GPS, RH, acoustic, ultrasonic, video sensor, microphone, sounder, magnetometer |
| User interface | 3 LEDs | 1 LED** | 3 LEDs** | USB client/ host | USB | 3 LEDs | 3 LEDs** |
| Expansion connector | 51-pin | 19-pin | 51-pin | 40-pin and 20-pin | 6-pin and 10-pin | 51-pin | 51-pin |
| Serial communication | UART | UART | UART | UART 3x | UART | UART | UART |
| Other interfaces | Digital I/O, I2C, SPI | DIO (8 channels) | DIO, I2C, SPI | GPIOs, I2C, DI0, JTAG, SPI2x, I2S, AC97, Camera | Digital I/O, I2C, SPI | Digital I/O, I2C, SPI | DIO, I2C, SPI |
| Transceiver chip | CC2420 | CC1000 | CC1000 | CC2420 | CC2420 | Atmel RF230 | CC1000 |
| Frequency band (Mhz) ISM band | 2400–2483.5 | 868/916 | 868/916 | 2400–2483.5 | 2400–2483.5 | 2400–2480 | 868/916 |
| Number of channels | In steps of 1 MHz*** | 4/50 | 4/50 | In steps of 5 MHz | In steps of 1 MHz*** | In steps of 1 MHz*** | 4/50 |
| Data Rate | 250 Kbps | 38.4 K Baud | 38.4 K Baud | 250 Kbps | 250 Kbps | 250 Kbps | 38.4 K Baud |
| RF Transmit power (dBm) | −24 to 0 | −20 to +5 | −20 to +5 | −24 to 0 | −24 to 0 | +3 | −20 to +5 |
| Receive (dBm) Sensitivity | −94 | −98 | −98 | −94 | −94 | −101 | −98 |

*Without batteries, **User programmable, and ***Programmable.

is captured but energy is also not wastefully spent. On the contrary, frequent data acquisition will cause huge amount of packets being transmitted and this exhausts the energy of the batteries quickly. In agriculture, the sampling rate for data acquisition is not usually high. However, it could be made adjustable based upon the environment, type of crop and resources.

As mentioned in Section 3.1, various wireless transmission technologies are available for use. A data transmission strategy could also be strategized so that lesser transmissions are made, thus conserving the energy. This may include local storage of data at sensor nodes and intelligent transmission of data e.g. the aggregated values or only the changed ones etc. Moreover, the implementation of options like sleep mode may be exercised so as to wake up the transmitters only when needed. Also in order to have reliable communication links, sensor nodes must be placed close enough to each other to ensure reliable multi-hop communication.

#### 3.3.3. Fault tolerance

Sensor nodes being placed in open harsh environment are prone to physical damage, blockage and interference. In order to maintain the reliability of a WSN, the failure of a sensor node should not affect the overall task of the network. Redundant use of sensor nodes, reorganization of sensor network, and overlapped sensing regions etc. are few of the techniques employed to increase the fault tolerance or reliability of the network.

#### 3.3.4. Sensor node size and housing

The sensor node size must be small and suitable for deployment. The node should be encased in a protective housing making it resistant to harsh environmental factors like heat and rain, and physical mishandling by human or animals.

#### 3.3.5. Sensor placement

Senor Node Placement is an important issue regarding the design of the network, algorithms, topologies used, and the parameters being sensed. It needs to be carefully designed and smartly implemented so that a WSN could be established that may work reliably and autonomously. Placement of sensors should be such that the whole area under the concern is covered and sensors are placed in position and altitudes so as to measure the parameters without hindrance. For example, light sensors must be placed at heights so as to avoid blockage from plant leaves. Water level and moisture sensors, on the other hand, must be placed close enough to the ground necessary for accurate measurements. Strong winds and water currents may dislocate the sensors from desired positions, so proper fixtures need to be mounted to support the nodes.

## 4. WSN and WSAN applications in agriculture

Utilization of sensors, actuators and their network in the field of agriculture is now in advanced stages. WSN and WSAN are in use with different technologies especially with context-aware computing and grid computing [17,18]. Agricultural services like irrigation, fertilization, pesticide spraying, animal and pastures monitoring are reviewed in this section. Horticulture is also taken into consideration due to its importance.

### 4.1. Irrigation

Irrigation is defined as the artificial application of water in agricultural land and it is considered as one of the most important constituents of agriculture. Scarcity of water in several areas instigates the need of proper use of water that is water should be provided to only those places where it is needed and in required quantity. Different methods of irrigation are in use like drip irrigation, sprinkler irrigation etc. to cope up with the water wastage problem in traditional methods like flood irrigation, furrow irrigation etc.

Damas et al. [19] developed and tested a remote controlled, automatic irrigation system for irrigated area in Spain. The area was divided into seven sub-regions. Each sub-region was monitored and contended by a control sector. The seven control sectors were connected with each other and with the central controller via WLAN network. The results showed significant water conservation i.e. up to 30–60%.

Evans and Bergman [20] worked on precision irrigation control of self-propelled, linear-move and center-pivot irrigation systems. Wireless sensors were used in the system to assist irrigation scheduling using remotely sensed data and weather data.

Morais et al. [21] implemented wireless data acquisition network to collect climate data with soil moisture for smart irrigation in Portugal. In order to improve irrigation efficiency, several SPWAS (Solar Powered Wireless data-Acquisition Stations) have been deployed for the measurement of soil moisture. Various techniques have been used for soil moisture sensing.

Keeping the importance of controlling irrigation water for better yield production, several sensor based projects have been developed. Tapankumar et al. [22] designed and developed a computer based drip irrigation control system having the facility of remote data acquisition. They also presented the benefits of storing sensor data for statistical analysis to find out the irrigation requirements of different crops.

Yunseop Kim et al. [23] developed sensor based irrigation system. Soil moisture and temperature, weather information and sprinkler position were monitored remotely using the Bluetooth and GPS technologies. The concept behind the development of project was to maximize productivity while saving water.

Kim and Evans [24] developed a real-time wireless in-field sensing and control software for site-specific sprinkler irrigation. They integrated a site-specific irrigation controller with infield data feedback and supported the decision making and real-time monitoring of irrigation operations via Bluetooth wireless radio communication.

### 4.2. Fertilization

Fertilizers are used to increase the soil fertility that directly affects plant growth and quality of food. Several ways of fertilization are used like broadcasting, manual spreading and spraying. The optimal supply of fertilizer to the required place is a difficult task and it requires sensing capabilities. Researchers have presented different solutions for appropriate fertilization.

Cugati et al. [25] built an automated fertilizer applicator consisting on Input, decision support and output modules using GPS technology, real-time sensors and Bluetooth technology. The input module is used to provide GPS and sensor data values to Decision Support System (DSS) that calculates the optimal quantity and spread pattern of fertilizer based on real-time sensor data acquisition through Bluetooth communication modules. The DSS calculations were used to regulate fertilizer application rate.

D. Ehlert et al. [26] used their own designed mechanical sensor (Pendulum meter) for site specific fertilization. Pendulum meter was mounted at the front of tractor that was used to measure the crop density. The sensor was utilized in combination with a fertilizer spreader, a modified CAN-bus onboard computer and job calculator to estimate the application of nitrogen within the field.

J. He et al. [27] developed and integrated optimal fertilization decision support system using wireless sensors LAN using IEEE 802.11 protocol (WiFi) and GPS analysis server. Sensors were used to acquire real time data of soil moisture, conductivity, temperature, PH value, air temperature, humidity, $CO_2$ concentration, illumination etc. The system was designed using B/S (browser/Server) structure mode to provide high interactivity. GIS analysis server was used to interpolate the data from small experiment plots for larger plots to exploit data reduction for energy conservation. They utilized “3414” test [28] in their fertilization decision making system that refers to the fertilization experiments including 3 factors (i.e. nitrogen, phosphorus and potassium), 4 levels and 14 treatments of fertilizers.

“3414” fertilizer efficiency test is predominately used in fertilization decision-making systems. It is a statistical model about fertilization and crop yield. Through this model crop's optimal yields in theory and the corresponding fertilization amounts can be calculated [29]. The scheme is designed to absorb the advantages of optimal regression design of less treatments and high efficiency. 3414 test utilizes four levels of fertilizer that are 0, 1, 2 and 3. Level 0 means level of no fertilizer while 2 is the best fertilizer level for the local approximation. Level 2 is known as standard level. Other levels are defined as follows:

$$1\,\text{level} = 2\,\text{level} \times 0.5 \text{ and } 3\,\text{level} = 2\,\text{level} \times 1.5$$
$$(\text{level 3 represents over} - \text{fertilization}).$$

Different fertilization schemes (based on different NPK fertilization rate) on 14 treatment places of test field are applied which are then used to find optimal fertilization application rate and its relationship with the crop yield.

### 4.3. Pest control

Agricultural pest management strategies and product quest have long been dominated for better 'pests' control. Major emphasis remained on the development of new and effective product to replace toxic and non-effective old product rather on application strategies. Pest control could be more sustainable when the farming practices become more compatible with ecological systems.

Sensor networks have also been used to overcome fungus and pest problems. Aline Baggio [11] developed a project to deal with the potato crop Phytophtora disease. Sensors were used to sense humidity and temperature. Monitoring of these two facts helped them to reduce the disease.

Plant disease often occurs in patches of crop that requires variable rate fungicides rather uniform application over the whole field. K.H. Dammer [30] proposed the use of CROP-meter controlled variable rate field sprayer. Using CROP-meter (real-time sensor to measure crop biomass density) information about the spatial distribution of plant leaf area to be sprayed by pesticides could be obtained. The sensor information is used by their developed algorithm to control the dosage of fungicides to be sprayed by the field sprayer.

### 4.4. Animal and pastures monitoring

Butler et al. [31] developed a moving virtual fence algorithm to control cow herd. A smart collar consisting of GPS receiver, PDA, WiFi flash card for WLAN and audio amplifier with speaker is used for each cow in the herd. Animal's location is verified using GPS relative to the virtual fence. In case of approaching virtual fence, a sound stimuli is generated to take away animal from the fence perimeter.

Cattle monitoring at large scale engender several requirements and challenges. M. Radenkovic and B. Wietrzyk [32] presented a peer to peer distributed architecture based on mobile ad-hoc wireless sensor network for nationwide cattle monitoring.

The core of their research is to propose novel data storage and routing based on Distributed Hash Tables (DHT) that reduces the major problem of disconnections among nodes. Cattle's farming is closely related to the agriculture domain. Green pastures are used by cattle for grazing. Tim Wark and his other team members [33] at CSIRO ICT center, Australia created a pervasive, self configurable sensor based solution to analyze the behavior of animals and their control as well as the pastures assessment. Grass growth was analyzed through photographic sensors so that animals can be moved towards green pastures. Their major focus of work was to design rugged hardware that could be used outdoor for modeling animal's individual and herd behavior. They used specially designed sensor to monitor animal behavior like sleeping, grazing, ruminating etc. In their opinion such kind of behavior analysis in combination with their movement behavior could be used for Cow–Calf relationship as well as trends in herd behavior.

Cattle monitoring is an important task but it poses several challenges like radio attenuation caused by animal body, mobility etc. Ivon Andonovic et al. [34] designed an improved low cost and low power collar having solar power relay router and two antennas placed at carefully selected location that optimizes the collar radio coverage. They also proposed Implicit Routing Protocol (IRP) to cope up with high number of packet loss due to animal mobility.

### 4.5. Horticulture

Horticulture deals with the cultivation, production, distribution and use of flowers, fruits, greenhouse, ornamentals etc. It is also known as small scale or low intensity farming. Greenhouse and viticulture are discussed under this section due to major concern of research community towards those areas.

Zhang et al. [35] 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.

In [17], the authors presented system's water conservation over traditional irrigation methods. They developed context-aware irrigation control system using TelosB sensor motes and Ech2o soil moisture sensors. The system was tested for University green area irrigation. Field testing showed the 30–50% water conservation.

Development of reduced cost irrigation control system by developing sensor/actuator node and WSAN protocol indigenously is presented in [36]. University garden area irrigation was controlled using 5 sensor nodes having light, humidity and soil moisture sensors. The node was designed using Atmel ATMega64L AVR microcontroller due to its support of 6 sleep modes (Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby) and XBee/X-Bee-Pro OEM RF module for its low power consumption features. Preference was given to the power consumption and the low cost properties in design rather to the size of sensor mote.

#### 4.5.1. Greenhouse

The environment monitoring and control of greenhouses is crucial as it is not dependent on natural agents.

Morais et al. [12] implemented a wireless data acquisition network using several Solar-Powered wireless data Acquisition Stations (SPWAS) to collect outdoor and indoor climate data for greenhouses in Portugal. Up to 32 SPWASs and a base station were used and connected using RF links. The climate data was collected successfully and without errors.

Mizunuma et al. [37] deployed a Wireless LAN in farm field and greenhouse of Japan to monitor plant growth and implemented remote control for the production system to get improved productivity and reduce labor requirement.

Gang [38] developed a hardware and software of greenhouse data acquisition system based on Bluetooth technology. The temperature and relative humidity were measured.

Wang et al. [39] developed wireless sensor node to acquire temperature, relative humidity and light parameters of a greenhouse.

Kolokotsa et al. [40] developed an intelligent environment and energy management system for greenhouses. The greenhouse's indoor luminance, temperature, relative humidity, $CO_2$ concentration and the outside temperature were monitored. Two fuzzy logic controllers were developed, consisting of fuzzy P (Proportional) and PD (Proportional–Derivative) control using desired indoor climatic set-points. Output actuations of heating units, motor-controlled windows, motor-controlled shading curtains, artificial lighting, $CO_2$ enrichment bottles and water fogging valves were controlled.

#### 4.5.2. Viticulture

Burrell et al. [41] presented a study about the potential use of sensor networks to aid work in vineyards. They described a variety of sensor network configurations and applications that can address different priorities in the vineyard.

Beckwith et al. [42] implemented a 65 nodes multi-hop WSN in a vineyard for 6 months. The collected information was used for addressing two important parameters in wine production: heat summation and potential frost damage.

Morais et al. [13] have shown the feasibility of a ZigBee based remote sensing network named as MPWiNodeZ, intended for precision viticulture. The network nodes were powered by batteries that are recharged with energy harvested from the environment from up to 3 sources (solar power, wind power and hydro power).

## 5. System frameworks for agriculture

Framework that could help in developing complete system from context acquisition to the modeling and from decision support system to the actuation is deficient in agriculture domain. Context-aware sensor grid framework is one of such frameworks [17,43] that comprises over three layers namely sensor network layer, grid computing layer and context-aware application layer. Authors presented the need of several different building blocks for each layer that could help in better interactivity from sensor based data acquisition to the context-aware application for on time decisions.

C. Goumopoulos et al. [18,44] presented the concept of mixed societies of communicating plants and artifacts. Their PLANTS ontology comprises over two major concepts (ePlants and eGadgets). Utilizing PLANTS ontology, authors developed system architecture for precision agriculture application. In their opinion, local decision making at each node will make the system scalable and proactive.

There is no standard body that is providing standard methodology for developing sensor based agricultural systems from data acquisition to the modeling and decision making. Several research groups are working independently and developing such systems using standard technologies under the Precision Agriculture terminology. The Food and Agriculture Organization of the United Nations (http://www.fao.org) is performing one of standardization efforts by working towards the development of multilingual Agriculture Vocabulary (AGROVOC) to support the development of context modeling through ontology. In this regard they have also presented the concept of Agricultural Ontology Service/Concept Server (AOS/CS) [45] to standardize agricultural vocabulary and providing rich and semantically sound terminology.

## 6. Conclusion

Agriculture is a context rich domain in which the potential of using WSN and WSAN is very high. A review of several solutions and efforts has been presented in this paper towards agriculture domain. The major concerns that we feel are:

- Solutions are too complex to implement and requires major technical support
- Intense Cost is involved
- Lack of generalized solution to different services and problems
- Majority of the research works present solution in parts like only context modeling, data acquisition, data processing and storage techniques or network related problem solutions. The complex or sometimes unavailable interlinks among part solutions reduces the impact of several researches.

Adaptation of WSAN based solutions on large scale requires the following:

- Development of low cost and rugged sensor/actuator nodes
- Generalized solutions to different problems
- Complete frameworks to develop systems from acquisition to the modeling and the decision support.
- Solutions in part should be supported with comprehensive details of other compatible procedures that could make the intended resolution complete.

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