IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

REVIEW PAPER ON WIRELESS SENSOR NETWORKS FOR AGRICULTURE

Prof. Rahul Satpute, Shital Korade, Harshada More, Sharaddha Phadale,

Assistant professor, Students, Student, Student

Department of Electronics and Telecommunications Engineering.

Samarth Group of Institutions, College of Engineering, Belhe (Pune),India.

ABSTRACT:

The advent of Wireless Sensor Networks (WSNs) spurred a new direction of research in agricultural and farming domain. In recent times, WSNs are widely applied in various agricultural applications. In this paper, we review the potential WSN applications, and the specific issues and challenges associated with deploying WSNs for improved farming. To focus on the specific requirements, the devices, sensors and communication techniques associated with WSNs in agricultural applications are analyzed comprehensively. We present various case studies to thoroughly explore the existing solutions proposed in the literaturein various categories according to their design and implementation related parameters. In this regard, the WSN deployments for various farming applications in the Indian as well as global scenario are surveyed. We highlight the prospects and problems ofthese solutions, while identifying the factors for improvement and future directions of work using the new age technologies.

I.INTRODUCTION

Modern day farming demands increased production of food to accommodate the large global population. Towards this goal, new technologies and solution are being applied in this domain to provide an optimal alternative to gather and process information to enhance productivity. Moreover, the alarming climate change and scarcity of water demand new and improved methods for modern agricultural fields. Consequently, the need for automation and intelligent decision making is becoming more important to accomplish this mission In this regard, technologies such as ubiquitous computing, wireless ad-hoc and sensor networks, Radio Frequency Identifier (RFID), cloud computing Internet of Things (IoT) satellite monitoring, remote sensing context-aware computing are becoming increasingly popular.

A. MOTIVATION

Among all these technologies, the agriculture domain is mostly explored concerning the application of WSNs in improving the traditional methods of farming. The Micro-Electro-Mechanical Systems (MEMS) technology has enabled the creation of small and cheap sensors. The ubiquitous nature of operation, together with self-organized small sized nodes, scalable and cost-effective technology, enables the WSNs as a potential tool towards the goal of automation in agriculture. In this regard, precision agriculture, automated irrigation scheduling, optimization of plant growth, farmland monitoring greenhouse gases monitoring agricultural production process management and security in crops are a few potential applications. However, WSNs have few limitations such as low battery power, limited computation capability and small memory of the sensor nodes. These limitations invite challenges in the design of WSN applications in agriculture.

In agriculture, most of the WSN-based applications are targeted for various applications. For example, WSNs for environmental condition monitoring with information of soil nutrients is applied for predicting crop health and production quality overtime. Irrigation scheduling is predicted with WSNs by monitoring the soil moisture and weather conditions. Being scalable, the performance of an existing WSN-based application can be improved to monitor more parameters by only including additional sensor nodes to the existing architecture. The issues present in such applications are the determination of optimal deployment strategy, measurement interval, energy-efficient medium access, and routing protocols. For example, a sparse deployment of nodes with a long data collection interval is helpful for enhancing the lifetime of a network. However, challenges may emerge from the choice of the deployment region. As an example, if the field area is separated by obstructions then it will lead to attenuation of signal, thereby affecting the inter-node communication. In the Indian scenario, the WSN-based farming solutions need to be of very low cost to be affordable by end users. However, with the increasing population, the demand of food-grain is also rising. Recent reports warns that the growth in food grain.

B. CONTRIBUTIONS

In this paper, we surveyed the variants of WSNs and their potential for the advancement of various agricultural application development. We highlight the main agricultural and farming applications, and discuss the applicability of WSNs towards improved performance and productivity. We also classify the network architecture, node architecture, and communication technology standards used in agricultural applications. The real-world wireless sensor nodes and various sensors such as soil, environment, pH, and planthealth are also listed in this paper. In Section V, we study and review the existing WSN deployments both in the global as well as the Indian scenarios. In summary, the contributions of this paper are listed as follows.

- We study the current state-of-the-art in WSNs and their applicability in agricultural and farming applications.
- The existing WSNs are analyzed with respect to communication and networking technologies, standards, and hardware.
- We analyze the prospects and problems of the existing agricultural applications with detailed case studies for global as well as the Indian scenarios.
- Finally, we present the futuristic applications highlighting the factors for improvements for the existing scenarios

II.WIRELESS SENSOR NETWORK AND IT'S POTENTIAL AGRICULTURAL APPLICATION.

A.TERRESTRIAL WIRELESS SENSOR NETWORK

WSNs are a network of battery-powered sensors inter-connected through wireless medium and are typically deployed to serve a specific application purpose. In TWSNs, the nodes are deployed above the ground surface. The advancements in MEMS technology has enabled the creation of smart, small sized, although low cost sensors. These powerful sensors empower a sensor node or mote to accurately collect the surrounding data.

Based on the sensed information, these nodes then network among themselves to perform the application requirements. For example, consider a precision agriculture environment where WSNs are deployed throughout the field to automate the irrigation system. All these sensors determine the moisture content of the soil, and further, collaboratively decide the time and duration of irrigation scheduling on that field. Then, using the same network, the decision is conveyed to the sensor node attached to a water pump. Gutierrez ´ et al. proposed one such automated irrigation system using a WSN and GPRS module.

Figure 1 depicts a typical wireless sensor network deployed on field for agricultural applications. The field consists of sensor nodes powered with application specific on-board sensors. The nodes in the on-field sensor network communicate among themselves using radio-frequency (RF) links of industrial, scientific and medical (ISM) radio bands (such as 902-928 MHz and 2.4-2.5 GHz).

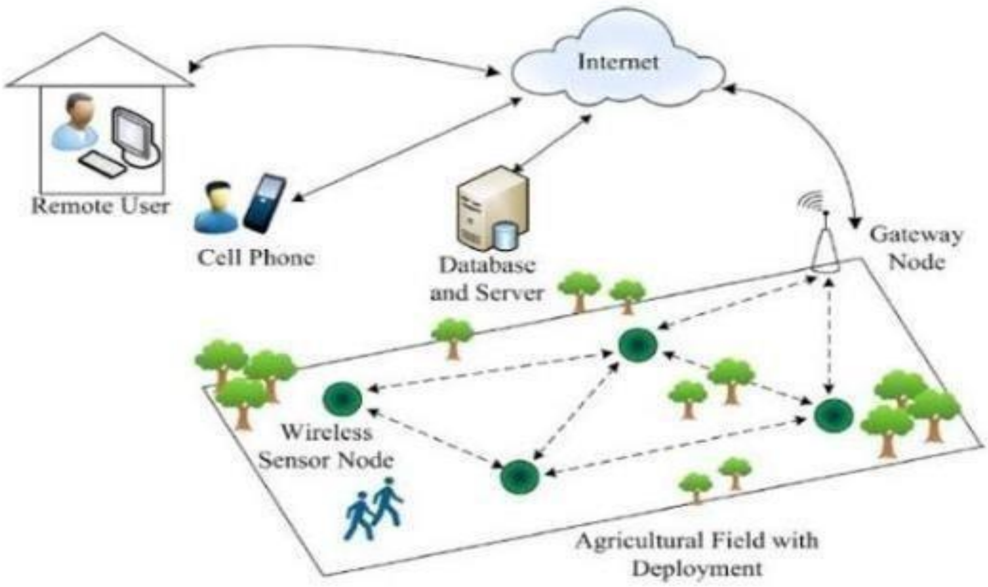

Fig. 1: A typical wireless sensor network deployed for agricultural application

Typically, a gateway node is also deployed along with the sensor nodes to enable a connection between the sensor network and the outer world. Thus, the gateway node is powered with both RF and Global System for Mobile Communications (GSM) or GPRS. A remote user can monitor the state of the field, and control the on-field sensors and actuator devices. For example, a user can switch on/off a pump/valve when the water level applied to the field reaches some predefined threshold value. Users carrying mobile phone can also remotely monitor and control the on-field sensors.The mobile user is connected via GPRS or even through Short Message Service (SMS). Periodic information update from the sensors, and on-demand system control for both type of users can also be designed.

B. WIRELESS UNDERGROUND SENSOR NETWORKS

Another variant of the WSNs is its underground counterpart — Wireless Underground Sensor Networks (WUSNs) .In this version, the wireless sensors are planted inside soil. In this setting, higher frequencies suffer severe attenuation, 100 and comparatively lower frequencies are able to penetrate through the soil. Thus, communication radius gets limited and the network requires higher number of nodes to cover a large area. The application of wired sensors increases the network coverage by requiring relatively smaller number of sensors. However, in this design, the sensors and the wires may be vulnerable to farming activities.

A typical agricultural application based on underground sensor networks is shown in Figure a. Unlike the TWSN-based applications shown in Figure 1, in this figure, the sensor nodes are buried inside soil. One gateway node is also deployed to transmit the information collected by the underground sensor nodes to the surface sink placed over the ground. Thereafter, the information can be transmitted over the Internet to store in remote databases, and can be used for notifying a cell phone carrying user. However, due to comparatively shorter communication distance, more number of nodes are required to be deployed for 109 use in WUSNs.

C. USEFULNESS OF WSNS

In the following, we highlight the salient features of WSNs that have enabled themselves as a potential tool for automation in the agricultural domain.

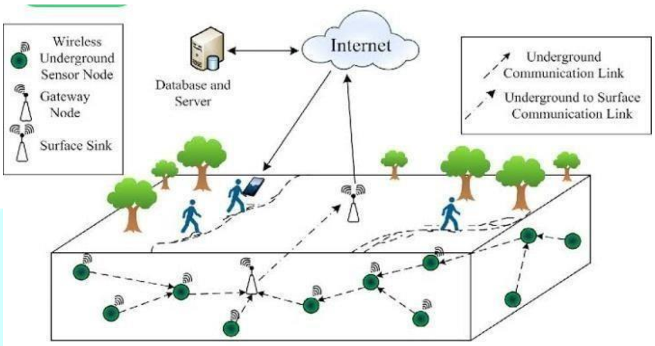

Fig. 2: typical wireless underground sensor network deployed for agricultural applications

Intelligent decision making capability: WSNs are multi-hop in nature. In a large area, this feature enhances the energy efficiency of the overall network, and hence, the network lifetime increases. Using this feature, multiple sensor nodes collaborate among themselves, and collectively take the final decision.

Dynamic topology configuration: To conserve the in-node battery power, a sensor node keeps itself in the ‘sleep mode ’most of the time. Using topology management technique the sensor nodes can collaboratively take these decisions. To maximize the network lifetime, the network topology is configured such that the minimum number of nodes remain in the active mode .

Fault-tolerance: One common challenge in deploying the WSNs is that the sensor nodes are fault-prone. Under such circumstances, unplanned deployment of nodes may lead to network partitioning, and in turn, the overall performance of the network is affected.

However, in countermeasure, the sensor nodes can ‘self-organize’ by dynamically configuring the network topology.

Context-awareness: Based on the sensed information about the physical and environmental parameters, the sensor nodes gain knowledge about the surrounding context. The decisions that the sensor nodes take thereafter are context-aware.

Scalability: Generally, the WSN protocols are designed to be implemented in any network irrespective of its size and node count. This feature undoubtedly widens the potential of WSNs for numerous applications.

Node heterogeneity: WSNs are often assumed to be comprised of homogeneous sensor attached devices. However, in many realistic scenarios, the devices are heterogeneous in respect of processing and computation power, memory, sensing capability, transceiver unit, and movement capability.

Tolerance against communication failures in harsh environmental conditions: Due to the wide range of applications in open agricultural environments, WSNs suffer the effects of harsh environmental conditions. The WSN protocol stack includes techniques to withstand the effect of communication failures in the network arising due to environmental effects. (viii) Autonomous operating mode: An important feature of WSNs is their autonomous operating mode and adaptiveness [95]. In agricultural applications, this feature certainly plays an important role, and enables an easy as well as advanced mode of operation.

Information Security: The WSNs carry raw information about on-field parameters. To ensure the security of sensed information, WSNs provides access control mechanisms [96] and anomaly detection [97] to restrict unauthenticated users.

III. DESIGN OF A WIRELESS SENSOR NETWORK FOR AGRICULTURAL APPLICATIONS A. NETWORK ARCHITECTURE FOR AGRICULTURE APPLICATIONS

In this section, we discuss the network architecture considered in various agricultural applications. We classify the architectures in various categories and highlight the potential agricultural applications suitable for each one. Figure 3 provides a visual depiction of the architectures classified with respect to different parameters.

Based on the movement of the networked devices and nodes, we classify the existing architectures in the following categories:

Stationary Architecture: In the stationary architecture, the sensor nodes are deployed at a fixed position, and during the application duration, they do not change their position. Typically, applications such as irrigation management system, ground water quality monitoring, and controlling the use of fertilizers require stationary architectures. In such applications with TWSNs, the data logger (data collector) sensor nodes are typically placed over the field. However, in WUSNs, the data collector sensor nodes are placed under-ground. Also, as shown in Figure 2, aggregator nodes may be placed under-ground to collect all the data of the underground sensors and communicate with the outside TWSNs.

Mobile Architecture: Mobile architectures comprise of devices which change their position with time. An example of applications based on such architecture will be an autonomous network of tractors and cell phone carrying farmers serving the purpose of ubiquitous farming operations.

Hybrid Architecture: In the hybrid architecture, both stationary and mobile nodes are present. For example, architecture is applicable to farming applications consisting of stationary field sensors, mobile farming equipment's, cell phones carrying users, and moving cattle.

B. ARCHITECTURE OF SENSOR NODES

***1. EMBEDDED MULTI-CHIP SENSOR NODES**:* The components of a typical multi-chip sensor node are shown in Figure 5(a). Typically, a sensor node consists of an application-specific sensor array with a transceiver unit for communication. A processor or micro-controller unit is used as the "brain" of the node. Optionally, a sensor board includes memory units to store data.

Depending on the application demand, the architecture of the sensor nodes varies to meet the demands. For example, the processing power and on-board memory size are increased to meet the requirements of more intense or intelligent processing. In this respect, another important technology is System-in-Package (SiP), which is defined as any combination of multiple chips including passive components (such as resistors and capacitors) mounted together keeping provision to attach external components later. SiP reduces the product cost with optimized size and performance. Thus, the SiP technology has potential for applications in agricultural scenarios. SiP based agricultural systems can be applied in different applications simply by attaching different sensors with the main package.

In the following, we discuss the associated factors in the selection of the components of a sensor node as per the requirement of agricultural applications.

Processor**:* The computation power of the sensor node solely depends on the choice of the processing unit. A micro-controller provides few advantages such as low cost, flexibility to communicate with other nodes, ease of programming, and low power consumption over the traditional processors. Mostly, these micro-controllers work on 3.5–5 V . However, power consumption is one of the most important factors in sensor nodes. Considering this fact, micro-controllers are preferred over general purpose processors. ***Transceiver: Transmission and reception are the two major reasons of energy consumption in sensor nodes. In agricultural applications, the network planner chooses the deployment to ensure optimal power consumption of the sensor nodes.

Memory: The sensor nodes have two types of on-board memory — memory associated with processor and external memory. Depending on the application requirement, sensor nodes need to store historical data for intelligent decision making. In this regard, flash memories are used for additional storage.

Power: It is also an important factor for selecting the sensor nodes, as the battery power of the sensor nodes is limited. In many agricultural applications, the nodes possess alternate energy sources such as solar power. However, solar power is available during the day time only, and at other times, the nodes rely on battery power. Also, frequent change of battery increases the cost of maintenance. Thus, we need energy-efficient algorithms such that the energy consumption of the sensor nodes are reduced.

***Cost**:* One very important selection factor of the sensor nodes is the total hardware cost. A low cost application design is always preferred for any application level, and consequently, it is the most important issue in terms of applications

targeting the low and middle income country (LMIC) markets.

2. *SYSTEM ON CHIP (SOC) SENSOR NODES*:

The system-on-chip (SoC) architecture, on the other hand, follows more application specific design targeting minimization of the power requirements and design cost. SoC provides an integration of multiple programmable processor cores, co-processors, hardware accelerators, memory units, input/output units, and custom blocks. Figure 5(b) shows the components of a typical SoC based sensor node. The envisioned applications for SoC is mainly in designing Network on Chips (NoCs) systems for multimedia and streaming applications which are computationally intensive.

Currently, in agricultural applications, the use of SoCs are very rare. However, the advent of SoC has a lot of potential for the agriculture and farming domain. Firstly, the use of So Cs based sensor nodes instead of current day embedded multichip sensor nodes will increase the computation power, and decrease the energy-consumption. Also, the size of the nodes will be less and thereby, portability of the overall system increases. Compared to multiple silicon dies in SiP, SoC is single die based, and thus, SoCs result in lesser size, but, higher cost.

IV. FUTURE WORK DIRECTIODIRECTION

A. Factors for Improvement

The factors associated with WSNs that need further attention in the future are listed as follows.

- Cost: A low cost solution is always desirable for increasing the scope and outreach of the applications.
- Autonomous Operation: The future solutions should include the provision for autonomous operations surviving for long time.
- Intelligence: An inherent intelligence, which will enable the futuristic solutions to react dynamically to multiple challenges – from conserving energy to real-time response.
- Portability: For easy of application, portability of the system is essential. Recent advances in embedded systems, such as System in package (SiP) and System on Chip (SoC) technologies will help in this regard.
- Low Maintenance: It is essential to design a system which require minimum maintenance effort. This will certainly minimize the average cost in the long run.
- Energy-efficiency: To ensure extended lifetime with autonomous operation, the solutions need to be more energy-efficient by incorporating intelligent algorithms.
- Robust Architecture: A robust and fault-tolerant architecture for the emerging applications is required to ensure sustained operation.
- Ease of Operation: Typically, the end users of these applications are non-technical persons. Therefore, these applications need to be simple and easy to use.
- Interoperability: Interoperability between different components and different communication technologies will enhance the overall functionality of the system.

In addition to the global challenges, there are specific problems in Indian scenarios with respect to the agricultural WSN systems. We list few India specific challenges in the following.

- Cost: The high cost of the sensors and associated systems is the major deterrent for these applications in the LMICs.
- Variable Climate & Soil: The most challenging part in designing a WSN-based system for agriculture for India is the different temperature and soil types throughout the country. The application parameters are required to be tuned such as to function properly at different locations.
- Segmented Land Structure: Unlike the USA, India has partitioned farming land, a specific challenge which demands suitable deployment architecture for WSN-based agricultural applications like irrigation management.

B. Futuristic Applications

In recent times, with the advent of the new technical concepts such as sensor-cloud technology, big-data analytics, internet of things (IoT), new applications are envisioned. We briefly describe such concepts, and enlist a few potential futuristic applications in the following.

• Sensor-cloud Computing: Sensor-cloud computing refers to the on-field WSN applications empowered with cloud computing. This integrated framework benefits the WSNs with improved processing power and storage capacity.

Furthermore, sensor-cloud improves the data management and access control while increasing the resource utilization. Few potential application for the agricultural domain are,

– A cloud-enabled storage of spatial variation of soil and environmental profile with respect to different seasons is need to be developed.

– Crop health monitoring and yield prediction using mobile sensor-cloud services.

– Designing a sensor-cloud controlled smart irrigation system for large fields.

– To design a sensor-cloud operated environment control system for off-season production of vegetables and flowers in greenhouse farming.

• Big-data analytics: Big-data analytics techniques are applied to find meaningful insight from large volume of data with various data types. Big-data analytics based techniques are helpful for finding hidden correlations, unknown patterns, business trends, customer preferences, detecting crimes and disasters, etc. We list few big-data application for the agricultural domain as, – Building crop growth and disease management models based on farm data.

– Designing a web-enabled analytics service for the farmers to provide improved information on agriculture.

– Easy farming equipment control system for large-scale agriculture

– Decision support service to improve crop productivity with optimal cost considering a large-scale contextual agricultural and climatic information.

– Optimal policy determination based on data analytics for government and industries.

• Internet of Things: IoT extends the ubiquitous computing concepts with heterogeneous smart devices or ‘things’ integrated with interoperable communication technologies. The IoT paradigm defines ‘things’ which are capable of identifying, communicating and interacting with their surrounding. Empowered by these pillars, IoT provides flexible control mechanism for on-field parameters in real-time. Due to this, IoT is a potential solution for various agricultural applications. Few potential IoT-based agricultural applications are,

– Cost-effective agricultural supply chain management using RFID tags.

– Remote monitoring of animal movement in open pastures.

– Automated pest counting and remote reporting in farms.

– Remote control and scheduling of pesticide sprays at an user-defined rate and time.

– Leak detection and remote water flow control in large-scale agricultural field water supply.

V.RESULT

The inclusion of WSNs is envisioned to be useful for advancing the agricultural and farming industries by introducing new dimensions. In this survey, we present a comprehensive review of the state-of-the-art in WSN deployment for advanced agricultural applications. First, we introduced the variants of WSNs — the terrestrial WSNs and underground WSNs. Then, we highlighted various applications of WSNs, and their potential to solve various farming problems. The consecutive sections of this paper presented the network and node architectures of WSNs, the associated factors, and classification according to different applications. We review the various available wireless sensor nodes, and the different communication techniques followed by these nodes. Then, using case studies, we discussed the existing WSN deployments for different farming applications, globally and in India. Finally, we presented the prospects and problems associated with the existing applications. Finally, we listed several directions for future research with associated factors for improvement.

The survey of the existing works directs us in concluding few remarks. The current state-of-the-art offers WSN-based solutions for irrigation management, crop disease prediction, vineyard precision farming mostly. Simplified, low cost, and scalable systems are in demand, specifically for the LMICs. At the same time, with the advent of modern technologies, there exist a lot of scope for innovating new and efficient systems. Specifically, low cost solution with features like autonomous operation, low maintenance is in demand. Overall, futuristic pre-planning is required for the success of these application specifically to overcome the problems in global as well as LMICs.

ACKNOWLEDGMENT

We thank our Principal and faculties from Samarth group of Institutions College of Engineering Belhe who provided insight and expertise. We express our sincere thanks to Prof. Rahul Satpute whose supervision and inspiration as well as valuable discussion and constructive criticism provide during the paper. We are also thankful to Prof. Nirmal S.Kothari, HOD (E&TC) his constant guidance. We shall ever be grateful to his for the encouragement and suggestions given by his from time to time.

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