Review of Multiparameter Techniques for Precision Agriculture Using Wireless Sensor Network

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Abstract – The main focus of Precision Agriculture is to draw out the attention to make the availability for controlling, monitoring and exploring the agricultural practices. Wireless Sensor Network system, equipped with reasonable software characteristics and hardware configuration, is a competent choice for Precision Agriculture. For PA well-suited with WSN, an efficient and reliable technique is strongly recommended that could preserve energy and improve the network lifetime. Thus, a well-designed assembly of WSN in PA can be an efficient solution for developing countries like India. The network lifetime and energy efficiency are the chief issues to be considered.

Index Terms – Wireless Sensor Network, Network Lifetime, Energy Efficiency, Agriculture.

1. INTRODUCTION

1.1 Precision Agriculture

I. Mampentzidou et al. [30, 2012] stated Precision Agriculture (PA) as the technique to decipher, to estimate and to evaluate the condition of the crops aiming to know about the effective use of fertilizers and the requirements to water the fields at the time of sowing and harvesting period. PA may be defined as the streamlined process of agriculture by applying proper quantity of water, fertilizer, pesticide etc. at proper place in order to enhance the yield of good quality by following ideal conditions of the environment.

1.2 Wireless Sensor Network

I. F. Akyildiz et al. [1, 2002] described Wireless Sensor Network (WSN) as a network composed of low-cost, low-power and low-memory, small computational capacity, multi-functional nodes, called sensors. These nodes are minute in dimension. These nodes can intellect the data, process the collected data and communicate with each other in a collaborative manner within small displacements. These nodes are great in number. The schematic diagram of a WSN is depicted in figure 1.

A WSN itself is a very minute body or an infrastructure of almost beyond concrete experience. Generally, the sensor nodes are heavily installed intermittently in the vicinity of the phenomenon in a manner which is not pre-determined. So the sensor network algorithms and protocols have to exhibit self-configuring potential. However, the sensor nodes may fail at any stage due to certain reasons. Also, the sensor network alters its topology very often. The sensor nodes do not enclose universal credentials due to their huge number and bulk overhead involved. The sensor nodes can be employed to sense the locations constantly, detect the events, identify the events and perform confined control of actuators.

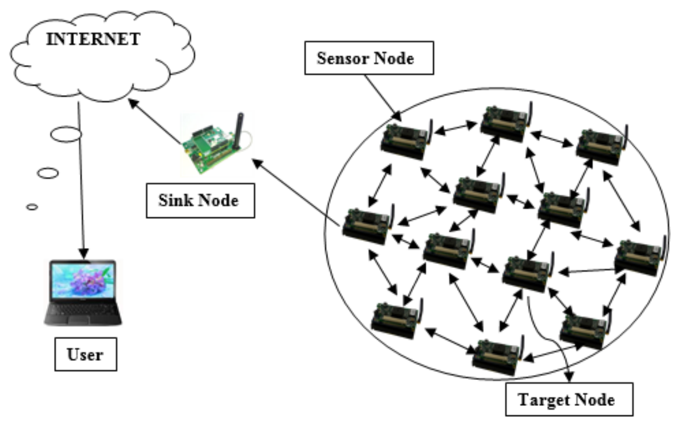

Figure 1: Wireless Sensor Network

1.3 Precision Agriculture using Wireless Sensor Networks

The rudiments in deployment of Wireless Sensor Networks for Precision Agriculture are discussed by I. Mampentzidou et al. [30, 2012]. The main components existing in utility of WSN systems, such as node platforms, operating systems, power supply, etc. are reviewed. Before applying the practice of WSNs in agriculture especially in crop monitoring, certain guidelines are proposed. In PA, the scenario should be clear for the deployment of WSN in a Greenhouse or in an open space. One should be clearheaded about the monitoring of the specific crop. There must be a precise summary of the crop that is to be observed. The most common decisive agricultural parameters are soil moisture, soil temperature, water retention capacity, salinity, leave photosynthesis, leave temperature, leave moisture, wetness, weather humidity, atmospheric pressure, wind speed and wind direction etc. The choice of the kind of sensors for exploitation depends on the precision, resolution, communication range, energy utilization, meticulousness and cost etc.

By and large, PA in consonant with WSNs will play a vivacious role and contribute to improve the growth of the crop and therefore the yield. The repercussion of the above mentioned technology if deployed in an efficient manner will enhance the revenue of the country, the remunerating capacity and the general health of the common man. In a nutshell, this particular technology will come to the expectations of the peasantry and will progress by leaps in the future.

2. LITERATURE REVIEW

"P. C. Robert [2, 2002] discussed about the emergence of Precision Agriculture in the mid-1980s, using newly available technologies, to improve the application of fertilizers by varying rates and amalgams as needed within fields. It offers a variety of potential benefits in profitability, productivity, sustainability, crop quality, food safety, environmental protection, on-farm quality of life, and rural economic development.

G. Mercier et al. [3, 2005] suggested developing a technique that allows high or low variations detected at a regional scale to be assessed from the two sensors: SPOT VEGETATION and SPOT High Resolution Visible InfraRed (HRVIR) images. In this study, the link between the images from is achieved from the design of an artificial neural network method based on Kohonen self-organizing map. N. Wang et al. [4, 2006] presented an outline on the development of WSN technology and its use in agriculture and food industry. The merits and demerits regarding fast adoption are also discussed.

The efficiency of a proposed topology to build a WSN, based on measuring the electrical conductivity of the field, is discussed by K. Konstantinos et al. [5, 2007]. The work tells how electrical conductivity influences the decision to build the WSN topology. T. L. Dinh et al. [6, 2007] stressed the WSN deployment to monitor the real time water quality measurements together with the amount of water being pumped out in the area, and to investigate the impacts of current irrigation practice on the environment, in particular underground water salination.

Y. Kim et al. [7, 2008] recommended the design and instrumentation of variable rate irrigation, a WSN and software for real-time in-field sensing and control of a site specific precision linear move irrigation system. The communication signals from the sensor network and irrigation controller to the base station are successfully interfaced using low-cost Bluetooth wireless radio communication. For PA, A. Dwarakanath et al. [8, 2008] stressed the applicability of WSNs where real time data for meteorology and atmospheric possessions are sensed and imparted to the sink. The real time deployment of WSN based greenhouse management is recommended by X. Li et al. [9, 2008] to realize the modernization in agriculture. The system is capable to monitor the nature of greenhouse atmosphere, to control the equipments, and to provide better services to customers with compact devices.

K. H. Kwong et al. [10, 2009] opined on the application of WSNs for monitoring the livestock and the issues regarding hardware realization. The main purpose of the study is to employ reasonable and efficient sensor nodes having the capability of providing real-time communication at cheaper hardware cost. L. Bencini et al. [11, 2009] recommended the utility of a practical case study, starting from a real problem and reaching the best architectural solution, with particular focus on the hardware implementation and communication protocol design. J. Zhang et al. [12, 2009] discussed the classification of the existing routing protocols for WSNs. The comparison and analysis research are also provided on route structure, energy consumption, robustness, expansibility, node mobility, data fusion technology, whether QoS is supported and maximizing the network lifecycle of all kinds of routing protocols.

An experimental agro-meteorological sensor based wireless distributed network is described by P. Mariño et al. [13, 2010]. The purpose is to provide real measurements to validate the different biological models used for viticulture applications. H. Sahota et al. [14, 2010] recommended the utility of MAC and Network layers for a WSN deployed for PA application as it needs the collection of sensor readings periodically from pre-set locations in a field. The design of an agricultural environmental monitoring system with sensor technology is proposed by L. Xiao and L. Guo [15, 2010]. The system is capable to monitor the environmental conditions such as temperature, humidity, and light intensity pertaining to agriculture. An intelligent water-saving system based on ZigBee WSN for agricultural irrigation strategy is proposed by Z. Yao et al. [16, 2010]. It provides science basis for using water resources under the technologies of soil moisture sensors, air temperature sensors, precise irrigation equipments, intelligent controller, and computer-controlled devices.

G. H. E. L. D. Lima et al. [17, 2010] focused the research on the integration of existing computer tools in order to establish an application development environment for WSN, uniting the robustness of programming languages with the usability of a friendly interface. The case study encompasses the developed simulation environment applied to the irrigation of soccer fields. Z. Li et al. [18, 2010] discussed the use of 2.4GHz wireless sensor modules to set up a test platform to evaluate the data transmission performance. Indexed packets transmitted from a module are received by another equal module to calculate packet delivery rate (PDR). Canopy height, transmitter height, receiver height and transmitter-to-receiver distance are considered as impact factors on data transmission.

The results indicated that, with the increase of the plant height, path-loss and PDR became more correlated with each other.

R. A. Santos et al. [19, 2011] evaluated a new WSN platform and its application in PA. To validate the technological platform and the embedded operating system, hierarchical and flat routing strategies are tested in a small-scale network applied to a watermelon field. This incorporates a modified version of a wireless location-based routing algorithm that uses cluster-based flooding. The modified algorithm includes a metric to monitor residual battery energy. The results show that the new version functions better with the flat algorithm in a small-scale agricultural network. A. U. Rehman et al. [20, 2011] demonstrated the work to reassess the requirement and relevance of WSN technology in various phases of agricultural domain and to report on existing system structures.

Y. D. Kim et al. [21, 2011] proposed a new WSN architecture with autonomous robots based on beacon mode for real time agriculture monitoring system. For the large scale multi-sensor processing, the proposed system accomplished the intelligent database, which generates alert messages to the handheld terminal by means of the sensor data. S. E. Díaz et al. [22, 2011] discussed the methodology consisting of a set of well-defined phases that cover the complete life cycle of WSN applications for agricultural monitoring. J. Xia et al. [23, 2011] recommended the design by deploying a monitoring system based on WSN for PA in a red bayberry greenhouse especially in a hilly area. It automatically collects the data - temperature, humidity, illumination, voltage and other parameters and transfers the data to the remote server through GPRS.

S. Li et al. [24, 2011] suggested the design of a WSN for PAMS (Precision Agriculture Monitor System) to monitor the atmospheric conditions of the crops. P. Patil et al. [25, 2011] suggested an automatic irrigation monitoring system for PA. It regulates the required moisture level in agricultural soil. It also proves useful in both dry and heavy rainfall conditions. Y. Jiber et al. [26, 2011] suggested the iFarm framework to monitor the extensive agriculture over a vast area, to reduce the infertile land with better management of water in order to improve the paying capacity of farmers by providing the awareness time to time and planning the crop yields. X. Liu et al. [27, 2011] recommended the use of a new Efficient and Portable Reprogramming Method (EPRM) by using pre-linked native code to reduce memory footprint and by the way to reduce the energy consumption. To validate this new approach, EPRM is implemented and its efficiency in terms of resource consumption (memory and energy) is evaluated. The obtained results show that EPRM is well adapted to high resource-constraint wireless sensor nodes.

A fuzzy decision-making method of irrigation amount based on Evapo-Transpiration (ET) and Soil Water Potential (SWP) is designed by Z. Wei et al. [28, 2011]. The WSN is used to transmit the irrigation control signal including the SWP signal and the relative humidity, air temperature, solar radiation, wind velocity etc. The test results show that the method and hence the system have economic advantages with high communication reliability and control accuracy. L. Karim et al. [29, 2011] proposed Energy Efficient Zone-based Routing Protocol (EEZRP) that works by deploying a minimum number of sensor nodes for agricultural monitoring in developing countries. Experimental results show that EEZRP protocol outperforms the existing LEACH and DSC protocols in terms of network lifetime.

M. K. Gupta et al. [31, 2012] demonstrated the growth of tomato seedlings under greenhouse conditions. The microenvironment of the seedlings (temperature and solar radiation) is correlated with the seedling growth factors. Seed emergence is studied for five different temperatures, and a mathematical model is developed to fit the data to determine relationship between seed germination and soilless medium temperature. In post-emergence phase, a model is developed to estimate the dry weight attained by the seedlings as a function of cumulative heat units and cumulative solar radiation. N. Rajput et al. [32, 2012] submitted the report after surveying the land area used for apple farming. The work also discussed several obstacles encountered using WSNs for apple farming. A. Mittal et al. [33, 2012] proposed mKRISHI platform for WSN for deprived farmers for modern agricultural applications. The proposed framework deployed over a period of two months shows very good results. F. Philipp et al. [34, 2012] proposed an adaptive sensor node system combining a flexible hardware prototype and innovative energy harvesting technique to optimise the performance of the network operating in a large farming environment.

A state-of-art technology with solutions pertaining to PA is demonstrated by J. M. B. Ordinas et al. [35, 2013]. The applications and experiences of the work enlighten how WSNs can be used for agricultural purposes. B. Singh et al. [36, 2013] recommended the fertilizer nitrogen application to irrigated wheat in two split doses at planting and at crown root initiation stages of the crop. The wheat grain yield at maturity is determined by the level of greenness of leaves at MT stage - whether measured by a chlorophyll (SPAD) meter or an optical sensor (GreenSeeker). J. Jao et al. [37, 2013] suggested the use of sensor technology to collect the moisture content in the soil. The work enlightens the comprehensive design to package the sensor nodes for external development and shows the collected data to validate the design. The results are obtained by using sand soils with different water conditions.

P. Tokekar et al. [38, 2013] discussed the problem of coordinating an Unmanned Aerial Vehicle (UAV) and an Unmanned Ground Vehicle (UGV) for a PA application. In this work, the ground and aerial measurements are used for estimating Nitrogen (N) levels on-demand across a farm. The goal is to estimate the N map over a field and classify each point based on N deficiency levels. These estimates in turn guide fertilizer application. The constant-factor approximation algorithms are used. Finally, utility of the system is demonstrated with appropriate simulations. E. Kampianakis et al. [39, 2013] proposed the design of a novel WSN consisting of low-power and low cost sensor nodes, deployed in a bi-static architecture and achieving long-range backscatter communication. The backscatter sensor network performs environmental monitoring over a relatively wide area. A proof-of-concept prototype WSN application is developed for capacitive relative humidity sensing.

G. Ngandu et al. [40, 2013] performed the experiments to determine the effect of surrounding vegetation on the wireless signal in terms of link reliability, and signal strength for three different types of agricultural crops, namely, ground foliage, medium height and density vegetation, and very dense types of foliage is analysed and discussed. The objective is to demonstrate that current radio propagation foliage loss models are not optimised for use in PA. X. Dong et al. [41, 2013] suggested the use of a proof-of-concept towards an autonomous precision irrigation system provided through the integration of a centre pivot irrigation system with Wireless Underground Sensor Networks (WUSNs). The results highlight that the wireless communication channel between soil and air is significantly affected by many spatio-temporal aspects, such as the location and burial depth of the sensors, soil texture and physical properties, soil moisture, and the vegetation canopy height.

A. L. Diedrichs et al. [42, 2014] presented the development of a low-cost and low-power WSN based on IEEE-802.15.4, for frost characterization in PA by measuring temperature. The key objective is to reduce the power consumption of the network. The design and development of an agricultural controlling system using WSN is recommended by B. B. Bhanu et al. [43, 2014] to enhance the yield and to improve the quality of farming without observing it for all the time manually. M. R. M. Kassim et al. [44, 2014] considered WSNs as the superlative way to solve the agricultural problems pertaining farming resources, decision making support, and for monitoring the land. The proposed work focused on the software practice management, metalwork structural design and set-up style of the system.

S. R. Nandurkar et al. [45, 2014] presented the design to provide simple, easy-to-operate, credible and reliable technology within the reach of every farmer to conserve the ground water resources. K. K. Khedo et al. [46, 2014] proposed the implementation of a PA application, PotatoSense, for monitoring a potato plantation field in Mauritius. Different energy efficient algorithms are used to ensure that the system lifespan is prolonged. Additionally, a monitoring application is developed to process the data obtained from the simulated WSN. The monitoring application is able to indicate the regions of the potato field that need irrigation, pesticides or fertilizers. I. Mat et al. [47, 2014] presented a practical, low-cost and environmental-friendly Greenhouse Monitoring System based on WSN technology, to monitor the key environmental parameters such as the temperature, humidity and soil moisture.

M. Biglarbegian and F. A. Turjman [48, 2014] discussed the strategy of Cognitive Path Planning for mobile Data Collectors in WSNs to efficiently collect the sensed data in a PA application. Energy consumption is the major attribute that impacts the performance of the proposed approach. W. Yitong et al. [49, 2014] presented the design of a multi-parameter wireless monitoring system. The experiment proved that the system could completely meet the daily PA for crop growth environment and the requirements of monitoring on the soil composition content, and the system had high reliability. C. Wang et al. [50, 2014] described an RFID sub-soil system that is capable of hosting a range of sensors and communicating their measurements wirelessly to farming vehicles. The work describes the implementation of a prototype sensor node and the implementation of the RFID reader using National Instruments PXI RF modules controlled using LabVIEW.

T. Nakanishi [51, 2014] suggested the use of a generative WSN framework that can satisfy the requirements and constraints of individual farmers within a prescribed scope. H. Sahota and R. Kumar [52 and 53, 2014] presented the network based localization of sensors, placed in multiple media, based on the measurements of received signal strength and time of arrival. The localization problem is formulated with the goal of parameter estimation of the joint distribution of the ranging measurements. The study presented a sensitivity analysis of the estimates with respect to the soil complex permittivity and magnetic permeability.

M. H. Anisi et al. [54, 2015] classified and described the state-of-art of WSNs and analyse the respective energy consumptions based on their power sources. WSN approaches in PA are categorized and discussed according to their features. C. T. Kone et al. [55, 2015] proposed to properly tune IEEE 802.15.4 MAC parameters and the sampling frequency of deployed sensor nodes. An analytical model of network performance is derived and used to perform the tuning of these trade-off parameters. Simulation analysis shows that the scheme provides an efficient increase of sampling frequency of sensor nodes while satisfying application requirements. A. R. D. L. Concepción et al. [56, 2015] proposed an innovative solution for the realization of WSNs suitable to characterize the microclimatic behaviour in agriculture fields. The nodes equipped with sensing units to measure several physical parameters, are designed in order to minimize power consumption.

E. L. Pontes et al. [57, 2015] suggested analysing some methods to locate and increase the lifetime of a sensor network through its potential application in PA. V. T. Varghese et al. [58, 2015] presented a survey of WSN systems deployed for the agricultural domain. Keeping in mind, the working methodologies and the drawbacks of existing systems, a new WSN approach for estimating crop yield is proposed.

N. Chen et al. [59, 2015] discussed the overview of an integrated geospatial sensor web for agricultural soil moisture monitoring in China. The satellite sensors, in-situ sensors, and WSNs are firstly coupled by sensor web based cyber infrastructure. Then multisensory collaboration methods are designed to make full use of these different monitoring capabilities. In addition, web processing service is utilized to achieve online soil moisture estimating, fusing, and mapping. Finally, an integrated online service platform is constructed to query and display all soil moisture related resources. The experiments conducted in Hubei province demonstrated that this region's agricultural soil moisture monitoring capability is improved in terms of spatial temporal continuity and accuracy.

M. Joordens et al. [60, 2015] suggested the utility of a fully autonomous aerial and ground system that would provide efficient and cost effective retrieval of soil and vegetation data for use in PA. The aerial system will survey the site and collect spectral imagery to analyse plant density, stress and nutrition. The ground sensors will collect soil moisture content readings throughout the site. The data from both systems will be collated at a central base station. The base station will also provide housing and interface with the aerial system.

J. A. Jiang et al. [61, 2016] proposed a WSN based controlling platform with dynamic converge-cast tree topology based approach for precision agriculture management in orchid greenhouses for reliable data acquisition. This comprises a springy scheduling based scheme for the MAC protocol to attain greater communication reliability. A ubiquitous WSN framework using Internet technologies and Smart Object Communication Patterns was demonstrated by F. J. F. Pastor et al. [62, 2016] which proved to be beneficial in terms of cost and power consumption."

Table 1. Summarized Table of Existing Techniques for Precision Agriculture using Wireless Sensor Networks

Reference	**Author(s)**	**Technique Used**	**Advantages**	**Limitations**
[3, 2005]	G. Mercier et al.	Multi-Source Multi-Resolution Image Fusion by Covering Soils with Vegetation	-Reduces water pollution -Restricts the pollutant fluxes to aquatic systems -Protects soils from raindrop impact and splash -Allows excess surface water to infiltrate -Consumes some of the excessive nitrogen in soils	-Limits the location accuracy of the land cover classes
[5, 2007]	K. Konstantinos et al.	Topology Optimization based on Measuring the Field's Electrical Conductivity	-Finds the optimal sensor topology	-Lack of electrical conductivity measurement locally -Absence of evaluation of the performance of using a mixture of network topologies
[6, 2007]	T. L. Dinh et al.	Underground Water Content and Saline Level	-Monitors the quality of water	-Saltwater intrusion should be minimised -Network connectivity is to be improved -Network outage needs to be handled efficiently
[7, 2008]	Y. Kim et al.	Variable Rate Watering	-Enhances application efficiencies -Reduces environmental impacts -Provides stable wireless connectivity	-Requires to support the assimilation of efficient watering mechanism and effective synthesis of sensors

[8, 2008]	A. Dwarakanath et al.	Controlling Irrigation and Fertigation by Controlling Agricultural Parameters	-Optimizes the network topology -Communication efficiency	-Supports only static hierarchical architecture -Not suitable for high mobility environments
[10, 2009]	K. H. Kwong et al.	Cattle Observing	-Real time health monitoring	-Needs improvement in the field of visceral prosperity and operating proficiency
[11, 2009]	L. Bencini et al.	Monitoring Physiology and Pathogens Control	-Prevents plant vine diseases -Vineyard water management -Pest management -Reliable	-Needs to be extended to support decision making mechanism by implementing Decision Support System (DSS)
[12, 2009]	J. Zhang et al.	Dynamic Clustering	-Organizational management of nodes -Network scalability	-Leads to high transmission power and therefore high or uneven energy consumption -Reduces load balance degree of the network -Influences lifetime of the network
[13, 2010]	P. Mariño et al.	Instrumentation of Biological Models	-Risk prediction -Disease assessment	-Fails to detect other threatening pests -Crop tracking needs to be upgraded
[14, 2010]	H. Sahota et al.	Designing MAC and Network Layers using A New Wake-Up Synchronization	-Saves energy during wake-up synchronization -Balances load balance degree of network -Minimizes the energy consumption	-Fails in fault detection and fault mitigation
[15, 2010]	L. Xiao and L. Guo	Self-Motivated Clustering	-Energy efficiency -Improves network longevity	-Not robust in terms of packet delivery -Requires an Event-Condition-Action framework
[16, 2010]	Z. Yao et al.	Monitoring Water Level	-Optimal scheduling -Improves efficiency	-Real time deployment has not been performed
[18, 2010]	Z. Li et al.	Correlation Analysis on Impact Factors of Data Transmission	-Evaluates the data transmission performance	-Deals only with the path loss as QoS indicator -Absence of evaluation of other QoS factors such as packet delivery rate and spatial resolution
[19, 2011]	R. A. Santos et al.	Localization of Nodes with Cluster-based Flooding	-Monitors residual battery energy	-Lack of impacts posed by QoS parameters -Deals with limited power management
[21, 2011]	Y. D. Kim et al.	Bonfire Custom founded Designing Self-Directed Automatons	-Energy efficiency -Reliable -Handles unanticipated failures in communication links	-Non-existence of effects posed by QoS parameters

			-Ensures recovery of transmission path	
[23, 2011]	J. Xia et al.	Monitoring Various Agronomic Parameters	-Network scalability -Stable -Delivers accurate service -Energy preservation	-Needs to synchronize with respect to time -Requires the concept of localization of nodes
[26, 2011]	Y. Jiber et al.	Decision Support System for Land Monitoring	-Improves land productivity -Optimizes the use of resources -Efficient watering mechanism -Controls disease -Predicts and plans yield of the crop -Considers socio-economic factors	-Fails to reveal the agronomical and technological factors
[27, 2011]	X. Liu et al.	Efficient and Portable Reprogramming Mode	-Reduces memory footprint -Reduces energy consumption -Efficient consumption of resources -Implementation effectiveness	-Inapplicable in heterogeneous environments
[28, 2011]	Z. Wei et al.	Determining Water Volume by Computing Evapo-Transpiration and Water Retaining Capacity of Soil	-High communication reliability -Accuracy control	-Lacks in accuracy of the imprecise computations
[29, 2011]	L. Karim et al.	Zone-based Routing Localization	-Energy efficiency -Extends network lifetime -Fault tolerance	-Lack of link recovery mechanism -Requires Decision Support System (DSS)
[33, 2012]	A. Mittal et al.	Received Signal Strength Indication	-Improves communication range -Energy efficiency -Enhances the overall network lifetime -Reduces the maintenance overhead	-Issues related to throughput, scalability, latency and security are to be resolved
[34, 2012]	F. Philipp et al.	Hybrid Heterogeneous Energy Harvesting	-Tracks maximum power points	-Inflexible in hardware/software interfaces -Inefficient in terms of energy consumption and robustness -Overall performance of the network is to be optimised
[36, 2013]	B. Singh et al.	Supplementing Fertilizer Nitrogen Application	-Improves Nitrogen nutrition -Predicts fertilizer Nitrogen requirements	-Inappropriate recommendations for maintaining high yields
[38, 2013]	P. Tokekar et al.	Planning for a Symbiotic UAV and UGV Coordination	-Power efficiency -Energy management	-Flops to cover the factors like autonomous landing and soil sampling

[39, 2013]	E. Kampianakis et al.	Prolonging Communication Ranges by Frequency Modulation	-Accuracy control -Better communication range -Promotes scalability -Lower power consumption	-Real time deployment has not been performed
[40, 2013]	G. Ngandu et al.	Determining the Effect of Surrounding Vegetation	-Evaluates how the consistency of communication link varies through vegetation	-Deals with static nodes only -Inappropriate to provide highly reliable communication
[41, 2013]	X. Dong et al.	Centre Pivot Irrigation Scheme	-Considers the spatio-temporal aspects	-Fails to reveal how soils have influences on quality of communication and scalability of network -Requires error control scheme in transmission of data packets -Energy efficiency needs to be improved
[42, 2014]	A. L. Diedrichs et al.	Frost Monitoring	-Enhances network lifetime	-Energy harvesting module is needed -Not scalable -Lack of frost prediction mechanism
[45, 2014]	S. R. Nandurkar et al.	Automatic Drip Irrigation	-Water conservation -Enhances yield quality -Saves water and electricity	-Needs to minimize the effects of fertilizers on the value of soil moisture
[46, 2014]	K. K. Khedo et al.	Clustering using Hybrid Energy Efficiency Distribution Mechanism	-Energy efficiency -Ensures better network lifespan -Able to indicate the regions which need irrigation, pesticides and fertilizers -Lessens the loss of data packets while transmission	-Needs evaluation of the system in practical field
[48, 2014]	M. Biglarbegian and F. A. Turjman	Cognitive Path Planning Strategy for Mobile Data Collectors	-Efficient energy consumption -Prolongs network lifetime	-Deficiency of dynamic environments
[49, 2014]	W. Yitong et al.	Designing Agro-Parameters	-Highly reliable -High applicability communication link -Easy to extend	-Imprecise measurement results are obtained
[50, 2014]	C. Wang et al.	Plough-able RFID Sub-Soil Classification	-Power harvesting efficiency -Better power consumption -Performance of the backscatter wireless communication link	-Real time deployment has not been performed

[51, 2014]	T. Nakanishi	Using a Paradigm of Software Product Line	-Optimization of system composition -Energy harvesting functionality	-Needs evaluation of the framework in real scenario
[52 and 53, 2014]	H. Sahota and R. Kumar	Network based Localization	-Received signal strengths based estimates offer a cheaper solution but not very accurate -Time of arrival measurements offer more costly but accurate solution	-Extensive tests are needed to validate and calibrate the performance evaluation models -Accurate modelling is required for multi-path fading and path loss effects
[55, 2015]	C. T. Kone et al.	Tuning MAC Parameters	-Extends network lifetime -Reliable	-Real time deployment has not been performed
[56, 2015]	A. R. D. L. Concepción et al.	Distributed Microclimatic Diffused Monitoring	-Low power consumption	-Lack of support for multimedia sensing
[57, 2015]	E. L. Pontes et al.	Node Localization	-Balances power consumption -Extends network longevity	-Real time deployment has not been performed
[59, 2015]	N. Chen et al.	Soil Moisture Geospatial Web Processing Service	-Improves spatio-temporal continuity and accuracy	-Requires to support the assimilation of efficient watering mechanism and effective synthesis of sensors
[60, 2015]	M. Joordens et al.	Covering Soils with Vegetation for Fully Autonomous Aerial and Ground Structure	-Provides efficient retrieval of soil and vegetation data -Conformable for unmanned ground vehicle	-In-optimal specifications
[61, 2016]	J. A. Jiang et al.	Cultivation Management with Dynamic Converge-Cast Tree Topology based Approach	-Reliable data acquisition -High transmission reliability	-Lack of decision support system -In-optimal cultivation scheduling
[62, 2016]	F. J. F. Pastor et al.	Ubiquitous Platform using Internet of Things and Smart Object Communication Patterns	-Cost effective -Low power consumption -Less water depletion -Better data aggregation service	-Does not deal with energy consumption of embedded devices using harvesting resources -Needs application based on expert system

Reference	***Characteristic(s)/ Specification(s)***	***Description(s)***
[3, 2005]	Routing Protocol/Algorithm	ANN Kohonen Self Organizing map
	Technical Contribution	Multi-Source Multi-Resolution Image Fusion
	Installation Area Covered (size)	1210 ha
	Factors considered	Spatial Resolution & Spectral Resolution
	Types of Sensors	High Resolution Visible & Infrared Sensor (HRVIR) and Vegetation Sensor
[5, 2007]	Topology/ Architecture	Grid & Optimised Veris topology
	Node Platform	Mica
	Routing Protocol/Algorithm	Logical Grid Routing Algorithm
	Node OS	TinyOS
	Language	nesC
	Communication Network	RF technology
	Installation: Area Covered (size)	50 acres
	Types of Sensors	Soil Sensor
	Sensed Parameters	Moisture, Conductivity
	Performance Metrics	Latency, Throughput, Success/Loss rate, Energy Consumption/ Efficiency
	Factor considered	Field's Electrical Conductivity
	Tool used	MATLAB
	Application used	RMASE (Routing Modeling Application Simulation Environment)
[6, 2007]	Topology/ Architecture	Highly Dynamic Network topology
	(Single hop or Multi hop)	Multi hop
	Microcontroller / Processor	Atmel ATmega128
	Node Platform	Fleck3
	Node OS	TinyOS
	Radio tranceiver	NRF905
	Number of nodes	8
	Factor considered	Field's Electrical Conductivity
	Types of Sensors	Electrical Conductivity sensor, PS100 Pressure sensor, Analog sensor , Soil sensor (Salinity, Flow/Water Volume Sensor, Flow Rate sensor)
	Routing Protocol	Surge_Reliable (state-of-the art sensor network Routing Protocol)
[7, 2008]	Communication Network	RF technology Bluetooth Spread Spectrum Radio Technology
	Number of nodes	6
	Sensing Measurements	15 minutes
	Power supply	Solar
	Types of Sensors: Sensed Parameters	Soil sensor (Temperature, Moisture, Conductivity, Volumetric Water content) & Weather sensor (Air Temperature, Relative Humidity, Wind speed, Wind direction, Solar radiation precipitation i.e. Total Flux & Flux density
	Software used	WISC (Wireless Infield Sensing & Control Software)
	Programming Framework	Microsoft Visual C++.Net
[8, 2008]	Topology/ Architecture	Hierarchical Network Topology (Tree-based Routing scheme)
	Routing Protocol/Algorithm	Static Addressing algorithm

	Installation: Area Covered (size)	26.7 ha
	Types of Sensors: Sensed Parameters	Soil sensor (Temperature, Moisture, Electrical Conductivity, pH)
	Paradigm used	IOT (Internet of Things)
	Communication Network	LR-WPAN (Low rate Wireless Personal Area Network)
[10, 2009]	Topology/ Architecture	Multi hop (Solar powered Relay Router)
	Node Platform	Mica2 & Micaz
	Microcontroller / Processor	Atmel ATmega128
	Power supply	Solar
[11, 2009]	Monitoring System	Laptop
	Topology/ Architecture	Multi hop
	Sensing Measurements	15 minutes
	Types of Sensors: Sensed Parameters	Soil (Moisture)
	Routing Protocol	TCP/IP standard Routing Protocol STAR (Synchronous Transmission Asynchronous Reception) LEPS (Link Estimation Parent Selection)
	Node Platform	MIDRA mote
[12, 2009]	Number of nodes	100
	Installation: Area Covered (size)	100X100 m2
	Routing Protocol	Cluster-based LEACH Protocol (Dynamic Clustering)
	Topology/ Architecture	Hierarchical Routing theory
	Technology used	RF/ZigBee
	Tool used	NS2
[13, 2010]	Location of Monitoring	Vineyard
	Power supply	Solar
	Types of Sensors: Sensed Parameters	Leave Wetness sensor, Relative Weather Humidity sensor, Wind Speed sensor, Wind Direction sensor, Solar Radiation Precipitation sensor
	Routing Protocol	Network time Protocol, Polling Protocol
	Technology used	RF/ZigBee
[14, 2010]	Monitoring System	LCD/LED
	Topology/ Architecture	Multi hop
	Microcontroller / Processor	8051 MCU
	Technology used	RF
	Tool used	TOSSIM
[15, 2010]	Monitoring System	LCD
	Node OS	TinyOS
	Technology used	RF/ZigBee
[16, 2010]	Node OS	TinyOS
	Sensor Specifications	Model, Range, Accuracy, Power
	Types of Sensors: Sensed Parameters	Soil sensor: Temperature, Moisture, Conductivity Weather sensor: Temperature, Light Intensity, Relative Humidity
	Technology used	RF/ZigBee
	Concepts used	Neural Network & Fuzzy Logic
[18, 2010]	Monitoring System	Laptop
	Node Platform	IRIS Motes
	Technology used	RF/ZigBee
[19, 2011]	Microcontroller / Processor	ARM Microcontroller system (LPC2148F model)

	Sensing Measurements	60 minutes
	Number of nodes	20
	Protocols/ Algorithms	Location Routing Algorithm with Cluster Based Flooding
	Node OS	PaRTiKle OS
	Language used	POSIX
	Types of Sensors: Sensed Parameters	Soil sensor: Temperature, Moisture Weather sensor: Ambient Temperature, Relative Humidity
[21, 2011]	Monitoring System	Monitoring System/PDA
	Topology/ Architecture	Dynamic Mesh Network Multi hop
	Protocols/ Algorithms	Beacon Only Period and Last Address Assignment Algorithm
	Node OS	TinyOS
[23, 2011]	Monitoring Object	Waxberry
	Location of Monitoring	Greenhouse
	Deployment type:	Prototype
	Deployment duration:	15 months
	Topology/ Architecture	Self-Organized Multi hop
	Node Platform	Telos B
	Sensing Measurements	6 minutes
	Number of nodes	9
	Node OS	TinyOS-2.1.0
	Routing Protocol	FTSP (Robust, hHHigh Synchronization accuracy achiever)
	Data Aggregation Protocol	CTP
	Data Structure used	Stack (FIFO)
	Power supply	Solar
	Installation: Area Covered (size)	1500 m2
	Types of Sensors: Sensed Parameters	Weather sensor: Temperature, Humidity, Photosensitivity, Light Intensity
	Microcontroller	IEEE 802.15.4/Zigbee Wireless Microcontroller
	Processor	ARM9
	Framework used	NAV (Advanced Vineyard Network)
	Technology used	GPRS
[26, 2011]	Deployment type:	Prototype
	Types of Sensors: Sensed Parameters	Weather sensor: Ambient Temperature, Relative Humidity Soil sensor: Moisture, Water level Crop sensor: pH value
	Communication Network	Mesh Network
[27, 2011]	Microcontroller	AT91SAM7S256
	Node OS	JAVA Virtual Machine simpleRTJ (Multithreading & Run-time Notifications)
	Method used	Efficient and Portable Reprogramming Method
	Types of Sensors: Sensed Parameters	Weather sensor: Temperature, Humidity, Light Soil sensor: Water level
	Technology used	ZigBee
	Simulator used	SHAWN
[28, 2011]	Location of Monitoring	Vineyard

	Types of Sensors: Sensed Parameters	Weather sensor: Temperature, Humidity, Wind Speed sensor, Wind Direction sensor, Solar Radiation Precipitation sensor Soil sensor: Soil Water potential Crop sensor: Crop Evapotranspiration
	Paradigm used	Decision Support System
	Concept used	Fuzzy Controller
[29, 2011]	Topology	Tree
	Architecture	Multi hop
	Number of nodes	20
	Routing Protocol/ Algorithm	EEZRP (Energy Efficient Zone based Routing Protocol) Dynamic Flood Routing using RELMA Localization approach
	Installation: Network size	100X100 m^2
	Simulation Environment	C and statistical analysis
	Sensing range	10m
	Technology used	GPRS
	Communication range	20m
[33, 2012]	Framework used	mKRISHI Sensor Network Platform
	Routing Protocol	Mesh Protocol
	Instrument used	Texas Instrument's CC2530
	Node OS	TinyOS
	Language used	nesC
	Technology used	GPRS
	Types of Sensors: Sensed Parameters	Weather sensor: Ambient Temperature, Humidity Soil sensor: Temperature, Moisture
[34, 2012]	Algorithm used	MPPT (Maximum Power Point Tracking) Algorithm
	Method used	Perturb & Observe
	Scheme used	Energy Harvesting
	Mode applied	Heterogeneous
	Technology used	GPRS
[36, 2013]	Sensors used	Chlorophyll (SPAD) meter and Optical Sensor Greenseeker
	Crop observed	Wheat
	Types of Sensors: Sensed Parameters	Soil sensor: Water potential
	Technology used	GPRS
[38, 2013]	Concept used	TSPN (Traveling Salesman Problem with Neighborhoods)
	Sensor used	Minolta SPAD-502 Chlorophyll meter
[39, 2013]	Terms used	FM (Frequency Modulation), FDMA (Frequency Division Multiple Access)
	Types of Sensors: Sensed Parameters	Weather sensor: Capacitive Relative Humidity
	Communication range	50m
[40, 2013]	Concept used	Vegetation
	Module used	XBee
	Sensing measurement	RSSI (Received Signal Strength Indicator)
[41, 2013]	System used	(WUSA-CP) Wireless Underground Sensor-Aided Centre Pivot system
	Sensor used	Wireless Underground Sensor

	Node platform	Mica2
	Node OS	TinyOS
	Types of Sensors: Sensed Parameters	Soil sensor: Temperature, Moisture, Permittivity, Salinity
	Sensing measurement	RSSI (Received Signal Strength Indicator)
[42, 2014]	Sensor used	Silicon Temperature Sensor (TC1047A), SDI-12 sensor
	Concept used	Frost characterization
	Term used	CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance)
	Microcontroller	PIC12F683, ATmega128IV
	Transceiver	AVR AT86RF30
[45, 2014]	Microcontroller	ATmega16
	Module	RF
	Sensors used	LM-35DZ Soil Temperature sensor, Soil Moisture sensor
	Monitoring system	LCD
[46, 2014]	Crop Monitored	Potato
	Energy Efficient Method	Energy Balancing & Conservation
	Types of Sensors: Sensed Parameters	Soil sensor: Temperature, Moisture, Humidity, PH value
	Topology/Architecture	Grid
	Algorithm used	Hybrid Energy Efficiency Distributed Algorithm
	Method used	Recursive Converging Quartiles Method
	Process used	Clustering
	Routing Algorithm	Hierarchical Routing
	Database used	Postgres
[48, 2014]	Proposed system	Smart Environment Monitoring System
	Strategy used	Cognitive Path Planning
	Energy Efficient Method	Energy Consumption Reduction
	Topology/Architecture	Grid
[49, 2014]	Types of Sensors: Sensed Parameters	Soil sensor: Temperature, Humidity, Soil Organic Matter Weather sensor: Light Intensity/ Illuminance, Wind Speed sensor, Wind Direction sensor
	Simulator used	LabView
[50, 2014]	Technology used	Radio Frequency IDentification
	Simulator used	LabView
[51, 2014]	Paradigm used	Software Product Line
	Power source used	Solar Cell & Wind Power Generator
	Types of Sensors used	Digital & Analog Sensors
[52 and 53, 2014]	Types of Sensors used	Multimedia Sensors
	Process used	Node Localization
	Measurements performed	Received Signal Strength & Time of Arrival
	Number of Nodes	25
	Installation: Area Covered (size)	150m X 150m

Table 2. Summarised Table of the Specifications in the Existing Techniques for Precision Agriculture using Wireless Sensor Networks

3. PROBLEM FORMULATION

The intention of this research is to develop a Wireless Sensor Network system to monitor and control of various ecological parameters coupled with Precision Agriculture. The WSN routing protocol could be designed in such a way, to exhibit the following criteria:

1. The protocol will be scalable and function efficiently for networks of any size.
2. The failure of some nodes will not affect the working of the protocol.
3. The protocol will be energy efficient and will extend the network lifetime.
4. The protocol will be computationally simple and easy to implement.
5. The protocol will be Quality of Service (QoS) based.

4. RESEARCH OBJECTIVES

The research objectives are the following:

1. To study various Wireless Sensor Network techniques and their applications in Precision Agriculture.
2. To examine the major shortcomings of existing WSN approaches. The network lifetime and energy efficiency are the chief issues to be considered.
3. To propose a new WSN technique for improving the above issues.
4. To demonstrate the applicability of the proposed technique in the field of Precision Agriculture.
5. To perform the simulation study of the proposed technique and analyze the results under varying simulation scenarios using simulation tool.

5. RESEARCH METHODOLOGY

The various phases of the research activity are described as below:

Phase 1: The techniques, benefits and limitations of the existing approaches in Precision Agriculture using Wireless Sensor Networks are to be reviewed.

Phase 2: On the basis of Phase 1, the major shortcomings will be addressed, and a new WSN technique will be proposed to improve those limitations.

Phase 3: The proposed WSN technique will be demonstrated for its applicability in the field of Precision Agriculture.

Phase 4: Then, the performance of the proposed technique will be evaluated through simulation studies to meet the design objectives.

Phase 5: The conclusions and recommendations will be given and report writing will be done.

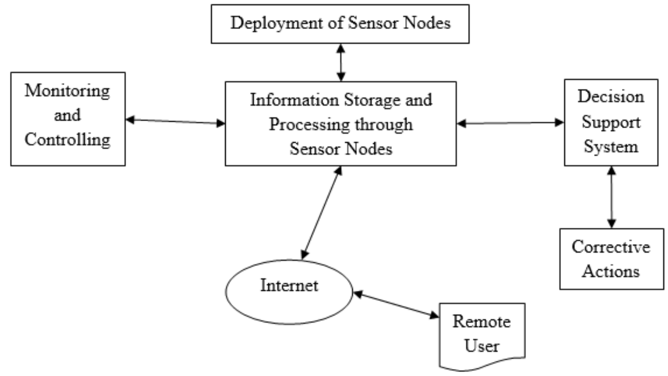

Figure 2. Architecture of Proposed System

6. PROPOSED TOOL

MATLAB (Matrix Laboratory) [63, 64] is the "Language of Technical Computing.

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