A Framework for Deployment of Easy to Use Wireless Sensor Networks for Farm Soil Monitoring and Control: A case Study of Horticulture Farms in Pwani Region Tanzania

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ABSTRACT

Monitoring and control of soil parameters such as temperature, moisture and micronutrients play an important role in producing quality horticulture crops. The farms at Pwani Region needed close monitoring and control of soil parameters because the type of soil in this place is alluvial which can drain water and loose macronutrients easily.

Recently Wireless Sensor Network (WSN) has been used to monitors soil parameters, however many systems developed from existing frameworks were unable to meet requirements for small and medium scale horticulture farmers.

This paper addresses the challenges mentioned above and provides solution that fits the left gap by improving previous frameworks. The gap was identified after comparing different WSN related technologies and requirements obtained from experts and farmers. The framework designed from this information was used to develop WSN system which can be easily used by farmers of different levels of education.

KEYWORDS

Precision agriculture; Sensor; Wireless Sensor Network; Monitoring; WSN Framework; Horticulture Crop; Soil Parameters.

1. INTRODUCTION

The Tanzanian government has made a special emphasis on agricultural export diversification stressing the switch from traditional to non-traditional exports such as horticulture products like flowers, vegetables and manufactured goods [5]. The underutilization of available resources and poor soil management has led to land degradation. Agriculture in Tanzania is dominated by small farm holder farmers (peasants) cultivating an average farms of small sizes mostly by using hoes. The major factor affecting the agriculture sector is the lack of precise utilization of resources caused by lack of proper technology to provide current information which can help in proper and timely decision making. [3].

Horticulture is a sector which has been identified as one of the important sectors in the "Kilimo Kwanza" Resolution. The resolution which in English means "Priority Agriculture" , is expected to become one of the main sources of foreign exchange earnings and a significant driver of economic growth [5].

Horticulture crops need close monitoring and control compared to other crops in order to maintain crop qualities and increase production. In response to this, there is a need of having a technology that would help farmers to monitor and control soil parameters in real time.

Currently, there are technologies that have been used to solve this problem. These include grid soil sampling, yield monitoring and crop scouting. However, despite these technologies being non real-time, they involved use of expensive technologies and they were labour intensive [9].

Wireless Sensor Network (WSN) technology has been used for many years in different countries to collect soil parameters information. In contrast to this, in Tanzania, agriculture parameters are still obtained by collecting soil and water samples for laboratory analyses [6]. This method requires a highly human involvement and it is not conducted in timely manner. Furthermore, the method is normally not specifically tailored for specific area or specific crop and reports do not reach farmers in the right time. WSN technology can operate in a wide range of environments and provide advantages in cost, size, power and flexibility compared to other technologies [10].

According to [1], every deployment has its own needs imposed by the type of the monitored crop and other special application design requirements. To develop and deploy WSN which can meet both application and user requirements, the framework has to be well designed. This can be done by using well selected type of sensors, nodes, topology, data fusion algorithms, dissemination protocols, and type of suitable interface [11].

The designed WSN framework makes it easier to work with complex technologies; it ties together a bunch of discrete components into something more useful [12]. In this study, the proposed WSN framework required to meet the specific requirements of horticulture crop and their related design requirements which fit low and medium scale farmers with little or no Information and Communication Technology (ICT) literacy.

Much research has been done on deployment of WSN for different applications like precision agriculture and so forth. Some frameworks /guidelines have been proposed. However, many of these frameworks are not complete and practical as they just mention only few technologies like routing protocols. For those few developed frameworks they do not lead to systems which can be easily used by users who are ICT illiterate and with little knowledge on horticulture sector.

Many current WSN systems use coordinators equipped with both ZigBee module for intra communication and GPRS module for external communication through cellular network. When both modules were powered up, the ZigBee module was losing connection resulting in a total network failure which required manual reset [4]. This type of design is not proper for horticulture crop because as it was mentioned earlier in this paper, horticulture crops are different from other crops as they can easily be affected by slight changes in agriculture parameters (if not quickly identified and corrected). Hierarchical topologies used by many WSNs are not scalable and are difficult to maintain; meaning when someone needs to change position of a node in the farm it can be difficult for a farmer to reconfigure the system [13].

Mafuta[4] presented a Wireless Sensor Network for Precision Agriculture developed in Malawi in Manja Township, City of Blantyre (shown in figure 1). This system combined sensors and actuators in a wireless sensor/actuator network so as to guide successful deployment of WSNs for Precision Agriculture. The system collects soil parameter values like Temperature and moisture and sends to the coordinator node. This node is equipped with both ZigBee and GPRS modules. GPRS module was used to connect to the cellular network and ZigBee was used for intra communication. In this architecture when both modules were powered up, the ZigBee module was losing connection resulting in a total network failure which required manual reset [5]. This design is not good for developing WSN for horticulture crop because it may not able to perform real-time communication.

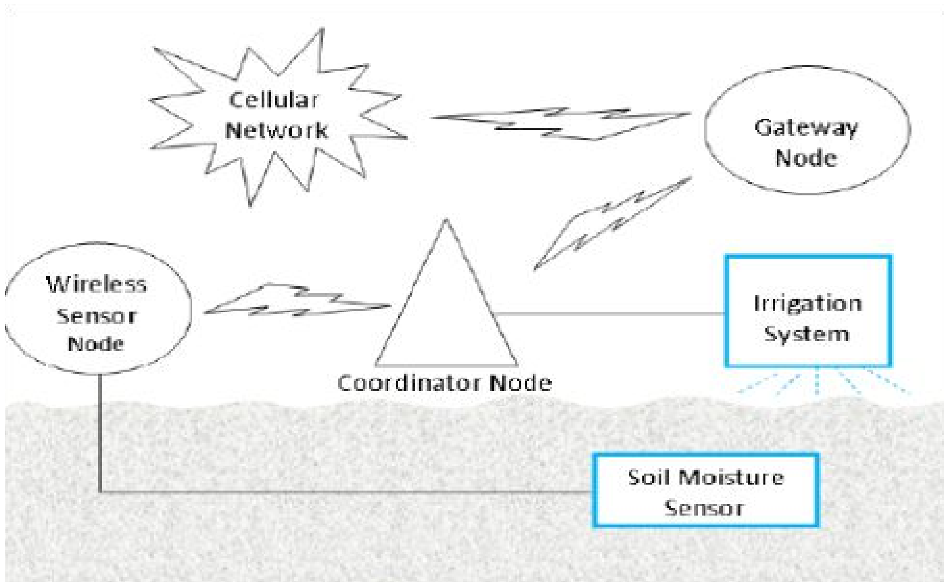


Figure 1. System Architecture for Precision Agriculture in Malawi ***Source: [4]***

Shah [7] presented WSN system developed and deployed at IIT Bombay India for field monitoring of vineyard. The system used a combination of wired and wireless sensors to collect sensory data such as soil pH, soil moisture and soil temperature. Data collected by the sensors were wirelessly transferred in multi-hop manner to a sink node connected with embedded gateway. The sink node is equipped with ZigBee Module for intra communication and IP module for communication to the internet. Data is transferred through the internet to the remote server and to the users with internet enabled devices. Meanwhile users with mobile phones receive information later through cellular network after being processed in the remote server [7]. This type of architecture was trying to solve the problem identified by Mafuta [4] by avoiding conflicts between Zigbee and GPRS communication. However the approach is not effective for developing countries like Tanzania with unreliable Internet, because when the internet connection is down, farmers will fail to receive information to their mobile phones in real time

The system introduced in [7] used cluster architecture for data aggregation. In cluster based architecture all regular sensor nodes send data packet to a cluster head (local aggregator) which aggregates data packet from all the regular sensor nodes in its cluster and sends the aggregated data to a gateway. Cluster based fusion system is not robust to changes. If a node is disconnected from the communications network, it cannot be easily re-introduced and information synchronized. and Once the cluster head fails all nodes under it become useless [8].

As aforementioned, many of existing frameworks are not complete and practical; they just mention only few technologies like routing protocols, or intra-communication technologies within the farm. For those few developed frameworks, they do not lead to systems which can be easily used by users who are ICT illiterate and with little knowledge on horticulture sector. This is due to the fact these systems use complicated and expensive technologies.

The aim of this study was to develop the technical guideline/framework which can be easily modified, understood and which can incorporate all necessary technologies to guide development of WSN for monitoring agriculture parameters for horticultural crops.

2. APPROACH

In order to solve the mentioned challenges, the author surveyed different WSN related technologies that have been used and presented by other researchers in order to make comparison of such technologies. Specific user and crops requirements were obtained from agriculture experts and farmers at Pwani Region. The information obtained was used to design a framework (shown in figure 2) which was later used to develop a WSN model to represent the designed framework. The components in the framework include devices and technologies such as sensors, sensor nodes, network topology, aggregation algorithms, communication protocols, coordinator, base station and user interface.

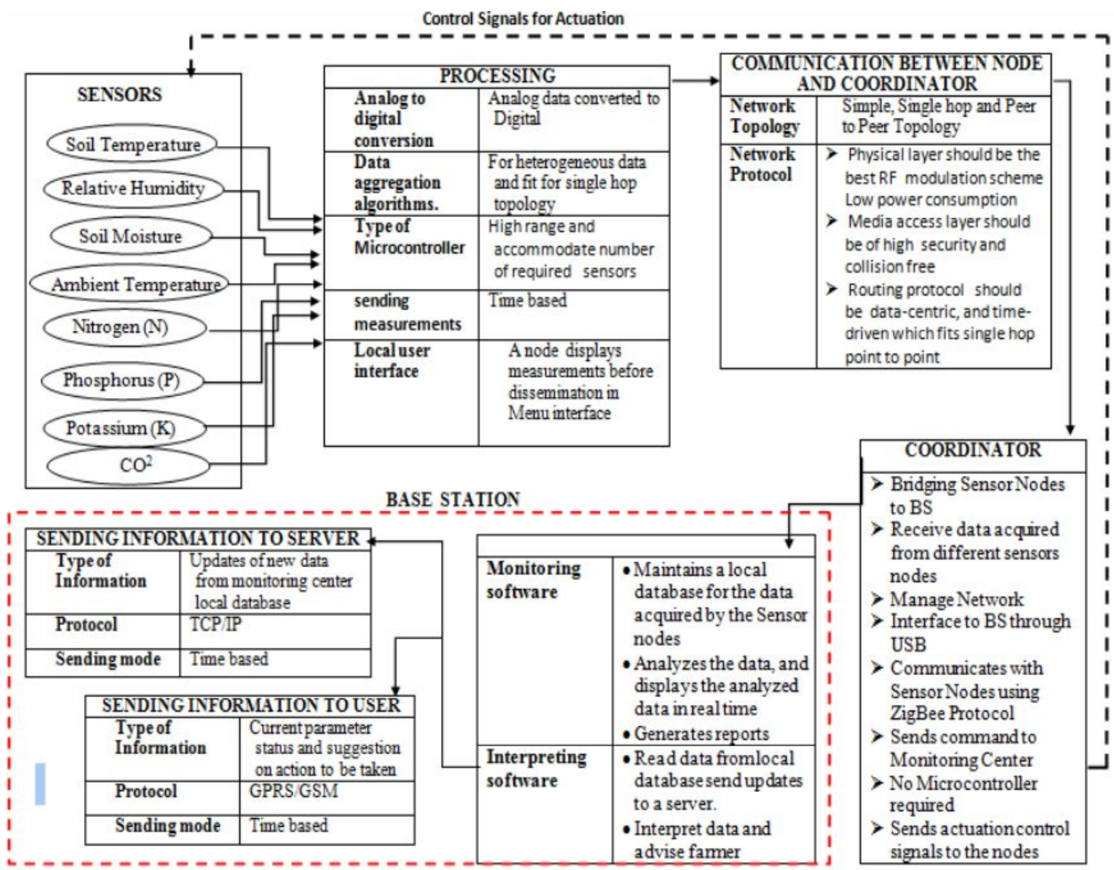


Figure 2. WSN Framework for Horticulture Crop

In this framework, communication within the network (intra communication) is done through ZigBee module in the Coordinator while analysis, interpretation, and transfer of information to farmers and remote server is done in the base station connected to the coordinator. The base station shown in doted lines in Figure 2 and detailed in Figure 3 is an extended block which comprises of software designed to analyze and deliver soil information and suggesting corrective measures for specific region of farm to the specific farmer in real time.

In this framework data collected from the soil is analysed in the local server in the field and is sent to the remote farmer directly to their mobile phones through

cellular network in real time. Internet service is used to send information to the remote server in which farmer can still receive information even if the internet connection is not available.
The conflict between intra-communication and cellular communication is avoided because Coordinator node is equipped with ZigBee only for intra communication while GPRS modules is installed in the base station which initiate all external communications through cellular network and Internet Connections.

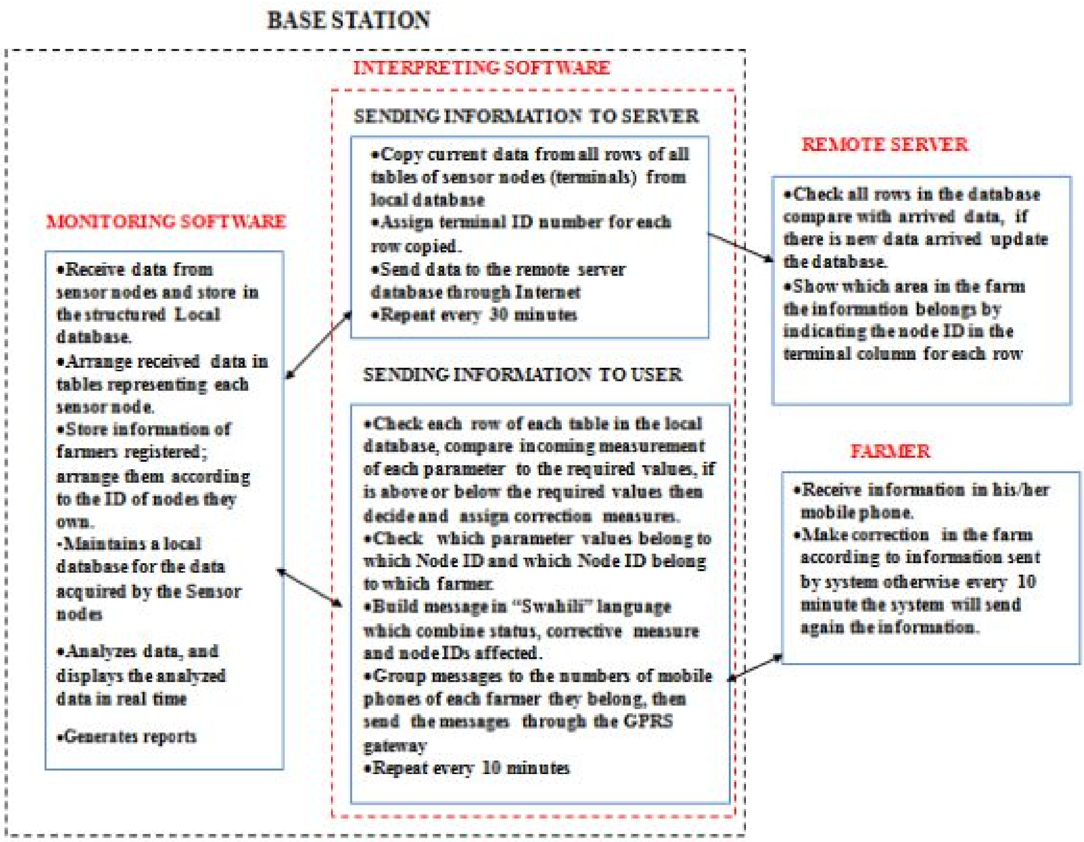


Figure 3. Algorithms in Base Station

The summary of the best technologies identified and deployed in this study is shown in the Table 1.

Table 1. WSN Technologies for Designed Framework

SN	COMPONENT	DESCRIPTION
1.	**Topology**	Simple Star Topology single hop Communication It includes the sensor nodes, a sink node and pc as a BS and the Server for data storage
2.	**Microcontroller**	ATmega8A
3.	**Radio transceiver**	IEEE 802.15.4 (ZigBee) compliant RF transceivers are used for intra-network communications between sensor nodes and sink node

4.	**Actuators**	The actuators will be placed somewhere in between the controlled sensor nodes.
5.	**Sending measurements to BS**	Time-based every 30min
6.	**Number of sensors**	The number of sensors depends on number of critical parameters to be monitored.
7.	**Number of nodes**	The number of nodes in the farm depended on the size of the farm, soil characteristics and the ground nature of the farm.
8.	**Communication within the LAN**	▪ In the physical layer IEEE 802.15.4 (ZigBee) with (DSSS, CSMA/CA) modulation scheme ▪ For media access layer, Fixed Assignment CDMA protocol will be used. ▪ The routing protocol is Sensor Protocols for Information via Negotiation Point to Point (SPIN-PP)
9.	**Communication to remote users**	• GPRS between BS and Mobile phones. • TCP/IP to remote server
10.	**Data Aggregation**	Decentralized based architecture is used as aggregation type where data aggregation occurs locally at each sensor node on the basis of local observations and the information obtained from sensors.
11.	**User Interface**	Menu driven Interface for mobile user and GUI for monitoring user interface
12.	**Monitoring Software**	Lab Windows/CVI is a software development environment chosen for this study. It maintains a database for the data acquired by the wireless sensor nodes. The program provides a facility to save the fundamental data, generates reports. This program can handle 256 nodes
13.	**Interpreting Software**	• The software interprets data stored in local database and integrates control measures information before sending the information to a farmer. It advises the farmer what to be done due to the current observed parameter values • It reads the local database and send updates to the remote server
14.	**Gateway Software**	• Ozeki NG used as SMS Gateway to sends information to user mobile phones. It allows sending of SMS messages toward the GSM/GPRS networks.

3. DEVELOPMENTS

By using the designed framework, the WSN model was developed. This model developed is for monitoring and control horticulture crop farm parameters as per user and crop requirements. In the development of the system to represent the framework, the Rapid Application Development method was used. This method is used in order to quickly produce high quality system. Active user involvement, and computerized development tools were used. These tools included Graphical User Interface (GUI) builders, Computer Aided Software

Engineering (CASE) tools, Database Management System (DBMS), fourth generation programming languages, code generators, and object-orient techniques.
The wireless sensor network for horticulture crops in this study consists of individual nodes that are able to interact with the environment by sensing physical parameters like soil temperature, moisture, humidity and nutrients (potassium, nitrogen and phosphorus). The nodes communicate by using wireless links and each node is able to communicate and collaborate with each other. In this design the nodes are equipped with a display screen so that the farmers without monitoring devices like mobile phones can directly see the measured parameter values of these nodes in their farms.
As shown in Figure 4, the wireless sensor network comprises of the standard components like sensor nodes used as (source), gateway/coordinator and control computer. The sensor nodes in this design send sensed data to the gateway using ZigBee while at the same time; these nodes display the measured data in the display screen. In this architecture the computer is used as a base station which analyses and sends information to the server through internet and mobile phone through cellular network.

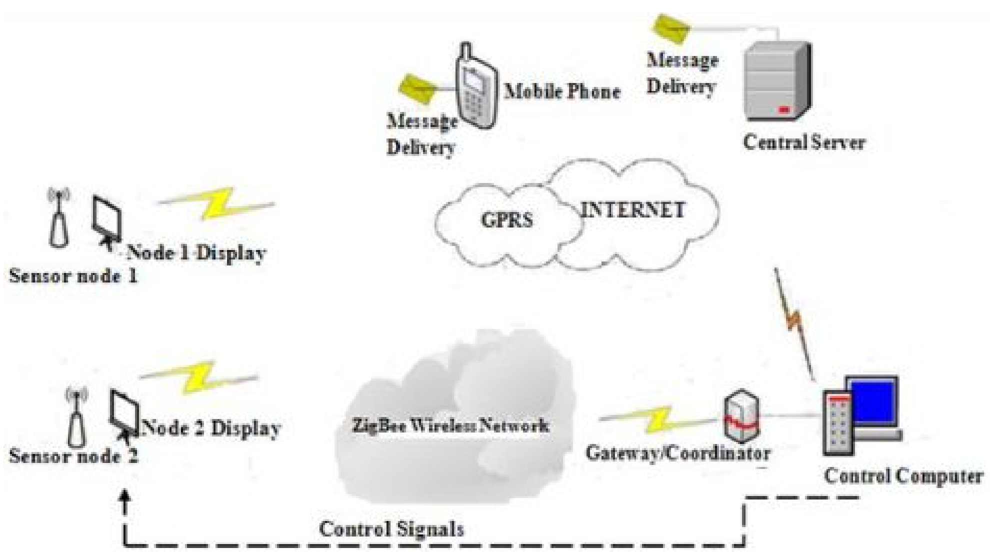


Figure 4. System Architecture of Proposed WSN system

Software that is used to analyze data stored in database in Base station was developed; this software interprets data and integrates control measures information before sending the information to a farmer. This makes it possible for the system to advise the farmer on what needs to be done due to the current observed parameter values. The software also sends and updates the data to the server every 3 hours.

Ozeki NG was used as SMS Gateway to send information to mobile phones; it is a software that allows connection from the system to a mobile network. It allows sending of SMS messages toward the GSM/GPRS network using GSM Modem [2]. The software was downloaded, installed and configured to send SMS to predefined users.
The communication technology used in this Gateway/coordinator node is the same with that in the sensor node (ZigBee (SZ05). This node receives power from the computer through the SPI bus, which ensures that the node is online all the time. Since many computers do not have COM ports, this system uses universal serial bus (USB) interface instead of serial port.
Under normal communication process the computer commands the coordinator/

gateway node via serial port. The physical address is used to collect commands, read the network status, locate the network address and send the data commands to the sensor nodes through ZigBee wireless communication modules[14]. After the sensor nodes collect the measurement or control command, they return the sensor data to coordinator/ through ZigBee wireless communication modules. The communication algorithms between sensor node and Coordinator node is shown in figure 5a and figure 5b respectively.

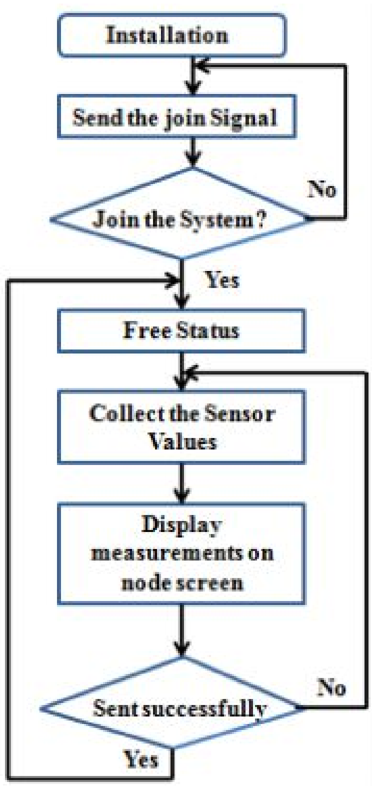


Figure 5a. Coordinator Process Flow Chart

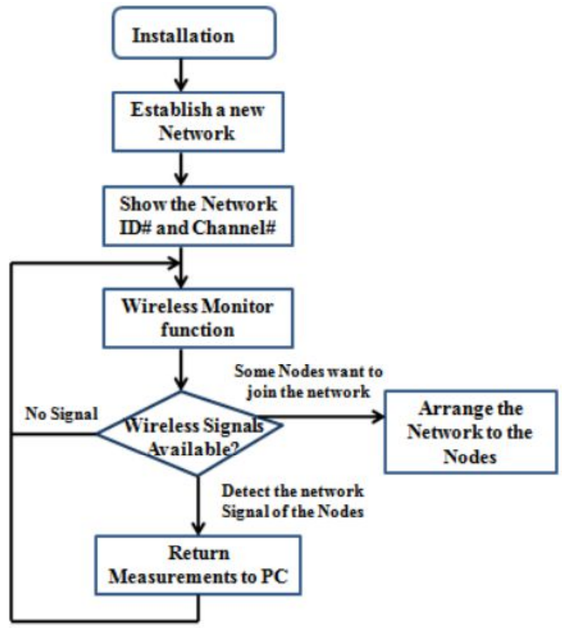


Figure 5b. Sensor Node Flow Chart

4. RESULTS

In this work, the Wireless Sensor Network was implemented and tested at Ruvu area Pwani Region Tanzania. The system measured environmental parameters of ambient temperature (Ta), soil temperature (Ts), relative humidity (RH), soil moisture (SM), and soil macronutrients of nitrogen (N), phosphorus (P) and potassium (K), sensors of light intensity (Li) and carbon dioxide (CO2). Each node processed the raw data and displayed the results on LCD screen continuously.

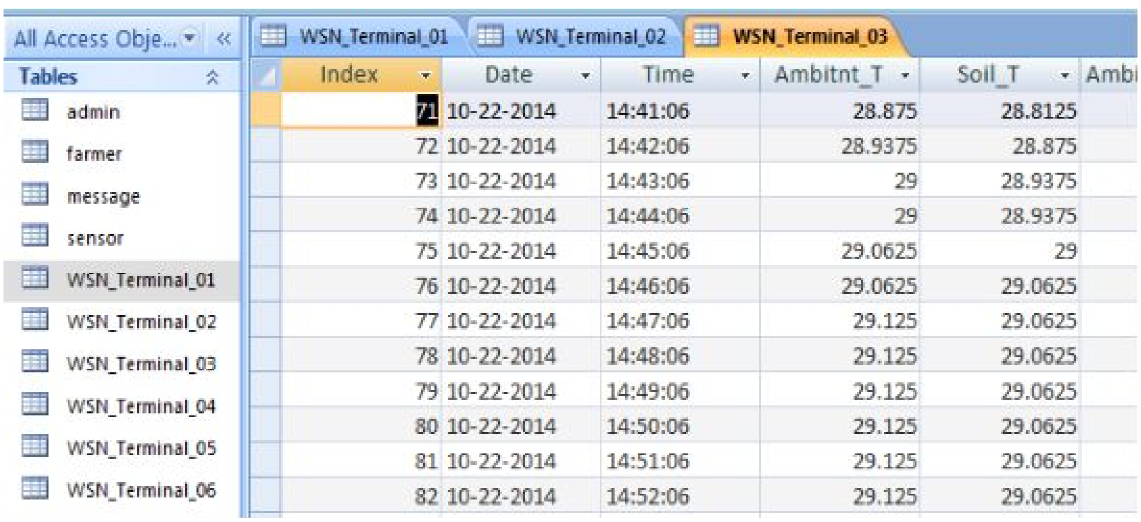
Figure 6 shows the sensor node displaying acquired data of ambient temperature (Ta), Relative humidity (RH), Soil temperature (Ts). All sensor nodes were capable of displaying the status of irrigation pumps and humidifies on the current state. The node was able to display other parameters in the next page through menu functions. The user was comfortable to use this user-friendly interface with keypads to calibrate different parameters of interest, set the optimum values range, and reset.

Figure 6. Sensor Node

The smart nodes sent measured data through the coordinator node to monitoring software in base station (Laptop) in real time. Through a comparison with standard parameters, control signals were issued to drive relays for driver motor for irrigation in case temperature measurement is high or soil moisture is below the standard threshold value. The actuators were placed in between the controlled sensor nodes, while the sink node (Coordinator) was placed indoors connected to the base station computer near to the field.

The software graphical user interface (GUI) platform enabled user to observe and modify the related values of soil environment easily. Its function is to manage the network and send signals to the control routine which switches on an actuator to correct the relevant condition such as water valve, aerator pump and heater pump.

The monitoring software receives data from sensor nodes and stores it automatically in the structured local database. Received data was arranged in tables representing each sensor node according to their IDs as shown in figure 7. Database also stored information for registered farmers, administrators and sent messages.



Index	Date	Time	Ambitnt_T	Soil_T	Ambi
71	10-22-2014	14:41:06	28.875	28.8125	
72	10-22-2014	14:42:06	28.9375	28.875	
73	10-22-2014	14:43:06	29	28.9375	
74	10-22-2014	14:44:06	29	28.9375	
75	10-22-2014	14:45:06	29.0625	29	
76	10-22-2014	14:46:06	29.0625	29.0625	
77	10-22-2014	14:47:06	29.125	29.0625	
78	10-22-2014	14:48:06	29.125	29.0625	
79	10-22-2014	14:49:06	29.125	29.0625	
80	10-22-2014	14:50:06	29.125	29.0625	
81	10-22-2014	14:51:06	29.125	29.0625	
82	10-22-2014	14:52:06	29.125	29.0625	

Figure *7. Deployed data at Local Database*

The user-interface provides features for the complete real-time measurement, control, data processing, display result output, report printing and other functions. The main features include real-time measurement and display of environment values. The implementation of the environmental parameters are real-time displayed in a variety of experimental

curve display and can always switch observation and zoom, and save operation curve very conveniently. In figure 8, the system was configured to display three graphs for Nitrogen, Phosphorus and Potassium in real time.

The system evaluates the collected data and makes the decision based on the requirement of the horticulture crop. It managed to build a message in "Swahili" language which combined status, corrective measure and node IDs affected. The messages were sent to farmers through cellular network (see Appendix A). Ozek Short Message Services (SMS) gateway application was used to send messages every 10 minutes to the farmers in their language "Swahili".

The information collected from sensor nodes was sent to the remote server every 3 hours. The current data from all rows of all tables of sensor nodes (terminals) from local database was copied, assigned terminal ID number (for each row copied) and then sent to the remote server through Internet.

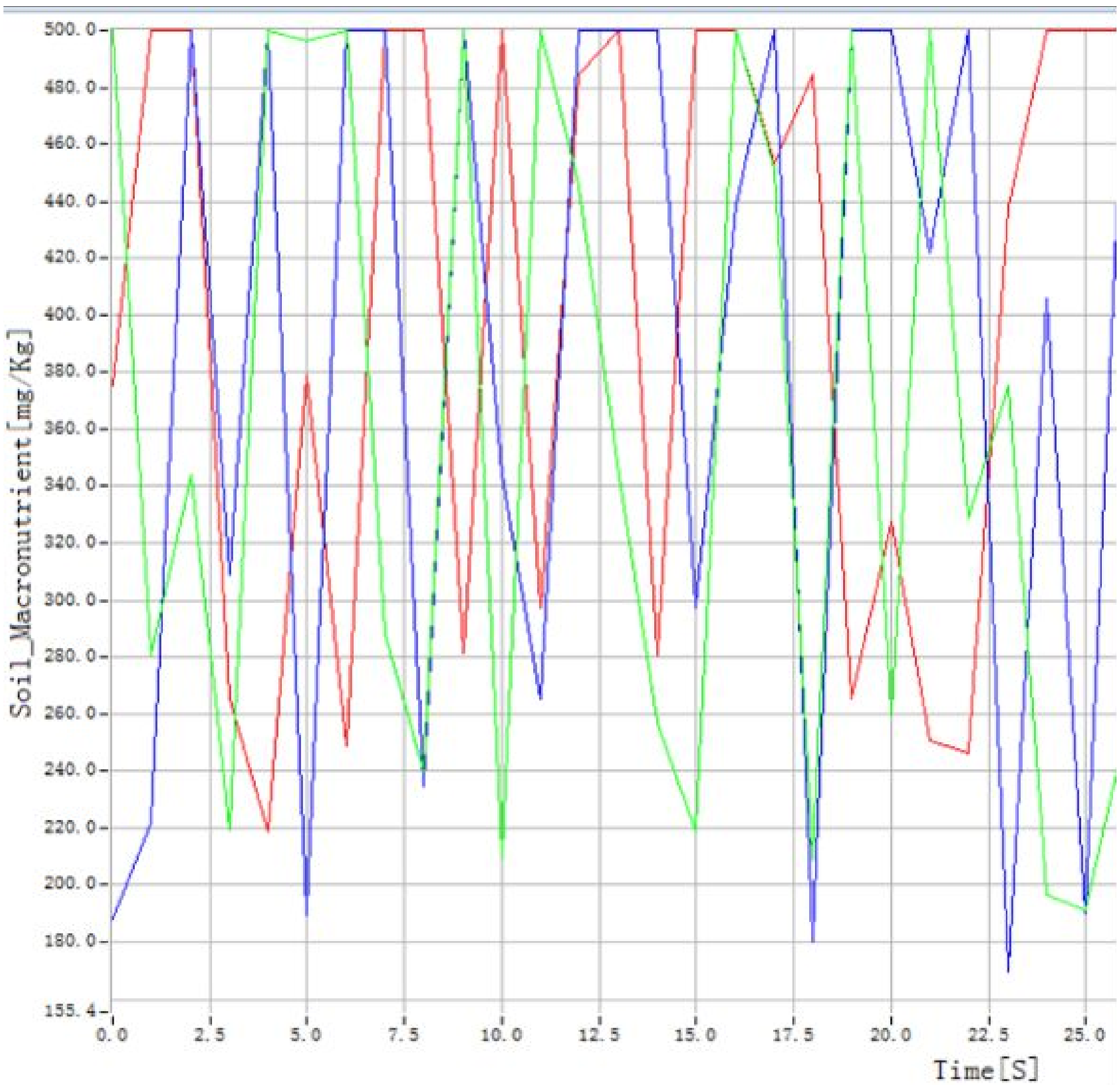


Figure 8. Nitrogen, Phosphorus and Potassium *Measurements*

5. BUSINESS BENEFITS

This study is very important for horticulture farmers and the growth of Tanzanian economy in general. The proposed model will help farmers produce crops which meet the quality standards and requirements so as to effectively compete and access the regional and international markets. The outcome of this research will also benefit farmers of all education levels and even those who are ICT illiterate because it will result into a system which can be used by farmers to get necessary information in their own language through their normal mobile phone.

The horticulture farmers will be able to get information on the status of their farms and what needs to be done in a timely manner and take required measures in time. This will help them monitor their horticulture fields and prevent damages which will eventually increase crop production. In addition, the outcome of this study will help farmers monitor, control and increase the size of their farms for maximum agricultural productivity..

6. CONTRIBUTION

The contribution of this work is to develop a technical guideline/framework which includes all necessary technologies which are simple, reliable and easy to use. The framework can be easily understood and used to develop a WSN for monitoring agriculture parameters for horticulture crops. This framework as compared to others, it can be modified easily to fit development of WSN for other applications. Furthermore, in comparison with other frameworks where data is transmitted to remote server through the Internet for analysis and then sent to users who eventually encounter problems when the internet is down, this framework solves this problem by first analyzing data in the field. Data is analyzed in a computer at the field, sent to the farmer's mobile phones through a cellular network and to the remote server through the internet. This ensures reliability and timely delivery of information to the farmers while avoiding communication conflict within intra-communication.

7. CONCLUSIONS

In this work we presented a framework/guideline for deployment of easy to use wireless sensor networks (WSN) for the Horticultural farm soil monitoring and control. In this study both the requirements for horticultural crop and the farmers were identified. The technologies related to WSN frameworks were surveyed and the best technologies were identified. The technologies for the WSN framework namely sensors, smart nodes, sink nodes, network topologies, algorithms, communication protocols, and type of suitable user interfaces are discussed in detail. In this paper, we have demonstrated how the WSN model was developed from the framework/guideline and tested. We found that simple star topology and decentralized aggregation architecture when used together produce the system which is easy to use as a farmer can easily move a node from one region to another a farm or add new nodes in different areas in the farm without the need to reconfigure the system manually. The node placement metric presented was found to control the number of nodes to be deployed. Our experimental results show that using sink node equipped with ZigBee module, while GPRS modules incorporated separately in the base station, real time communication were maintained without conflicts.

Future development efforts should involve enhancing the WSN by integrating WSN of different application to a single server, and to make the system web-based so that users can access the data through web interface. Also there a need of linking the data to the cloud or smart grid so that they can be timely accessible statistical purposes.

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