A Test-bed on Real-time Monitoring of Agricultural Parameters using Wireless Sensor Networks for Precision Agriculture

Siuli Roy[1], Somprakash Bandyopadhyay[2]
[1] Heritage Institute of Technology, Kolkata 700 107, India
[2] Indian Institute of Management Calcutta, Kolkata 700104, India
siuli@.roy@heritageit.edu, somprakash@iimcal.ac.in

***Abstract* -- "Precision farming," describes a bundle of new information technologies applied to the management of large-scale, commercial agriculture. It promises higher yields and lower input costs by real-time and automatic monitoring of site specific environmental and soil conditions using different sensors and thereby improving crop management, reducing waste and labour costs. Wireless sensor networking is gaining popularity for managing precision agriculture through real-time monitoring of agricultural parameters and climatic conditions. Reasonable simulation tools exist for evaluating large scale sensor networks, however, they fail to capture practical aspects of wireless communication. Real life test-beds bring out actual challenges and important aspects related to large-scale deployment of sensor networks. In this paper, we present a testbed implementation of a wireless sensor network for automatic and real-time monitoring of soil and environmental parameters influencing crop yield. The paper describes the system architecture, physical setup, sensor node hardware and software for real-time monitoring and management of agri-parameters through a simple graphical user interface. The paper presents practical issues and technical challenges including the integration of sensors, placement of sensors in outdoor environment, energy management scheme and actual power consumption rates.**

I. INTRODUCTION

Agriculture provides the economic underpinnings for the majority of rural India. In past few years, new trends have emerged to improve the different areas of agricultural sectors using the modern technologies. Climatological condition monitoring is one of the most important aspects in agricultural production that has its direct impact on the productivity and maintenance of field crop. A huge loss is incurred every year due to damages of crop by various diseases caused by improper maintenance of some climatological conditions. Moreover, monitoring different climatological, soil parameters like temperature, humidity, soil moisture, soil pH, soil conductivity, leaf wetness, sunshine etc. in real time is important for better management and maintenance of agricultural production.

If these factors can be maintained properly, that, in turn, may prevent the severe attacks of diseases on the crops. This will also help the farmers to take proper and timely actions regarding irrigation and fertigation etc. to prevent any kind of damages in the crop, based on the circumstances in each individual field. This problem gives birth to a new domain called Precision Agriculture [1, 2, 3].

Precision farming relies upon intensive sensing of environmental conditions and computer processing of the resulting data to inform decision-making and control farm machinery. A *wireless sensor network* is an ideal candidate for monitoring such environmental conditions affecting agricultural practices.

This paper presents a real-life test-bed implementation of a *Wireless Sensor Network for agricultural parameter monitoring* and throws light on some of the practical and technical challenges faced during the deployment of WSN.

Related works are described in section II. The proposed system description, available technologies, system architecture, Hardware features, test-bed setup, data aggregation at control station and finally the system performance is reported in section III, IV and V. Finally, the paper is concluded with a brief discussion on further scope of enhancement of the system wherein a sensor-actuator based system will automatically take decision to control irrigation, and application of pesticides and fertilizers depending on the current requirements as identified by the different agricultural sensors in the field.

II. FEW INITIATIVES USING WIRELESS SENSOR NETWORKS FOR PRECISION AGRICULTURE

A. "Smart Fields" with Wireless Nano-sensors [4]

Since many of the conditions that a farmer may want to monitor (e.g., the presence of plant viruses or the level of soil nutrients) operate at the nano-scale, and because surfaces can be altered at the nano-scale to bind selectively with particular biological proteins, sensors with nano-scale sensitivity will be particularly important in realizing the vision of smart fields. The US Department of Agriculture (USDA) is working to promote and develop a total "Smart Field System" that automatically detects, locates, reports and applies water, fertilisers and pesticides - going beyond sensing to automatic application.

B"Smart Dust" Sensors/ motes [4]

Ten years ago, Kris Pister, a professor of Robotics at University of California Berkeley initiated the development of autonomous sensors that would each be the size of a match head. Using silicon etching technology, these motes ("smart dust" sensors) would feature an onboard power supply, computation abilities and the ability to detect and then communicate with other motes in the vicinity. In this way the individual motes would self-organize into ad hoc networks capable of relaying data using wireless (i.e., radio) technology.

Currently, motes are available from Crossbow Technologies [9], Dust, Inc., Ember and Millennial Net. Motorola, Intel and Philips are also working on the development of motes and Industry has already started experimenting with wireless sensor networks using motes for agriculture.

Computer chip maker Intel, whose chips have nano-scale features, has installed larger wireless sensor nodes (called 'motes') throughout a vineyard in Oregon, USA where the sensors measure temperature once in every minute. Intel's vision for wireless networks is 'proactive computing' - ubiquitous systems that anticipate the needs of the farmer and act before they are asked to do so.

In a similar venture, multinational consulting firm Accenture has partnered with mote-maker Millennial Net to run a network of sensors across a vineyard in California.

According to Crossbow Technologies, their motes can be used on the farm for irrigation management, frost detection and warning, pesticide application, harvest timing, bioremediation and containment, and water quality measurement and control.

C. SoilNet - A Zigbee based soil moisture sensor network [5]

Soil moisture plays a key role in partitioning water and energy fluxes, in providing moisture to the atmosphere for precipitation, and controlling the pattern of groundwater recharge.

SoilNet project aims to develop a soil moisture sensor network for monitoring soil water content changes at high spatial and temporal scale.

Main features of SoilNet are:

- ZigBee based Wireless Sensor Network with mesh topology,
- Very low energy consumption for long battery life
- Dynamic, expandable network,
- Different node configurations for adapted measurement setups,
- Measured data stored in a database (easy and variable access)

The small catchment area of the Wüstebach (about 26.7 ha) was proposed to be instrumented with the proposed soil moisture network, SoilNet. The sensor network consists of 286 sub nodes and 12 coordinator nodes. The whole network was managed by a main server that will also be connected with telecommunication (e.g. DSL) in order to enable online transmission to the workplace.

III. Proposed System Description

A. The system requirement

A Precision farming system should include following basic functionalities:

- Sensing agricultural parameters in real-time namely, soil parameters, environment parameters etc.
- Identification of sensing location and data aggregation
- Transferring the aggregated data from crop field to control station for better decision making

For this application, sensors need to be placed outside, in the open field, where power may not be available. So, sensors should be battery operated. Sensing location may be identified by integrating GPS with each sensor. However, that is not a cost effective solution. In this application, sensors are statically placed at different locations in a field, so the static location of each sensor with its unique sensor id can be stored in the sensors during network configuration and deployment phase.

In precision agriculture, continuous monitoring of sensor data at every minute may not be always needed. Instead, the data may be monitored on hourly basis or at different times of the day, e.g., morning, noon, afternoon and evening. This, in turn, helps in conserving the battery power of sensor nodes. It is also better to use "sleep and awake" cycle of the wireless sensors judiciously to sense and transmit the sensor data in wake-up phases and put the sensors in sleep mode rest of the time. It may be good idea to aggregate the sensor data captured over a period of time at each node before sending the aggregated data to the monitoring station.

Generally the monitoring station is located far away from the field; therefore, laying wires for transferring sensor data from field to control station is a costly proposition. But the range of battery-operated wireless devices is also limited. So, multi-hop communication is needed to send data to control station. Researchers are now exploring the use of multi-hop wireless sensor network for this purpose. Considering all these functional aspects and limitations in wireless nodes, low power, low data rate wireless mesh network is found to be a good candidate for realizing the wireless sensor network testbed.

B. Wireless Mesh Networking Technology

Wireless sensors are becoming an essential tool for bringing the vision of precision farming to maturity. When deployed on fields if these sensors can form a network among themselves automatically then that networked sensors are expected to provide detailed data on crop and soil conditions and relay that information in real time to a remote location.

Each sensor of this network is capable of sensing and monitoring various environmental conditions like temperature, humidity, pH content of soil, moisture and humus content of soil. The sensors with radio transceivers are capable of forming a wireless mesh network with other similar sensor nodes within its vicinity. This wireless network is used as a communication backbone to carry the sensor data from the field to a remote control station either directly or in multi-hop through other intermediate nodes. The sensor data accumulated at the control station is used for monitoring thus helping in real-time tracking of agriculture environment.

Briefly, Wireless Mesh Network of sensors essentially consists of wireless nodes integrated with sensors. These nodes have bi-directional radio transceiver through which data and control signals are communicated wirelessly in the network and nodes are generally battery operated. Those wireless nodes are arranged in a networking topology called “mesh”.

A typical mesh network topology is shown in Fig. 1. Mesh network is a type of network where each node can communicate with every other node through a direct path or indirectly through other nodes. Wireless mesh networks have the following characteristics:

1) They are *self-forming*. As nodes are powered on, they automatically enter the network.
2) They are *self-healing*. As a node leaves the network, the remaining nodes automatically re-route their signals through other available paths.
3) They support *multi-hop routing*. This means that data from a node can jump through multiple nodes before delivering its information to a host gateway or controller that may be monitoring the network.

The self-forming, self healing, and battery operable attributes of a mesh sensor network make it ideal for environmental monitoring applications in a wide range of facilities [7].

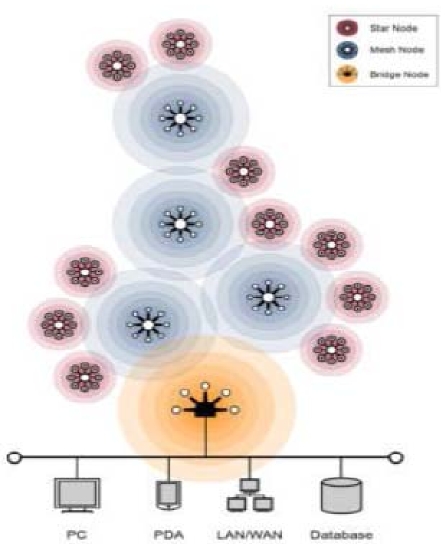


Fig.1 Wireless Mesh Network

The different wireless mesh networking protocols supported in ISM band is discussed below.

Wireless LAN (IEEE 802.11) is a flexible data communication protocol implemented to extend or substitute for a wired local area network, such as Ethernet. The bandwidth of 802.11b is 11 Mbits and it operates at 2.4 GHz frequency.

Bluetooth (IEEE 802.15.1) is a wireless protocol that is used for short-range communication. It uses the 2.4 GHz radio bands to communicate at 1 Mbit between up to eight devices. The Bluetooth is considered a cable replacement for mobile devices. It is mainly designed to maximize the ad hoc networking functionality.

IEEE 802.15.4 standard is a physical radio specification providing for low data rate connectivity among relatively simple devices that consume minimal power and typically connect over short distances. It is ideal for monitoring, control, automation, sensing and tracking applications for the home, medical and industrial environments [6].

From the above discussion it is evident that, different technology options are available to realize wireless mesh network with sensors. In order to choose the most efficient, cost effective as well as, power-efficient technology, we need to review the requirements of our application. It is identified that for real-time monitoring of agricultural parameter, each sensor node needs to send its sensed data (very low volume of data) at a periodic interval to the central control station. So, a sensor will generally follow this schedule: it will wake up at regular interval, sense data for a while, aggregate them and send it to the next hop and then will go to sleep again [10]. So, suitable routing and power management technique needs to be devised on the chosen technology.

In case of BlueTooth, a master can support only 7 child nodes therefore it is not suitable to support the application that involves hundreds of sensors to be placed around a small area. However, it is possible to achieve the above goal using 802.11 based technology but, those devices are generally power-hungry therefore not suitable to operate in outdoor environment for a long time with battery power. Moreover, our application does not require high data rate (11 Mbps) supported by IEEE802.11, since a lot of bandwidth will be wasted unnecessarily. Scalability is a major problem in WiFi ad hoc network. So, to support low-power, low data rate, scalable application, we proposed to work on IEEE802.15.4 based platform. IEEE 802.15.4.also supports more than 64000 nodes which is suitable to handle our application.

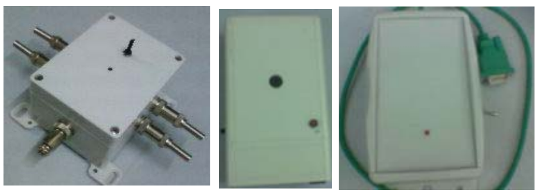
C. Proposed System Architecture

We have designed a WIRELESS DATALOGGER System called AgroSense (Fig. 2) for remote monitoring of agricultural parameters. AgroSense Datalogger system consists of following four components;

1) AgroSense Wireless Datalogger unit (Fig. 2 a)) with flexibility to attach maximum four different

types of agricultural sensors as per the requirement of a particular crop. Specifications of sensors are given in section III D.

2) Long Range Wireless Router (Fig. 2 b)) to relay sensor data from field to remote monitoring station
3) Coordinator (Fig. 2 c)) attached to a host computer at the monitoring station to receive sensor data relayed by the routers from the field
4) Web-based software with user-friendly GUI and report generation facility at the monitoring station to provide advisory services



a) b) c)

Fig. 2 AgroSense System Components

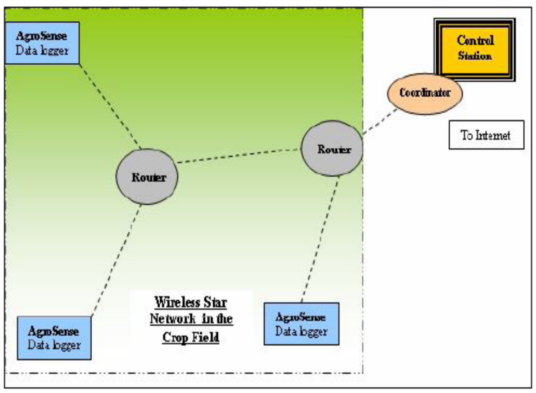


Fig. 3 AgroSense System Architecture

D. Hardware

Each AgroSense wireless Datalogger unit as well as Router and Coordinator unit in the system will contain IEEE802.15.4 based RF module for transmitting/ relaying/ receiving sensor data. AgroSense Datalogger modules have interfaces to connect different types of agricultural sensors to make it a complete sensor node. Since sensors and RF modules will be mostly battery-powered, in order to extend the battery life of those sensors as well as RF devices, we have devices a power management scheme so that they can be put to sleep mode during their idle phase. The devices can be awakened from sleep mode periodically. For this development, RF modules from Maxstream (Fig. 4) are selected and its detailed description is given in Table 1.

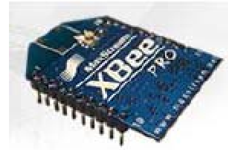


Fig. 4 XBee IEEE 802.15.4 based RF module

TABLE 1: SPECIFICATION OF XBEE PRO RF MODULE

Specifications	XBEE Pro (High Power)
Indoor [non line of sight] range	100 meter
Outdoor [line of sight] range	1Km
RF Data rate	250 kbps
Serial Interface data rate	1200-115200 bps
Supply Voltage	2.8 to 3.3 Volts DC
Transmit Current	155 mA
Idle/Receive Current	50-55 mA
Sleep Current	4.9-5.5 mA
Operating Frequency	ISM 2.4 GHz
Dimensions	(2.438cm x 3.294cm)
Operating Temperature	-40 to 85° C (industrial)
Antenna options	Integrated Whip, Chip or U.FL Connector
No. of Channels	12 Direct Sequence Channels
Supported Network Topologies	Point-to-point, Point-to-multipoint & Peer-to-peer

a) Humidity b) soil moisture c) soil conductivity d) soil Ph

Fig.5 Sensors

The specifications of sensors are given below.

- *RHI110A Relative Humidity Sensor*: (Fig. 5a))
  Humidity Range 10 to 90 %RH
  Output 0-2.97 Volts
  Power requirements 5 Volt DC
  Current consumption 5 mA

- *Tensiometer with transducer*: (Fig. 5b))
  Moisture Tension Range 0-100 Centibar
  Output 4-20 mA
  Power Requirements 12 to 24 VDC
  Current Consumption 20 mA max

- *Alpha Cond. 500 Transmitter with Conductivity Electrode (ECCS10-1-0S):* (Fig. 5c))
  Conductivity Range 0-20 mS
  Output 4-20 mA
  Operating Temperature 0-100 Deg C
  Power Requirements 12 to 24 VDC
  Current Consumption 20 mA max

- *Alpha pH 500 Transmitter with pH Electrode (EC100GTSO05B)* (Fig. 5d))
  pH Range 0-14
  Output 4-20 mA
  Operating Temperature 0-100 Deg C
  Power Requirements 12 to 24 VDC
  Current Consumption 20 mA max

E. *User Interface*

A User Interface has been created using JDK 1.6 and Java Enterprise Edition 5. Few snapshots of the GUI where the users will be able to configure the sensors (Fig. 6), the Dataloggers are provided below.

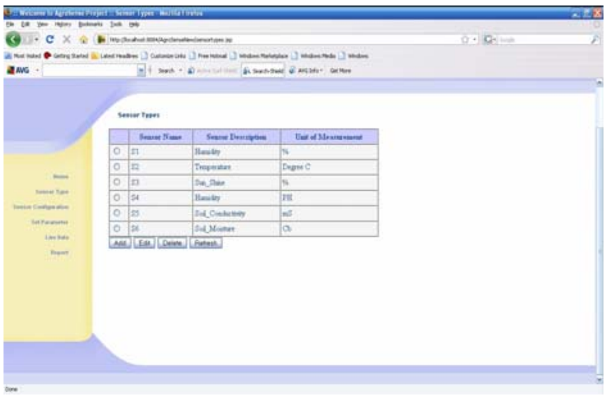


Fig. 6 Configuring different types of sensors

We have used JFreeChart to analyze the sensor data and generate various diagrammatic representations of the data like line diagrams for data generated over a long period of time, tabular views showing real time data (Fig. 7).

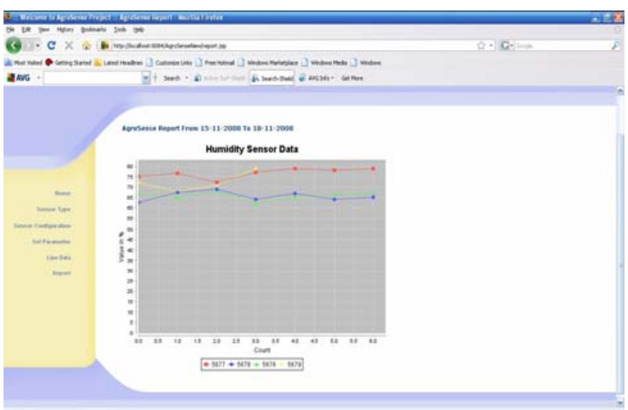


Fig. 7 Graph showing day-wise variation of Humidity observed by four different dataloggers

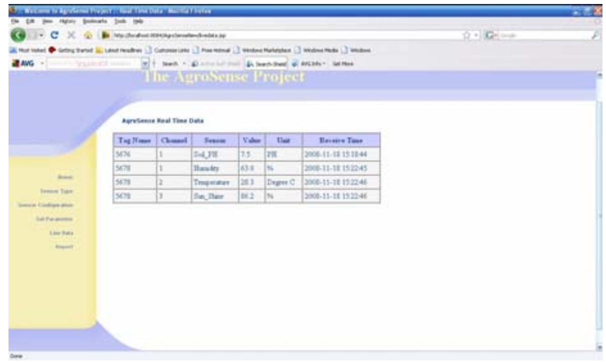


Fig. 8 Real-time sensor data from different dataloggers with timestamp

IV. Implementation Details

We have chosen a site in B.C.K.V. Kalyani for the deployment of our testbed with the following devices: i) 2 Dataloggers, ii) 1 Soil EC Sensor, iii) 1 Soil Moisture Sensor, iv) 1 Soil pH Sensor, v) 1 sensor box consists of Temperature, Humidity and Sunshine sensor, vi) 3 Routers, vii) 1 Coordinator, viii) 1 laptop, ix) 2 nos of 12 Volt DC battery.

The total length of the path was around 0.2 KM in [NLOS] (Fig. 9, 10). Dataloggers (with sensors) were placed in a green house and 3 routers were placed at a distance 0.12km, 0.15 km and 0.20 km respectively from the green house. Some are erected with pole and kept on rooftop to achieve line of sight communication.

Fig. 9: Deployment site

Fig. 10: Devices deployed at deployment site

Precautions:

• We managed AC power supply and/or battery power for all the routers. We had used 3V and 9V adapters.

• We packed all the routers and accessories by polythene wrappers, which we had placed in roof-top and on poles, for protection from rain and storm.

• We used Maxstream Pro chips with whip antenna as routers for a better range.

• We programmed the datalogger for 15 minutes sleep so that the lifespan of battery [12 V DC] would be maximized.

• As the weather was not supportive (due to heavy rainfall) for wireless transmission, we had to place the routers in an elevated position for a LOS condition approx 40 feet from the ground level.

V. Performance

The Agro-Sense system ran continuously in B.C.K.V. campus, Kalyani for 7 days from 13th May to 21st May, 2008. The system ran successfully during the period without any interruption and the data was collected for further processing and analyzing (Fig. 11, 12, 13). The real-time sensor data was also observed through software GUI.

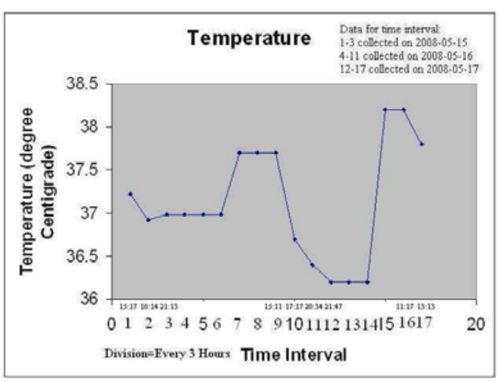


Fig. 11: Variation of temperature

Temperature data at every three hours (for three days) was plotted and found to vary in between 36 to 38 degree Celsius. The ambient temperature was little more than the temperature of the greenhouse as because greenhouse environment is a controlled environment.

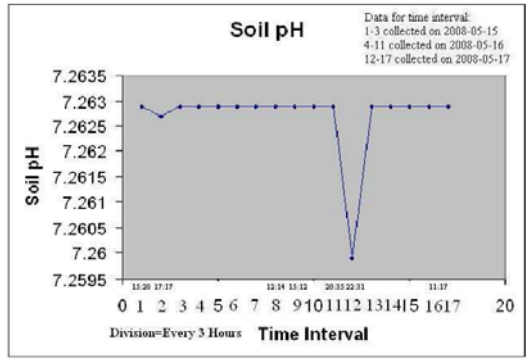


Fig. 12 Variation of soil pH

Soil pH is almost in between 7.26 to 7.263. In the graph we can see the values have varied apparently but the values were not varying so much. It means that the crop field has a 'basic' soil. Those plants which need a 'basic' soil for their growth should be used for harvesting in that field.

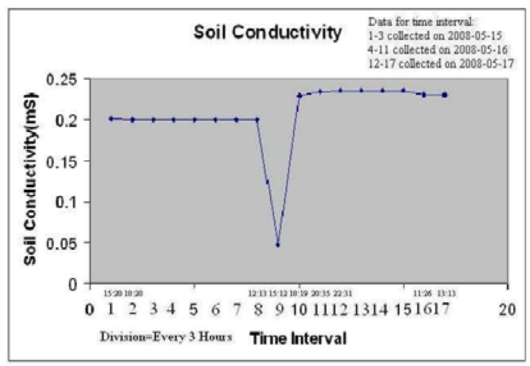


Fig. 13 Variation of soil conductivity

Soil Conductivity is almost in between 0.05 to 0.225. It means the place is not highly conductive. There is a deficiency of basic minerals, which is not very supportive for plants. Because of water accumulation due to rain, the value falls to 0.05 but after few hours it becomes stable. It may be that the desired minerals had been washed out by the excess amount of water accumulation. We have added a little amount of saline water so the value rises to 0.225 from 0.2. The place needs a proper fertigation. The drainage system should be improved.

Based on the application requirement, we have developed a power management scheme and calculate the battery life of the devices based on that scheme.

According to the scheme, the RF Device of the Wireless Data logger will wake up and power up the sensors for 3 minutes and this process will be repeated 3 times a day. The rest of the day it will sleep. The sensors should be given a minimum amount of time to be stable, so that we can take the accurate reading. That is why, the 3 minutes has been given to those sensors to get an accurate and stable output. As the RF device goes to sleep the sensor power will also cut off. Thus, we can reduce the sensor power consumption along with RF devices.

To make this scheme successful, we have used Optocouplers in our circuit. The Optocouplers will be energized by the RF module and acts as a switch to power the sensors. The sensor will get the power and send its data to the RF module. Thus, each sensor will also be ON for 3 mins in a day as the RF device is ON.

In a day, total time of wakeup = 10 mins. (approx) and total time of sleep=1430 mins.

TABLE 2: CURRENT CONSUMPTION AND BATTERY LIFE TABLE

Components	**Current Consumption**		**Total (mA H) per day= [Total Current*time (wake/sleep) in minutes]/60**
	Current Consumption	**Time of consumption in minutes**	
Maxstream Pro	Sleep (with timer on) = 5.5 mA Wake up = 48 mA	1430 mins 10 mins	139 mA H
Opto-couplers 2 nos.	8.5 *2 mA=17 mA	10 mins	3 mA H
Voltage Regulator	5 mA	1440 mins (24 hours)	120 mA H
Sensors	Humidity =5 mA Soil Moisture =20mA max 4 mA min Soil pH=20mA max 4 mA min Soil EC=20mA max 4 mA min Total= 65 mA max.	10 mins	11 mA H

Battery Life Estimation:

The total power consumption = 139+3+120+11 = 273 mA H (Table 2)

The battery (12 VDC 7.5 AH) life = 7500/273 = 27 days (approx.).

VI. CONCLUSION

A sensing system combined with IEEE 802.15.4/Zigbee based wireless networking [8] has been tested to be quite effective. We have observed that wireless transmission range varies with humidity and environment condition. On that basis we have to design the placement of routers in a network. If possible then number of routers should be increased. The routers should be encased in such a way that it can tolerate sudden weather damage like rain falling, storm etc. To use this system in a crop field or in other greenhouses, the Maxstream-Pro with whip antenna is recommended for routers. The whip antenna rarely varies in case of range. It is very difficult for a router placed in ground level to send data to another router which is placed in 2nd or 3rd floor of a building. So in that case both the router should be elevated somehow to be in line of sight.

In the future, precision farming will resemble robotic farming as farm machinery is designed to operate autonomously, continuously adapting to incoming data.

ACKNOWLEDGMENT

This project “Agro-Sense” at IIM Calcutta was supported and funded by Media Lab Asia, Govt of India. We are indebted to Prof S K Samanta, Joint Director of Research, Bidhan Chandra Krishi Visyavidyalaya for his continued support and guidance in this project “Agro-Sense”.

REFERENCES

[1] Blackmore, S.(1994). Precision Farming: An Introduction. Outlook on Agriculture 23(4) 4, 275-280.

[2] Ning Wang, Naiqian Zhang, Maohua Wang, “Wireless sensors in agriculture and food industry—Recent development and future perspective”, published in Computers and Electronics in Agriculture 50 (2006) 1–14.

[3] Akyildiz, I.F., Xudong Wang: A Survey on Wireless Mesh Networks, IEEE Communications Magazine (September 2005)

[4] AZoNanotechnology Article: “Precision Agriculture - Nanotech Methods Used, Such as ‘Smart Dust’, Smart Fields’ and Nanosensors:” ttp://www.azonano.com/details.asp.ArticleID=1318

[5] “SoilNet - A Zigbee based soil moisture sensor network” Project Group, Institute Of Chemistry And Dynamics Of The Geosphere (ICG), Agrosphere Institute, ICG 4, Forschungszentrum Jülich GmbH, 52425 Jülich, http://www.fz-juelich.de/icg/icg-4/index.php.index=739

[6] IEEE Std. 802.15.4-2003, Wireless Medium Access Control (MAC) and Physical Layer (PHY)Specifications for Low Rate Wireless Personal Area Networks (2003)

[7] Kwang Koog Lee, Seong Hoon Kim, Yong Soon Choi, Hong Seong Park: A Mesh Routing Protocol using Cluster Label in the ZigBee Network, IEEE International Conference on Mobile Adhoc and Sensor Systems (October 2006)

[8] Ran Peng, Sun Mao-heng, Zou You-min, ZigBee Routing Selection Strategy Based on Data Services and Energy-balanced ZigBee Routing, IEEE Asia-Pacific conference on Services Computing (December 2006)

[9] Crossbow Technologies (www.xbow.com)

[10] Anurag D, Siuli Roy and Somprakash Bandyopadhyay, “Agro-Sense: Precision Agriculture using Sensor-based Wireless Mesh Networks”, ITU-T “Innovation in NGN”, Kaleidoscope Conference, Geneva 12-13 May 2008.