Smart Irrigation Using Low-Cost Moisture Sensors and XBee-based Communication

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***Abstract*— Deficiency in fresh water resources globally has raised serious alarms in the last decade. Efficient management of water resources play an important role in the agriculture sector. Unfortunately, this is not given prime importance in the third world countries because of adhering to traditional practices. This paper presents a smart system that uses a bespoke, low cost soil moisture sensor to control water supply in water deficient areas. The sensor, which works on the principle of moisture dependent resistance change between two points in the soil, is fabricated using affordable materials and methods. Moisture data acquired from a sensor node is sent through XBEE wireless communication modules to a centralized server that controls water supply. A user-friendly interface is developed to visualize the daily moisture data. The low-cost and wireless nature of the sensing hardware presents the possibility to monitor the moisture levels of large agricultural fields. Moreover, the proposed moisture sensing method has the ability to be incorporated into an automated drip-irrigation scheme and perform automated, precision agriculture in conjunction with de-centralized water control.**

Keywords—smart irrigation; moisture sensors; Xbee communication;

I. Introduction

Agriculture plays a vital role in Pakistan's Economy. Major portion of Pakistan economy depends on agricultural products. According to Economic Survey of Pakistan (2011), it contributes about 20.9% to GDP and more than 60% rural population's income depends on this [1]. But climate changes and lack of precision agriculture have resulted in poor yield as compared to population growth. Irrigation is mostly done using canal systems in which water is pumped into fields after regular interval of time without any feedback of water level in field. This type of irrigation affects crop health and produces a poor yield because some crops are too sensitive to water content in soil. A similar situation exists in many other countries of South Asia.

Many smart irrigation systems have been devised. A smart irrigation system, contrary to a traditional irrigation method, regulates supplied water according to the needs of the fields and crops. The feedback mechanism of a smart irrigation system is a moisture sensor. Evapotranspiration (ET), thermal imaging, capacitive methods, and neutron scattering method and gypsum blocks are some of the technologies that enable moisture sensing. Capacitive sensors, however instantaneous, are costly and need to be calibrated often with varying temperature and soil type [2]. Neutron probe based moisture sensors are very accurate but present radiation hazards, calibration difficulty and are costly. Gypsum blocks are however less expensive but they dissolve in water and change their response with passage of time [3]. Thermal imaging is an effective method but is prohibitively expensive. Due to the above reasons, an alternative, low cost sensor must be produced enabling the use of smart irrigation systems in the third world countries.

A large agricultural field presents an additional problem in the sense that different parts areas of it may have different evaporation rates due to foliage, the presence of rocks at different heights underground, parts of the field being in close proximity to canals or ponds, etc. Hence, moisture measurement at a single location in the filed does not make much sense. Consequently, what is required is a distributed number of sensor nodes and some scattered pumping units to pump water to those specific locations covered by the sensor units. The need for multiple sensors further emphasizes the need for an inexpensive moisture sensor. Furthermore, the requirement of multiple sensors spread out over the field means the presence of many wires in it. This will create a lot of problems to ploughing, harvesting, etc. and isn't practical. Wireless connectivity to the sensors is a novel idea in this context. In this regard, this paper proposes a low-cost wireless device for data communication.

An automated irrigation unit, in conjunction with a low-cost moisture sensor, is proposed in this paper. A system level description is provided, detailing the hardware and software design. Section II provides a description of the working principle of the sensor. The subsequent section introduces the XBee technology. Then, two sections are provided detailing the hardware and the software used followed by some description of the experimentation.

II. Moisture Sensors

Moisture sensor is a device that measures the relative moisture of any environment. There are various types of moisture sensors but most common are the impedance based ones. Impedance based sensors works on the change of impedance between two electrodes due to varying moisture content in the surrounding medium. Hence, when the electrodes are kept in soil, its moisture level changes can measured in a relative manner. This is the fundamental by which the proposed sensor works.

III. XBee Wireless Technology

XBee is a low-cost and low-power wireless technology. XBee wireless technology was first introduced with XBee alliance being formed between Philips, Motorola, Honeywell, Invensys and Mitsubishi Electric in October 2002 under IEEE 802.15.4 WPAN standard. XBee operates in the 2.4 GHz band with a data transfer rate of 250kbps and it supports peer to peer, point to point and point to multipoint networking methods with current consumption ranging between 30 to 40mA for data transmission.

TABLE I. A COMPARISON OF DIFFERENT WIRELESS RECHNOLOGIES

Wireless Mode	Bluetooth	Wi-Fi	XBee
Operating band(kB/s)	1000-3000	11000+	20-250
Coverable Distance(m)	20(Class 2) 100+(Class 1)	100+	20-70 100+ (Amplifier)
Number of Nodes	7	32	25400
Power Consumption (mA)	42-Class 2 <150 (Class1)	300	30
Memory /kB	50+	70+	40+
Technical Advantages	Cost. Efficient	Bandwidth spectrum	Low Power consumption and Cost

Having the ability to connect to a number of devices into a network makes it feasible for larger sensory networks with over maximum of 65000 possible nodes achievable. [4,5,7]. The host acts as the hub or controller of the system that can communicate with any number of similar devices. Hence, it is possible to use this for data transfer, for example, from sensors that are located remotely. In this work, one XBee node is coupled to a ground moisture level detector unit in order to record moisture data on a host computer. The XBee host communicates with the computer via a USB or an RS232 serial port.

The current widely used technologies of Bluetooth and Wi-Fi are compared with the XBEE technology and the advantages of XBee over Bluetooth and Wi-Fi are numerous for our application as seen from Table 1. XBee works over a larger distance then the Bluetooth and with lower power requirements then the Wi-Fi tech. This allows for a mesh network to be created which can cover more area and can also remain active for 6months-2 years on two AA batteries .The XBee has better latency and takes 15ms to wake up from sleeping mode as compared to the Bluetooth which requires 3-4 seconds. With this small wake-up time it is possible for the node to sleep until critical data needs to be sent at which point it can wake-up, synchronize itself with the host node, transmit and go back to sleep. This results in higher power efficiency with the batteries lasting for longer periods of time. XBee also provides Self-organization method to form a network with flexible topology. This allows for an efficient route for data transmission possible due to the dynamic routing protocol. The XBee technology exhibits a high three-tier security , using protocols such as ACL or advanced encryption standard(AES-128) for security[8].

DASH7is a new protocol which has been introduced to cover the area of WSN but it being in developing stages with no finalized specifications, no devices can be currently found which support this protocol. The DASH7 works upon a lower frequency of 433MHz, which allows easier penetration of water and even concrete walls This allows for a more area coverage with less amounts of power consumed but Since it remains to be completed, the XBee remains the single protocol available and dedicated for WSN[9].

Apart from precision agriculture being applied in this paper, further applications are mentioned here for better showcasing and appreciation of the potentials of the XBEE Technology. Healthcare monitoring system: Monitoring systems are an essential in helping doctors diagnose diseases for treatment with monitoring systems also being placed to sound the alarm when the patient exhibits abnormal behaviour[10]. The XBEE is used to communicate between the different peripheral devices and construct an overall image of the patient's vital signs at the host computer e.g. heart rate monitoring[11]. Smart Home App: for Automatic Switch-state management and Control of Ambient devices .[12].

With the following knowledge we proceed to further our case in this paper on the use of XBee wireless transmission for precision agriculture i.e. accurate moisture detection.

IV. HARDWARE

Figure 1 shows a schematic of experimental setup containing hardware as well as software module. In this figure,

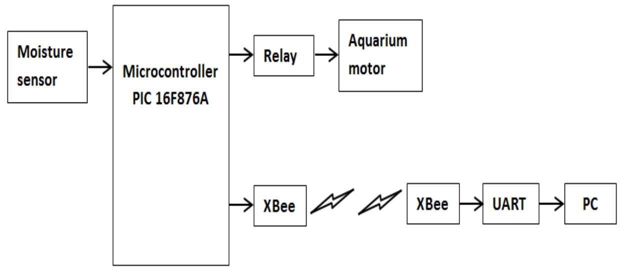

Figure 1 Hardware configuration

moisture sensor, microcontroller (PIC 16F876A) and the XBee module are connected to form a sensory node. This node then sends data to the hub that is connected to the PC in order to deposit data into a database.

The basic principle is to measure the potential difference between the two galvanized metallic electrodes of the impedance sensor. These electrodes are placed at a distance of 30 mm from each other. Both electrodes are placed on an acrylic sheet for providing mechanical stability and maintaining constant distance between them. Almost equivalent resistance to that of soil is to be placed for voltage divider, which will be determined using a sensitive voltmeter or by trial and error. This resistance is very important because it controls the sensitivity of sensors. If the resistance is too large, sensor can become too sensitive to small changes in moisture and if it's too small, the sensor will not be sensitive enough as per our needs. Therefore we have applied both methods to determine its value and the value of the resistance most suitable is found to be 10 kΩ.

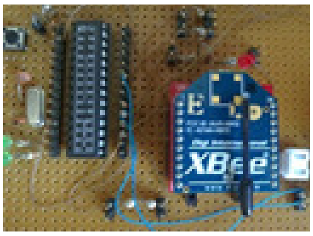

Figure 2 The XBee node with the microcontroller

The voltage across electrodes is then fed into the ADC of the microcontroller for further processing. A switching device, in form of a relay, controls the actuator, which in turn controls water flow in the field in response to the data received from the XBee node. The hub XBee is placed in the secondary board as shown in Figure 2. It receives data from the Xbee node in the main board and send data to the PC using serial communications.

In the prototype, an aquarium pump is to supply water to the soil. The aquarium pump's motor is controlled via a relay on the control board that operates the motor under specific

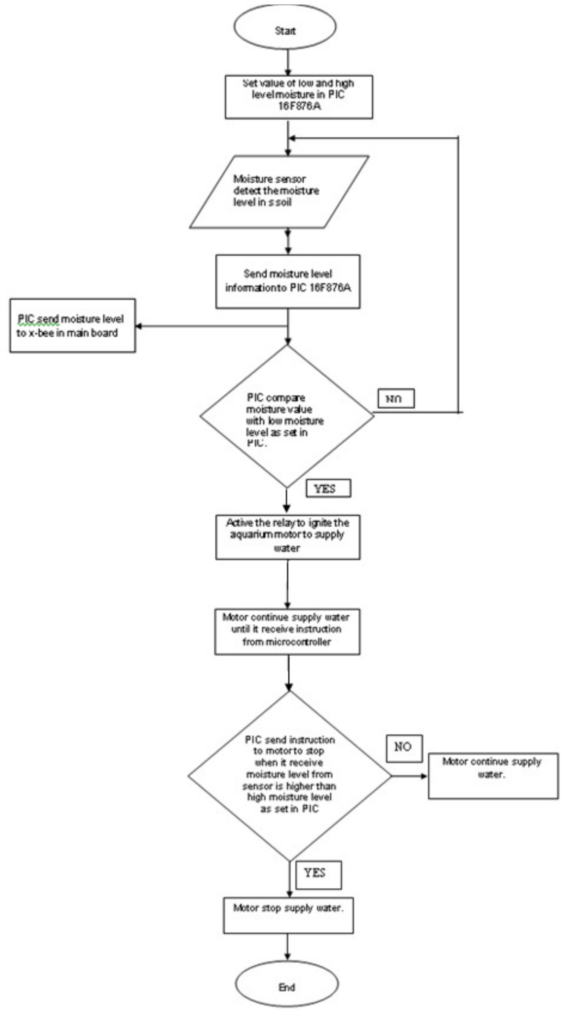

Figure 3 The flowchart of the embedded software of the microcntroller

conditions explained in the algorithm in Figure 3. The relay is controlled by a transistor interfaced to microcontroller.

V. SOFTWARE

The microcontroller is programmed with the embedded C

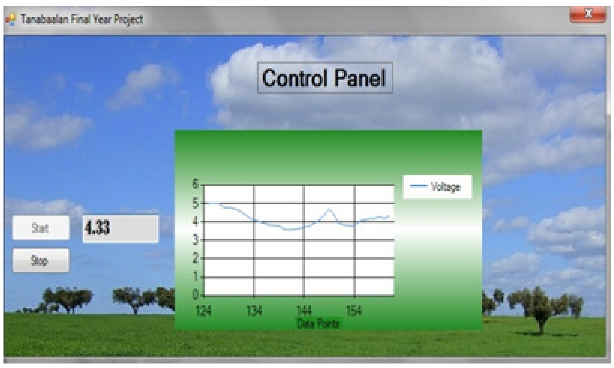

Figure 4 Developed GUI

language. A GUI is developed using Microsoft VB.net to run on the PC. The developed GUI serves as a communication link between the wireless sensor and the computer at the base station. The developed software records moisture in a backend database (MS-Access file). In addition, it helps in visualize moisture data by displaying it. Figure 4 shows the developed GUI.

TABLE II. SENSOR READINGS VS MOISTURE LEVELS

Water level (ml)	ADC output for an electrode depth of 50 mm (bit value)	ADC output for an electrode depth of 25 mm (bit value)
65	**0**	**0**
97.5	**57**	**154**
130	**76**	**319**
162.5	**105**	**380**
187.5	**126**	**470**
227.5	**319**	**525**
260	**448**	**597**
292.5	**474**	**697**
325	**570**	**570**
257.5	**673**	**673**
390	**739**	**739**
422.5	**784**	**770**
455	**800**	**814**
487.5	**821**	**821**
520	**864**	**850**
552.5	**877**	**862**
585	**900**	**885**
617.5	**930**	**892**

VI. EXPERIMENTATION

An experiment was conducted by placing the moisture sensor in a plastic container filled with 1320 cm^3 of soil as shown in Figure 5. A volume of 32.5ml of water was added to the container, at a time, and measurements were performed. This experiment was continued until the moisture level reading reached a constant value. These observations are shown in Table II.

At the start, the sensor was placed in dry soil in the middle of the plastic container, and the voltage across resistor (other than electrodes) was measured and converted to ADC values.

Figure 5 The container with soil and the elctrodes

After adding the stipulated amount of water in the container the voltage was measured. Water was added until voltages became saturated and from the experiment we observed that at water level greater than 600ml, values became constant. From both tables we observed that initially vales changed very rapidly. From this, we concluded that initially minerals in soil start to dissolve with addition of water in soil but as they all dissolve, values did not changed rapidly. Figure 6 shows the plot of water level versus ADC output bit values with electrodes dipped at depth of 50 mm and its fourth degree polynomial curve fitted graph. The coefficients of the polynomial are given below under in Equation (1). Figure 7 consists of the experimental plot and a cubic fit to the data for an electrode depth of 25 mm respectively. The cubic fit parameters are given in Equation (2).

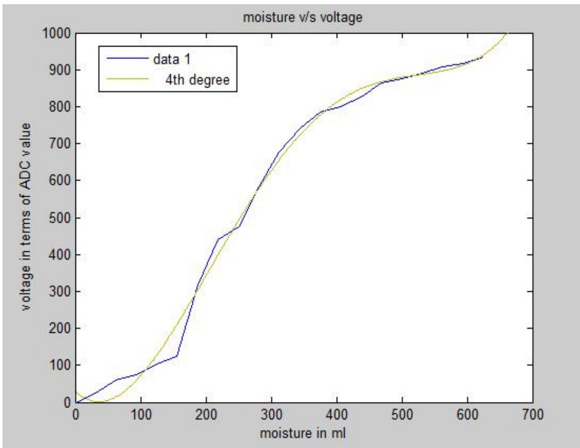

Figure 6 A fourth order fit for the water level (ml) verses moisture (ADC output) with electrode depth of 50 mm

Moisture sensor works on principle of varying voltage, due to varying impedance. This can be represented using voltage divider equation

$$V=R1/(R1+R1) \qquad (1)$$

Where R1 is resistance of soil

R2 is resistance comparable to R1

V is potential drop across R1.

Using this, we have made sensor which have following response curves, which are plotted in Figures 7 and 8.

$$Y=P_1*x^4+P_2*x^3+P_3*x^2+P_4*x+P_5 \quad (2)$$

Where $P_1=4.1*e^{-8}$

$P_2=-6.01*e^{-5}$

$P_3=0.0268$

$P_4=-1.7$

$P_5=30.6$

Y=volts in terms of ADC values (electrode depth of 50 mm)

x= water level in ml

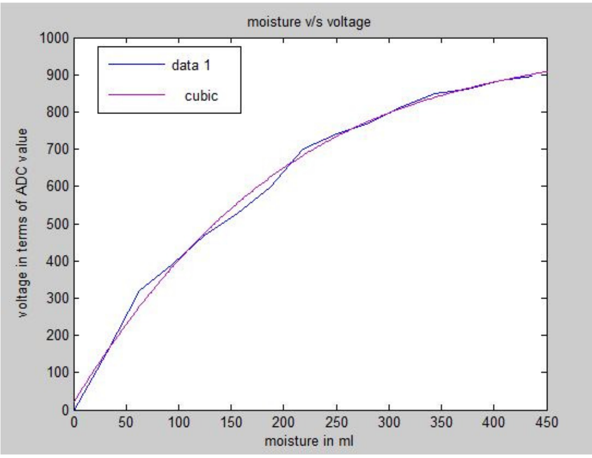

Figure 7 Experimental measurements and a cubic fit to water level (ml) verses moisture (ADC output) with electrode depth of 25 mm

$$Y=P_1*x^3+P_2*x^2+P_3*x+P_4 \quad (3)$$

Where $P_1=5.8*e^{-6}$

$P_2=-0.0085$

$P_3=4.62$

$P_4=18.3$

Y=volts in terms of ADC bit values (electrode depth of 25 mm)

x= water level in ml

VII. CONCLUSIONS

It has been shown that a low-cost sensor fabrication performs well, in a consistent manner, in sensing ground moisture. The communication device and the controller setup are shown to work as expected and record the moisture data to a PC remotely.

VIII. FUTURE WORK

Many features can further be added to this system which includes web-based communication, mobile alerts and weather adaptive systems. This type of system is a good solution for condition monitoring of agricultural setups as it is low in cost. This idea should be implemented to large scale farms in the form of sensor grids in which each sensor will be treated as a Zig Bee node. Figure 8 shows a schematic of proposed design in which zones contains N X N matrices of moisture sensors. These zones makes up MXM matrix of XBee nodes. Each node is then connected to XBee master receiver, which then feeds data into hub for further processing.

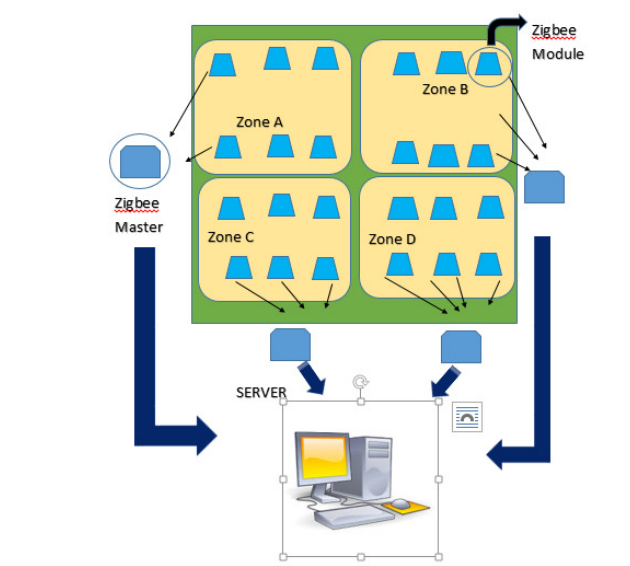

Figure 8 Proposed schematic of moisture sensor network

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