

# An IoT Based System for Remote Monitoring of Soil Characteristics

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**Abstract**—Remote monitoring of soil parameters is an emerging trend which has the potential to transform agricultural practices and increase productivity. pH value, temperature and moisture content of soil are the basic parameters which help in characterizing the soil and therefore in taking proper decisions regarding fertilizer application and choice of crops sown. In this work, antimony electrode is used for pH measurement. For soil moisture content estimation, the inverse relation between soil resistance and soil moisture has been utilized and corresponding circuitry has been developed. The determination of soil temperature is done using the DS18B20 sensor working on the Dallas one wire protocol. The system is integrated with Bluetooth for the transfer of data to a nearby cell phone. The entire system is developed on STM32 Nucleo platform.

**Keywords**—*Internet of Things, Smart Agriculture, Soil pH, Soil Temperature, Soil Moisture Content*

## I. INTRODUCTION

Internet of Things (IoT) is a concept and paradigm that enables interaction among objects pervasively present in an environment. Internet of things today, has reached many different areas, taken different forms and uncovered a multitude of applications. These applications permeate into practically all areas of our lives. The development of an IoT based infrastructure that facilitates precision agriculture is one such application that has acquired high attention. To be successful, a farmer must maximize per acre yield, reduce spoilage from inadequate or overuse of fertilizers, reduce the risk of crop failure and minimize the operating costs. Effective management of input resources like water, fertilizers and seed quality is the key to achieve this success. Many farms around the world - particularly those in developing countries are small, comprising of only a few acres. These smallholder farmers continue to follow conventional farming practices and often face the brunt of high crop losses, low yield, inferior quality of farm produce etc. Conventional methods like crop investigation and soil analyses are very time consuming. By using IoT and data based decisions and by predicting the implications of each and every decision, a farmer can reap high profits and use his field more efficiently. This is a means of assisting farmers in optimizing yield, minimizing input costs and reducing environmental impact on crop growth.

There has been a pressing need to provide real time farm information like soil moisture, temperature and pH to the farmer. These are vital soil parameters that influence overall

crop growth and in turn the farm produce. Monitoring of soil moisture in different areas of a farm can help in overall irrigation management. Different crops require different irrigation strategies and using real time data of soil moisture a farmer can increase yield by maintaining an optimal soil moisture for a specific crop. For example, while waterlogging is threatening for the life of most of the crops, it is a must for paddy farms. Sometimes the standing water in paddy fields gets heated by sunlight and negatively affects crop growth. To avoid such situations, farmers drain off the warm water and refill their paddy fields with fresh water. Real time soil moisture and temperature monitoring can be used to alleviate some of these problems faced by farmers. Soil temperature on its own is an important factor to determine the crop growth, it has been found that soil temperatures below 20°C inhibit nitrogen fixation which leads to decline in soil fertility [1]. Changes in acidity of soil may change the availability to plants of different nutrients in a number of ways. As pH of a soil increases, ions such as iron, aluminum, manganese, copper and zinc become less soluble. Thus neutralizing a soil makes the condition more favorable to growth of bacteria and speeds up processes by which nutrients are made available to plants [2].

Numerous researchers and manufacturers have developed sensors to measure the mechanical, chemical and electrical properties of soils. Vellidis, Tucker, Perry, Kvien, and Bednarz [3] developed a relatively low cost sensor array which measured soil moisture and temperature and was used in automated irrigation scheduling. Multiple sensor nodes were deployed in the field and were connected to a centrally located receiver which provided the amount and timing of irrigation at different locations in the field. In another work, Mirell and Hummel [4] developed a real time soil analysis system based on Ion Selective Field Effect Transistor (ISFET) technology. An automated soil extraction system was used and ISFETs were used to calculate the soil pH and nitrate content. Adamchuk et al. [5] have also developed an automated soil sampling system which was mounted on a shank and had a pH meter with a flat surface electrode. They used linear regression to calibrate their results with soil pH obtained by standard laboratory tests [5].

A general trend found in the above mentioned studies was that electrical or electromagnetic sensors were used for measuring pH value, temperature and moisture content of soil. However there has been an inability in implementing an inexpensive, precise and a real time sensor system for this purpose.

In this work, a device for remote monitoring of soil characteristics through smartphones is proposed. The proposed device is reliable, cost effective, power efficient, and works in real time. By means of Bluetooth communication, the sensor node sends data to a nearby smartphone, where an application, BT Terminal, is used to view the soil characteristics. Soil sensor calibrations have shown satisfactory results and the device can be used with reliability. This work makes an important contribution by proposing a reliable and feasible IoT based device for remotely monitoring soil characteristics and takes a step forward in the integration of IoT and agriculture to achieve the goal of smart agriculture.

The contents of this paper are organized as follows. Section II deals with various design aspects. It discusses the Microcontroller Unit (MCU), firmware flowchart, sensor design specifications and power supply. In section III, sensor calibration procedures are discussed in detail along with resulting calibration curves. Section IV describes the results of our work. On field implementation is also discussed along with validation and errors found after testing. In section V, we discuss future scope for research in the area of agricultural IoT. We present some specific domains within agricultural IoT that require more attention and have higher potential for further work. Section VI presents the conclusion of this work.

## II. SYSTEM DESIGN

The objective to design the proposed system is to collect soil sample and measure its pH value, temperature and humidity remotely in real-time through smartphones. The block diagram of proposed system is shown in Fig. 1. The system is developed on STM32 NUCLEO platform. It has three basic blocks viz. microcontroller block, sensing block, and communication block.

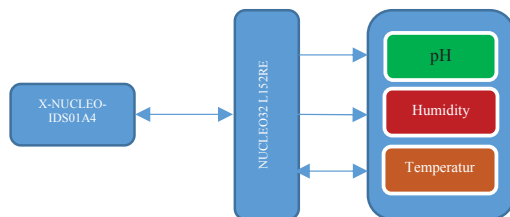


Fig. 1. Block Diagram of Proposed system

Microcontroller is the heart of the device. It is responsible for controlling the sensing and communication blocks of the device and reading soil parameters such as pH, moisture, temperature. It is also responsible for sending the data acquired from the sensors to a smart phone via Bluetooth. In the proposed device we have used STM32L152RE which is a Microcontroller unit (MCU) of the STM32 series of development boards. The MCU used in this work has an additional feature of low power consumption. This is implemented in the form of several power saving modes such as standby mode and sleep mode. Firmware of MCU is developed and debugged using the

freeware version of IAR. The flowchart of Firmware showing its working is given in Fig. 2.

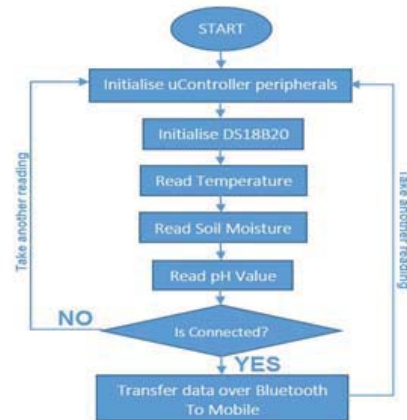


Fig. 2. Firmware Flowchart

The proposed system works as follows. When powered on, MCU initializes the peripherals to be used to control and manage the sensing and communication blocks of device. MCU takes samples from sensors one by one and also checks if the device is connected or not. If it is, it transfers data to mobile, otherwise takes another sample. We have also implemented hibernate mode in the device keeping in the mind the fact that the device has to be used in outdoor applications. STM32L152RE has five power modes, out of which we have used the standby mode. In standby mode controller's use is minimized as it draws a current of about 0.1mA. The controller goes into standby mode for six hours after every one hour of data transmission.

The sensing unit contains various agriculture sensors to measure pH value, moisture, and temperature of soil sample. These sensors are interfaced with a 10 bit ADC of MCU. DS18B20 is used as soil temperature sensor, which is a digital sensor based on the Dallas's one wire protocol. It codes temperature data using 12 bits, and thus provides a high level of accuracy. The soil moisture sensor is designed using the inverse relation between soil resistance and soil moisture. Fig. 3 shows the schematic of moisture sensor used in this work.

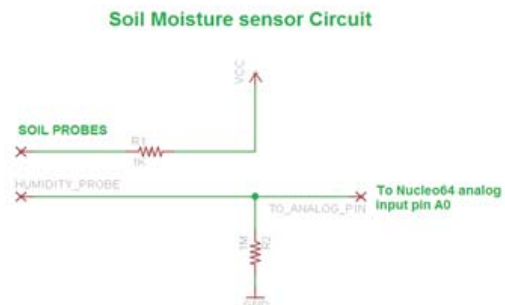


Fig. 3. Soil Moisture Sensor Circuit

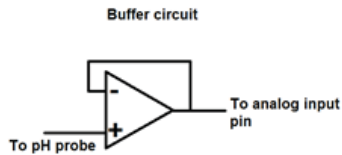


Fig. 4. Soil pH Buffer

The pH sensor, as shown in Fig. 4, consists of an antimony electrode for pH and another electrode for soil moisture. It is a purely analog device and does not require any power supply to function. However, a supply is needed for biasing the buffer-amplifier circuit. The output leads from the pH probes are connected to the buffer input, and the output of buffer circuit is sent to an analog pin of STM32 board.

The system is powered using two 1.5V AAA batteries. In the present prototype, these batteries can last up to 30 days, after which they are recharged and used again. In future, we intend to work on integrating solar power into the system to make it self-sufficient in terms of power usage.

### III. SENSOR CALIBRATION

The developed system was calibrated and tested at Zakir Hussain College of Engineering and Technology, Aligarh Muslim University, Aligarh, and also for some duration at STMicroelectronics office in Noida. Calibration and testing has been undergoing from March, 2016 for optimization purposes.

The pH sensor was calibrated by comparison with standard laboratory pH buffer solutions. A total of 16 pH buffer solutions were made using pH buffer tablets, two each in the range of 3-10 with a step of 1. The pH electrode was dipped in each of these solutions and the corresponding voltage was read by the microcontroller. The calibration curve so obtained is shown in Fig. 5.

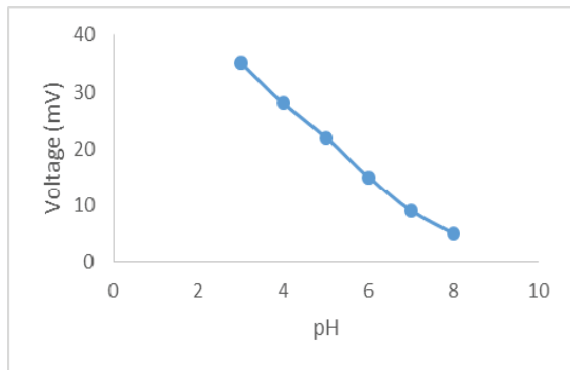


Fig. 5. pH Calibration Curve

Further, to make implementation simple, the voltage values were quantized such that a step of 8 mV resulted in a pH drop of 1 point. It was also experimentally found that pH

values below 3 and above 8 were not representative of the actual pH of soil and so the samples having pH value above 8 and below 3 were removed from the calibration set.

The moisture sensor uses the principle of inverse relation between soil moisture and soil resistance. More the soil resistance, lesser its moisture content and vice versa. The soil moisture sensor was tested with various samples of completely dry, intermediate, and completely wet soils. The completely wet soils returned a voltage value ranging from 2.62 to 3.21 Volt, whereas the completely dry soils gave rise to a maximum of 0.4 Volt. Moderately wet soils returned a voltage reading in approximately a linear relationship with the degree of soil wetness. Using this trend, the calibration equation was formulated in Eqn. (1), where ADC\_Value is simply the analog voltage read by the ADC –

$$\text{Moisture Content} = (\text{ADC\_Value}/3.3) * 100 \quad (1)$$

Soil temperature sensor, DS18B20, is a commercially available, digital, high precision, and water proof sensor. It uses 12 bits to encode soil temperature and so, even the slightest soil temperature variation can be detected accurately. For our application, there was no need to further calibrate the soil temperature sensor.

### IV. RESULTS AND DISCUSSION

The developed prototype was tested in garden pots and agricultural fields and satisfactory results were obtained. Over various cycles of testing, multiple factors were considered and improvements were made accordingly. Fig. 6 shows the working prototype of the developed system in a pot. Bluetooth communication was used for communicating sensor data to a nearby mobile phone. Mobile application BT Terminal was used at the mobile phone end for receiving data from device. In the graphic shown, a USB power supply is being used to power the microcontroller board. However, during actual field testing, a DC supply comprised to two AAA cells was used. To make the device power efficient, a standby mode, which is inbuilt in STM32 firmware, was employed.

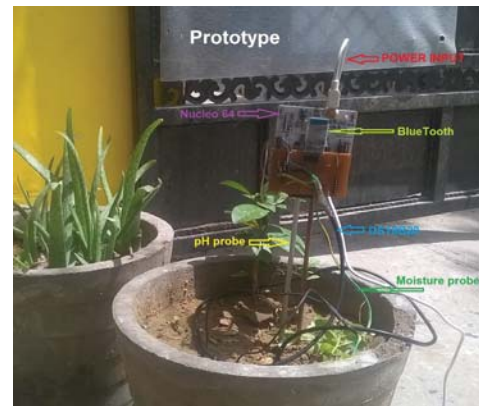


Fig.6. Working Prototype

During various on-field tests, the pH sensor was found to exhibit a maximum error of 1, caused when the voltage deviation was equal to or greater than 4mV. However, this

error was reduced to negligible limit by adding a buffer circuit. It is to be mentioned that there is further room for improvement in the pH sensor design process, such that the need for voltage quantization is removed and pH step size can be reduced to around 0.1.

Field tests showed the moisture sensor error to be largely dependent on the degree of wetness. In the moderately wet soil, the error is more likely to occur. As the soil moisture content increases, the error decreases and tends to zero at 100% soil moisture content. Fig. 7 shows the validation curve obtained for soil moisture measurement.

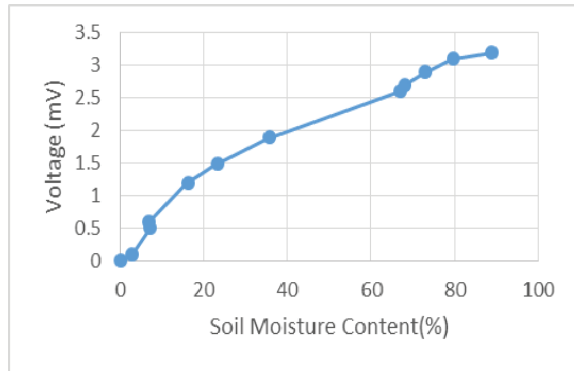


Fig. 7. Soil Moisture Validation Curve

As can be seen from fig. 7, the voltage tends to deviate from the linear curve in the region of 10-40% moisture most highly. The mean error, averaged over 12 samples, was found to be relatively low (of the order of 9.4%). This is sufficient to accurately indicate the water requirement of soil and can be taken as an insignificant error value. The use of ultra-accurate moisture sensors, although increases the reliability of data obtained, is counterproductive as it increases the cost of the system abruptly. Thus, there is presently a trade-off between the desired accuracy and the cost of sensors used. In our work, the results have been found satisfactory while maintaining low cost of the system and so an efficient trade-off has been found.

## V. FUTURE SCOPE

As technology advances, so does the requirement for food, which is directly related with the increasing population. There is an immense potential in the agricultural domain for the application of emerging technologies such as IoT, cloud computing, robotics, GIS and remote sensing, among others. Here, we list some specific areas, which are among the most important ones for further research work relating to ICT in agriculture.

### A. Agricultural Sensors

The most fundamental area for further research lies in the design and development of new sensors suited to agricultural applications. Sensors for moisture and temperature of soil are commercially available but are subject to cost constraints. Cheap soil moisture and temperature sensors are a requirement, especially in developing nations, where small scale farmers cannot afford the high costs of available

sensors. pH sensors, though available, are scarce, and also very costly. Those that are comparatively cheaper are not digital and cannot be readily integrated with ICT infrastructure.

A pressing need in agricultural sensor domain is that of soil nutrient sensors. Cost effective, on-the-go, and real-time soil nutrient sensors, specifically NPK sensors, are lacking in the electronics industry. Those that are available are so costly that they cannot be used by small scale farmers. Market analysis done by the authors revealed that a single nutrient sensor can cost as high as \$300 at starting value. Having soil nutrient sensors employed on the farm equips the farmers with invaluable data about the quality of farm soil and the fertilizer requirement on an accurate and real-time basis. This can prove highly effective in increasing soil productivity and can lead to a large increase in the farmer's revenue, for a small initial investment.

### B. Power Efficiency

Deploying ICT infrastructure on a farm hold, besides being a costly affair, can also cause issues related to power usage. A multitude of sensors nodes, actuators, gateways, and processors on the farm will require power to run, which can add to the farmer's troubles. It is therefore required that farm hold ICT infrastructure be made self-sufficient in terms of power.

One method of doing this is by integrating renewable energy into the ICT infrastructure. Specifically, solar energy can be utilized to make the various sensor nodes, actuators, and gateways power efficient. Another method is by the incorporation of energy harvesting technologies. Z. W. Sim, et al., have developed a folded shorted patch antenna for harvesting energy to power wireless soil sensor networks [6]. J. M. Gilbert and F. Balouchi have presented a comprehensive review of energy harvesting technologies for WSN applications [7].

### C. Cloud Integration

With the internet becoming the medium for all kinds of communication and information exchange, it is imperative that agriculture be integrated with cloud services. Farmers, especially in developing nations like India, are isolated from supply chains, government, agronomists, and academicians. Cloud services can reduce this gap. Also, cloud services like real time weather forecast and online price lists can prove highly helpful to these isolated farmer communities.

## VI. CONCLUSION

In this work, an IoT based system for soil pH, temperature, and moisture measurement has been presented. Sensor designs for pH, temperature and moisture have been successfully implemented and tested with minimal error. The system has been developed on STM32 board, with Bluetooth being used for communication with farmer's smartphone. Further work is underway for integrating 6LoWPAN for networking. Also, a website has been developed for uploading sensor data to the cloud. The website can be visited at [www.soilhealthcard.pe.hu].

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