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Design of Smart MOTE For A Precision Agricultural Application

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Abstract

This research is an electronic device designed to act as an aid for precision farming by enabling remote monitoring of the physical properties of the agricultural fields, namely soil moisture, soil pH and soil temperature. The data collected from the sensor at the transmitter module are transmitted wirelessly to a receiver module connected to a computer for database maintenance. The model is designed keeping in mind the low-power, low cost and high robustness requirements pertaining to wireless sensor networks to be placed in farmlands for long periods of time to collect data continuously. The advantage of this module is that it is easy to use, low cost and aids in remote data collection and data processing. It can be further modified to collect other related parameters by including suitable sensors.

Keywords: Precision Agriculture, Wireless Sensor Node, Soil monitoring.

Introduction

The ability to assess a biophysical variable over a whole culture is key to improving its management. If successfully conducted, this approach, called precision farming, yields ecological benefits with sustainable management of arable soils and also considerable economic savings for the farmer. In spite of being the oldest job in the country, farming still lacks the proper technological support that would make it more efficient and easier. The primary requirement of precision farming is the so called “ground truth” that is the true values of biophysical parameters of the field. Collecting such information over the area of a particular field, along with the GPS locations of the sensor module enables development of an overall mathematical model of the agricultural field with respect to the parameter. There are several algorithms for the development of this mathematical model. This would assist analysis of the field or the enabling of necessary control actions.

For example, upon detection of decreased moisture levels in a cultivated soil, the irrigation mechanisms may be activated to increase the moisture content in that part of the field. This solution, although thorough is extremely expensive. An attractive alternative is to use satellite imaging to analyze the properties of an agricultural field. Covering the entire expanse of the field with sensor modules is not economical for the average farmer.

This project aims to develop a user-friendly, low cost and low power consuming module for the continuous monitoring and data collection for analysis of an agricultural field.

Design Methodology

In an effort to scale down the size of wireless sensor nodes, one of the design implements an autonomous 16 cubic mm sized solar powered mote [10]. The design includes extremely small sized MEMS sensors integrated into the system powered by a solar cell array fabricated on a small dimension of 50 micrometers. The wireless transmission and reception is done using an optical link which requires a line of sight link for efficient communication[23]. A system [11, 21, 22] has been designed to simply acquire and store the humidity information continuously along with the GPS information of the node. A design- mKRISHI [9, 20] has used Zigbee Technology for wireless transmission of the soil parameters using the Texas Instruments ZigBee RF transceiver, IC CC2530, the drawback of the design being the limited range. Zigbee technology is reported to be far superior to other Wireless Personal Area Network Technologies due to its low power, high security, and high range in spite of having a fixed low data rate (250 kbps). The performance analysis of ZigBee topologies in the agricultural fields of thick vegetations has been done in the implementation of one of the designs[5, 16]. The result based on their experiments conducted at 1000m distances of sensor nodes reveal that Tree Topology is superior to the usual mesh and Grid topologies realized in ZigBee networks. Another design developed ways to remotely control the parameters of a greenhouse [1, 12, 13], where they have used CY3271 PSoC First Touch Starter Kit, which is a low-cost USB thumb drive kit including related IDE software for sensing, control of the data collection and wireless transmission up to a short range distance of 50m. GSM Technology has been integrated into similar wireless sensor modules provide immediate alerts through SMS to the farmers, apart from intelligent system designs that have actuator control to activate irrigation or fertilizer spray mechanisms [3, 4, 15]. A system for monitoring the water level of soil using several wireless sensor nodes with a common base station has been designed [2, 14]. Some nodes have been designed as forwarders, some given a node-node link while others are linked directly to the base station. The existing designs for remote monitoring of soil parameters have used different methods of sensing and data acquisition. Some systems have relied on data from satellite images of the fields for analyzing the parameters of soil up to a certain depth. The common methods of sensing are,

Physical Parameter: Soil Temperature

Soil temperature assumes a vital part in numerous methods, which occur in the dirt, for example, compound responses and organic cooperations. Soil temperature differs in light of trade courses of action that happen essentially through the dirt surface. These impacts are proliferated into the dirt profile by transport forms and are impacted by such things as the particular hotness limit, warm conductivity and warm diffusivity.

Measurement Methods

Any temperature measurement can be done primarily in two ways- using contact sensors and non-contact sensors. Temperature measurement in the previous designs has been done using thermocouple, thermistor (RTD), IC based sensor or MEMS sensor. In some cases Non contact sensing methods like IR Reflectometer and thermochromic materials which exhibit a change of color upon exposure to temperature beyond a threshold.

Thermocouple

Is a transducer of two dissimilar metals that gives a voltage (in millivolts) proportional to the difference in temperature between the two metal junctions. Its functioning is based on the Thermo-electric Effect or Seebeck Effect Phenomenon. The advantage of this transducer is the high range of temperature that can be measured (up to 2700 degree Celsius) and it does not require external supply arrangement. There are different types of thermocouples for different ranges of temperature and the type of metal pair chosen also depends on the application for which it is to be employed. The disadvantage of this is that it needs special sets of connector cables that are made of the same metal as that of the thermocouple for bringing out the voltage to the system. The use of any other ordinary cable causes the formation of another junction leading to errors. Thermocouple requires room temperature compensation for which RTD or IC sensor may be used.

RTD

Correlating resistance of the RTD element temperature is measured by resistance temperature detectors ('RTD's) sensor. Due to their fragility they are mostly enclosed within a probe type sheath. RTD sensors are known for their very high accuracy, though having a comparatively shorter range. To overcome the effect of error, two to four wire lead RTD measurements may be taken. Since the variety of temperature shows up as a safety variety, it requires an outside supply alongside a scaffold course of action for estimation.Apart from this RTDs are mostly made out of inert materials like platinum and are comparatively more costly. They are more stable than thermocouples, but also more susceptible to EMF noises.

IC sensor – LM35:

IC sensors for temperature, cover a small range and are primarily used for the purpose of ambient temperature measurement. Operation of IC temperature sensors is based on the behavior of silicon PN junctions, as a function of temperature. A current is forced through two PN junctions with different active areas. The difference between the forward voltages on the two junctions is proportional to absolute temperature:

$$V1 - V2 = (kT/q) \ln(J1/J2)$$

They are very small in size and of low cost and power consumption, but are susceptible to error at higher temperatures. However, they provide better accuracy and flexibility with outputs that require minimum signal conditioning.

MEMS based Temperature Sensor

In this novel approach, the cantilever beam of the MEMS sensor is coated with a nano-polymer material that absorbs ambient water vapor and holds in to the surface by weak van der Waal forces. An On-Chip temperature sensor detects the temperature of these water vapor molecules.

This project requires a temperature measurement of soil, which falls in the range of 25 – 50 degrees, for which the most suitable option is using an IC sensor (LM35). It is low cost, low power consuming, easy to integrate into the system and is also found to have sufficient accuracy and sensitivity range suitable for the application.

In order to make the LM35 suitable for insertion into the soil, the IC is placed inside a probe-like plastic structure and the pins are thermally and electrically insulated to avoid shorting of the pins.

Physical Parameter: Soil Moisture

Soil dampness is fundamentally of two sorts. The most generally known sort is the dampness content held between the particles of the dirt while the other kind is the dampness because of deterioration of the dirt particles that happens at high temperatures. Henceforth the amount thusly gets to be subject to the temperature of the dirt at high soil temperature conditions. Soil dampness data is significant to organizations concerned with climate and atmosphere, spillover potential and surge control, soil disintegration and slant disappointment, repository administration, Geotechnical building, and water quality.

Soil Moisture Measurement Methods

Remote soil moisture quantity is obtained by using numerous methods; also include the direct and indirect of soil moisture. Soil water content is maintained and based on the direct measurement the soil quality is evaluated to balance the water content by evaporation.

The measurement is evaluated between the dry soil and balanced content soil. The soil content can affect if indirect methods involve in the measurement and this method can also used to measure the object placed in the soil. Normally porous absorber is placed in soil. From the Soil surface, through electromagnetic energy the measurement of remote sensing of soil moisture takes place. The intensity variation of electromagnetic radiation depends on either the index of refraction or soil temperature or both. Normally, satellite system involves in measuring the spectral reflectance differences of the soil surface.

By leaching, evaporation or chemical reaction the sample water is removed and measured the soil content, based on this the gravimetric measurement is taking place. Removed water quantity can be determined by weight reduction or by reaction with a suitable chemical reagent or distillation. Standardization of other soil moisture techniques consists a standard method oven drying.

The slow neutron density or thermal are measured to evaluate the soil content measurement. It takes place by neutron scattering method and it is an indirect soil moisture method to determine the soil content. In water molecules if the lowest atomic weight of hydrogen atoms is with neutrons collide, then the thermalization and average energy loss will be much greater. Thus, by determining the concentration of thermal neutrons and the distance at which it is present enables an estimation of the moisture content of the soil. The primary drawback of this method is its poor resolution and high complexity.

Soil content is determined by the radioactive technique within a 1 to 2 cm soil layer. The intensity of the soil is reduced or attenuated by mono energetic gamma rays and its depends on the soil column density and its essential elements. The gamma transmission technique is used to measure the wet density changes and changes based on the soil content is maintained.Moisture potential is measured based on the force of the water in the soil. The energy or capillary tension is measured by the Tensiometer with the water content in soil.

The propagation velocity pulse is measured at the end to detect the reflected pulse. The difference between the reflected and transmitted pulse delay are defined in this measurement. The transmission line loss, frequency and dielectric constant are defined for the velocity. Thus, the fixed frequency and transmission line loss, soil moisture can be obtained as a function of the dielectric constant in this method.

Porous blocks are used to avoid the issues in measuring the soil capacitance, thermal conductivity and electrical measurement. Indirectly resistivity measurement takes place in soil by using these blocks. If the stability is reached by the blocks in soil then the soil water content considered the current properties as an index.

Thermal emission of the soil is the properties of dielectric and the soil surfaces of the microwave region are determined by this method. Measurement of the parameter is the brightness temperature and it will be emissivity soil surface. The media properties of dielectric determine the electromagnetic wave characteristics. Therefore, in soil surface the properties are affected. As a result, the soil surface properties depend on the content of the soil.

Hygrometer is a sensor that is used for the measurement of relative humidity. Standardized soil content is determined by the relationship of the atmosphere moisture and porous resources. There are several methods for Relative Humidity measurement based on capacitance, Dew point, psychometric etc.

Model based moisture detection

This method involves the long term monitoring of the moisture patterns of a specific field based on which an algorithm can be developed for determining the moisture of the soil at any given time.

This algorithm or mathematical model development apart from being time consuming and intensive, is also extremely specific and can be applied for only one particular field with a set of initial conditions.

MEMS based moisture sensor

As discussed earlier, in this method the sensor is a cantilever beam of micro-dimensions upon which a nano-polymer material that is sensitive to water is coated. It adsorbs the surrounding water molecules and holds them onto the surface of the cantilever beam (by weak Van Der Waals forces) due to which the frequency of vibration of the beam differs. It is a highly accurate method primarily suitable for the water vapor measurement. It is not robust and its placement into the soil layer to the required depth is difficult.

Most of the designs mentioned above have one or more of the following drawbacks: high cost, high power consumption, very short range for wireless data transmission. The solar powered soil sensor module is designed to overcome the above mentioned difficulties.

Proposed System

The system primarily collects three sets of data, soil moisture, soil pH and soil temperature, from three different sensors. After proper signal conditioning, these are wirelessly transmitted from the field to a receiver at a remote location. The receiver being connected to a computer, transfers the received data to the database in the computer. The data received through the serial port can also be viewed directly through a hyper terminal interface window. This project aims to develop a cost-effective and low power sensor module for data acquisition of various parts of a field for control or analysis. An overall block diagram of the project module is shown in the following figure1:

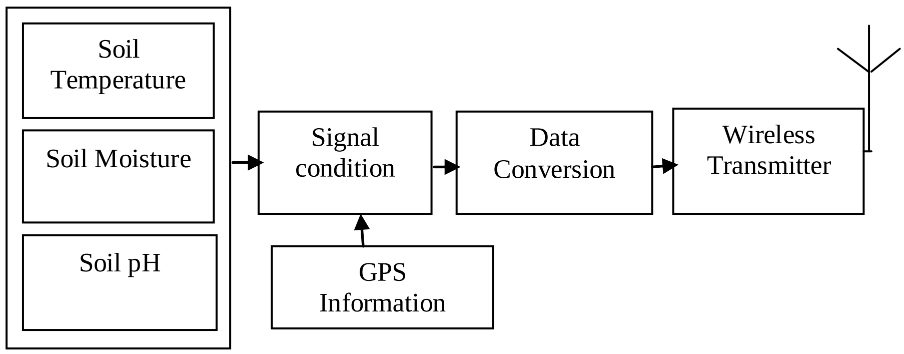

Figure 1.1: Transmitter Module

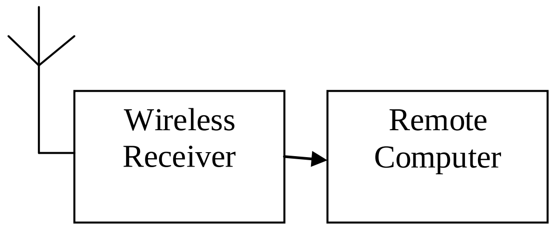

Figure 1.2: Receiver Module

Solar MOTE
The module is a wireless sensor node that has a transmitter and a receiver. The transmitter has a soil temperature, soil moisture sensors and a GPS receiver that is connected to a PSoC microcontroller IC. The information from the sensors and the GPS location of the transmitter are given to the ZigBee wireless module (Tarange F4) by the microcontroller IC. At the Receiver, the wireless receiver module is connected to a desktop or laptop to display the information received.

Soil Temperature Sensor
The temperature of soil lies in the range 25 degree to 50 degree Celsius for which IC based temperature sensor LM35 is suitable. It has the advantage of being low cost, having an output voltage proportional to the temperature in degree Celsius and an accuracy of 0.05 degree Celsius. In order to insert the IC sensor into the soil, it is inserted into a tube encasing and both ends of the encasing are made leak proof to avoid short circuit between the pins of the IC. The modified sensor is calibrated against a standard Haake's Temperature Bath.

Soil Moisture Sensor
The soil moisture sensor chosen is Hygrometer based which gives an analog output voltage proportional to the moisture of soil. The sensing principle is that moisture of any porous material is directly proportional to the relative humidity of the air immediately above it, which affects the resistance of the porous medium. Since soil moisture is highly dependent on the type of soil, the sensor has to be calibrated against one particular type of soil.

Programmable System-on-Chip
Conventional FPGA-based SoC architecture consists of configurable logic blocks (CLB's), configurable I/O blocks, programmable interconnect, and a soft or hard processor core. The CLB is the basic building block in an FPGA. It contains RAM for lookup tables (LUT), flip-flops for clocked storage elements, and multiplexers for routing signals to and from the CLB. Programmable interconnect within the FPGA is used to connect different CLB's and I/O blocks together and act as buses to route the signals between the different components of the FPGA.

PSoC (Programmable System-on-Chip) is a family of integrated circuits made by Cypress Semiconductor [8, 19]. The chip family is fabricated in a 0.45-micron Sonos CMOS technology, offering speeds to 24 MHz at 5 volts (12 MHz at 3.3 V) and flash memory sizes to 16k. These chips include a CPU and mixed-signal arrays of configurable integrated analog and digital peripherals. Similar to an FPGA-based SoC, a PSoC consists of a fixed processor core, a number of configurable digital blocks, and programmable interconnects. The primary block of the Programmable System on Chip is the digital block which is a higher level of digital abstraction than the CLB of FPGA.

A PSoC consists of four main elements,

1. **PSoC core** in PSoC1 contains a proprietary 24MHz M8C CPU core, on-chip RAM and flash memories, multiple clock sources, a sleep-and-watchdog timer, and an interrupt controller.
2. **Digital System** contains a number of digital blocks. A Digital Block consists of the data path, input multiplexers, output de-multiplexers, configuration registers, and chaining signals. Through the RAM-based configuration registers, a Digital Block may be configured to perform any one of seven functions: timer, counter, pulse width modulator (PWM), pseudo random sequence (PRS), cyclic redundancy check (CRC), SPI, and a full duplex UART. Each Digital Block provides 8 bits of resolution (8-bit timer, 8-bit counter …etc.). Multiple Digital Blocks can be chained together to provide functions with higher resolution.
3. The **Analog System** contains a number of analog blocks. The analog blocks are divided into programmable Switched-Capacitor (SC) blocks, Continuous-Time (CT) amplifier blocks and programmable reference generators. The SC and CT blocks are arranged in a 4 x 3 array. Local interconnect is based upon a nearest-neighbor scheme and is programmable to allow communication between blocks to create more complex functions. Each analog block can be configured and reconfigured to perform one of several analog functions such as filters, amplifiers, tone generators, DAC, and ADCs.
4. Finally, **System Resources** provide the additional PSoC capability. They include Multiply-Accumulator (MAC), decimators, I2C, a Switch Mode Pump (SMP), and a full speed (12Mbps) USB.

Global Positioning System Receiver

The Global Positioning System is a group of 27 satellites. 24 solar powered satellites in actual operation and three in case any one satellite fails. These solar powered satellites are at a height of 12,000 km and make two complete rotations every day around the earth. They are positioned such that from any point on earth at least four satellites are visible at a time. A GPS receiver module is a device that identifies the visible satellites, finds out the distance from the satellites and uses this information to determine its own location. This is done by the technique of trilateration. These satellites are travelling at speeds of roughly 7,000 miles an hour with small rocket boosters on each satellite to keep them flying in the correct path. GPS satellites transmit two low power radio signals, which is designated to L1 and L2. The L1 frequency is used by Civilian GPS of 1575.42 MHz in the UHF band. The GPS module SIM18 of power specifications of 1.8V and 45mA for acquisition equipped with a passive antenna at 1.8V is used in the design. It uses the NMEA protocol standard with an accuracy of 2.5 mCEP (CEP: Circular Error Probability). The latitude and longitude data are taken from the string output of SIM18.

Example GPS Receiver String:

$GPGGA,091926.000,3113.3166,N,12121.2682,E,1,09,0.9,36.9,M,7.9,M,,0000*56<CR><LF>

The GPS information which we recive from the GPS receiver is shown in Figure 2.

The PSoC microcontroller is programmed to extract the required latitude and longitude information from the string.

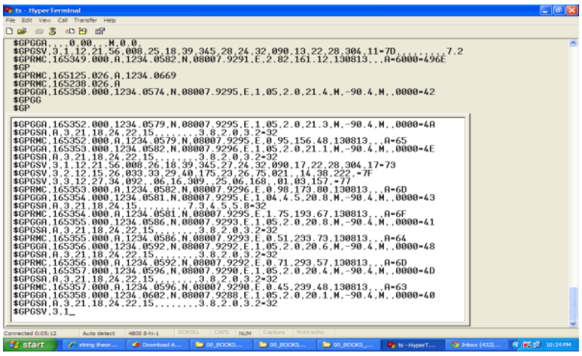

Figure 2: GPS receiver information

Zigbee Module

The wireless technology ZIGBEE addresses the unique needs of low-cost, low-power wireless M2M networks. The protocol allows devices to communicate in a variety of network topologies and can have battery life lasting several years. ZigBee is designed to communicate data through hostile RF environments that are common in commercial and industrial applications.

ZigBee protocol includes the following features:

1. Support for numerous system topologies, for example, point-to-point, point-to-multipoint and mesh networks.
2. Low duty cycle – provides long battery life
3. Low latency
4. Direct Sequence Spread Spectrum (DSSS)
5. Up to 65,000 nodes per network
6. 128-bit AES encryption for secure data connections
7. Collision avoidance, retries and acknowledgement

A key component of the ZigBee protocol is the ability to support mesh networking. In a mesh network, the nodes are interconnected with other nodes so that multiple pathways connect each node. The links between nodes are dynamically updated and optimized through built-in mesh routing table.

There are several wireless standards that pertain to the WLAN. For a dedicated wireless sensor node network application, Wireless Personal Area Network solutions are more suitable in terms of cost and power requirement. There are three wireless personal area networking, standards- Wireless Fidelity, Bluetooth and Zigbee standard. WiFi operating at a frequency of 5GHz has a high data rate of 54 Mbps with a distance of coverage that depends on the kind of antenna used. Its high cost and power consumption are the major drawbacks.

Bluetooth technology, intended for short range applications (1m, 10m or 100m range) has the advantage of very low power consumption, but has a wake up delay that is up to 3 seconds. For the design presented here, ZigBee standard, in spite of having a low data rate of 250 kbps, is the most attractive solution due to its low power consumption and less cost. It operates best in line-of-sight conditions and performance in the presence of obstacles is sight dependent. The module used here is Tarang F4 ZigBee transceiver in Melange systems that has the desired features: distance range of 50 km and mesh topology. The baud rate for the link connecting psoc and the Zigbee module is 9600 bps.

Powering The Mote

Power is more important for mote to receive the following two forms else the mote will be shutdown.

1. Battery energy
2. Solar energy

It is mandate to receive the farm truth through mote, only if the battery energy is active. Maintaining of battery level is more important to balance the power once it comes low. But it is difficult to check the battery is alive or dead. If not alive, receiving of farm information will not be correct and the decision making will be wrong. To avoid such circumstances, the mote charging way will be differ from battery energy to solar energy. In solar energy, the energy is stored in the rechargeable batteries and it can be used by the mote from it whenever it requires the power.

Solar panels

A solar panel is a device that gathers photons of daylight, which are little packets of electromagnetic radiation vitality, and believers them into electrical current that can be utilized to power electrical burdens. In this design, solar energy is used to power the sensor and wireless transmitter circuitry, since the soil sensor circuit is required to be placed in open fields where the most abundant and readily available energy is sunlight. It is connected to a rechargeable battery which powers the soil sensor circuit. Standard Solar panel specifications available are,

1 watt solar panel - 100x80x2.5 mm
1 watt solar panel - 100x80x2.5 mm
10 watt solar panel - 348x 292x25mm
20 watt solar panel - 430x430x28 mm

20 watt panel has been procured for powering the circuit

Charge controller device

When the sunlight is more- during the daytime, the solar panel will produce more voltage. This exorbitant voltage could harm the batteries. A charge controller is utilized to keep up the best possible charging voltage on the batteries. It is used to protect batteries from overcharge and to block a reverse current. Basic charge controllers quit charging a battery when they surpass a set high voltage level, and re-empower charging when battery voltage drops again underneath that level.

The charge controller outline consolidates the accompanying features:

1. Based on PWM technique
2. Battery temperature compensation
3. Reverse-current protection
4. Over-current protection (fuse and automatic load disconnect)

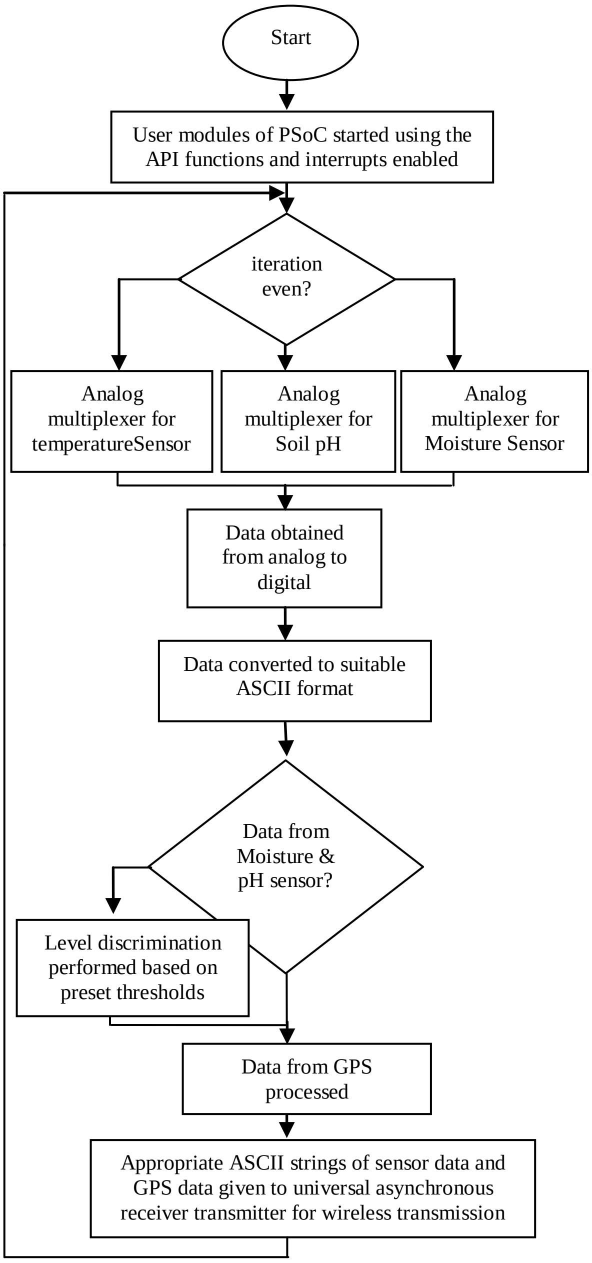

Figure 3: Flow Chart of Microcontroller

Pulse Width Modulation (PWM) and Maximum Power Point Tracker (MPPT) technologies are more electronically sophisticated, adjusting charging rates depending on the battery's level, to allow charging closer to its maximum capacity.

Solar cells have a complex relationship between solar irradiation, temperature and aggregate safety that delivers a non-linear output efficiency, which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given ecological conditions. MPPT gadgets are ordinarily coordinated into an electric power converter system that provides voltage or current conversion, filtering, and regulation of driving various loads, including batteries, power grids, or motors.

The software code driving the system is the program written for the psoc microcontroller. The microcontroller is programmed to sample the data from the soil temperature and moisture sensors, convert them from analog to digital, convert the digital float values to ASCII format to be given to a UART terminal. Based on the voltage value of the moisture sensor, the soil moisture is categorized into three levels-low, medium and high and this information are also wirelessly transmitted. The string received by the GPS receiver module is also processed and the latitude and longitude information are retrieved by the program in the microcontroller. The overall working of the system is modeled in the flow chart in figure 3.

Table 2: Threshold values set for moisture sensor level discrimination

Voltage Value	Moisture Level
Greater than 3 volts	Low moisture level
Greater than 2 volts	Medium moisture level
Less than 2 volts	High moisture level

Results

The proposed design is tested under laboratory conditions and is found to have a good response for a long range. The calibration graph of the soil temperature sensor is shown in figure 4. The error incurred in the temperature sensor is expressed in terms of an equation which is included for correction in the PSoC microcontroller to ensure higher accuracy.

The moisture sensor output is an analog DC voltage value which varies from a maximum of 5 V at very dry soil conditions to near zero values for highly moist soil conditions. Since the soil moisture values are dependent on the ambient environment and the type of soil and terrain conditions, the calibration of these sensors must be field specific. The values based on which the microcontroller is programmed to perform level demarcation is given in table 2.

The first stage of system design includes the sampling, A/D conversion and wireless transmission of the sensor data. The information transmitted from the transmitter is sent wirelessly to the receiver at a data rate of 9600 bps. The receiver is directly connected to the serial RS232 port of a computer where the wirelessly received information can be viewed using a Hyperterminal window.

As an enhancement to the proposed design, the GPS receiver may be included in the design and integrated into the existing application module. The output from the GPS receiver is taken as a string by the PSoC IC and processed. Figure 2 shows the data as received by the GPS module in case of receiving the signal.

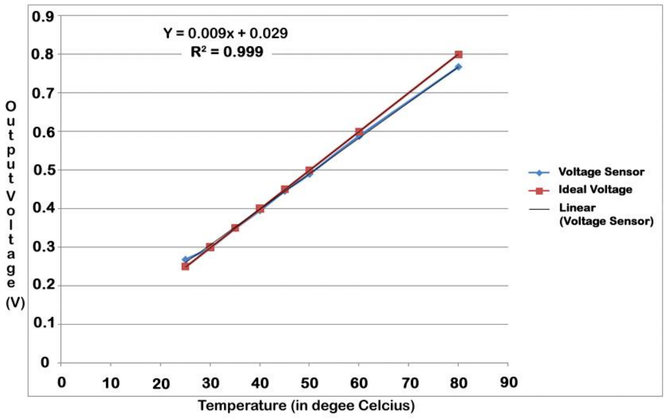

Figure 4: Soil Temperature sensor calibration curve with correction polynomial

Conclusion

The design for acquiring physical parameters of the soil like soil temperature and soil moisture and transmitting it along the GPS information of the wireless sensor node to a remote location where a database can be maintained. The module is realized and tested under laboratory conditions. The following modifications can be made to develop the module further and increase its functionality.

1. The number of physical parameters being monitored can be increased by increasing the number of sensors attached to the module
2. The module can be equipped with actuators and motors to develop it into a control system so that it can be programmed to take necessary actions like automatic irrigation based on the information gathered from the sensors.
3. The system can be designed to act as an intelligent system by modifying it to be a fuzzy control system that acts based on fuzzy if-then rules to handle multiple sensor inputs.
4. The system can be solar powered since it is going to be placed in the open field all the time.

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