Building a Prototype Real-time Soil Moisture Monitoring and Forecasting System

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Abstract: Soil moisture, which broadly describes wetness or amount of moisture in a certain volume of soil, is an important climatic variable that controls many hydrologic processes e.g. rainfall runoff processes, land atmospheric interaction etc. Measuring soil moisture potentially throws many important advantages in our daily life e.g. it helps farmer to save water and increase crop yield. Soil moisture monitoring system (SMMFS), envisioned through this project at GD Goenka University, will perform: sense soil moisture in the sampling points, read and store the soil moisture data over certain time (do averaging and data filtering), transmit the processed data to a server through wireless nodes, do spatial interpolation, visualization and interpretation of the sampled data. Soil moisture sensors are based on a variety of physical phenomenon and there are many advantages if the soil moisture sensors are connected with a wireless data transfer e.g. data can be transferred to a server for visualization in real or near real time. In this project, data loggers will collect, stores soil moisture data and transfer in real-time to a computer server. Then it will use geo statistical models to convert point source data to data over certain spatial domain. The approach can be explained as: (i) fit point source data in some time series model e.g. ARIMA, (ii) find out geo statistical kernel function to fir point data spatially, and (ii) Finally use the spatial function and merge with the ARIMA model and predict SM at certain grid points. SWMFS system build through this project will be linked to an irrigation network in future, Intelligent Irrigation System (IIS), which will help in providing optimal moisture content for crops in a particular area.

***Keywords:* Soil moisture probe, Wireless communication, Soil moisture modelling and forecasting**

I. INTRODUCTION

Soil moisture is an important climatic variable that controls many hydrologic processes e.g. rainfall runoff processes, land atmospheric interaction etc. It influences food productivity and hence acts as an important agricultural variable for food security also.

Soil moisture broadly describes wetness or amount of moisture in a certain volume of soil sample. There are many ways to denotes soil moisture in soil e.g. (i) Gravitational soil water content (SWC) which signifies amount of water (in weight basis) in the soil; (ii) Volumetric soil water content is calculated by multiplying SWC with soil bulk density; and (iii) soil water potential denotes the amount of energy required to extract water from a dry soil sample.

Measuring soil moisture potentially throws many important advantages in our daily life e.g. it helps farmer to save water and increase crop yield. Often excess irrigation does increase cost of agricultural production and can bring negative effects to the environment in terms of excess runoff or waterlogging. Moreover it intensifies the problem of pollutant release to the streams or groundwater and washes off good amount of the fertilizer applied in the field vies-a-vies reduce crop productivity. Monitoring soil moisture have many important applications in different areas including: Bioremediation, Wastewater Reclamation, Landfill Management and Agriculture.

We as an interdisciplinary team at GD Goenka University, with the help of some student members, have started a project to build a real time soil moisture monitoring system in the campus. The project includes: (i) designing and developing a soil moisture probe, (ii) recording and transferring soil moisture data to a server wirelessly, (iii) profiling, modeling and forecasting soil moisture, and (iv) exploring it's potentiality in emerging areas e.g.: Expert Irrigation System design.

Objectives of this project is to help students: (i) became aware about the concepts of different disciplines, (ii) learn about designing an instrument and how to connect it with a computer/server, and (iii) learn about complex mathematical modeling.

II. SOIL MOISTURE MONITORING AND FORECASTING SYSTEM (SMMFS): OVERVIEW

Soil moisture monitoring system (SMMFS), envisioned through this project, will perform following tasks: sense soil moisture in the sampling points, read and store the soil moisture data over certain time (do averaging and data filtering), transmit the processed data to a server through wireless nodes, do spatial interpolation, and do visualization and interpretation of the sampled data. Different time series algorithm will be employed to do temporal forecasting with the data obtained from the point locations (Figure 1).

Hence our Soil moisture monitoring system will have following components to it e.g. (1) the soil moisture sensing probe, (2) the power supply, (3) the data collection device, (4) the data transmitter, and the base station (Figure 2).

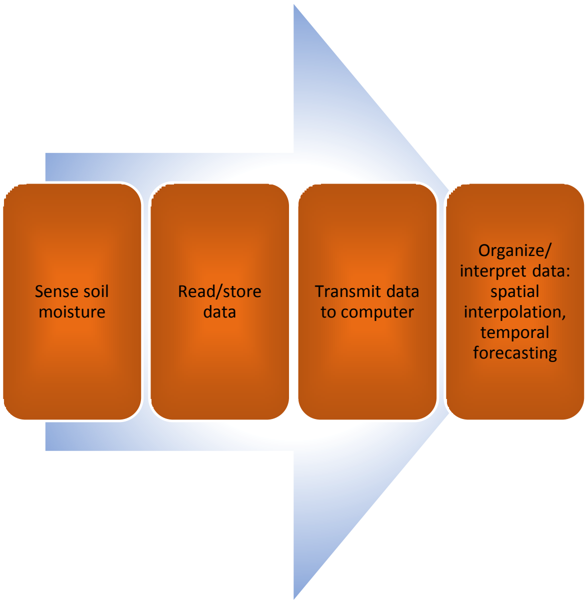

Fig. 1. Functions of a soil moisture monitoring system

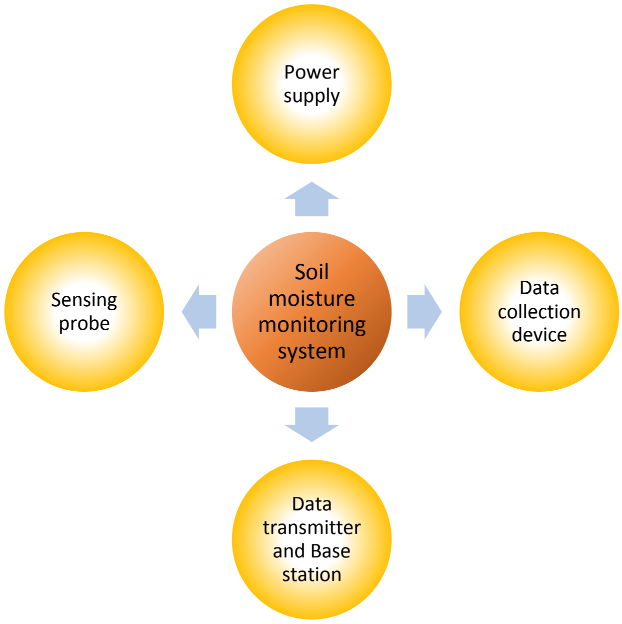

Fig. 2. Components of a soil moisture monitoring system.

III. SELECTING SOIL MOISTURE PROBES

'The soil moisture sensing probe or soil moisture sensor is a device that measures or estimates how much water the soil contains at a given depth and time'. Soil moisture sensor uses indirect method to estimate soil water content. It measures such soil properties that depends on soil moisture e.g. soil water tension and/or the ability of soil to conduct or store electricity. A variety of sensors exist for measuring volumetric soil moisture content (http://mea.com.au/soil-plants-climate/soil-moisture-monitoring/learning-centre/sensor-technology). Sensors are typically based on a variety of physical phenomenon like:

1. Inserting electrodes and flowing a current on application of voltage can directly track conductivity of wet soil.
2. Vacuum is created when water exits the pores which is measurable by sensitive vacuum probes or by measuring a very small change in temperature in this region due to change in thermal conductivity due to vacuum.
3. Change in dielectric constant of solid with change of water content (Frequency

domain reflectometry and time domain reflectometry)

Tracking resonant frequency is chosen as measuring volumetric soil moisture content technique. This particular choice of the sensor for our experiment depends on accuracy of required data, working conditions, cyclic performance of hysteresis effects of sensors and reaction time of sensor.

For our purpose, a simple sensor tracking change in dielectric constant of the soil sample (capacitive effects) serves the purpose. Dry soil has a dielectric constant of 2-5 (http://cgiss.boisestate.edu/~billc/dielec.html) whereas water shows a dielectric constant of 80. Two ring shaped electrodes establish a resonant circuit using electrodes immersed in the soil sample and applying a voltage. The current, which oscillates in this medium, shows sensitivity towards water content for resonant frequency of this circuit changes with dielectric constant (ability to hold charge) of the medium.

By measuring the change in resonant frequency, accurate measurements about volumetric soil moisture content can be recorded for the volume of soil sample within electrode assembly. The choice of electrode material depends on corrosion effects on electrode material in the medium. It is important to note that these sensors can differentiate between pure and salty water too, since they differ considerably for their dielectric constant value. A variety of salts can be distinguished from each other, thus giving an added value to the experiment. The sensor works with a wide range of temperatures as temperature coefficient of dielectric constant for water between 0C and 100C is almost constant (http://nvlpubs.nist.gov/nistpubs/jres/56/jresv56n1p1_a1b.pdf). Sensor shows quick reaction time, which depends on how fast we can track the change in resonant frequency.

There are many advantages if the soil moisture probes are deployed over a longer time frame in a particular sampling site e.g. (i) It gives temporal moisture profile with its variability, and (ii) provides both moisture and temperature data over longer temporal scale which then can be used to find out correlations between the variables.

A reliable source of electricity will also require for the soil moisture monitoring system as there are many electronics components attached to it. Typically soil moisture monitoring system uses DC power sourced from a large battery. Such battery can be assembled with a solar panels which will keep recharging it.

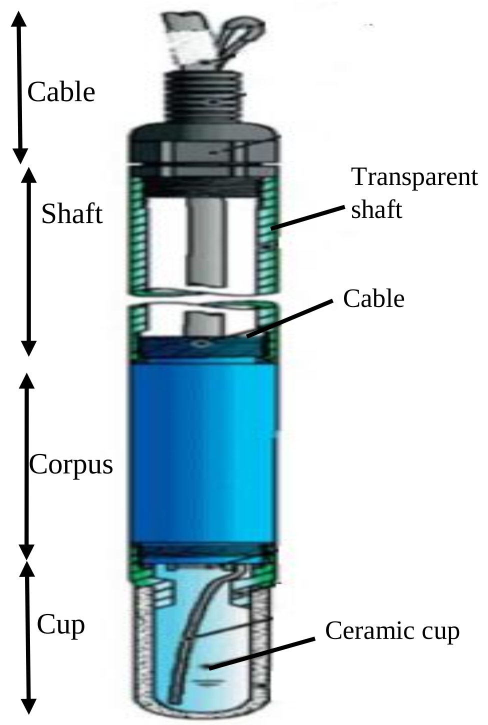

Fig. 3. A typical soil moisture probe

[Adapted from: Soil water monitoring an information package. 2nd edition, Charlesworth. CSIRO/CRC Irrigation Futures 2014]

IV. WIRELESS COMMUNICATION FOR SOIL MOISTURE PROBE

There are many advantages if the soil moisture sensors are connected with a wireless data transfer e.g. data can be transferred to a server for visualization in real or near real time. In our project, data loggers will collect, stores soil moisture data and transfer it in real-time to a computer server for processing the data further. If data in not needed to transfer in real-time, data logger can be used to store data over a longer timeframe and the data can be transferred to a computer periodically. In our work, a wireless communication system will be built for real time data transfer from the data logger.

Wireless communication can be achieved via different means e.g. satellite, radio or cell phone. Each of these options will require some special equipment e.g. radio transmitter, satellite transmitter or a cell phone modem. In a wireless communication system a computer can be treated as base station which is equipped with various data receiver like cell modem or satellite receiver. There are some specific software, installed in the base station, which are needed for communicating and downloading data from the data loggers. In our project we will implement ZigBee modules to build the wireless sensor network.

Wireless Sensor Network is one of the strongest and effective domains of wireless communication. It is easy to design and implement wireless sensor network using ZigBee modules. These modules can be used to form a wireless sensor network which can operate in two modes i.e. one-to-one communication mode or one-to-many communication mode. ZigBee is a specification for a suite of high-level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard. Following table gives the comparison details between Wi-Fi, Bluetooth and ZigBee. From this table we can analyse that the battery life for ZigBee modules is several years which is the most important advantage of ZigBee nodes.

Brand Name	Wi-Fi [IEEE802.15.11b]	Bluetooth	ZigBee [IEEE802.15.4]
Battery Life	Several hours	Several days	Several years
Maximum Network Capacity	32nodes	7nodes	64000nodes
Communication Distance	100m	10m	>30m
Communication Speed	11Mbps	1Mbps	250Kbps
Security Method	SSID	64bit, 128bit	32,64,128 bit AES
Applications	Wireless LAN	Wireless speech	Remote control Measurement, Control

Table 1. Specification for ZigBee sensor nodes [Source: www.lapis-semi.com/en/semicon/telecom/zigbee.htm]

In our design we have used ZigBee to transmit temperature and humidity levels gathered from sensors installed at ZigBee nodes to a remote site where after analysis of the received data necessary steps are taken. Two analogue sensors are installed on every node which will collect physical temperature reading and humidity values from soil. These collected values will be converted into digital data using analogue to digital converter. The converted digital result is collected by the microcontroller and transmitted to the remote site using ZigBee protocol. The following figure (Fig. 4) gives you a brief idea about one-to-many where one ZigBee module communicates with multiple sensor nodes.

Fig. 4. Sensor nodes

[Source: www.afterhourscoding.wordpress.com/tag/xbee]

In our design we have used 5 sensor nodes and these nodes are placed at different locations to get temperature and humidity values. We have designed the system in such a manner that after collection of data the present values will be stored in the RAM of on board microcontroller and at an interval of 30 minutes these values will be transmitted to the remote site. The same process is followed by all the five sensor nodes and this cyclic process continues for infinite duration or as long as there is battery supply in the sensor nodes. The transmission time of collected values is set to be at 30 minutes interval time since these values will not change in the specified time and accordingly the subsequent task can be performed. The boards are designed in a really flexible way, in these boards the sensor probes are coming out from the sensor node and it can be replaced with any analogue type of sensor hence we have given it a name as plug-n-play sensor probes.

Fig. 5. System showing radio transmitter.

[Source: Drought Adaptation Option: Soil moisture monitoring: José Payero, Ahmad Khalilian, and Rebecca Davis: Clemson University, Published by Southeast climate extension]

V. MODELLING AND FORECASTING MECHANISM

There are many ways to predict soil moisture. One the most commonly used system is Global Forecast System (GFS). In GFS, mesoscale models uses precipitation data to estimate soil moisture through the Noah land surface model. The key GFS model physical parameterizations include the simplified Arakawa Schubert convection scheme, long-wave and short-wave radiation, explicit cloud microphysics, non-local vertical diffusion, and gravity wave drag. (Source: http://www.cpc.ncep.noaa.gov/soilmst/index_jh.html). Another widely used forecasting setup was built in Princeton University and it is based on a statistical design called the Extended Stream-flow Prediction (ESP) and a dynamic seasonal model called the Climate Forecast System (CFS). (Source: http://hydrology.princeton.edu/forecast/current.php).

In this project, we will use some simple geo statistical algorithms and time series functions to do the above jobs. This project involves modelling/extrapolating soil moisture over a spatial domain from soil moisture data obtained at different sampling point locations. Soil moisture modelling system will use some standard geo statistical models, e.g. kernel interpolator function, to convert point source data to data over certain spatial domain which will be divided into number of grid points. Then it will use time series model to forecast soil moisture in the given domain with certain lead time (typically in weeks). The overall approach can be explained in following steps: (i) fit point source data in some time series model e.g. ARIMA, (ii) find out geo statistical kernel function to fit point data spatially, and (ii) finally use the spatial function and merge it with the ARIMA model and predict soil moisture at the grid points.

In later part of the work, we will use soil moisture data predicted by a simple hydrological model 'VIC' (Variable Infiltration Capacity model) and ensemble it with the data obtained from soil moisture probes. Such ensemble of soil moisture data will be very useful for improving prediction capabilities of our soil moisture forecasting system.

VI. CONCLUSION

Monitoring and forecasting soil moisture throws up many interesting applications. It can be merged with metrological or hydrological forecasting system for making robust and effective predictions. But to build such capabilities, soil moisture monitoring system needs to capture wide scale spatial variability and process complexities. This study proposes a small scale system (proto type study) which can be extended to a larger area by building large scale soil moisture observation network. Such large scale system can be linked to ecological or agricultural modelling activities. Large scale soil moisture monitoring, which will be a logical extension of this work, suits quite well with basin-scale hydrological and meteorological modelling also. But there are multiply challenges to make effective use of such system e.g. spatial density of sampling locations, temporal frequency of data transfer, managing huge data efficiently etc.

Such system can also be employed to monitor drought or flood or predicting it. Typically drought indicates the substantial lack of rainfall over a particular region over certain period of time. Drought brings down crop productivity (agricultural drought) and hence monitoring soil moisture is an important component to any sustainable agro ecology system. There are many parameters to quantify drought, amongst which Parmer Drought Severity Index (PDSI) is the most widely used one. PDSI basically assesses total soil moisture over a geographic region by using temperature and precipitation, and by computing water supply-demand for the area. This index is most suitable for monitoring non-irrigated cropland and for long term drought monitoring.

Soil moisture monitoring system can have another interesting application in the area of 'precision agriculture'. Purpose of any irrigation system is to provide optimal water content for particular crops so as it produces maximum yield. SWMFS system build through this project can be linked to an irrigation network and help in providing optimal moisture content for crops in a particular area. Our team is interested to build such Intelligent Irrigation System (IIS) in future.

Engaging undergrad students to research activities is another important dimension of this project. After completing this project students will: (i) gain knowledge on designing, developing soil moisture probe and transferring data, and (ii) learn about mathematical modeling and importance of tracking soil moisture by exploring its capabilities. At the end, we also have a plan to conduct a workshop,

amongst colleagues, to share knowledge gain through this project.

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