Water Management Using Remote Sensing Techniques

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***Abstract*--Water is the most conservative and natural resource for agriculture. But unfortunately in our country the well known fact is that the gap between the demand and supply of water for agriculture is becoming larger. Due to rapid increase in population growth, much of the water resources are being diverted from agricultural to non agricultural purposes. Instead of going into augmentation, water management policies emphasize each and every farmer to take an initiative in limiting water consumption by implementing need based irrigation. To do so, a systematic monitoring of water content at the surface of soil and its root zone is essential at each stage of the growth of a crop. In this process several methodologies like Gravimetric, TDR, TDT, FDR, ADR, Phase Transmission and Nuclear have evolved in determining soil moisture content and are successful to some extent. These methods are chosen based on factors like soil type, field maintenance, measurement time, operating temperature, measurement range, accuracy, power consumption, cost and ease of use. Information on soil moisture can be obtained by using above techniques but are time consuming and will have limited spatial coverage. In that case Remote Sensing Techniques provide better spatial and temporal coverage of soil moisture readings. The role of electronics and computers in Agriculture in designing sensors is very significant. This paper is limited to remote sensing techniques in this respect.**

***Index terms*—Remote Sensing, Electromagnetic Spectrum, Hydrological Modeling, Soil Moisture Retrieval, Data driven Modeling, Fresnel's reflection coefficient, brightness Temperature, and Root Mean Square Error.**

I. INTRODUCTION

Remote sensing techniques are meant for observing the earth's surface or atmosphere using satellites (space borne) or using aircrafts (airborne). Any information about an object can be known without any physical contact using electromagnetic energy in remote sensing [1]. Whenever an electromagnetic energy radiation falls on a surface, some of its energy will be absorbed or transmitted and the rest is reflected. The sensing devices (cameras, scanners, radiometers, radar etc) that are mounted on aircrafts or satellites record the electromagnetic energy that is reflected or emitted by the earth's surface. The information is recorded on photographic films, videotapes or as digital data on magnetic tapes. Different objects on earth's surface return different amount of energy at different wavelengths in different bands of electromagnetic spectrum. Sensors that are mounted on satellites or on aircrafts take images of earth's surface in various wavelengths of electromagnetic spectrum. Wavelength under which object reflects or emits radiation depends on the property of material, surface roughness, angle with which ray is incident on earth's surface, intensity and wavelength of radiant energy.

A. *Stages in Remote Sensing*

- Emission of electromagnetic radiation from source
- Transmission of energy from source to surface of the earth
- Electromagnetic energy interaction with the earth's surface (reflection and emission of EM energy)
- Electromagnetic energy transmission from surface of the earth to the sensor
- Recording of information from the reflected or emitted electromagnetic energy in a specified format by the optical sensors.

Regions of Electromagnetic Spectrum available for Remote Sensing Systems are given in the following table1.

B. *Behavior of Electromagnetic Waves when Incident on Vegetation crops, Soil and Water*

- When an EM wave is incident on the vegetation, chlorophyll in the leaves absorb the radiation in red and blue wavelengths but reflect green wavelengths.
- When an EM wave incidents on the water, it is not reflected instead it will be either absorbed or transmitted.

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- When an EM wave is incident on a soil surface, it is either reflected or absorbed but only little will be transmitted.

The reflectance property determines the characteristics of the soil.

TABLE1
Regions of EM spectrum available for Remote Sensing [1]

Photographic ultraviolet rays	0.3-0.4 micrometers	Available for remote sensing
Visible	0.4-0.4 micrometers	Available for remote sensing
Near and Mid Infrared	0.7-3 micrometers	Available for remote sensing
Thermal	3.0-14 micrometers	Available for remote sensing
microwave	0.1 to 100 cms	Available for remote sensing and can pass through cloud, fog and rain
Radio	>100 cms	Not normally used for remote sensing

II. Instruments used for remote sensing

A. *Remote Sensors*

Remote Sensor is an instrument that measure and record electromagnetic energy.
Remote sensing instruments are categorized into two types

- Passive Sensors
- Active Sensors

B. *Passive Sensors*

A passive sensor senses the electromagnetic radiation that is emitted or reflected from an object from source other than Sensor. According to Norman [2] these sensors do not produce electromagnetic energy on their own; instead depend on the external sources like Sun and sometimes the earth. These sensors cover the electromagnetic spectrum in a wavelength ranging from less than 1 picometer (gamma rays) to greater than 1meter (microwaves).

From the irrigation perspective MICROWAVE RADIOMETER is one of the most popular passive sensor instrument that is used in soil moisture estimation in the field. It is also used in mineral exploration, snow and ice detection. This instrument measures the intensity of radiation that is emitted or reflected from the object within the microwave range (0.1cm to 100cms). The depth from which energy is emitted depends on the properties of the material such as water content in the soil. The recorded electromagnetic radiation is termed as brightness temperature.

The other popular passive Sensor that comes in discussion is Aerial Camera which is termed as airborne sensor (a sensor used in aircrafts). Low orbiting satellites and NASA space shuttle Mission use the aerial Cameras for accurate navigation. Even Global Navigation Satellite systems (GPS-USA) use the Aerial camera systems to take the photographs of the objects on the earth's surface at precise points. Navigations are most essential in survey areas where especially topography maps won't work. These sensors have film which record the electromagnetic radiation in this specified wavelength range (400nm-900nm).

The other popular passive remote Sensor is Multispectral Scanner with which observations can be made point by point and line by line manner. These sensors can measure electromagnetic radiation in both visible and infrared spectrum. These sensors can give information about mineral compositions of the soil.

Imaging Spectrometer can measure intensity of radiation in very narrow spectral bands (5nm-10nm).These are used in determining chlorophyll content of surface water.

Thermal Scanner measures the electromagnetic radiation that falls within the specified range (8 micro meters to 14 micrometers). The wavelength in this range is related to temperature of the soil and hence effects of droughts on agricultural crops can be studied. The major disadvantage in passive remote sensing systems is that they are sensitive to climatic conditions especially when the sky is cloudy and the incoming radiation cannot be sensed. To overcome this problem Active remote sensing systems are used and they allow the signal to pass through clouds, fog and rain.

C. *Active Remote Sensing Systems*

The most distinguishable feature of active sensor is that they provide electromagnetic energy on their own to illuminate the object on the earth's surface. These sensors also measure the electromagnetic radiation that is emitted or reflected from the object. RADAR is one of the well noted Active Remote Sensing systems which can operate at microwave wavelength range. One of the most popular radar is Synthetic Aperture Radar [3].It transmits and receives the electromagnetic radiation that fall within the microwave range (1mm to 1m). The electromagnetic energy that is emitted from sensor can be penetrated into deeper parts in the soil mantel and can be reflected from that point. This radar system can be made to operate during daylight as well as in darkness. These sensors give the knowledge of deep and under canopy soil moisture.

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RADARSAT is a popular Synthetic aperture radar operate at 5 GHZ and is used worldwide in giving response to disasters such as flooding, volcanic eruptions and severe storms.

The other active remote sensing system is ALTIMETER transmits microwave pulses and measures round trip delay with which distance from object to sensor is known. If the object is sea surface then its height can be predicted and hence wind speed is estimated. These sensors can be mounted on aircrafts and satellites and can be used for topological mapping. JASON-I is an altimeter which can provide the altitude of earth's ocean surface and is operated at frequencies of 13.6GHz to 5.3GHz.

Scatterometers are the active sensors that measure the back scattered radiation in microwave region and derive the information about the wind direction and speed over the earth's surface with the help of the maps.

TABLE 2
Characteristics of Active Remote Sensing System

D. *Measurement Principle*

The emission of microwave energy is proportional to the product of surface temperature and surface emissivity [4]. Here the brightness of an emitter of a microwave radiation is related to temperature of a source through emissivity

T_B is proportional to T_{eff}

characteristics	SAR (Synthetic Aperture radar)	Altimeter	Scatterometer
Radiated Power(W)	1500	20	100
Range(km)	695	1344	1145
Viewing Geometry	Side looking	Nadir looking	Six fan beam in azimuth
Spectrum width	20-300MHz	320MHz	5-80KHz
Service Area	Land/coastal/ ocean	Ocean/ice	Ocean/ice/land

$$T_B = (1-R)T_{eff} = eT_{eff} \quad (1)$$

R- Directional Reflectivity of surface

T_{eff} - Effective Radiation temperature

e- Effective emissivity = 1-R, which depends on dielectric constant of medium and latter can be used to determine soil moisture content.

E. *Measuring Soil Moisture content using L Band Radio Metric System*

Microwave radiometer is one such Passive remote sensing device measures the power level of the incoming radiation. The power level (P) is expressed based on the following relationship

$$P = K^*T_b^*B \quad (2)$$

T_b is brightness temperature (defines the measure of intensity of radiation at microwave frequencies)

K Boltzmann constant; B Bandwidth of the instrument

For a flat surface, Brightness temperature is proportional to the physical temperature of the surface as

$$T_b = e^*T = (1-r)\,T \quad (3)$$

e- Emissivity; r = Fresnel's reflection coefficient

From Microwave Radiative Transfer Model [5] L-MEB (L-Band Microwave Emission of Biosphere) the brightness temperature (T_{BP}) is expressed as

$$T_{BP} = (1-w_p)(1-\gamma_p)(1+\gamma_p r_{Gp})T_c + (1-r_{GP})\gamma_p T_G \quad (4)$$

T_c,T_G - vegetative and effective soil temperatures.

r_{GP} soil reflectivity

γ_p vegetation attenuation factor

T_{BP} polarized brightness temperature, where

$\gamma_p = {}_e\text{-}\tau_p/\cos\theta$

θ Is incident angle, τ_{p}- vegetation optical depth

Soil reflectivity (r_{GP}) depends on dielectric properties of the soil such as permittivity, permeability, conductivity etc which in turn depend on physical properties of soil such as soil moisture, temperature, salinity and geometric roughness.

Fresnel's reflection coefficient(r) determines the reflectance of the soil

$$r \;\alpha\; \theta_I \quad (5)$$

- Small change in angle of incidence (θ_i<10°c) exhibits small change in r values with variation in dielectric properties of soil water mixture.
- Variation in soil moisture (θ) affects dielectric properties of the soil (ϵ,μ,σ,f) which in turn affects their value (reflection coefficients) and in turn the difference in received power level of the incoming radiation.

III. Analysis of Remotely Sensed Data Using Hydrological Modeling Techniques

In order to perform analysis on remotely sensed data such as soil moisture, hydrological models are mainly used. These are further classified into two categories namely physical based and empirical based. Physical based modeling technique uses mathematical equations derived from the system physical process. Hence it is necessary to know about physical parameters in detail. Especially in modeling the soil moisture component

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with respect to time and/or space, the physical parameters like evapotransiration rate, infiltration rate, percolation, soil type, and vegetation cover are to be considered. The latter model which is empirical based uses mathematical equations, derived from time series data analysis. Without knowing explicitly the physical behavior of the system one can use the Data Driven Modeling (DDM). As the name implies it is based on analysis of data about a system [6]. In particular, it finds a way in relating system state variables (input and output variables) without the physical behavior of system , The model is trained on sample data of soil moisture aiming at reducing the error which is shown as difference between observed and predicted output.

A. *Different Types of Data Driven Modeling Techniques*

Data Driven Modeling is classified into two categories i.e. parameterized and non parameterized. Recent survey on non parameterized data driven modeling reveals the fact that statistical and Neural Network modeling (NN) approaches are simple and efficient in soil moisture retrieval.

B . *Soil Moisture Retrieval using Statistical Approach*

Support vector machines (SVM) and Relevance vector machines (RVM) are supervised non parametric statistical modeling techniques that are known for producing desired estimations of soil moisture content using inexpensive and readily available data. From the experiments conducted at Walnet Creek Watershed in Ames, South Central Iowa, USA, it is derived that RVM model performs much better with RMSE of soil moisture content depts. Of 5,10,20,30 and 50cm for about 227 days. On the fourth day 1cm 0.014%v/v compared to SVM whose RMSE value is 0.017%v/v [7].

Their research starts with the development of three models for soil moisture estimation. The first model uses remotely sensed input consisting of meteorological variables, field measurements and crop physiological actors for training SVM and RVM models in order to retrieve surface soil moisture at 0-6cms of top soil layer. Once the model is trained, the soil moisture content is estimated to check the model performance with a RMSE value. The second model is trained with inputs like soil temperature for 0-6 cms precipitation, number of days last rained, including soil moisture readings of model1 and surface soil moisture content at 30cm depth is estimated. The Model III is trained in two steps. In the first step RVM and SVM models are trained in a similar manner as Model I to estimate surface soil moisture content. In the second step the model is trained on remotely sensed data at a larger scale to estimate soil moisture content at 30cms depth.

In order to measure the error between observed and estimated data, the parameter, Root Mean Square Error is used. The performance of a model is directly proportional to the value of RMSE.

With reference to experimental study made on Landsat images of study area superimposed with land use in the year 2002, RMSE values obtained for soil moisture retrieval at three models during training and testing phases are tabulated as shown in table3.

TABLE 3.
RMSE values of soil Moisture Retrieval for SVM and RVM Models [7]

Phases	Training phase	Testing Phase	Training Phase	Testing Phase
Model 1	2.0%v/v	4.3%v/v	1.2%v/v	3.8%v/v
Model 2	0.36%v/v	0.66%v/v	0.02%v/v	0.48%v/v
Model 3	0.76%v/v	1.7%v/v	0.38%v/v	1.4%v/v

The results indicated in the table 3 show that RVM model comparatively provides better performance in all respects during training and test phases. This proves that it has good potential of soil moisture estimation. With reference to data taken from Soil climatic Analysis network site at Rees centre, Texas, USA, MVRM(Muitvariate Relevance Vector Machine) trained on input variables like soil temperature, depth of soil model, RMSE value for soil moisture retrieval is recorded as 1.31% which indicate that observed data and modeled values are close and model is performing well. Even at the end of the 4th day at a depth of 2mts, RMSE reading is reduced to 0.15% which shows the closeness of modeled value to the observed value .Decrease in RMSE is a signature of good performance of a model.

C. *Soil Moisture Retrieval using Neural Network Model*

A multilayer layered feed forward Artificial Neural Network model used for research with input layer consisting of selected input variables, a hidden layer with ‘n’ number of hidden neurons and output layer consisting of predicted soil moisture values. The sigmoid and linear transfer functions are used in hidden and output layers. The model uses an algorithm to train the network. During forward phase the selected inputs are propagated though the network from layer to layer. An error is computed by comparing the difference between desired and predicted output. This error is propagated backwards and correspondingly weights and bias are adjusted to minimize the error. The results of the model show that with the appropriate selection of

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inputs, the error is minimized and hence the accuracy in soil moisture retrieval can be improved.

With reference to the National Airborne Field Experiment 2005[8] conducted in Southern Australia for Goulburn catchment, it is explicitly stated that the near surface soil moisture measurements were taken over eight farms at the same time by using active remote sensing systems. The measurements were also taken at many locations within a farm. For the study of soil moisture estimation in a farm, a two layer perceptron model consisting of 2 nodes in the input layer, four neurons in the hidden layer and one at the output layer is chosen. The model is trained with several back propagation algorithms to adjust the weights in the hidden and input layers so as to minimize the root mean square error between actual and predicted soil moisture output measurements. The results obtained for RMSE are found to be between ranges of 3.93%v/v to 5.77%v/v, as shown in table 4.

In the table 4 it is explicitly stated that RMSE value obtained after training the network with Quasi Newton Algorithm-BFGS is comparatively less and this proves that it is the only method that is capable of retrieving soil moisture with the desired accuracy.

TABLE 4
Root Mean Square Error (RMSE) of soil moisture retrieval for various backpropogation algorithms [8]

sno	Back Propogation algorithm	RMSE (Root Mean Square Error)% v/v
1	Batch Gradient with Momentum	4.86
2	Gradient Descent with Adaptive Learning	4.88
3	Gradient descent with momentum and adaptive learning rate	4.88
4	Resilient backpropogation	4.93
5	Conjugate gradient backpropogation with Fletcher-Reeves updates	4.82
6	Conjugate gradient backpropogation Polak-Ribiere updates	4.83
7	Conjugate gradient backpropogation with Powell-Beale restarts	4.83
8	Scaled conjugate gradient backpropogation	5.77
9	Quasi-Newton Algorithm-BFGS	3.93
10	Quasi-Newton Algorithm: One step Secant algorithm	5.51
11	Levenberg-Marquardt	4.04

D. Soil Moisture Retrieval using Classification and Regression trees Algorithm (CART)

With reference to observations taken from experimental study conducted at Yongdam Basin from May 16th to August 19th, 2008[9], it is observed that use of CART algorithm and neural networks provide proper soil moisture field estimations and even represent soil moisture behavior very well.

TABLE 5
RMSE values of soil moisture retrievals at four sites

Area	RMSE(%v/v)
Jucheon	1.3925
Bugui	1.0254
Sangjeon	1.8783
Ahncheon	1.0037

For experimental study a neural network model was built with input layer consisting of five nodes, hidden layer consisting of five nodes and an output layer with one node. The input variables to the model includes in suite soil moisture measurements taken from Korean water resources corporation (KWRC), precipitation , surface temperature provided by Korean Meteorological Administration (KMA), Normalized Difference Vegetation Index (NDVI) from Moderate Resolution Imaging Spectro radiometer (MODIS).

IV. Irrisat- Water Management Service

Irrisat is an irrigation water management service uses high level technology to deliver information to the farmers. It was developed in New South Wales, Australia by CSIRO Land and Water for collecting the satellite images though remote sensing methods along with the information from local weather stations and sending the information to the farmers cell phones as an SMS so that this would help the farmers to schedule their irrigation at appropriate times [10]. The service sends one SMS per day to each farmer who subscribes the service. The whole system functions in such a way that the light reflected from the vegetation and land surface is captured by the remote sensors that are mounted on satellites and are being processed using software and hence crop vigor is extracted showing evapotranspiration rate. At the same time from local weather stations, farmers in different regions collect data on temperatures, wind speed, solar radiation and relative humidity and deliver the information to Irrisat SMS database. The weather information combined with satellite data determines the condition for actual water consumption by crops on a particular farm. The Irrisat service so far implemented successfully in Australia and can even be implemented in Asian countries too where cell phones are used extensively. Irrisat is a promising service rough with which farmers will be given a flexible irrigation management system meeting their specific needs. *In India, IFFCO SAN*CHAR Limited has been offering services on IKSL Green SIM CARD covering diverse areas including soil management/crop production.

CONCLUSIONS

This review demonstrates the role of Remote Sensing in Irrigation water Management. It is known that remotely sensed data on soil moisture at larger scales can drive the farmer to perform better water management operations in scheduling the irrigation. A discussion has been made on different instruments that perform remote sensing, their characteristics and their applicability at various types of soil. From the observations made on L Band Radio Metric System, it is clearly noticed that the difference in received level power level of incoming radiation from the soil is an indicator of variation of soil moisture content. It is mentioned that there are several physical and data driven models that perform soil moisture estimation. The survey on these models reveals the fact that data driven modeling is one among that is dominating in recent trends. It is to mention that all over the world several countries including India, are offering water management services to the farmers by integrating remote sensing with mobile technology.

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