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Development of Low Cost TDR System for Soil Moisture Measurement

[I]Bhushan N. Patil, [II]P. H. Zope, [III]K. S. Patil
[I]M.E. Scholar (Digital Elec.), [II]Assistant Professor (E&TC Dept.), [III]Assistant Professor (Applied Sc. Dept)
[I,II,III]SSBT's College of Engineering and Technology, Bambhori, Jalgaon, Maharashtra, India.

Abstract

*Soil moisture measurement is one of the difficult at same time much important task. Numbers of methods are available for soil moisture measurement. But after reviewing all these methods at last we come to the conclusion that each of these techniques has some of the limitations. So, it is always said that the ideal method for soil moisture measurement is yet to be perfected. After studying all of these techniques comparatively it is seen that Time Domain Reflectometer method has very much scope to develop most superior system for the task. TDR is nothing but a technology which measures frequency dependent and independent properties of dielectric material with the use of electromagnetic waves. First off all EM wave is generated and gets transmitted in the sensor transmission waveguide put into the soil. Due to impedance mismatching fraction of the transmitted signal reflected back whose travelling time is a function of dielectric constant of the soil which depends on the amount of moisture present in the soil. High cost of TDR system is most serious limitation to use this technique. A care is taken while designing to provide highly accurate, low cost solution for soil moisture measurement. To reduce the cost instead of using complex FPGA, simpler low cost microcontroller is used. GSM module is used which gives the low cost, wireless communication so that the reading of the TDR can be send wirelessly in short time. A simple 16*2 LCD display is used, to provide the TDR reading at the site itself. Gravimetric method is used as reference for the calibration.*

Keywords

Soil Moisture Measurement, Time Domain Reflectometer, Sensor Transmission Waveguide, Gravimetric Method.

I. Introduction

Though, large numbers of methods are available for soil moisture measurement. Then also there is no method available which is fully integrated, accurate and fulfilling low cost requirement. So here is a try to develop a low cost solution for measuring soil moisture measurement with higher accuracy. In the initial part of paper a review of different eight techniques which are currently used. Each of the technique is discussed with basic principle, methodology, advantages and disadvantages. At last comparative analysis is also provided.

Basic technique used is a Time Domain Reflectometry concept. TDR is nothing but the generation, transmission and reflection of EM wave through soil sample. TDR is used for measurement of frequency dependent and independent properties of dielectric materials like soil, wood, cement etc. As moisture content of soil changes so dielectric constant varies. This variation results into the variation of propagation time of transmitted EM waves which is a measure of soil moisture content. The developed system includes microcontroller and it's board, soil sensor, GSM module, LCD display, Relay, switch and RS232 cable.

1. Necessity

Most of the physical and chemical characteristics of soil vary with amount of moisture present. Determination of soil moisture is necessary in every type of soil study like hydrology, agrology, plant science, forester, soil engineering and civil engineering. The amount of moisture in the soil has been of great interest in agriculture from the past. Soil Moisture Measurement is necessary due to:

A. In agriculture and plant science field to determine best time to sow and plow the field.
B. Various physical and chemical properties of soil changes with amount of moisture present in soil.
C. To measure changes in infiltration, irrigation. To study ground water recharge and Evapo-transpiration.
D. It is also important in the fields like Hydrology, Forestry and Agrology.
E. To study and determine the parameters like soil profile, surface tension related with civil and soil engineering.

2. Objectives

A. To reduce the cost of the previously developed system.
B. To design universal system to measure soil moisture with high accuracy.
C. To provide fully integrated and reliable solution for soil moisture measurement.
D. To design a system that can work even at higher frequency (in MHz range).

3. Theme

Basic theme of this project is to develop a analytical instrument for soil moisture measurement. It is a try to develop a low cost solution for soil moisture measurement. The developed system is fully integrated so there is no requirement of any outside control circuitry. Also wireless transmission through GSM module enables measurement of soil sample remotely. Measurement using TDR concept yields more accurate results. Results are available in digital format so it is much easier to record, display, process and analyse. The comparative analysis with other techniques leads to the conclusion how this system is cheaper, accurate and reliable with the other existing systems. LCD display is also provided which indicates the reading at the site itself. The developed system is user friendly and easy to handle as once it is set there is no need of any frequent maintenance.

4. Organization

This paper is organized in such a way that it describes the complete system design, results and it's analysis in much interesting way. Figure, photographs, Tables are provided for clarity of the concepts. Description about each chapter is as follows:

Thesis starts with section-I, the introduction of the system. This section gives detail over view of the system and explains the

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necessity, objectives, basic theme and the organization of the system.
Section-II deals with the literature survey to clear the idea about what kind of work is done in the past until now. Mainly two reviews are put forward, first describes various soil moisture measurement techniques used, where as the second is about different systems designed with the TDR technique.
Section-III is about complete system design. Initially basic working principle i.e. TDR concept is explained, followed by description of the proposed system. Architecture and the circuit diagram of the proposed system are also provided here.
It also describes the software and hardware over view.
Section-IV is about the calibration of the system. Initially various calibration techniques for TDR instruments are introduced. Next to that detail procedure used for calibration of the developed system using Oven Dry Technique is described.
Section-V is very much important as it provides the results of the system. A table is provided to indicate the results of Gravimetric Method as well as the TDR method at the same place.
Section-VI deals with the statistical analysis of the developed TDR instruments. Results of this section explain the performance analysis of the developed system.
Section-VII gives the final conclusion of this thesis. It also gives the future scope, applications and benefits of the developed system.

II. Literature Survey

Soil moisture measurement is not a new task but a technique used here that is Time Domain Reflectometry is a recent concept. TDR is popularly used in various fields like fault diagnosis systems, geological and agricultural fields. Two reviews are put forward [11]. Detailed discussion with respect to basic principle, methodology of each technique is provided. Also a comparative study of each technique with respect to cost, accuracy, range and measurement volume is provided.

1. review of different soil moisture measurement techniques

First review is about various techniques of soil moisture measurement which are used till now. This includes review of eight different techniques of soil moisture measurement. [8]

Table 1 : Different Soil Moisture Measurement Techniques

Technique	Principle used and Methodology
Gravimetric Method (GM)	Depends on the weight of original sample and oven dried sample. Take Weight of the original sample (Wt) Apply oven drying at 105°C for 24 Hr & weight (Ws). Calculate % M = $\frac{Wt - Ws}{Ws}$ x 100
Neutron Moderation (NM)	Depends on the amount collision between fast neutrons and Hydrogen atoms in moisture. Insert probe into access tube installed in soil. Linear calibration between the count rate of slowed neutrons gives the reading of % moisture content.
Time Domain Reflecto-meter (TDR)	Depends on the propagation time required by EM wave to transmit and reflect back from sensor transmission waveguide Insert probe into access tube & transmit EM wave. The propagation time required for transmit & reflect back gives the % moisture content depending on the dielectric constant [2]
Frequency Domain Reflecto-meter (FDR)	It is a dielectric method obtaining moisture content by observing response at different frequencies Probe is introduced into soil After applying electric field gives reading due to capacitance effect
Amplitude Domain Reflecto-meter (ADR)	Depends on the variation in amplitude of transmitted signal after reflecting from the section of different impedance depending on content of moisture [7] EM wave is generated & transmitted using sensor Amplitude change gives the reading [5]
Phase Transmission (PT)	Based on the property of the travelling sinusoidal wave showing relative phase after travelling a fixed distance. EM is generated and transmitted Phase difference at the start & end fives the reading
Time Domain Transmission (TDT)	Similar to TDR measurement of the propagation time only change is that measured over known distance. Methodology is exactly similar to TDR system
Tensiometer	Depends on the suction produced by water into sealed tube coming into equilibrium with the soil solution through porous medium Tip of ceramic cup is placed into the soil Water is drawn out side to form equilibrium a suction is created inside tube Depending on the amount of suction produced moisture content is indicated

2. Comparative Analysis of different soil moisture measurement techniques

Table 2 gives the tabular representation of comparative analysis of different Soil Moisture Measurement Techniques.
Table 2 : Comparison of different Soil Moisture Measurement Techniques [6-12]

Technique	Operating Range (ft^3ft^{-3})	Accuracy (ft^3ft^{-3})	Measurement volume	Cost
NM	0 to 0.6	± 0.005	Sphere (radius 6-16 inches)	$10,000-15,000
TDR	0.05 to saturation	± 0.01	About 1.2 inches radius around waveguide	$400-23,000
FDR	0 to saturation	± 0.01	Sphere (radius 1.6 inches)	$100-3,500
ADR	0 to saturation	± 0.01 to 0.05	Cylinder (radius 1.2 inches)	$500-700

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PT	0.05 to 0.5	± 0.01	Cylinder	$200-400
TDT	0 to 0.7	± 0.05	Cylinder (radius 2 inches)	$400-1,300
Tensio-meter	0-0.80 bar	±0.01 bar	Sphere (Greater than 4 inch radius)	$75-250

Table 3 : Advantages and Disadvantages of different systems

Tech-nique	Advantages	Disadvantages
GM	• Highly accurate and reliable • No need of specific calibration • Unaffected by salinity & air gaps	• Takes much more time (24 Hr) • Affected by environmental conditions like heat, humidity etc. • Automation is not possible • Heavy & cumbersome
NM	• High accuracy & robust • Unaffected by salinity & air gaps • Large soil sensing volume • Single probe can measure at different depths • Stable soil specific calibration	• Not much safety • Require certification • Difficult use • Expensive • Heavy & cumbersome • Time consuming • Readings closer to surface not easily possible • Can't be automated • Requires specific calibration
TDR	• Highly accurate • Easily expanded using multiplexing • Varity of sensor probes availability • Very less soil disturbance • Insensitive to normal salinity • Measure electrical conductivity	• Relatively expensive • Fails at high salinity condition • Specific calibration required
FDR	• Can work in high salinity • Better resolution • Easy to connect with conventional loggers • Flexibility in probe design • Inexpensive than TDR	• Low accuracy • Small sensing volume • Installation affects readings • Sensitive to temp, air gaps, bulk density • Needs specific calibration • Exhibits more variability [10] [14]
ADR	• Better accuracy with soil specific calibration • Can measure in highly saline condition [17] • Minimum soil disturbance • Easy to connect with conventional loggers • Inexpensive • Unaffected by temperature	• Soil specific calibration needed • Sensitive to air gaps, stones, channel watering on probes • Small sensing volume
PT	• Inexpensive • Accurate by soil-specific calibration • Large sensing soil volume • Easy to connect with conventional loggers	• Soil disturbance during installation • Requires soil-specific calibration • Sensitive to salinity • Reduced precision. • Need Permanently installment in the soil
TDT	• Higher Accuracy • Large sensing soil volume • Inexpensive • Easy to connect with conventional loggers	• Reduced precision • Need Permanently installment in the soil • Higher Soil disturbance during installation
Tensio-meter	• Minimal skill • Not affected by soil salinity • Direct reading • Continuous reading • Avoids electronics and power consumption • Well-suited for high frequency • Inexpensive	• Not suited for swelling or coarse soils • Frequent maintenance is Required • Limited range • Time consuming

3. Review of the systems developed using tdr concept

Second review is about the recent systems in which TDR concept is used. The problem faced and limitations of these systems are provided. [4-15]

Table 4 : Different systems developed using TDR technique

Name	Advantages	Disadvantages
Campbell Scientific TDR	Integration in automated measurement system	Required additional ext. control setup [4]
Lee et al	Random equivalent sampling TDR	Requires two extremely stable oscillators
Xudong et. al.	Developed TDR system cable fault diagnosis	Expensive off the shelf laboratory equipment
Purisima et. al.	Developed FPGA based TDR system	Direct sampling scheme is limited
Negrea and Rangu	Small microcontroller based sequential sampling with three programmable delay lines	Resolution is only 250 ps.
Schimmer et. al.	Portable high frequency TDR meter. It can be used even at very high frequency components up to a few GHz.	Limited overall recording time, a limited temporal resolution, high power consumption, the need of calibration, & limited availability on market

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Sokoll and Schimmer	Replaced the programmable delay lines by two programmable but free-running oscillators. Excellent performance and high accuracy	The system cannot easily be adapted for long transmission lines, as required in many geological and agricultural applications

III. System Design

The importance and the need of soil moisture measurement is not a new concept. As discussed earlier it is important in various fields. As described in the literature survey section various techniques are used till now to achieve this task. But each of the technique has some limitations so it is called that the ideal system for the soil moisture measurement is yet to be perfected. After reviewing all the techniques it can be concluded that a TDR technique has much more potential to idealize. Limitations faced by these systems can be easily overcome with the application of some modifications in the design. All these points are considered while designing the TDR system. Limitation due to high cost is resolved with the use of low cost hardware and making the system simpler. In the following section detailed discussion of system design is put forward. Basic block diagram, circuit diagram, photograph of the proposed system is provided for detailed clarification.

1. System Concept

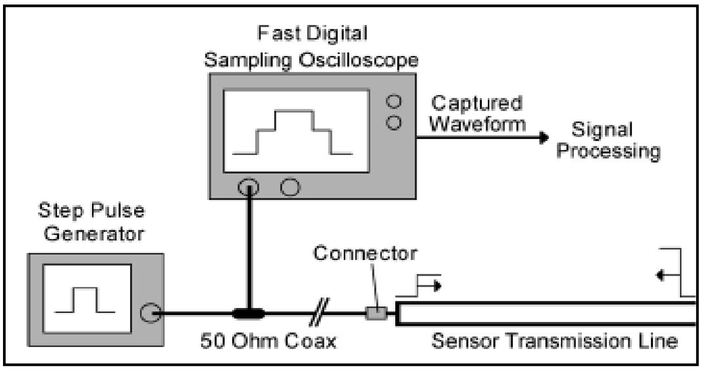

Fig. 1: Basic operating principle of TDR technique [1]

Fig. 1 illustrates the general concept based on a typical laboratory setup using a step pulse generator as a signal source and a fast digital sampling oscilloscope for capturing waveform of the measurement signal.
Fig. 2 illustrates the resulting typical waveform at the beginning of the line. The first rising edge at t_0 up to approximately $U_G/2$ in the signal is caused by the voltage divider formed by the generator output impedance R_{out} and the matching wave impedance Z_W of the coaxial line. After travelling along the coaxial line, the signal enters the connected flat ribbon cable a partial reflection occurs due to impedance mismatching. [2]

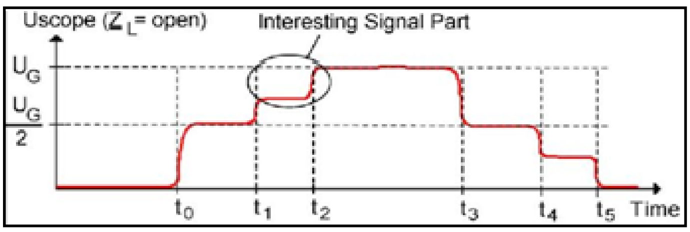

Fig. 2: Typical Waveform seen at oscilloscope [1]

The partially reflected signal can be observed at t_1. The transmitted part of the signal travels along the ribbon cable and is distorted along the cable depending on the dielectric properties of the surrounding media (e.g., soil). After reaching the end of the open line, the signal is reflected and travels back to the generator. The last rising edge at t_2 can be observed at the beginning of the line [1]. Only a small fraction of the signal contains relevant measurement information, & only a fraction of the vertical resolution is used. IN optimized TDR system, it is desired to directly connect the output of the generator as input of the sensor transmission line. [3]
Circuit diagram of the proposed system is as shown in fig. 4 GSM module and microcontroller can be connected by using RS232 cable through IC MAX232.

2. System development

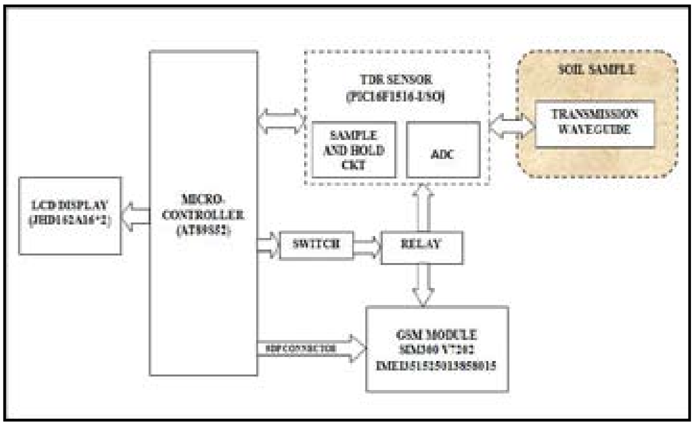

Fig. 3 : Architecture of the proposed system

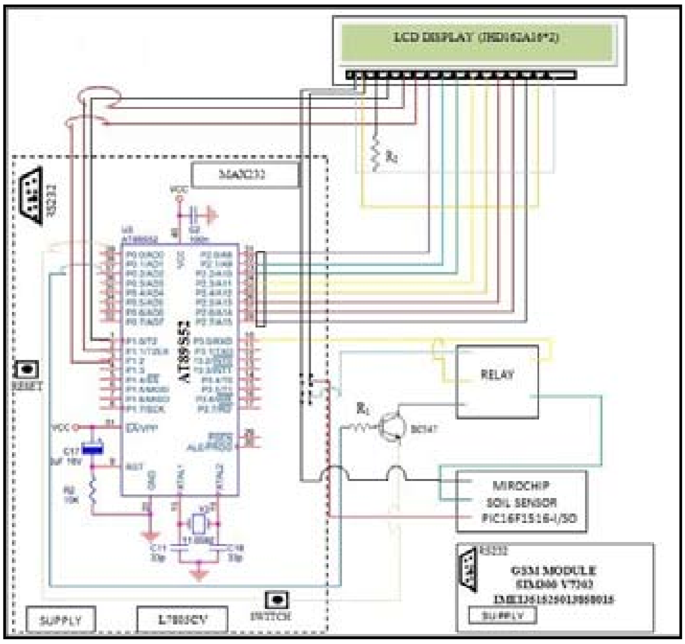

Fig. 4 Circuit diagram of the proposed system

3. software and hardware overview

Table 5 provides the list of the hardware components required for the designing of the proposed system with the cost and the function provided.

Hardware Used:

To fulfil the objective of providing low cast solution, a low cost, easily available microcontroller AT89S52 is used. For sensing purpose a low cost and readily available soil sensor micro-chip

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PIC16F1516-I/SO is used which is much easier to handle. This sensor uses TDR concept for soil moisture measurement. GSM module is used which gives the low cost communication so that the reading of the TDR can be send wirelessly in short time. A simple 16*2 LCD display is provided which provide the TDR reading at the site itself. Relay is used to demultiplex the sensor and GSM module while interfacing with microcontroller. [25]

Table 5 : Components used, their function and cost

Component	Function	Cost
Microcontroller Board	To implement Microcontroller and assembly	125
Microcontroller (AT89S52)	CPU of system	90
MAX-232ECPE	Serves as TTL Converter	25
RS232 Cable	Provide communication between controller and GSM module	45
Regulator IC-L7805CV	Provide regulated 5V supply	25
Relay (VK8FF-S-DC5V-C)	Provide switching between GSM and sensor	85
LCD (JHD162A16*2)	Display VWC and propagation Time to travel EM wave	180
MICRO-CHIP Soil Sensor	Generate, transmit and receive reflected EM wave to and from transmission waveguide	2000
GSM (SIM-300 V702)	Provide wireless communication	1600
Supply Unit	To provide Power supply	80
	Other Expenses	120
	Total	4375/-Rs

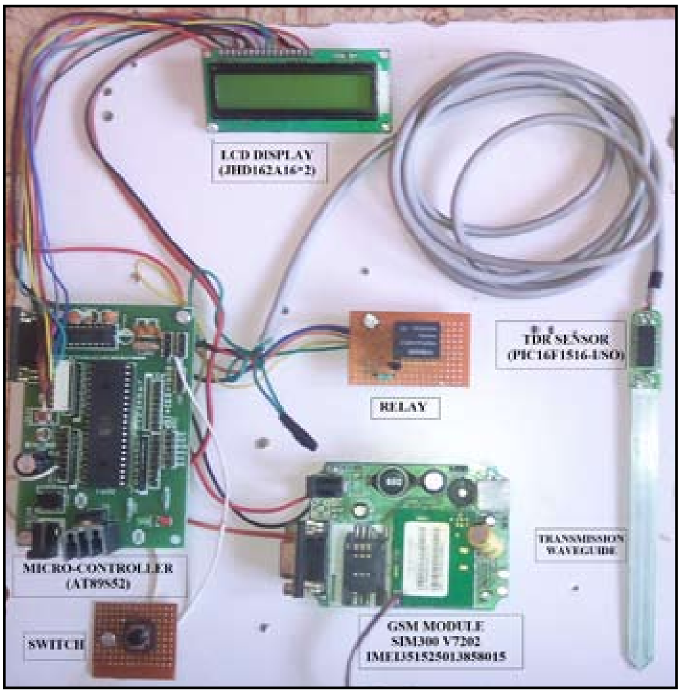

Fig. 5 : Photograph of the developed system.

Software and Programming Language used:

Embedded C programming is used for interfacing of GSM module LCD display and Soil Sensor. [24] The Keil software is used to upload the program to microcontroller. Embedded C is a set of language extensions for the C Programming language by the C Standards committee to address commonality issues that exist between C extensions for different embedded systems. Embedded C programming needs nonstandard extensions to the C language for supporting exotic features like basic I/O operations, multiple distinct memory banks and fixed point arithmetic. [21-2]

IV. calibration of the system

Although TDR methods are useful in terms of their ease of use and ability to take measurements quickly, there are complications and challenges with using and installing TDR instruments. Modelling temporal variations in soil moisture profiles first needs the ability to measure moisture in a variety of soil textures and over a range of depths accurately [20]. So, the important question always asked while using TDR is: how accurate are the results of soil moisture measurement? Weather TDR moisture values differ from the values measured by GM, what are the causes behind that? The best way to answer these questions is by calibrating the TDR instrument. [19] [9]

2. methods available for tdr calibration

A. using empirical function

This is the traditional method for calibrating TDR measurements. Calibration is done through an empirical function which describes the relationship between moisture content and the bulk dielectric constant of a soil (Topp et al., 1980).

B. using neutron probe

Some designers have calibrated TDR moisture measurements to soil moisture measured with the neutron probe (Evett and Steiner, 1995; Laurent et al., 2005). The TRIME probe used, an initial calibration is applied to TDR measurements through a standard calibration equation internally stored that is considered to be suitable for use for a large range of mineral soils. It will measure amount of moisture content in soil with a stated accuracy up to +2% to 3% values (IMKO, 2006a). For measurements made in different types of soil, it is considered that deviations from the standard equation are really relatively small valued and results in errors of a few percent of soil moisture value by volume.

C. using dielectric mixing

This is the method which uses the specific calibration of soil. Here, the modelled bulk dielectric constant has relation with the individual dielectric values of specific components of the system including bound water, air and mineral grains (Dobson et al., 1985). With assumed dielectric value for each parameter as a constant, a modelled value of soil moisture can be determined. But, in complex heterogeneous environments, it is difficult to model because of difference in properties of minerals, a variety of soil chemistry parameters, soil texture and moisture content in soil. [13-14]

D. using depth, bulk density values, volumetric water content(vwc)

It involves relating soil moisture using VWC, bulk density values and depth, measured from cores taken in a pit excavated surrounded to an access-tube with the bulk dielectric constant, (Whalley et. al., 2004). This type of approach may be unpractical in heterogeneous conditions present at many field sites or in conditions where significant depths are involved.

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E. using gravimetric method

It is one of the most proven, accurate and reliable method use for calibrating instruments for moisture measurement. Therefore, it is selected for TDR calibration. Procedure is explained in the following section briefly.

Gravimetric measurement of soil water content is based on removal of water from the soil sample. Water is removed by leaching, chemical reaction or evaporation. Once sample water is removed, the amount of water removed from the sample is determined and used to calculate VWC. The determination of water content removed is done using one of the several methods. The most simplest and accurate method to determine water content removed is by measurement of loss of weight of the soil sample. Sample water content can also be determined by collection of the water through distillation or absorption in a desiccant used. Extraction of substances which replace sample water and measurement of a physical or chemical property of the extracting material that is affected by water content can be used. Now, sample water content can be determined by quantitative measurement of reaction products displaced from a soil sample. In these methods the water and soil are separated and the amount of water removed is measured. Oven drying technique is the most widely used of all gravimetric methods. The oven dry technique is the standard for the calibration of all other soil moisture determination techniques. [19] [20]

3. procedure to calibrate tdr using oven dry method

Soil moisture measurement using oven dry method i.e. (GM) is the most reliable and accurate method. So a factor i.e. % VWC per TDR COUNT is found from the measurement taken by Gravimetric Method and the TDR method.

Fig. 6: Oven Dry Technique used for Gravimetric Method

Detailed procedure:

I. Weight of the original soil sample (wet) is taken using precision weighing machine. This is then stated as W_t.

II. This sample is then applied for complete oven drying for 24 hours at 105^0C. After this the sample is taken out side from hot air oven and cooled to the room temperature. A care must be taken that the sample should not be come in touch with the environmental humidity because it can affect the measurement. Then this oven dried sample is also weighted and stated as W_s.

III. From these two readings then the % Moisture contained i.e. volumetric water contained on weight basis is determined using following formula:

$$\%\ \text{Moisture Content} = \frac{Wt - Ws}{Ws} \times 100$$

Here: Wt = Weight of original sample (Wet sample)
Ws = weight of oven dried sample.

IV. The original sample of soil is also applied for TDR Method in parallel. TDR then senses the amount of moisture present in the soil and depending on the travelling time required by EM wave to transmit and reflect back from TDR transmission waveguide a proportional COUNT is then displayed.

V. After obtaining the TDR count, next step is to find out a factor % VWC per count as:

$$\%\ VWC\ Per\ Count = \frac{\%\ VWC\ by\ Gravimetric\ Method}{COUNT\ by\ TDR\ Method}$$

VI. Same procedure is then repeated for the samples containing different moisture contents. Care is taken that these all samples must of the same soil type only having different amount of moisture content. Next to this average of all factors is determined.

VII. So now our TDR instrument is calibrated with reference to the Gravimetric method. % VWC by TDR then can be easily found out using the average % VWC per count belonging to that soil type.

$$\%\ VWC\ (xn) = Average\ \%\ VWC\ Per\ Count \times COUNT\ by\ TDR\ Method$$

V. Results and discussion

As discussed in last section, soil moisture measurement by TDR technique is done with reference to the Gravimetric method. GM is most proven, accurate and reliable method for calibrating other instruments for soil moisture measurement. Complete measurement of soil moisture content is done on weight basis. Table 5 and table 6 indicate the result of the complete measurement discussed in the previous section. The final results of soil moisture measurement are indicated by y_n and x_n i.e. % Volumetric Water Content on weight basis measured with Gravimetric Method and TDR Method respectively. Measurement is done on number of samples from different three soil types noted as I, II and III.

1. percent vwc measurement results

Graph 1 plots the % VWC by GM and TDR method. Graph 1 represents the plot of percent VWC by two methods. Graph 2 gives the plot of TIME, COUNT and %VWC measured with TDR system for soil sample III.

Table 6 : Measurement results of Percent VWC using GM

	Gravimetric Method		
Soil Sample	**W_t (gm)**	**W_s (gm)**	**% VWC (y_n)**
I.	150	128.08	17.11
	150	124.30	20.68
	150	116.77	28.46
	150	111	35.14
II.	150	125.66	19.37
	150	123.95	21.02
	150	122.60	22.35
III.	150	127.66	17.50
	150	116.67	28.51
	150	115.50	29.87
	150	111.34	34.72

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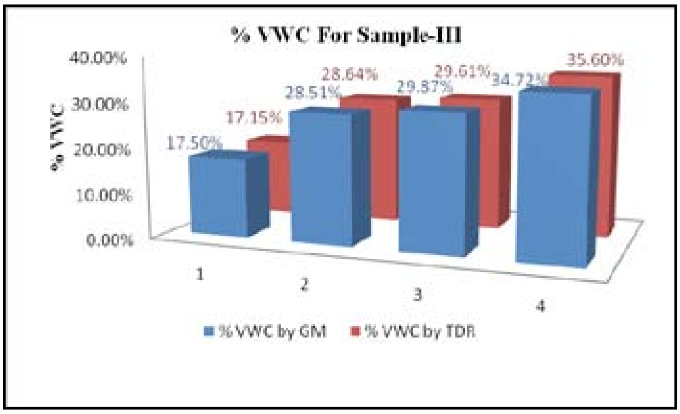
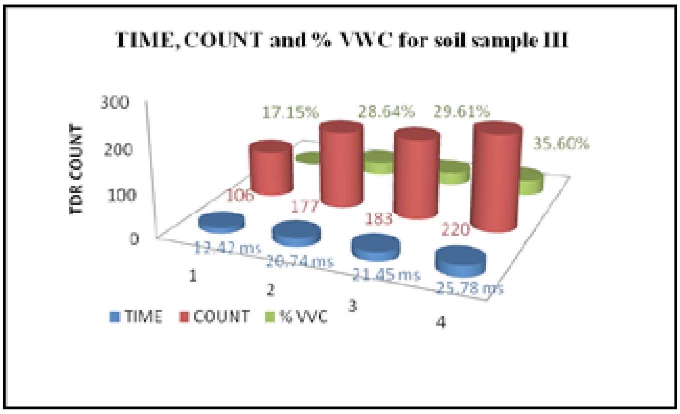
As soil moisture content i.e. VWC depends on the type of soil so count indicated by TDR system varies with the type of soil. Graph 3 indicates the variation in the % VWC per COUNT for different types of soil samples at different amount of moisture content.

Table 7 : Measurement results of Percent VWC using TDR Method

	TDR Method				
Soil Sample	TIME T_s (ms)	COUNT	% VWC Per count	Avg. % VWC Per count	% VWC (x_n)
I.	11.25	96	0.1782	0.1789	17.17
	13.24	113	0.1830		20.21
	19.69	168	0.1694		30.05
	22.27	190	0.1849		33.99
II.	18.05	154	0.1258	0.1288	19.84
	18.75	160	0.1314		20.61
	20.27	173	0.1292		22.28
III.	12.42	106	0.1651	0.1618	17.15
	20.74	177	0.1611		28.64
	21.45	183	0.1632		29.61
	25.78	220	0.1578		35.60



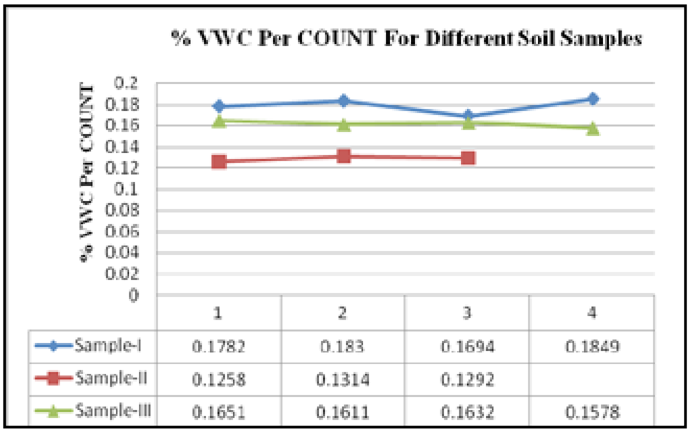
Graph 1: Measurement results of soil sample-III



Graph 2: TIME, COUNT and %VWC for soil sample-III

VI. Statistical analysis

Statistical analysis is much important in the study of any analytical instrument. Analysis of the measurement results stated in table 8 and 9 is done using the standard formulae used for statistical analysis. All of these formulae are considered with the reference of book Electronic Instrumentation and Measurement by H. S. Kalsi. [18]



Graph 3: % VWC per COUNT for different soil samples.

1. percentage error

It is the deviation of the true value (measured value) from the expected value i.e. the most probable value that calculations indicate one should expect to measure.

It is measured as

$$\% \; Error = \frac{Absolute\ value}{Expected\ Value} \times 100$$

$$\% \; E = \frac{e}{Yn} \times 100$$

Here,

Absolute Value (e) =

Expected Value (Yn) − Measured Value (Xn)

2. relative accuracy

It is the degree of exactness (closeness) of a measurement compared to the expected (desired) value. It is determined as:

$$\text{Relative Accuracy}(A) = 1 - \left|\frac{e}{Yn}\right|$$

Percent accuracy is determined by:

% Accuracy (% a)= A × 100 % % Accuracy (% a)= A × 100 %

Table 7 indicates the results of calculated error and accuracy of different measurements.

Percent VWC using GM, TDR method and Percent accuracy measured for Soil Sample type III is indicated in the graph 4.. As discussed earlier GM is used as the standard reference for soil moisture measurement.

Table 8 : Percent Error and Percent Accuracy of the system

Sample	(y_n)	(x_n)	e	%E	A	% a
I.	17.11	17.17	-0.06	-0.35	0.9965	99.65
	20.68	20.21	0.47	2.27	0.9773	97.73
	28.46	30.06	-1.60	-5.62	0.9438	94.38
	35.14	33.99	1.15	3.27	0.9673	96.73
	Average % E = 2.88 %				Avg. % a = 97.12 %	
II.	19.37	19.84	-0.47	-2.43	0.9757	97.57
	21.02	20.61	0.41	1.95	0.9805	98.05
	22.35	22.28	0.07	0.31	0.9969	99.69
	Average % E = 1.56 %				Avg. % a = 98.44 %	
III.	17.50	17.15	0.35	2.00	0.9800	98
	28.51	28.64	-0.13	-0.45	0.9955	99.55
	29.87	29.61	0.28	0.93	0.9907	99.07
	34.72	35.60	-0.88	-2.53	0.9747	97.47
	Average % E = 1.48 %				Avg. % a = 98.52 %	

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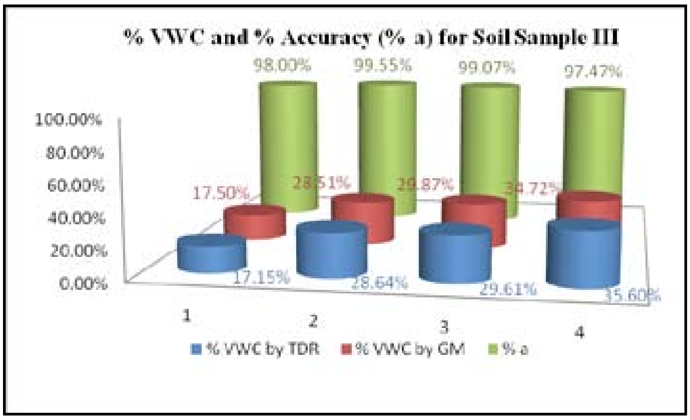
3. Arithmetic mean

It is the most probable value of a measured variable of the taken number of readings. The approximation becomes better with increasing the number of readings of the same quantity. It is given as:

$$\bar{x}_n = \frac{x_1+x_2+x_3+\ldots+x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n}$$

Here, x_n = value of nth measurement
n = no. of measurements



Graph 4: % VWC and % Accuracy for Soil Sample-III

4. Precision

It is a quantitative or numerical indication of the closeness of measured value with which a repeated set of measurement of the same variable agree with the average set of measurements.
It is determined as:

$$Precision\ (P) = 1 - \left|\frac{x_n - \bar{x}_n}{\bar{x}_n}\right|$$

Table 9 : Arithmetic Mean and Precision for different samples

Sample	x_n	$\bar{x}_n$	P
I.	0.1849	0.1789	0.9665
	0.1830		0.9771
	0.1782		0.9961
	0.1694		0.9469
II.	0.1258	0.1288	0.9767
	0.1314		0.9798
	0.1292		0.9969
III.	0.1651	0.1622	0.9821
	0.1611		0.9932
	0.1632		0.9938
	0.1592		0.9815

5. Deviation from mean

The departure of a given reading from the arithmetic mean of the group of readings is known as the deviation from mean of the measurement values.

$$d_n = x_n - \bar{x}_n$$

6. Average deviation

It is an indication of the precision of the instrument used in measurement.

$$D_{avg} = \frac{|d_1| + |d_2| + |d_3| + \ldots\ldots + |d_n|}{n} = \frac{\sum_{n=1}^{n} |d_n|}{n}$$

7. Standard deviation

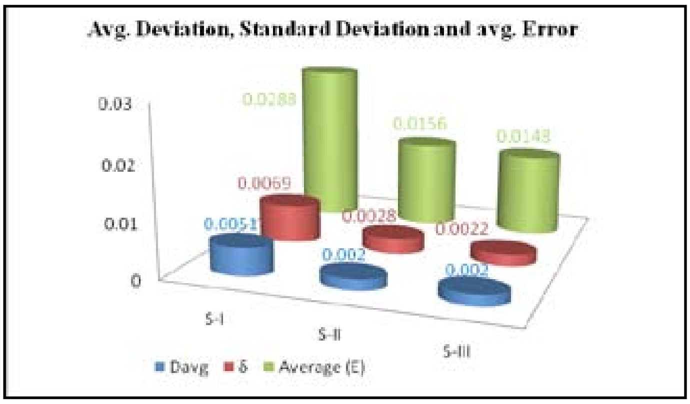
Reduction in this quantity effectively means improvement in measurement. It is given by,

$$\delta = \sqrt{\frac{d_1^2+d_2^2+d_3^2+\ldots\ldots+d_n^2}{n}} = \sqrt{\frac{\sum_{n=1}^{n} d_n^2}{n}}$$

Table 10 : Deviation from Mean, Avg. Deviation and Standard Deviation

Sample	x_n	$\bar{x}_n$	d_n	D_{avg}	δ
I.	0.1849	0.1789	0.0060	0.0051	0.0069
	0.1830		0.0041		
	0.1782		-0.0007		
	0.1694		-0.0095		
II.	0.1258	0.1288	-0.0030	0.0020	0.0028
	0.1314		0.0026		
	0.1292		0.0004		
III.	0.1651	0.1622	0.0029	0.0020	0.0022
	0.1611		-0.0011		
	0.1632		0.0010		
	0.1592		0.0020		

Table 10 gives the results of Arithmetic Mean, Deviation from Mean, Average Deviation and Standard Deviation for different soil samples. Standard Deviation for sample-I is highest among three which is decreases for Sample-II and III.



Graph 5: Avg. Deviation, Standard Deviation and % Error for different soil samples.

VII. Conclusions

At the end we can conclude that in this way we are succeeded to provide low cost solution for soil moisture measurement. It is always said that the ideal method for soil moisture measurement is yet to be perfected. A TDR instrument also has limitations like high cost, need of specific calibration, inaccuracy at higher salinity conditions. This system design is a step towards the perfection of this technique as it removes the limitation of the high cost. Need of the specific calibration can be minimize in the future by collecting large data base from large number of different soil samples. Solution for the reduction of inaccuracy problems faced at higher salinity condition is also available; some of the researchers are trying to solve this problem with the use of polyolefin coated TDR probes.
Automation of the agricultural field is possible by handling the process in it electronically. Though Gravimetric Method is most accurate and proven method but at the same time it has serious disadvantages like lengthy operation, time consumption. Also it

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can't provide measurement result at the site itself. TDR system on other side provides results at site as well as can transmit it wirelessly. GM is a manual method so results also have to be recorded manually. TDR gives result in digital form so it is much easier to record, transmit and analyse the results. TDR probe has very small area so it can be easily installed; also there is no requirement of frequent maintenance.

System design with a microcontroller reduces development cost and makes it more simple and reliable. LCD Display provides the result at the site where as GSM module provide results wirelessly wherever required. Comparative analysis with other system indicates how TDR system is superior one. Statistical analysis provided presents the system performance.

1. Future scope

As already discussed ideal system for soil moisture measurement is yet to be perfected, this system is only a step in that direction. For the future this system has much scope for getting higher accuracy. Further increase in accuracy and reduction in the cost can be achieved by the use of different materials for designing of the TDR probe. Lot of work can be done on the design of coated TDR probe using different materials like polyolefin to handle high salinity conditions. Very large amount of data base can be gathered for removing need of specific calibration of the system.

2. Benefits of the tdr system

I. Low cost.
II. Higher accuracy.
III. Simple software and hardware design.
IV. Wireless transmission of the readings is possible.
V. Fault detection and correction is easy as compared to existing system.
VI. No need of frequent maintenance, low maintenance cost.
VII. Easily expanded using multiplexing.
VIII. Varity of sensor probes availability.
IX. Very less soil disturbance.
X. Insensitive to normal salinity.

3. Applications

I. In agriculture and plant science field to determine best time to sow and plow the field.
II. In the Drainage engineering to measure changes in infiltration and irrigation.
III. To study ground water recharge and Evapo-transpiration.
IV. It is also important in the fields like Hydrology, Forestry and Agrology.
V. In the study of various physical and chemical properties of soil which changes with amount of moisture present in soil.
VI. To study and determine the parameters like soil profile, surface tension related with civil and soil engineering.
VII. Automation of Irrigation and Mushroom cultivation.

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Author's Profile

__Bhushan N. Patil__ has received his B.E. graduation degree in Electronics and Telecommunication in 2012 and now pursuing M.E. post graduation degree in Digital Electronics from SSBT C.O.E.T. Bambhori, Jalgaon. He has also worked as a Lecturer at TIT Polytechnic, Paldhi, Jalgaon and as an Assistant Professor at SSBT C.O.E.T. Bambhori, Jalgaon. He has attended two National Level Workshops organized by IIT, Kharagpur. He has participated in two International level conferences and has published two papers in International Journals.

__Pankaj H. Zope__ has received his B.E. degree in Industrial Electronics in 1999 from MGM J.N.E.C Aurangabad and Master's degree in Digital Electronics Engineering in 2007 from PRMIT Badnera, Amravati University. Subsequently he carried out his research from Jodhpur National University, Jodhpur and awarded PhD in 2013. Presently he is working as Assistant Professor in the Post Graduate Department of Electronics and Telecommunication Engineering at SSBT C.O.E.T. Bambhori, Jalgaon. He has published more than 60 research paper of national and international repute. He is working on many project of Nano-science and Nano-Electronics and his research interests include signal processing (Digital, Image), Power Electronics and Inverter, Analog Devices, Nano-Sensor, Solar Cell Fabrication and Super- Capacitors etc.

__Kiran S. Patil__ has received his B.Sc. degree in Physics in 1993 from M.J College Jalgaon and Master's degrees MSc.in Physics in 1995 from Pune University Pune. Subsequently he carried out his research from Jodhpur National University, Jodhpur and awarded PhD in 2012. Presently he is working as Assistant Professor in the Department of Applied Science at SSBT C.O.E.T. Bambhori, Jalgaon. He has published more than 20 research paper of national and international repute. He is working on many project of Nano-science and Nano-Electronics and his research interests include Bio-sensor, Thermoelectric Generator, Super Capacitor, DSSC etc,

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