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Drafting the Design and Development of Micro-Controller Based Portable Soil Moisture Sensor for Advancement in Agro Engineering

Guneet Mander and Gurinder Pal Singh

Abstract**—**Moisture is an important consideration in many aspects ranging from irrigation, soil chemistry, golf course, corrosion and erosion, road conditions, weather predictions, livestock feed moisture levels, water seepage etc. Vegetation and crops always depend more on the moisture available at the root level than on precipitation occurrence. In this paper, design of an instrument is discussed which tells about the variation in the moisture contents of soil. This is done by measuring the amount of water content in soil by finding the variation in capacitance of soil with the help of a capacitive sensor. The greatest advantage of soil moisture sensor is reduced water consumption. The sensor is also be used to set lower and upper threshold to maintain optimum soil moisture saturation and minimize water wilting, contributes to deeper plant root growth ,reduced soil run off /leaching and less favorable condition for insects and fungal diseases. Capacitance method is preferred because, it provides absolute amount of water content and also measures water content at any depth.

Keywords**—**Capacitive Sensors, aluminum, Water, Irrigation.

I. Introduction

FUTURE human welfare depends on the efficient use of agricultural inputs to produce abundant food and fiber. Environmental sustainability of agriculture depends on careful balance of inputs and outputs. In spite of vast expanses of rain fed cropland, much of the world's food supply comes from irrigated agriculture. The productivity, profitability, and environmental sustainability of irrigated systems are tied to careful management of water, so that the land is not subjected to undue irrigation induced leaching and erosion. With the development of new techniques in the measurement of moisture, irrigation is benefitting in a great way. From scientific perspective, the use of instrumentation for soil water determination can satisfy an academic interest in the dynamics of the flow of water and solutes [23]. From a practical engineering perspective, instrumentation of soil moisture measurement can provide guidance for irrigation management, helping to assure short term economic yield and long term environmental protection [23].

Moisture is present as adsorbed water at internal surfaces and as capillary condensed water in small pores. At low relative humidity, precipitation consists mainly of adsorbed water. At higher relative humidity, liquid water becomes more and more important, depending on the pore size. The soils hold water due to their colloidal properties and aggregation qualities

Basically water is held on the surface of colloids and other particles and in the pores. The forces responsible for the retention of water in soil after the drainage has stopped are due to surface tension and surface attraction which is referred as surface moisture tension [10]. The force with which water is held is called suction. The quality of crop output is greatly increased by measuring moisture content of the soil. Increased soil moisture will result in higher yields through maximized rainfall utilization and reduced risk of yield losses due to drought [26].

There are several techniques employed to monitor soil's characteristics which include gravimetric techniques, neutron scattering, resistive methods, capacitive sensors etc. [15]. Capacitive sensors are not only employed to monitor soil's moisture but also moisture content present in grain, paper moisture content [1], amount of rainfall [4], as a proximity sensor [5] even as a biomedical sensor [7]. There are various properties of soil like color, texture, water holding capacity, drainage, depth etc. which can be monitored, but the process is time consuming, costly and difficult [18]. In particular, the most important parameter is measurement of soil moisture. In India, traditional irrigation methods are no longer feasible. Thus, Drip Irrigation is preferred as it reduces distribution losses and leads to higher efficiency. This research paper is based on the development of a low cost soil moisture sensor, which is beneficial in many aspects including agricultural engineering, civil engineering, instrumentation, water management, geology etc. With a highly conveniently sensor probe; structure could be applied for a number of applications.

II. Methods of Measurement of Moisture

A. Gravemetric Techniques

The oven drying technique is probably the most widely used of all gravimetric methods for measuring soil moisture. This method involves removing a soil sample from the field and determining the mass of water content in relation to mass of dry soil. Though this technique ensures accurate measurements, it also has a number of disadvantages which includes drying time of 2 hours, laboratory equipment, sampling time etc. Moreover it is considered a destructive test

Guneet Mander is working as an Assistant Professor at Chandigarh Group of Colleges, Gharaun, Mohali, Punjab, India, 140413; (e-mail: guneetmander.cgc@gmail.com).
Gurinder pal Singh is working as an Assistant Professor at Chandigarh Group of Colleges, Gharaun, Mohali, Punjab, India, 140413; (e-mail: gurinderpalsingh900@gmail.com).

as it requires sample removal. Due to this, soil moisture cannot be measured exactly at the same point at a later date. Parameter measured is referred as mass water content which is a ratio of percentage of dry vs. wet soil weight [19].

B. Neutron Scattering

It is widely used for estimating volumetric water content. With this method fast neutrons emitted from a radioactive source are slowed down by hydrogen atoms in soil. Since most hydrogen atoms in soil are components of water molecules, the proportion of thermalised neutrons is related to soil water content [6], [12]. Advantage offered by this method is measurement of large soil volume and possibly scanning moisture content up to several depths [19]. However, the disadvantages include high cost of instrument, radiation hazard, insensitivity near soil surface, insensitivity to small variations in moisture content leading to an error of 15 percent. As Microwave remote sensing techniques have unique ability for direct observation of moisture content of soil. Microwave measurements have the advantage of being unaffected by cloud cover and variable surface solar illumination, but the greatest limitation lies in being limited to regions that have either bare soil or low to moderate amounts of vegetation cover. Advantage of passive microwave sensors is that in the absence of significant vegetation cover, soil moisture is the leading effect on the received signal [11], [13].

C. Resistive Techniques

Soil resistivity is dependent upon its moisture content. It is possible to measure the resistivity between electrodes in soil or to measure resistivity of material in equilibrium with soil. Another method of measuring matric potential is with gypsum or porous blocks. When the device is inserted in the soil, water moves in and out of the block until matric potential is obtained [19], [2]. The electrical conductivity is then measured with an alternating current bridge. The blocks come in a variety of configurations but generally incorporate two electrodes embedded in a gypsum material. The block may be entirely gypsum or covered with a porous material such as sand, fiber glass, or ceramic. Meters are portable and are intended for use in reading a large number of blocks throughout one or more fields. A meter is used to read the electrical resistance of moisture blocks installed in the ground. Since the blocks are porous, water moves in and out of the block in equilibrium with the soil moisture. Meter resistance readings change as moisture in the block changes which, in turn, is an indication of variation in the amount of water in the soil. The manufacturer usually provides calibration to convert meter readings to soil tension [25], [3].

Advantages offered by this method include low cost and measuring at the same point. The biggest drawback is in the variation of characteristics of each block in the complete block porous block system.

D. Capacitive Techniques

In electromagnetism and electronics, capacitance is the ability of a body to hold an electrical charge. Capacitance is also a measure of the amount of electrical energy stored (or separated) for a given electric potential.

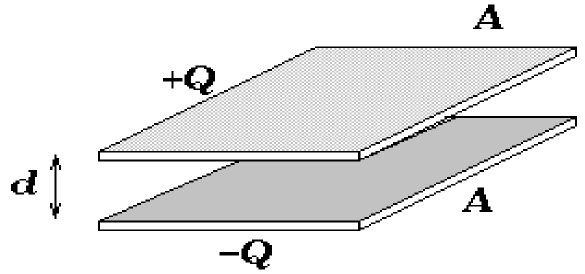

Fig. 1 Parallel plate capacitor

A common form of energy storage device is a parallel-plate capacitor. In a parallel plate capacitor, capacitance is directly proportional to the surface area of the conductor plates and inversely proportional to the separation distance between the plates. If the charges on the plates are +Q and -Q, and V gives the voltage between the plates, then the capacitance is given by C = Q / V.

$$C=\varepsilon A/d \tag{1}$$

ε =Relative permittivity; A =Overlapping area; d = Distance between two plates

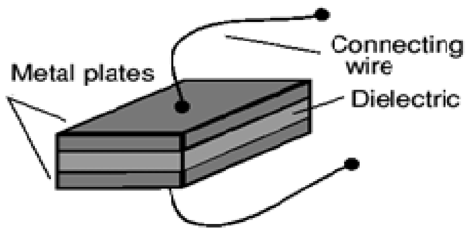

Fig. 2 Dielectric capacitor

As Dielectric constant or permittivity of a material is directly proportional to capacitance and distance between two plates and inversely proportional to the overlapping area of plates, so the relative permittivity of a material under given conditions reflects the extent to which it concentrates electrostatic lines of flux. Technically, it is the ratio of the amount of electrical energy stored in a material by an applied voltage, relative to that stored in a vacuum [16]. Similarly, it is also the ratio of the capacitance of a capacitor using that material as a dielectric, compared to a similar capacitor which has vacuum as its dielectric. This concept has been utilized, with soil serving as the dielectric medium and variation in capacitance is measured with the addition of water in soil [8]. Table I depicts various materials and their dielectric constants. Dielectric constant of soil is generalized to lie between the 3 and 4.

TABLE I
DIELECTRIC CONSTANT OF VARIOUS MATERIALS [9]

S.No.	*Material*	*Dielectric constant*
1.	Vacuum	1.0000
2.	Air	1.0006
3.	Paraffin Paper	2.5-3.5
4.	Transformer Oil	4
5.	Glass	5-10
3	Mica	3-6
7.	Rubber	2.5-3.5
8.	Wood	2.5-8
9.	Porcelain	6
10.	Soil	3-4

III. BASIC DESIGN OF SENSOR

This particular design of sensor is based on monitoring soil moisture content which is determined via its effect on dielectric constant by measuring capacitance between two electrodes implanted in soil where soil moisture is predominantly in the form of free water and is directly related to moisture content. The components used in making the hardware required for sensor are:

1. SENSOR
2. LM 7805 VOLTAGE REGULATOR
3. 555 TIMER
4. LM 29O7
5. ADC 0804
6. MICROCONTROLLER 8051
7. DISPLAY

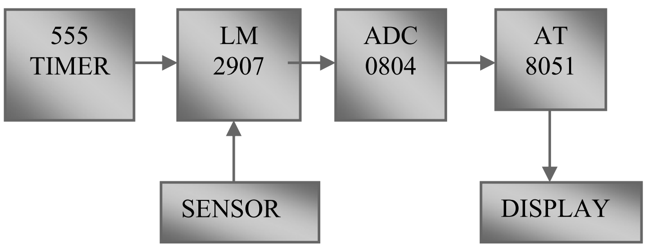

Fig. 3 Basic Block Diagram

A container made of plastic, cylindrical in shape closed from one end is taken. Sensor consisted of two cylindrical electrodes made of aluminum. Electrodes are made from aluminum as it is known to be a modern light weight material which has an excellent combination of various properties including strength, formability, durability, conductivity, corrosion, resistance etc. It is the second most common metal which is used in world today. Its extensive usage is due to various parameters which include ratio of strength to density, conductivity, its barrier properties, corrosion resistance and its recyclability. Because of being corrosion resistance in nature, it is commonly employed in architecture, construction, civil engineering, transport and heat exchange etc [24]. Aluminum exists only as a trivalent cation in majority condition. Thermal Conductivity of Aluminum exhibits a varying trend with the increase in temperature as depicted in Table II.

TABLE II
VARIATION OF THERMAL CONDUCTIVITY OF AL WITH TEMPERATURE

Temperature (K)	*Thermal Conductivity($Wcm^{-1}K^{-1}$)*
0	0
10	235
50	13.5
100	3.02
200	3.02
300	2.37
500	2.36

Pure aluminum is more resistant to corrosion than its alloys [22]. Its corrosion primarily depends upon oxygen concentration which in turn is dependent on water content. It is also dependent upon its type, conductivity and ph of soil. Comparative analysis of diverse soils with different types of metals and their consumption rate is shown in Table III. It is clearly interpreted from the table that consumption rate is minimum in case of aluminum in majority type of soils.

TABLE III
METALS AND CONSUMPTION RATE BY DIFFERENT TYPES OF SOIL [20], [21]

Metal	*Sandy*	*Clay*	*Marshy*	*Alkaline*	*sandy*
	Material consumption rate(g/m^2d)				
Aluminum 99.25Al	0.008	0.029	0.013	0.039	0.053
Duralumin	-	0.120	0.012	D	-
Al-Mn Alloy(1:12Mn)	0.032	0.017	0.018	0.026	D
Open Hearth Steel	0.820	0.470	D	D	D
Copper	0.012	0.037	-	0.012	G
Refined Lead 99.9	0.011	0.057	0.052	0.017	0.028

L=Local pitting, Pits not deeper than 0.15mm
G = Slit Corrosion, No Pitting
D=Perforations

According to an investigation carried out, pipelines of unprotected alloys including those clad with commercially pure Al, exhibit good resistance in an extremely wide range of soils [22]. Due to all these advantages offered by aluminum, it is used as electrodes.

Electrodes are separated by a finite distance which is encapsulated by a wooden block on the top. Then; this cylindrical container is filled with dry soil of fine quality. One of the electrodes is covered with a plastic wire so as to avoid ohmic conduction errors once the sensor enters the soil sample [17]. Due to Ohmic conduction errors, pouring small amount of water results in high conductivity of aluminum rods leading to percentage of moisture's value shoot to maximum. The sensor is then inserted into the sample and water of known quantity is poured and simultaneously percentage of water content is measured [14]. As the amount of water increased in the soil, simultaneously there is an increase in the amount of capacitance which obtains a constant value after reaching a specific value.

A. Specifications of Container

Height of container carrying soil=12.9cm
Diameter of container=14.8cm
Radius=7.4cm
Area of cylinder=2235cu.cm
(1litre=1000ml=1000cu.cm)

555TIMER is a highly stable device for generating time delays and oscillations. For this application timer is used in astable mode as free running frequency is required. Frequency is measured with the help of CRO.

Frequency of pulses and time period is given by:

$$f=1.44/(R1+2R2)\times C \quad (2)$$

$$T=1/f=0.69(R1+2R2)\times C \quad (3)$$

where R1=10ohm,R2=10ohm&C=10µF

LM2907 is a monolithic frequency to voltage convertor with a high gain op amp designed to operate a relay, lamp or other load when input frequency reaches or exceeds a selected rate. The configuration includes an 8pin device with a ground referenced tachometer input and an internal connection between tachometer and opamp's non- inverting output. This version is well suited for single speed or frequency switching or fully buffered frequency to voltage convertor applications. In this particular application frequency generated by 555 timers is converted into analog voltage. With the help of (4), analog voltage was found out from 5^{th} pin of LM2907. Calibration chart is prepared which helped in establishing relation between moisture content and analog voltage.

$$Vout = fin * Vcc * R1 * C \quad (4)$$

ADC0804 are CMOS 8bit successive approximation A/D convertors that use a different potentiometric ladder similar to 256R products. Conversion time required to obtain digital output is 100microseconds. AT89C51, CMOS 8bit microcomputer with 4K bytes of flash programmable memory is used for programming. The final display is taken on LCD screen which depicted percentage of moisture. JHD162A (LCD MODULE) is used to take display which is a 16pin IC. Pseudo Code for whole process is as follows:

For i=0 to n;
{{Sensor o/p to LM2907};
Frequency pulse is generated with 555timer;
Loop1:
{Frequency to voltage convertor}
Loop2: Data Conversion
{ADC for analog to digital conversion ;}
Digital Interrupt to controller for
Result analysis ;}

IV. Testing and Implementation

A small sample of soil is taken in a cylindrical container. Then, the sensor is inserted in the sample and power supply was switched on. An addition of consecutive 10ml of water is done and percentage of moisture is measured from the digital display LCD. All the above steps are repeated with an addition of 10ml water for each sample.

Total volume = (volume of sand + volume of water)

Moisture % by volume = (volume of water / total volume) * 100

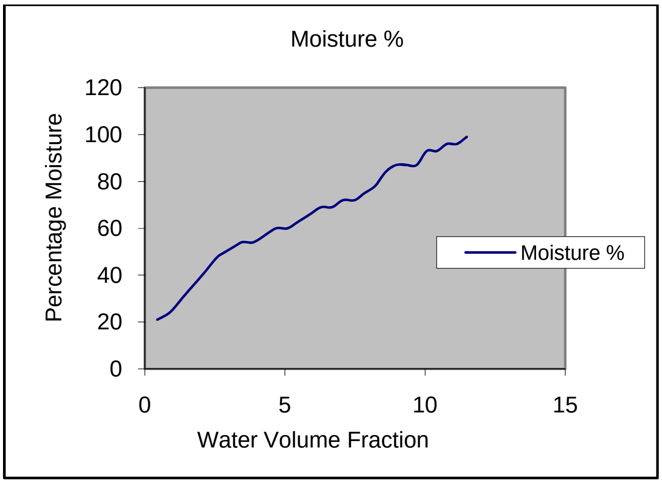

Fig. 4 Percentage of Moisture vs. Water Volume Fraction

For measurement of analog voltage LM2907 was used and measurements were made from 5^{th} pin. Capacitance is found out from the formula

$$C = \frac{V_{out}}{5.96kHz*9*100K} \quad (4)$$

Calibration chart is prepared for both analog voltage and capacitance and were plotted accordingly.

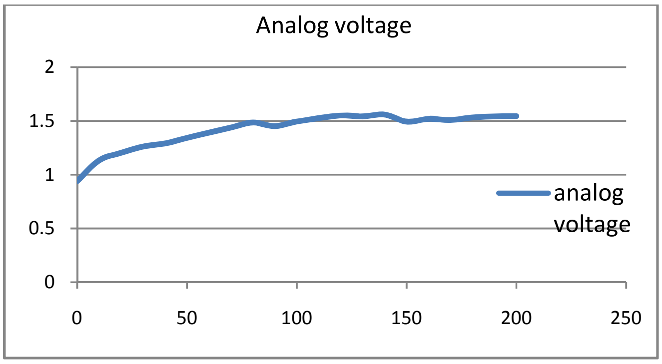

Fig. 5 Relation between amount of water (ml) and analog voltage (Volts)

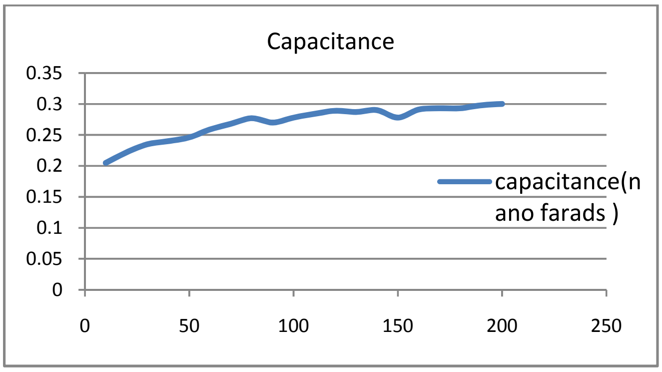

Fig. 6 Relation between amount of Water (mL) & Capacitance (Nano Farads)

It is clearly observed from the graphs that both capacitance and analog voltage follow an approximately linear pattern with the increase in amount of moisture (water content) in soil and attains a constant value after certain value (200ml) approximately.

V. Conclusion

In this paper applicability of a capacitive technique to measure soil moisture content has been analyzed. Three different graphs are obtained measuring variation in parameters like analog voltage, capacitance, and water volume fraction with respect to percentage of moisture content. The paper also describes the design and actual implementation of simple and cost effective sensor for measuring amount of water in soil. It is also helpful in finding moisture content of pulses, grains, wheat apart from soil's moisture The sensor also finds usage in industries where the grain size is less than 1mm or 2mm.Particularly, in the cultivation of strawberry and mushrooms which are known to be aquatic plants, the use of this sensor can prove to be very fruitful as these plants growth is highly affected due to absence of moisture which can be monitored with the help of this sensor. Another very useful application of this sensor is in drip irrigation where water is provided to soil without any human involvement. While working on sensor, it is found out that a high precision square wave oscillator could be used instead of 555 timer so that a stable value of frequency is obtained. Rigid sensor structure with display incorporated on it is more beneficial. Resolution could be enhanced by using ADC with high resolution.

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