"Design of Capacitive Sensor for Monitoring Moisture Content of Soil and Analysis of Analog Voltage with Variability in Moisture"

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Abstract*—An important parameter in today's world is food security as environmental degradation is a big threat. The need of the hour is proper utilization of resources .In developing countries where cultivation of land and crop production is a major source of income it becomes mandatory to manage the land in a beneficial manner. Moisture content in soil is optimal for plant growth .All the water held in the soil is not available to plants. Much of the water is available in the soil as a thin film which serves as a medium for supply of nutrients to growing plants. The paper describes design of a capacitance based soil moisture sensor which helps in finding moisture content of soil also depicting the variations in analog voltage with the change in moisture content. This low cost portable instrument can find many applications like drip irrigation and measuring moisture content of pulses, grains and wheat. India being an agricultural country where many people's livelihood depends on agricultural output it can provide to be highly beneficial.
Keywords— **Environmental degradation; Sensor; water .**

I. Introduction

In the fields such as agriculture and prevention of landslide disaster, maintenance of the embankment in the river, etc., it is very essential technology to measure the water that is included in the soil [1].Water held in pores of soil in liquid or vaporized form is referred as soil moisture. Changes in the percentage of soil moisture during the irrigation event can be controlled by indicating the amount of applied water to soil[2].Parameters like water holding capacity, infiltration rate, drainage and erosion vary from range of soil available. Agricultural soils consist of three component materials namely solid (mineral and organic), water and gas. As such, their mechanical, physical and chemical behavior is complex and is critically determined by the proportion of water in the soil matrix[4]. Soil moisture sensors can be implemented using various techniques like resistive, gravimetric, neutron scattering, capacitive techniques, time domain reflectometry etc.In this paper design of soil moisture sensor based on capacitive technique is used. In capacitive structures any measurand that affects the electrode separation distance, the electrode overlapping area, or the relative permittivity of the dielectric in the vicinity of the electrodes can be sensed by monitoring the changes in the structure's capacitance. Capacitive sensors have several distinct advantages over the other techniques, as a method of measuring changes near the sensor's surface. For instance, capacitive sensor measurements do not possess the potential health risks of radiation-based methods. Furthermore, fabricating and operating low-frequency capacitive sensors are relatively simple compared to RF-based techniques. However, if measurement of the high-frequency effects on the dielectric constant is required, then the RF-based techniques must be utilized. Capacitive fringing sensors are employed in monitoring moisture content in soil, grain, and paper moisture content, rain detection, as proximity sensors, as capacitive touch switches, as biomedical sensors etc [3].India being an agricultural country where GDP from agriculture sector contributes a major chunk to annual income, the design of this low cost portable sensor can be highly beneficial. India is second in the world in agriculture and its allied sector [5].Many Indian states including Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Andhra Pradesh, Bihar, West Bengal, Gujarat and Maharashtra contribute maximum to the agriculture output of the country. Therefore, careful management of water is necessary so as to gain maximum productivity.

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TABLE I: GROSS DOMESTIC PRODUCT (GDP) FROM AGRICULTURE AND ALLIED SECTOR AND ITS PERCENTAGE SHARE TO TOTAL GDP (1954-55 TO 2012-13)(RUPEES CRORE)

YEAR	GDP Total (At current market prices)	GDP Total (at Factor Cost) in Rs. Cr.	GDP Agriculture and Allied sector	% Share of Agriculture and Allied sector to total GDP	Growth Rate of GDP Agri. & Allied
1954-55	11,170	10,689	4,902	45.86	-14.93
1964-65	27,367	25,686	11,034	42.96	22.18
1974-75	80,770	74,930	30,204	40.31	9.55
1984-85	256,611	235,113	75,731	32.21	7.84
1994-95	1,045,590	955,385	270,107	28.27	15.15
2004-05	3,242,209	2,971,464	565,426	19.03	3.81
2012-13	10,028,118	5,503,476	5,503,476	17.37	12.10

II. PROBLEM RECOGNIZATION AND SOIL MOISTURE STATISTICS

Moisture measurements are of interest in many engineering applications today. Early assessment of soil moisture reserves, and monitoring of changes in available soil moisture, could assist in risk reduction strategies for the agriculture sector and effective delivery of government programs. Improved knowledge of emerging risks would also support the evolution from reactive federal response programs to proactive adaptation [6].In Northern India which is majorly referred as the agriculture belt of the country, a large number of crops are cultivated here and the soil also varies from area to area. Soil monitoring data was accumulated from a particular location but results are applicable to multiple locations .Various types of soils are available in India and each particular type has its own properties. For experimental analysis in this case sandy soil was used for analysis of moisture content in soil. The soil was first heated to 300 degree Celsius for 24 hours in dry heat oven so as to remove all moisture.

TABLEII: TYPES OF SOILS AND ITS COMPOSITION

SNo	Soil Type	Soil Texture Sand %	Soil Texture Clay %	Organic matter %	Conductivity (S/cm)
1	Loamy	78	2	2	66
2	Sandy	95	0	0	0
3	Clay	15	40	0.3	0.3
4	Organic	78	2	5.7	5.7
5	Ferromagnetic	82.5	2.5	0.1	0.1

The objective of the project was to design a microcontroller based instrument which can measure percentage of moisture in soil .For this sensor has been designed, whose capacitance as well as analog voltage varies as the percentage of moisture in soil changes. The basic design includes two electrodes separated by a distance served as a sensor as it can be easily inserted in the soil at any distance and for this project various components were used like resistances, capacitors, frequency to voltage convertor, power supply, 555 timer, LCD etc. capacitance is the ability of a body to hold an electrical charge. Capacitance is measure of the amount of electrical energy stored (or separated) for a given electric potential.

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

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. 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. Dielectric constant of soil is generalized to lie between the 3-4.

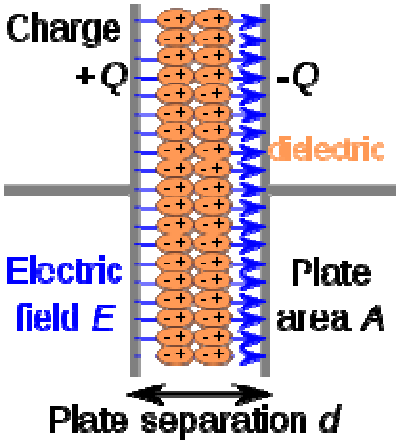

Fig 1: Parallel Plate Capacitor

III.DESIGN OF SENSOR

1. Signal acquisition and signal conditioning: Signal acquisition means acquiring signal for this parallel plate capacitor used as the sensor which will give capacitive signal as output according to dielectric strength of soil. Signal conditioning means making the output signal in that form which the electronic circuit can understand e.g. voltage. A frequency to voltage convertor converts the square wave coming from 555 timer into voltage signal.

2. Signal processing: Signal processing includes so many processes e.g. filtration for which capacitors are used, inductors etc. amplifiers for amplification so that ADC can access the signal because signal from the sensor can be of very less magnitude .ADC which converts output analog signal into the digital form and this digital output from the analog to digital convertor is given to microcontroller which is a digital device and the function is to control and display the output according to the input for which it is programmed.

3. **Selection of Hardware components and Software Used:** Basic designing of sensor consisted of two aluminum knitting needles serving as electrodes with wooden encapsulation on the top. One of the needles was covered with a plastic pipe which fully enclosed the aluminum needle so as to avoid short circuiting in the sensor. The Hardware Circuitry included the use of LM 7805 Voltage Regulator, 555 Timer, LM2907, ADC 0804, Microcontroller 8051 and LCD (JH162 A). The specifications of the container containing soil are given below:

Height of container carrying soil =12.9 cm

Diameter of container = 14.8cm

Radius =7.4 cm

Area of cylinder (amount of sand) = πr2h =2235 cu .cm

1 liters =1000ml =1000cu .cm

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

Moisture percentage by volume= (Volume of water/Total volume*100)

Fig2. Design of Sensor

The sandy soil present was dried using dry heat oven. Water was then added with an addition of 10ml consecutively and readings were taken.LM 7805 was used to regulate power given to the circuit. The sensor was used to observe the changes taking place in capacitance and analog voltage with the addition of water in soil.555 timer was used in astable mode to generate square wave as LM 2907 is essentially a frequency to voltage convertor and the relatively obtained voltage was observed on the 5^{th} pin of the IC. The LM2907, LM2917 series are monolithic frequency to voltage converters with a high gain op amp/comparator designed to operate a relay, lamp, or other load when the input frequency reaches or exceeds a selected rate. The tachometer uses a charge pump technique and offers frequency doubling for low ripple, full input protection in two versions (LM2907-8, LM2917-8) and its output swings to ground for a zero frequency input. The two basic configurations offered include an 8-pin device with a ground referenced tachometer input and an internal connection between the tachometer output and the op amp non-inverting input. This version is well suited for single speed or frequency switching or fully buffered frequency to voltage conversion applications [7].

The formula for calculating analog voltage is given as

$$Vout = fin * Vcc * R1 * C$$

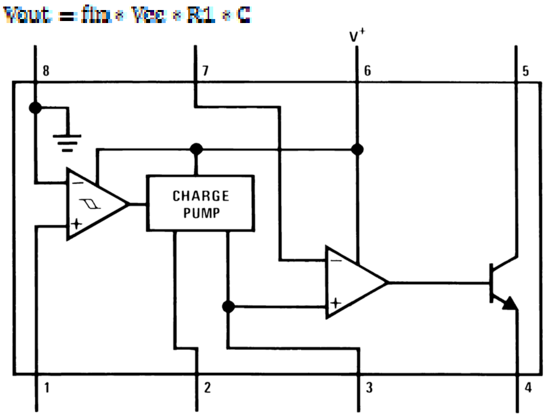

Fig3: Pin configuration of LM2907

The obtained analog voltage was then converted to digital form by using ADC 0804 which is an 8bit successive approximation analog to digital convertor. Conversion time for this operation was found out to be 100 microseconds. 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.Calibration chart is prepared and output is observed for analog voltage and capacitance and graphs are obtained.

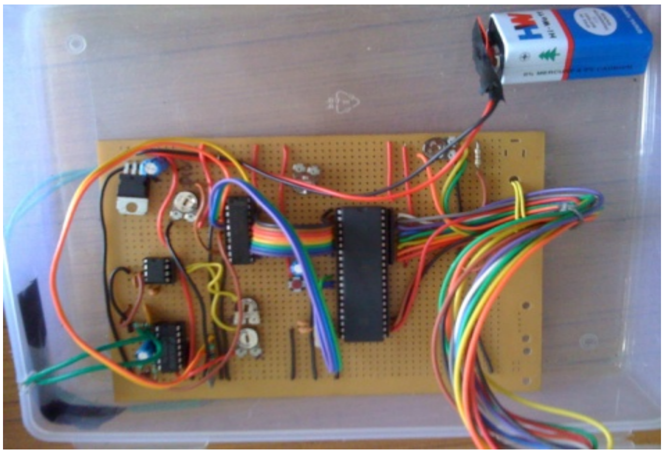

Fig4: Hardware Circuitry for Sensor

IV.SOFTWARE DEVELOPMENT

KIEL µ VISION4-This software is used to convert the assembly language program to Hex Files.

PROLOAD – It is an 89 series programmer device which is used to burn C – language program into microcontroller 8051 .Firstly all the hex files are generated and then program is burned into microcontroller through the programmer.

ORCAD – In ORCAD we simulation is done and output is checked with reference to the input before making hardware and finalizing the circuit.

CONTROL PROGRAM – The control program is developed in C language for easy implementation.

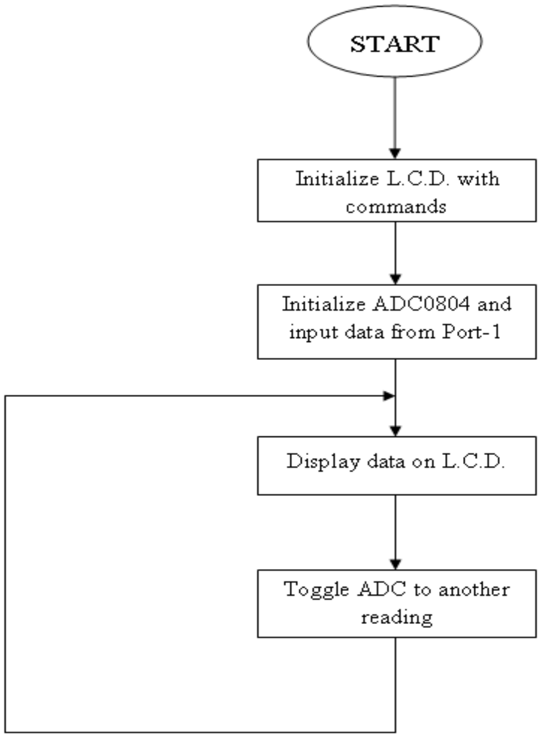

Fig5:Flow chart for software development

V. RESULTS

Different soil samples were taken and water was constantly added with a difference of 10ml and moisture content was found by the formula:
Total Volume= (Volume of water volume of sand)
Moisture percentage by volume= (Volume of water/Total volume*100)
Analog voltage was taken from 5th pin of LM 2907 and formula for calculating analog voltage is:

where R1=10ohm&&C=10µF

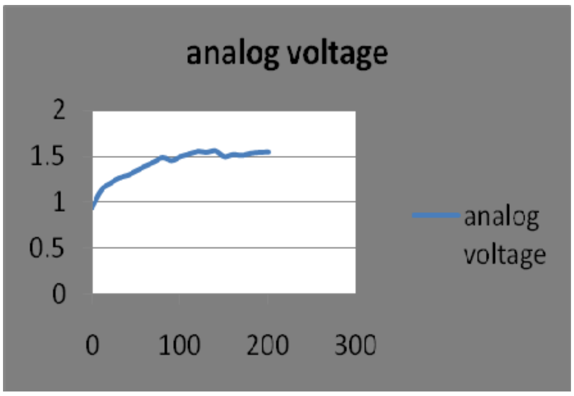

Fig.6: Relation between amount of water (ml) and analog voltage (Volts)

Capacitance was found out from the formula:

$$Vout = fin * Vcc * R1 * C \quad (2)$$

where R1=100K and f_{in} was found to be 5.96KHz.

$$C=V_{out}/5.96KHz\times9\times100K \quad (3)$$

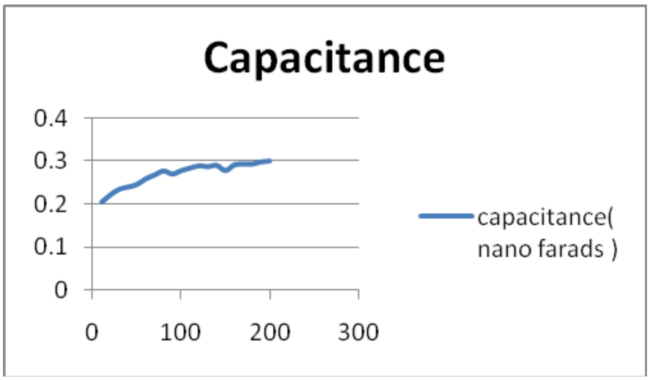

Fig7: Relation between amount of Water (mL) & Capacitance (Nano Farads)

It was clearly observed that for sandy soil 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.

VI .CONCLUSION

In this paper design and implementation of a microcontroller based soil moistures sensor has been discussed and analysis of variation of capacitance and analog voltage with addition of water in soil. It has been observed that both capacitance and analog voltage both follow a linear pattern with the addition of water and attain a constant value after a particular value. This sensor is capable of monitoring soil moisture automatically reducing labour time in irrigation. The instrument is also applicable in monitoring in infiltration rate, drainage and use of crop water. Further modification can be done in the sensor by incorporating the hardware in the wooden encapsulation provided at the top of the sensor by making it completely portable and easy to handle .Considering aspect of marketing LCD display could also be incorporated on the top of wooden box to make it more appealing. This sensor can prove to be highly beneficial in the agricultural belt specifically in small scale cultivation where majority revenue is generated from crop productivity because of its efficiency and cost effective nature. However, for real field large scale applicability a more rigid structure needs to be designed.

REFERENCES

[1] Yousuke Yamamoto, Yoshihito Yamamoto ,Akira Ogawa"; sensors, 2002 Proceedings of IEEE Vol.1," Novel Soil-Moisture-Sensors Applying Thermal Characteristics of Soil and Water,"

[2] Nurzharina Binti Abd. Karim, Idris Bin Ismail"Soil Moisture Detection Using Electrical Capacitance Tomography (ECT) Sensor", 2011 IEEE International Conference on Imaging Systems and Techniques,Date 17-18 May 2011.

[3] Robert Neal Dean, Senior Member, IEEE, Aditi Kiran Rane, Michael E. Baginski, Senior Member, IEEE, Jonathan Richard, Zane Hartzog, and David J. Elton," A Capacitive Fringing Field Sensor Design for Moisture Measurement Based on Printed Circuit Board Technology"; IEEE Transactions On Instrumentation And Measurement, Vol. 61, No. 4, April 2012.

[4] Q. Smit B.J.P. Mortimer J. Tapson ,"General Purpose Self-Tuning Capacitance Sensor";IEEE Instrumentation Measurement Technology Conference St. Paul, Minnesota, USA May 18-21, 1998

[5] Planningcommission.gov.in/data/datatable/data_2110/table_38planning commission of India.

[6] Heather McNairn, Member, IEEE, Amine Merzouki, Anna Pacheco, and John Fitzmaurice,"Monitoring Soil Moisture to Support Risk Reduction for the Agriculture Sector Usin RADARSAT-2"; IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing, Vol. 5, No. 3, June 2011.

[7] TexasinstrumentLM2907_N,LM2917_N,SNAS555C_June2000, revisedMarch2013