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Design and construction of a moisture level detector for Nigerian soil conditions

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ABSTRACT

This moisture level detector has two alternative power sources (3W, 11.5V solar panel and 9V battery) which supply voltages to the system and then regulated by a 7805IC voltage regulator to 5V required by a programmable hardware (microcontroller) with embedded analog digital converter (ADC). The microcontroller receives information from the probe (sensor) inserted into the soil, processes the information and displays the output on a Liquid Crystal Display (LCD) within few seconds. The moisture contents of four soil samples A, B, C and D (respectively clay soil, loamy soil, sandy soil and silt soil) obtained from different locations were determined using this detector. Samples A, B, C and D respectively showed moisture percentages of 85%, 71%, 43% and 21%. From the obtained results, sample A showed that the moisture level is above average, sample B showed that the moisture level is just average, sample C and D showed that the moisture levels are respectively below average and poor. From the obtained result, clay soil retained more water than other soil samples due to its high water holding capacity. The moisture level detector performed at an efficiency of 85%.

Introduction

Over the past decades, environmental monitoring has become increasingly important. Environmental factors such as climate change, gradual decrease in water resources, and threatened habitats are driving the need to monitor the environment and implement better policies to protect it. Monitoring soil moisture conditions provide necessary facts for the protection and understanding of local and regional water resources. Irrigation of crops represents about 90% of water used throughout the world. To maximize profits, irrigation water must be applied on a schedule for most efficient use of water and energy. Monitoring soil moisture in the root zone of crops will optimize irrigation. Optimizing irrigation scheduling increases crop yields, saves water, protect local water resources from runoff, save energy costs, saves fertilizer costs and increases farm profitability.

Erosion that results from changes in land use causes serious damages to properties and natural water systems. To understand the causes of erosion and make predictions about when and where erosion occurs, rainfall, sediment and soil moisture need be recorded. Monitoring of soil moisture is thus, an important input parameter into erosion prediction models. In recent years, climate change modelers have identified soil as a major source and a major sink for green house gases. As the fields are tilled in preparation for planting, organic soils become more available to micro-organisms. Each year, tons of green house gases are released into the atmosphere from agricultural tillage. Cultivating crops without tilling the field keep the carbon in the soil and reduce the emission of green house gases from the soil. Increase in the organic component of the soil increases the soil's water holding capacity. Thus, to measure and record the soil moisture content, data from soil sensors are used to characterize the effectiveness of number of tillage method and estimate the rate of green house production in specific soils.

To optimize irrigation schedule, characterize the hydrological requirements of biomass crops, understand the causes of erosion and make predictions about when and where erosion occurs, characterize the effectiveness of number of tillage method and estimate the rate of greenhouse gas production in certain soils, the ability to monitor the moisture content of the soil is the major aspect of developing good programs for water management. The tendency to over irrigate or under irrigate results due to the unavailability of information about the soil moisture status down the soil profile. The result of over irrigation results in production problems associated with water logging which leads to the recharge of underlying aquifers, leaching of plant nutrients in the soil, increased effect of plant disease and reduction in daily plant water use; affects soil – water – crop relationship, thereby creating ecological imbalance, depletion of oxygen in the root zone and increase saturation of carbon dioxide which adversely affects beneficial micro-organisms (Michael and Ojha, 2003).

Under irrigation on the other hand, results in stress being placed upon the water uptake mechanism of the plant for maintenance of transpiration rate. Research has shown that stem elongation in Canjanuscajan declined at a linear rate after 10% of available water was utilized by the plant until elongation was 40% of the maximum rate as the plant approach wilting point (Ludlow et al., 1989). Moisture content of the soil is a major factor determining the growth of plant (Allison et al., 1983). Currently, there are various methods for determining soil water content. Such methods include gravimetric, tensiometers, gypsum block, neutron probe etc.

Larry (1993) stated that gravimetric method of estimating soil moisture content is simple and accurate but however, a destructive technique that requires heating of soil sample and successive samples at the same location and depth are

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impossible. This method is however, not practical for scheduling irrigation because it takes a full day to dry the sample and in sandy soil that dries quickly; irrigation may be needed before the results of the measurement are obtained (Robert et al., 1996). Tensiometers according to Michael (2008), fundamentally act in a similar manner to a plant root measuring the force that plants have to exert to obtain moisture from the soil. It works on the principle that a partial vacuum is created in a closed chamber when water moves out through a porous ceramic cup to the surrounding soil. Tensiometers may give faulty readings if they are not serviced regularly. They require pre-installation, careful installation and also need multiple sites (Larry, 1993).

According to Gardener (1986), gypsum block do not measure the moisture content of soil at low potential (from 0 to -100kPa) well. Its operating range is suited from about -100kPa to -1500kPa as the soil dries. Gypsum blocks however, dissolves over a period of time, generally lasting for two or three irrigation seasons in good condition. Large errors up to 100% can occur due to slow equilibrium of blocks with the actual soil potential; the dependence of the resistance on the block temperature; the effect of hysteresis on calibration of block and actual contact with the soil; and blocked pores by fine material such as silt or clay particles (White and Zegelin, 1994). The sensitivity of the gypsum block is also affected by salts in the soil as well as the concentrations of fertilizer and varies with the type of soil (Michael and Ojha, 2003). The instrument is usually calibrated for the soil in which it is to be used by adopting the soil sampling method and it has short block life and requires multiple sites (Larry, 1993).

The neutron probe technique is based on the measurement of fast moving neutrons generated from a radioactive source called Americium 241/Beryllium that are thermalized (slowed) in the soil by elastic collision with existing hydrogen ion (H^+) present in the soil. The returning thermalized neutron causes an electrical pulse which charges the wire and this pulse is counted by the rate meter. The number of pulse counted over an interval of time is linearly related to the volumetric water content by a calibration curve (Larry, 1993). The rate meter is usually powered by a portable battery thus, limiting its use for a longer period (Michael, 2008). However, these methods for measuring soil moisture exist; they are referred to as indirect methods and differ in their ease of use, reliability, amount of labour required and cost. The basic requirements needed to measure accurately soil water content, is the ability to regularly obtain objective data (Gardener et al., 2001). Thus, the current trend is to build intelligent monitoring instrument that can emulate the sensory processing and decision making using computer integrated (CI) techniques in order to automate problem solving process in a dynamic fashion.

Materials and Method

Materials

Microcontroller (AT89C2501), Probe, Resistors (10K), Transistors (BC337), Read and Reset buttons, Crystal, Capacitors (10µF, 33pF), Lithium Battery (9V), 7805 IC (Voltage Regulator), Solar Panel, Diode (1N4007), Liquid Crystal Display (LCD) (2*16), Vero Board, Soldering Lead, Soldering Iron and Thermoplastic Casing.

Method

In order to choose the appropriate and cheapest method to adopt for the design, two things were considered.

(i) The processes that would be involved and the necessary technology required.

(ii) The availability of materials/components required for implementation.

The bottom- top approach method was used to realize the design. In this method, each section of the project was developed and tested first before the final coupling.

Design Procedure

System Design and Specification

The system design is divided into *the hardware sub-system*, *the software sub-system* and *the power supply system*. The power supply units consist of a solar panel with a peak power of 3W, output voltage of 11.5V, current output of 0.26A and a 9V lithium battery. The voltage supplied by the solar panel and the battery, is regulated by a 7805 IC voltage regulator to 5V required by the micro controller. The input unit consists of a probe which is inserted into the soil while the output unit is a 2*16 character Liquid Crystal Display (LCD) which displays the result in a digital form. A crystal-X used in the construction, determines the frequency of operation of the system while the 33pico-Farad (33pF) capacitors make for system stability.

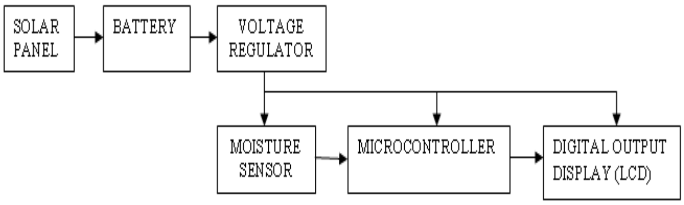


Figure 3.1: Block Diagram of the System

Hardware Subsystem

The hardware subsystem is made up of the input interface, the output interface and the control system (microcontroller).

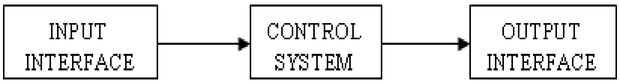


Figure 3.2: The Schematic Diagram of the Hardware Subsystem

Input interface

The input interface comprises the probe (moisture sensor), the micro-controller, transistors (BC 337), resistors (43K), a start button and an automatic reset button (R).

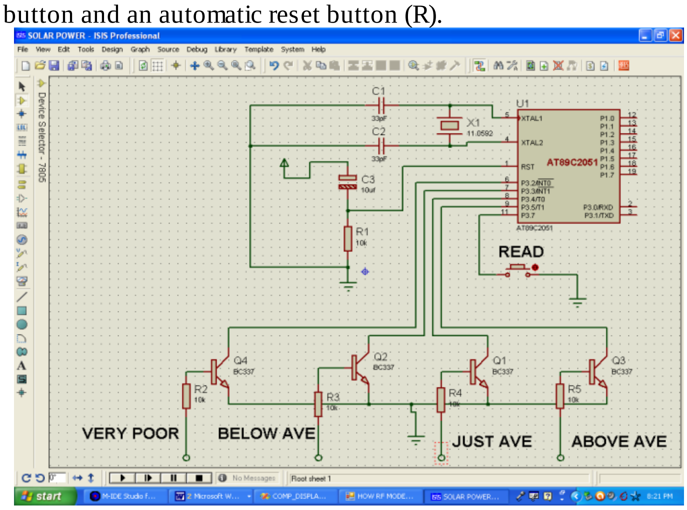


Figure 3.3: Circuit diagram of the interfacing of the input to the microcontroller

The probe which detects the presence of moisture in the soil, works based on the principle that water conducts electricity. The probe used in this project was constructed locally and has a length of 375mm. It was designed to detect moisture in four levels which are: *poor*, *Below Average*, *Just Average* and *Above Average*. The probe was also calibrated with respect to its length in terms of these four levels as shown in Table 3.1. The lower limits obtained from the calibration is then used to calculated the percentage of moisture in terms of its length, with respect to the four different levels.

Table 3.1: Calibration of probe for the different moisture levels on the basis of the lower and upper limits

Condition	Length of the Lower Limit from the Tip of the Probe (mm)	Length of the Upper Limit from the Tip of the Probe (mm)
Poor	80	112
Below Average	160	189
Just Average	239	268
Above Average	320	375

From the calibration of the probe on the basis of the lower limits, the moisture percentage for each level was converted to a base reasoning program, through the followings:

$$\%\text{ of moisture} = \frac{\text{Length of lower limit from the tip of the probe}}{\text{Total length of the probe}} \times 100\% \quad (3.1)$$

$$\text{Poor Level} = \frac{80}{375} \times 100\% = 21\%;$$

$$\text{Below Average Level} = \frac{160}{375} \times 100\% = 43\%;$$

$$\text{Just Average Level} = \frac{239}{375} \times 100\% = 71\%; \text{and}$$

$$\text{Above Average Level} = \frac{320}{375} \times 100\% = 85\%$$

The range of soil moisture with respect to the four moisture levels is given in Table 3.2:

Table 3.2: Percentage range of soil moisture with respect to the four moisture levels

Moisture Level	Range of Soil Moisture (%)
Poor	$\geq 21, < 43$
Below Average	$\geq 43, < 71$
Just Average	$\geq 71, < 85$
Above Average	$\geq 85, < 100$

Figure 3.4: Probe

The transistor used in the design is a BC 337 transistor. It was chosen considering the collector current I_C requirement through the coil for the micro-controller. The choice of the transistor determined the type of resistor used for the design of the system.

From Kirchhoff's voltage law,

$$V - V_b - V_{be} = 0 \quad (3.2)$$

$$\therefore V_b = V - V_{be}, \quad (3.3)$$

And $V_b = I_b R_b$ (3.4)

Where V_b is the base voltage, V_{be} is the base emitter on voltage, I_b the base current, R_b the base resistor. For silicon transistors, $V_{be} = 4V$, $V = V_{cc} = 5V$, where V_{cc} is the current from the 7805 voltage regulator

From Equation (3.3),

$$V_b = V - V_{be} = 5 - 4 = 1V$$

But

$$h_{fe} = \frac{I_c}{I_b} \quad (3.5)$$

Where I_C is the collector current = 20mA and h_{fe} is the emitter forward current which equal 200 typical. It is worthy to note that these values are constant for the AT89C2051 microcontroller as specified by the manufacturer (http://search.datasheetcatalog.net/key/AT89C2051).

From Equation (3.5),

$$I_b = \frac{I_c}{h_{fe}} \quad (3.6)$$

$$\therefore I_b = \frac{20 \times 10^{-3}}{200} = 1 \times 10^{-4} A$$

From Equation (3.4),

$$R_b = \frac{V_b}{I_b} \quad (3.7)$$

$$\therefore R_b = \frac{1}{1 \times 10^{-4}} = 10 \times 10^3 = 10K$$

$$\therefore R_b = R_1 = R_2 = R_3 = R_4 = R_5 = 10K$$

The start button as well as the automatic reset button (R) performs specific functions. On application of pressure on the start button, information is quickly sent from the probe to the microcontroller which processes and displays the output on the LCD. If the probe is not in contact with moisture, No Condition Detected would be displayed on the LCD. The start button also serves as the power button. The automatic reset button is an input and is active high (normally low). Upon applying a high pulse to this pin, the microcontroller will reset and terminate all activities. This is often referred to as a power on reset. In order for the RESET (RST) input to be effective, it must have a minimum duration of two machines cycles. RESET (RST) is set to 1second for every 12 tick (clock cycle) or oscillation (http://search.datasheetcatalog.net/key/AT89C2051). The time required for the effective input of the RESET (RST) was estimated using the equation below (Mazidi et al., (www.asadali.tk)):

$$\frac{1}{\text{Machine cycle frequency}} = \frac{\text{Value of crystal}}{\text{number of clocks per machine cycle}} \quad (3.8)$$

where value of crystal for AT89C2051 $= 11.0592\text{MHz} = 11.0592 \times 10^6\text{Hz}$

and number of clocks per machine cycle = 12

$$\therefore \frac{1}{\text{Machine cycle frequency}} = \frac{11.0592 \times 10^6}{12} = 921.6\text{kHz}$$

$$\therefore \text{One machine cycle}, t = \frac{1}{0.9216\text{kHz}} = \frac{1}{0.9216\text{Hz}} \times 10^{-3} = 1.085 \times 10^{-3}\text{s} = 1.085\mu s$$

But for effective input, the RESET (RST) must complete two machine cycles

$$\therefore \text{For two machine cycles}, t = 2 \times 1.085 = 2.17\mu s$$

The voltage charge in an RC circuit according to Theraja and Theraja (2008) is given by:

$$V_c = V\left(1 - e^{-t/\lambda}\right) \quad (3.9)$$

Where λ = time constant = RC

V_c = voltage discharged by C_3. Thus, the voltage across C_3 would be less than V_{cc} due to the discharging action of the capacitor.

Since $R = R_1 = 10K$, $t = 2.17\mu s$, $V = V_{cc} = 5V$, and $C_3 = 10\mu F$ which is the standard recommended for a RESET (RST) pin.

∴ From Equation (3.9),

$$V_c = V\left(1 - e^{-t/RC}\right) \quad (3.10)$$

$$\therefore V_c = 5\left(1 - e^{\frac{-2.17\times10^{-6}}{10\times10^{3}\times10\times10^{-6}}}\right)$$

$$= 5\left(1 - e^{\frac{-2.17\times10^{-6}}{10^{5}\times10^{-6}}}\right) = 5\left(1 - e^{\frac{-2.17\times10^{-6}}{10^{-1}}}\right)$$

$$= 5\left(1 - e^{-2.17\times10^{-6+1}}\right) = 5\left(1 - e^{-2.17\times10^{-5}}\right)$$

$$= 5(1 - 0.9999783) = 5(2.17\times10^{-5})$$

$$= 5\times2.17\times10^{-5} = 1.085\times10^{-4} = 0.0001085V$$

∴ The voltage discharged by the capacitor $V_c = 0.0001085V$

. Since the capacitor discharges a voltage of 0.0001085V, therefore the voltage flowing across the capacitor is given as:

$$\text{Voltage across capacitor} = V_{cc} - V_c \quad (3.11)$$

$$= 5 - 0.0001085 = 4.9998915V$$

From the result above, it can be seen that the voltage discharges by the capacitor is very small therefore, a capacitor of $10\mu F$ is recommended for use.

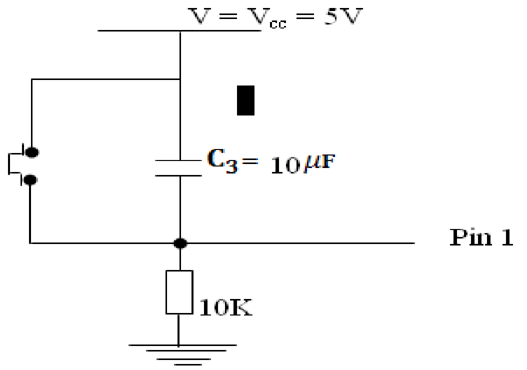


Figure 3.5: The schematic diagram of the automatic reset button

Control system

The control system which is the microcontroller is a low-voltage and high-performance integrated circuit (IC), which provides a highly-flexible and cost-effective solution to many embedded control applications. It has low power consumption, serial communication capability, fast response time and 20pins input/output ports.

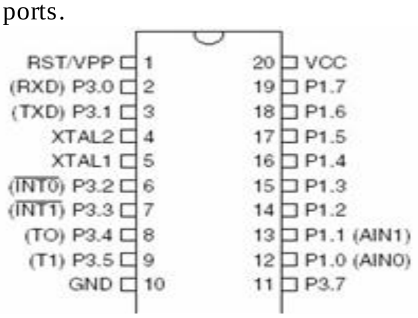


Figure 3.6: Port description of microcontroller

A crystal oscillator was connected to the XTAL1 and XTAL2 ports of the microcontroller. These ports are the input and output port respectively. The crystal oscillator which is an electronic circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency is commonly used to keep track of time to provide a stable clock signal for digital integrated circuits. The crystal oscillator determines the frequency of operation of the system while the 33pF capacitor makes for system stability during operation. The capacitor (33pF) is recommended by the manufacturer of the microcontroller. From the datasheet, C_1, C_2 ranges between 30pF ± 10pF for the crystal (http://search.datasheetcatalog.net/key/AT89C2051).

Output interface

The output interface shows the interfacing of the LCD to the micro-controller. The LCD requires 5V for its functionality. It is used to interact with the outside world. The LCD used is a 2*16 display i.e. 16 character line and 2 row. It has three control lines as well as eight input/output lines for the data bus. The three control lines are referred to as EN, RS and RW. The EN line is called "enable". It is used to tell the LCD that data is being sent to it. The RS line is the "register select." When RS is low (0), the data is to be treated as a command (such as clear screen, position cursor).When RS is high (1), the data being sent is text data which should be displayed on the screen. The RW line is the "write select." When RS is low (0), the information on the data bus is being written to the LCD. When RW is high (1), the program is effectively querying the LCD. The data bus consists of 8 lines which are referred to as DB0 to DB7.

Table 3.3: Pins description of LCD

No	Symbol	Function
1	VSS	Ground (0v)
2	VDD	Supply Voltage Logic (+5V or 3.3V)
3	VO	Contrast Adjustment
4	RS	Register Select
5	RW	Write Select
6	EN	Enable Signal
7	DB0	Data Bus
8	DB1	Data Bus
9	DB2	Data Bus
10	DB3	Data Bus
11	DB4	Data Bus
12	DB5	Data Bus
13	DB6	Data Bus
14	DB7	Data Bus
15	LED_A	LED Power Supply +(5V)
16	LED_K	LED Power Supply (0V)

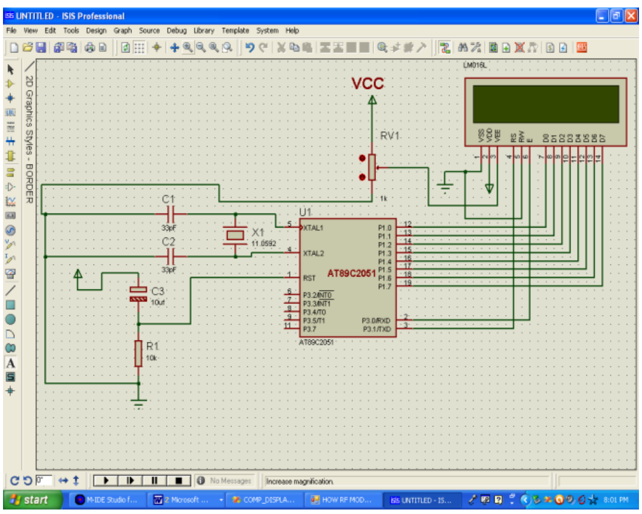


Figure 3.7: Circuit diagram of the interfacing of the output unit to the microcontroller

Software Subsystem

The software subsystem consist the flow chart for initializing the command for the microcontroller and the programming of the microcontroller. The microcontroller was programmed using assembly language with the aid of a programming kit.

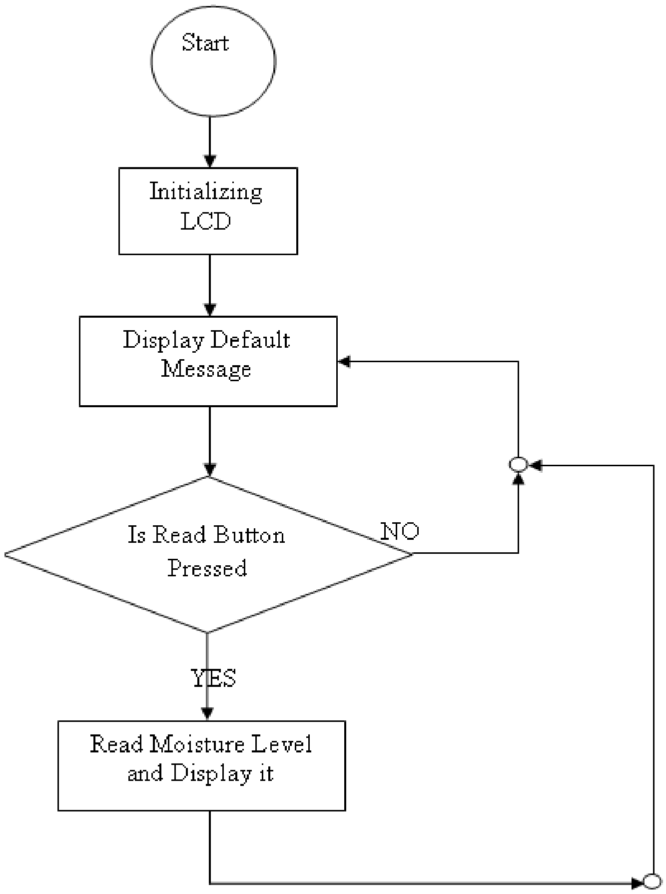


Figure 3.8: Flow chart of the software subsystem

Power Supply System

The power supply of the system according to the schematic block diagram consists of a solar panel, a 9V lithium battery and a voltage regulator.

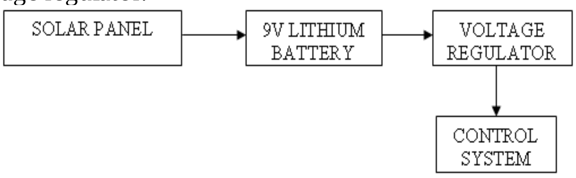


Figure 3.9: Schematic diagram of the power supply system

The solar panel has a peak power of 3W, an output voltage of 11.5V and an output current of 0.26A. During peak sunshine, the solar panel powers the system. At this point, the energy of the battery remained conserved. The battery however, powers the system during no sunshine.

Figure 3.10: Solar panel

The diode 1N4007 rectifies the voltages from the solar panel (11.5V) and the battery (9V) in the presence of a voltage regulator (7805) to 5V required by the micro-controller. The choice of the diode is because of its high current capability and low forward voltage drop. It also has peak current rating of 30A, which is well above the 20mA of the microcontroller. It is forward bias and allows the flow of current in one direction.

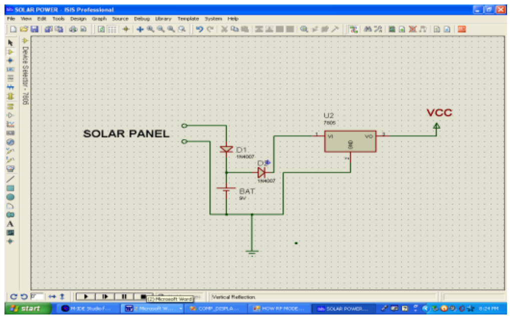


Figure 3.11: Circuit diagram of the power supply

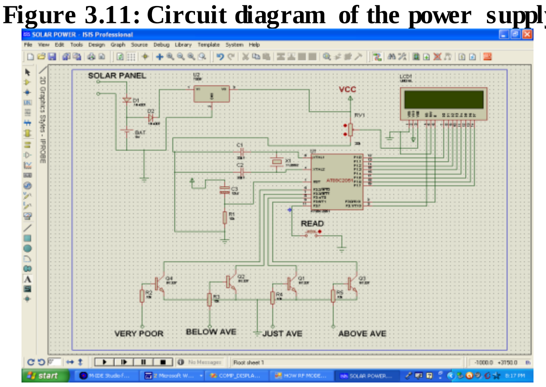


Figure 3.12: The overall circuit diagram

Results And Discussion

To determine the workability of the newly designed and constructed detector, four soil samples A, B, C and D respectively, where obtained from different locations in a sack and tested for their moisture content. Sample A contained clay soil, Sample B contained loamy soil; Sample C contained silt soil and Sample D sandy soil. The tests were carried out by inserting the probe into the different sacks containing the different samples and pressing the read button to read the moisture content of each soil sample. The results obtained are given in Table 4.1.

Table 4.1: Test result on the four different soil samples

Sample	Tested Soil Type	Moisture Level Displayed on LCD	Percentage of Soil Moisture (%)
A	Clay	Above Average	85
B	Loamy	Just Average	71
C	Silty	Below Average	43
D	Sandy	Poor	21

From the result, it is obvious that clay soil, when tested for the moisture content, showed a very high moisture level (i.e. 85%). This is so because clay soil has high water holding capacity. Loamy soil indicated a moisture content of 71%, showing that its moisture level is just average, while silt and sandy soil displayed moisture percentages of 43% and 21% respectively.

The efficiency of the detector was calculated using:

$$\text{Efficiency } \eta = \frac{\text{Total length of probe} - \text{Length of insulated portion of probe}}{\text{Total length of probe}} \times 100\% \quad (4.1)$$

$$\text{Total length of probe} = 375\text{mm}$$

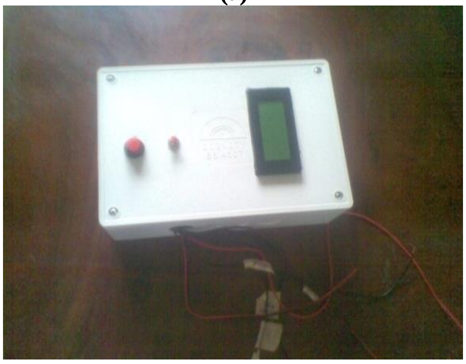
$$\text{Length of insulated portion of probe} = 56mm$$

$$\therefore \eta = \frac{375\text{mm} - 56\text{mm}}{375\text{mm}} \times 100$$

$$= \frac{319\text{mm}}{375\text{mm}} \times 100 = 0.850 \times 100 = 85\%$$

The detector performed at an efficiency of 85%.

(a)



(b)

Figure 4.1a and b: Image of electrical connection of system and top view of the system casing respectively

Conclusion

The moisture level detector proffers an efficient method for determining moisture contents of soils. The device employed simple programming of a hardware which processes information about soil moisture from the probe and displays the result on a Liquid Crystal Display (LCD). It is neither based on chemical kit nor requires complicated setting before doing the measurement. The system is highly reliable, user friendly and can be placed in the soil for a long time since the system generates its own power via solar energy, more so for Nigerian conditions.

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