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Original Article

Modification and Performance Evaluation of Time-Based Controller Smart Irrigation System

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Abstract *- Farmers around the world face the problem of meeting crops' water needs, especially those farmers in third-world countries. It is from this global problem that the inspiration to modify a time-based smart irrigation system that will not only optimize water resources management but also significantly reduce the required manpower for crop production was drawn. This system consists of three blocks, which include input or data collecting block, controller data processing block and output/actuator block. From the experiments, the following observation was made: from a particular soil sample with constant percentage of soil dryness 100%, it can be seen that the soil moisture content increases with an increase in irrigation, for instance, clay, loamy and sandy soils at 100% soil dryness, the soil moisture content increase from 8.7% to 26.5%, 8.6% to 26.0% and 7.4% to 12.3% respectively for irrigation time of 5, 1o and 15secs. Also, taking a constant irrigation time of 15secs for instance, and testing soil samples of different dryness of 100%,75%,50%,25% were decreased in soil moisture content after irrigation of 15secs to 26.5%,20.2%,13.4%,7.5% of clay, 26%,20%,13%,7.3% of loamy and 12.3%,11.7%,9.8%,7.3% of sandy soils respectively. With this, it could be seen that clay soil showed a higher tendency to hold more moisture than loamy and sandy soil, and sandy soil holds the least moisture compared to other soil types.*

Keywords *- Modification, Performance evaluation, Time-Based, Smart, Irrigation.*

1. Introduction

Water is required for crop and other energy production, industrial construction, as well as living beings and ecosystem needs. The agriculture sector uses the total extracted freshwater, whereas 19% is used by the industrial sector, and the rest is used by the domestic segment. However, water can be seen as an important requirement in the agriculture sector for posterity food security [6].

Therefore, increased demands for water by domestic industrial sectors and environmental quality have generated a challenge to every sector to minimize the water consumption in the farm and sustain the food requirement [5]. There is a need for urgent strategy creation, which will be dependent on science and technology for the sustainability of water. Industrialists and researchers are working to build efficient and economical automatic systems to control water usage in order to reduce much of the wastage [7].

The water requirement of soil depends on the soil properties such as moisture and temperature of the soil. Effective irrigation can influence the entire growth process and improve automation in irrigation systems by using modern technology, which provides better irrigation management. [5]

Non-automatic irrigation methods are cheap to handle because highly technical equipment is not needed. But they required high labour inputs. A simple technique for manual irrigation is the use of watering cans, which are found in semi-urban agriculture areas around big cities in some African countries [1]. The other water-efficient type of manual irrigation method is small-scale drip irrigation, which is very expensive. Other than these methods mentioned, there are some other manual irrigation methods that are less expensive and easy to use. These manual irrigations mentioned are easy to operate, very compatible and high-performance [4].

Automatic irrigation to crops can reduce costs, monitor the quantity of water, save labour and be convenient to farmers. Therefore, it is better if a steady water source is available for automatic irrigation systems for continuity of operation. It is preferred to have a water reservoir at full capacity or a big source of fresh water that will not be affected by weather variations [8,9].

Monthly reference evapotranspiration (ETr) increased from January to July, gradually decreasing to reach its minimum in December. Monthly ETr was 5.79, 10.94, and 4.80 mm/day in January, July, and December, respectively. There was a positive association between the change in ETr and the change in air temperature. The difference in ETr was negatively associated with the change in humidity. This is also reflected in the Crop water requirements for field crops, which ranged from 820 to 3406 mm for test crops [1].

Since the economy of many countries depends on agriculture, there is a need to achieve the best quality in terms of agriculture. It is important to focus on the appropriate amount of water supply and a suitable schedule for the irrigation of crops [16, 17]. The majority of the farmers around the world do not measure up to these standards, especially those living in poverty. The stability of a country's economy depends on agriculture. To achieve the best quality, it is important to focus on some characteristics, such as the appropriate amount of water supply and a suitable schedule for the irrigation of crops, which should be considered [2]. The agricultural sector has great importance, so it is necessary to solve all the problems of water scarcity by optimizing the use of available water for irrigation by developing a smart, time-based, intelligent irrigation system. A time-based automated irrigation system has several positive effects. Once installed, the water distribution in fields or small-scale gardens is easier and does not have to be permanently controlled by an operator.

Automatic irrigation to plants was classified into four methods of applications, which include;

- Empirical method and without any kind of ongoing measurement
- Monitoring soil moisture method
- Estimating water use from weather data
- Tracking the condition of the crop, usually referred to as crop water stress.

The project combines water use estimation from weather data and tracking the crop's condition, usually called crop water stress. It provides an amount of water required by each crop irrespective of weather conditions and also monitors the condition of the crop as it grows for water stress [12]

ATmega-328 sensor is basically an Advanced Virtual RISC (AVR) microcontroller used for the work. It supports the data up to eight (8) bits. ATmega-328 has 32KB internal built-in memory. This microcontroller has a lot of other characteristics (*Atmega328 Datasheet*). Atmega 328 has 1KB Electrically Erasable Programmable Read Only Memory (EEPROM). This property shows that if the electric supply supplied to the microcontroller is removed, even then, it can store the data and can provide results after providing it with the electric supply.

Moreover, ATmega-328 has 2KB Static Random Access Memory. ATmega 328 has several different features, making it the most popular device in today's market. These features consist of advanced RISC architecture, good performance, low power consumption, real timer counter having separate oscillator, 6 PWM pins, programmable Serial USART [13,14] Extremely high-tech solutions also exist using GIS and satellites to automatically measure the water need of each crop parcel and optimize the irrigation system, and this is similar to this project, but modified by adding a system that allows humidity and temperature of the soil to be set as variables to suit specific crop type. The modified machine that uses timed feedback control to measure the soil moisture and turn on the valve on demands in regular or preset intervals has not been fabricated. The machine that ensures adequate crop production water and optimizes water resources management by conserving water has not been constructed. This work aims to modify and evaluate the performance of a time-based irrigation controller, which will ensure adequate water for crops and conserve water.

2. Materials and Methods

The time-based irrigation system has detailed requirements for the materials/components used in constructing it. Several circuits are put together to ensure the proper working of this machine, and it is divided into units, which include the power supply unit, control unit (Microcontroller), sensor and actuator unit and display unit.

2.1. Design Calculations

The 16:1 turn ratio transformer was chosen to step down the voltage from 240V mains voltage to 15V for the power supply. The full wave rectifier circuit converted 15V alternate current to direct current. The circuit was designed using the formulas below:

$$\text{y} = \frac{\sqrt{\text{Vdv}^2 - \text{Vav}^2}}{\text{Vdv}} \qquad [13] \qquad (1)$$

V_b =2 x V_{dv}

V_p=1.414 x V_s

V_m=V_p - V_b

V_{av}=2/π x V_m

V_d= V_m/1.414

The output ripple is proportional to the output current and related to the filtering capacity, as shown in the formulas below.

$$\text{Q} = 1 \text{ x t} = \text{C x } dV_p \qquad [15] \qquad (2)$$

t = 2 x f

dV_p= V_r

V_r= y x V_p

$$2 \text{ x } 1 \text{ x f} = \text{C x } V_r \qquad [15] \qquad (3)$$

$$\text{C} = \frac{1}{2} \text{ x f } V_r \qquad [10] \qquad (4)$$

V_d= diode forward conduction voltage drop

V_b = voltage drop across the diode bridge at any instant

Vs =transformer secondary voltage

V_p =peak value of transformer secondary voltage

V_m=average value DC voltage from the diode

V_{av}=average value of the diode bridge output voltage
V_{dv}=ms value of output DC voltage of the diode bridge
y = ripple factor for a full wave rectification process using a diode bridge
V_r = ripple voltage
C = capacitance value
I = required output current from the power supply circuit
f =frequency of the AC mains supply voltage
Q =charge on filtering capacitor

The 220µF capacitor is still acceptable and the closest value that further reduces the ripple in the output voltage.

An µA7812 12 V regulator is used to regulate the output capacity to its capability and limit the current to prevent excessive current and power loss as heat in the circuit. The current picks up by applying 0.1µF noise filter capacitors to reduce the external or environmental noise voltages. The setup ensures that the circuit produces pure direct currents of 12voltage. To evaluate the moisture content of the soil as a percentage of the dry soil weight, the following formula was used;

$$MC = \frac{W_2 - W_1}{W_1} \text{ X } 100\% \qquad [3] \qquad (5)$$

Where:
W_1 = weight of dried soil (g)
W_2 = weight of moist soil (g)
MC = soil moisture content in percentage

2.2. Implementation and System Building Blocks

This project design includes several functional blocks, namely, the acquisition block, visual display block, microcontroller block for automatic and semi-automatic functional mode switch and monitoring block.

2.2.1. Acquisition Block

This block consists of one soil moisture sensor, which takes the data from the soil. It depends on the soil's moisture level whether to send high or low voltage to the microcontroller to show that it is wet or dry. When the soil is wet, it will send a low output voltage, whereas when it is dry, it will send a high output voltage. The acquisition block also has humidity and temperature sensors. These sensors are linked to an atmega328 microcontroller.

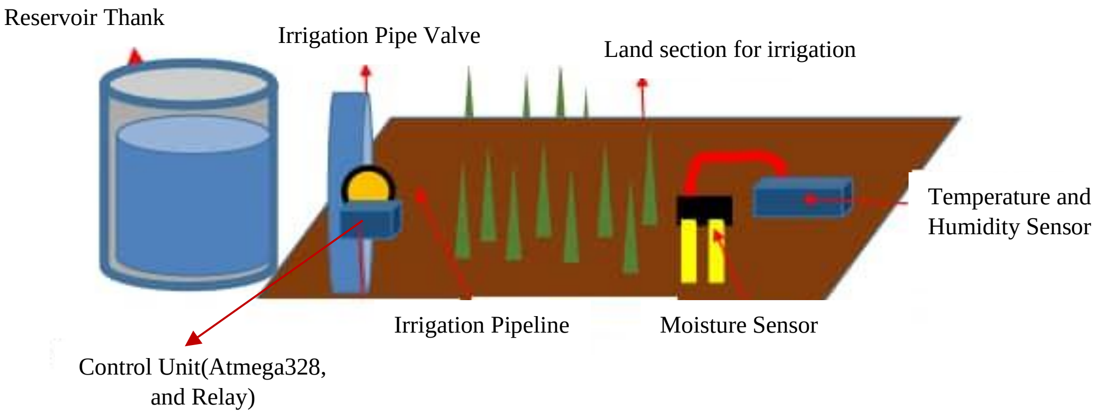

Fig. 1 3D Model of system building Blocks and setup

2.2.2. Visual Display Unit

This block includes an LCD display, which is used to monitor the level of soil moisture by showing the status of the moisture on the screen. When the soil is dry or wet and vice versa, in addition, it also shows the pump status, which is on or off, in which users will know the current pump status.

2.2.3. Microcontroller block for Automatic and semi-automatic Functionality Modes

This block includes the automated watering function of the system. The automated function consists of two main controlling hardware, which are the relay module and the DC watering pump. The relay is an automatic electric switch that uses an electromagnet to move the switch from OFF to ON or vice versa. The switch controls the electric signal that passes through the water valve. When the moisture level is below the threshold level (when the soil is dry), Atmega328 sends a signal to the relay module to automatically open the path for the electricity to pass through the water valve to water the plant. After the system detects a sufficient water level in the soil (wet soil detected), the relay will close the path for electricity. Thus, the water valve will be closed immediately.

The semi-automatic mode allows parameters like temperature irrigation time and delay between successive sprinkles to be preset according to the crop requirements. This allows the system to be adapted for irrigation in a wider range of crop types.

All the hardware will be assembled and linked to Atmega328, the microcontroller used to control all the hardware attached to it to achieve the desired function.

2.3. Working Principle

This system consists of three blocks, which include input or data collecting block, controller data processing block and output/actuator block. The input devices, which are sensors, collect environmental data like temperature, humidity and soil moisture and then transfer the data to the control unit. The control unit then asses these data and makes decisions according to preset instructions encoded on them through the firmware. This causes the valve to open for irrigation or close to stop irrigation, as the case may depend on the instruction given by the control unit. Simultaneously, the LCD receives the signal and displays the system's status at every point in time. The sensors act as input devices, collect environmental data, and the data are sent to the microcontroller. The microcontroller analyses the received data for decision-making before sending a command to the relay and/or LCD display for output actions as needed (opening or closing of the irrigation valves). This is shown in the functionality flow chart below.

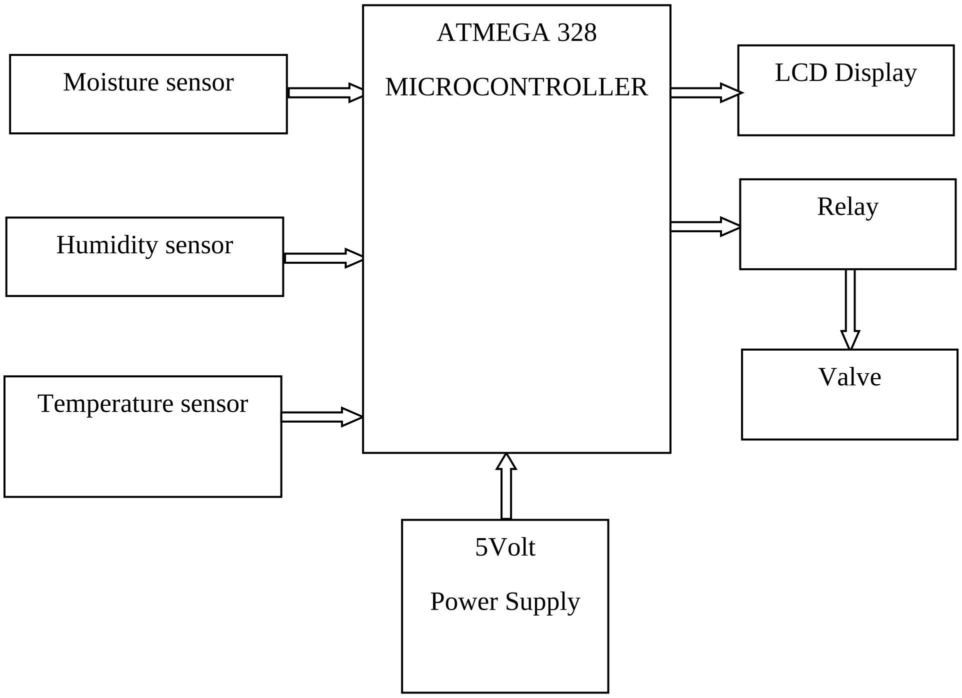

Fig. 2 functionality flow chart of automated irrigation system

The 16 by 2 Liquid crystal display and light emitting diode are used in this unit to physically show the various momentary status of the irrigation system [7]. A liquid-crystal display (LCD) or electronically modulated optical device is also a flat panel that displays the light-modulating properties of liquid crystals. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome.

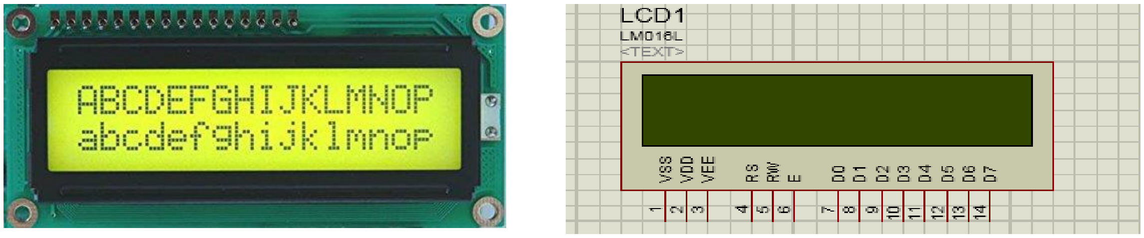

Fig. 3 16 by2 Liquid crystal display

The smoothed voltage is controlled in this stage to maintain a constant range. For this project, two voltage regulators, LM7805 and LM7812, which regulate the voltage to 5V and 12V, respectively, were used. 5V to power the microcontroller, Light Emitting Diodes (LED), Liquid crystal display (LCD) and 12V to power the relay.

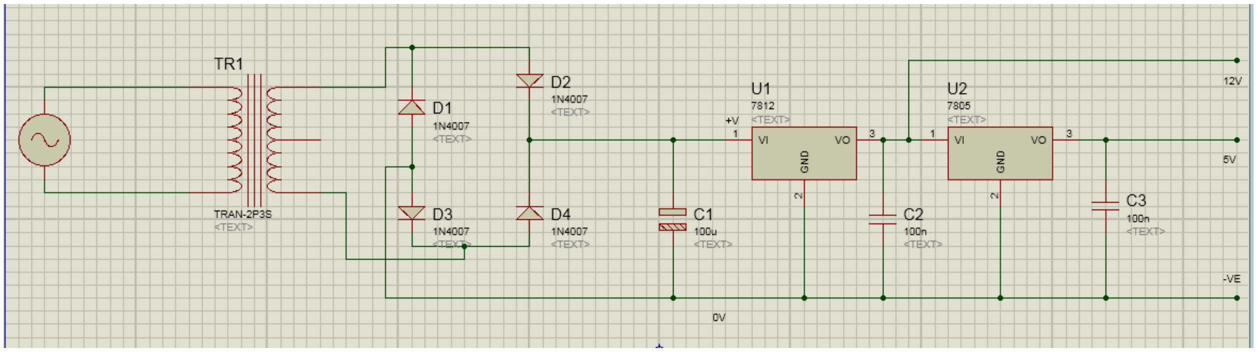

Fig. 4 Power unit diagram

2.4. Sensor and Actuator Unit

This unit is responsible for detecting the moisture, temperature and humidity of the soil to the microcontroller [12]. The sensor used here is a moist sensor, DHT11 (temperature and humidity sensor) and the solenoid valve (actuator) to control the opening and closing of water from the reservoir.

2.4.1. Solenoid Valve

An electromechanically operated solenoid valve differs in character from the electric current it uses. The strength of the magnetic field they generate, the mechanism they use to regulate the fluid, and the type and characteristics of fluid they control.

2.4.2. Soil Moisture Sensor

The soil moisture sensor consists of two probes that are used to measure the volumetric content of water [12]. The two probes allow the current to pass through the soil, which gives the resistance value to measure the moisture.

3. Results and Discussion

The system prototype was tested using three different soil types (clay, loamy, and sandy), and each soil type has five samples at various degrees of dryness in percentage (100, 75, 50, 25, and 0) [assumption: Soil water absorption and distribution is uniform with time]. The soil (clay, loamy, and sandy) was measured in an equal amount of 300 grams with 100% dryness to form one sample and water was added in steps to form the remaining four samples. The experimental box was divided into three samples to contain 300 grams of soil. The moisture sensor probes, whose length is 4 inches, are placed in the soil sample. Information such as moisture content at different irrigation times of the system was taken and recorded for different soil types at varied humidity and temperature, as shown in the tables below. Other indices measured for each soil type were temperature and humidity for irrigation durations of 5 seconds, 10 seconds and 15 seconds. The results of these sets of tests are presented in Tables 1 to 3.

Table 1. System performance on soil-water absorption for loamy soil

Soil Sample	Soil Dryness(%)	Irrigation Time(S)	Soil Moisture Content(%)	Temperature(^{0}C)	Humidity (%)
C1	100	15	26.0	30.0	86
C2	100	10	17.3	31.0	86
C3	100	5	8.6	32.0	86
C1	75	15	20.0	28.0	88
C2	75	10	13.5	28.5	88
C3	75	5	6.4	30.0	88
C1	50	15	13.0	26.0	91
C2	50	10	7.8	27.5	91
C3	50	5	4.5	28.0	91
C1	25	15	7.3	25.9	93
C2	25	10	4.4	26.6	93
C3	25	5	2.2	27.0	93
C1	0	15	3.2	24.8	95
C2	0	10	2.5	25.5	95
C3	0	5	1.0	26.0	95

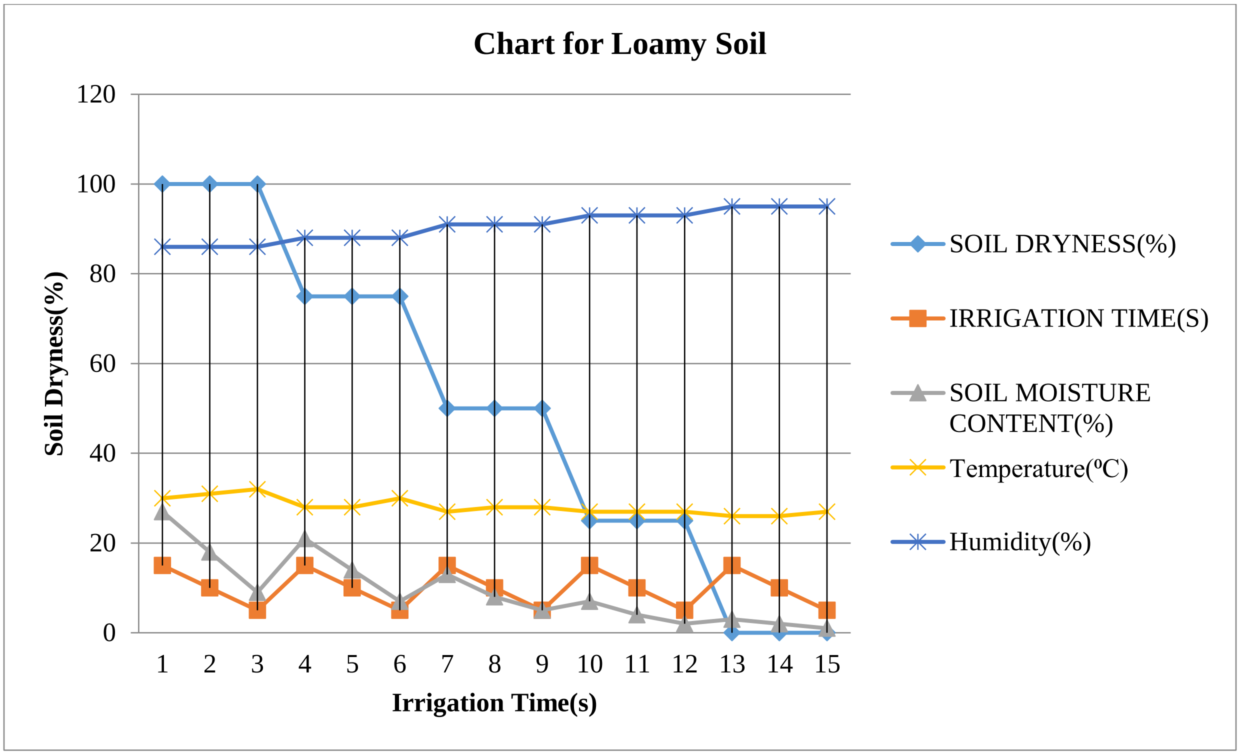

Fig. 5 Graph of irrigation time against soil dryness for loamy soil.

Table. 2 System performance on soil water absorption for clay soil

Soil Sample	Soil Dryness (%)	Irrigation Time(s)	Soil Moisture Content (%)	Temperature(^{0}C)	Humidity(%)
C1	100	15	26.5	31	86
C2	100	10	17.5	31	86
C3	100	5	8.7	31	86
C1	75	15	20.2	29	88
C2	75	10	13.8	29	88
C3	75	5	7.1	29	88
C1	50	15	13.4	28	91
C2	50	10	8.2	28	91
C3	50	5	5.3	29	91
C1	25	15	7.5	27	93
C2	25	10	4.4	27	93
C3	25	5	2.5	27	93
C1	0	15	3.8	26	95
C2	0	10	2.2	26	95
C3	0	5	1.5	26	95

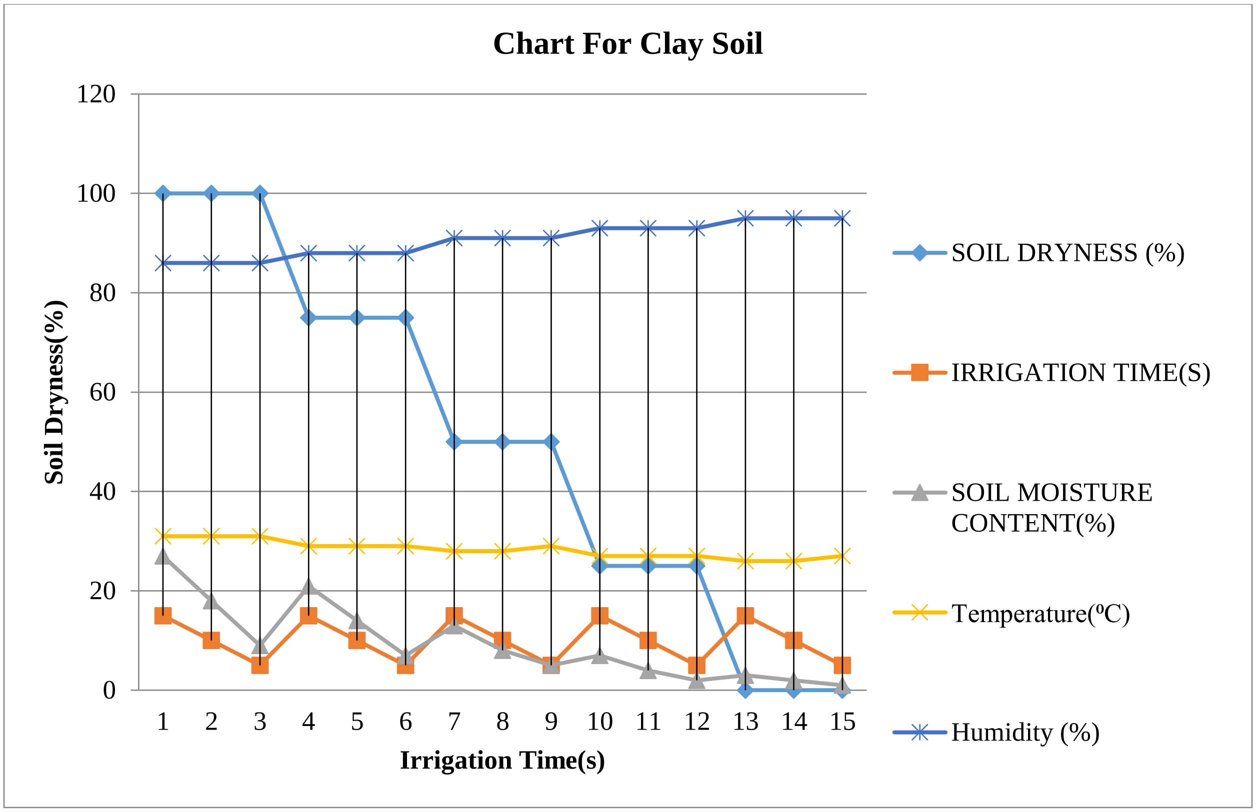

Fig. 6 Graph of irrigation time against soil dryness for Clay soil.

Table 3. System performance on soil absorption for sandy soil

Soil Sample	Soil Dryness(%)	Irrigation Time(S)	Soil Moisture Content(%)	Temperature(ºC)	Humidity(%)
C1	100	15	12.3	31.3	86
C2	100	10	10.3	32.1	86
C3	100	5	7.4	33.2	86
C1	75	15	11.7	28.9	88
C2	75	10	11.4	30.2	88
C3	75	5	7.5	30.9	88
C1	50	15	9.8	28.4	91
C2	50	10	7.3	27.4	91
C3	50	5	5.2	29.2	91
C1	25	15	7.3	28.3	93
C2	25	10	4.3	28.6	93
C3	25	5	2.5	29.0	93
C1	0	15	3.9	26.8	95
C2	0	10	2.7	27.2	95
C3	0	5	1.2	28,0	95

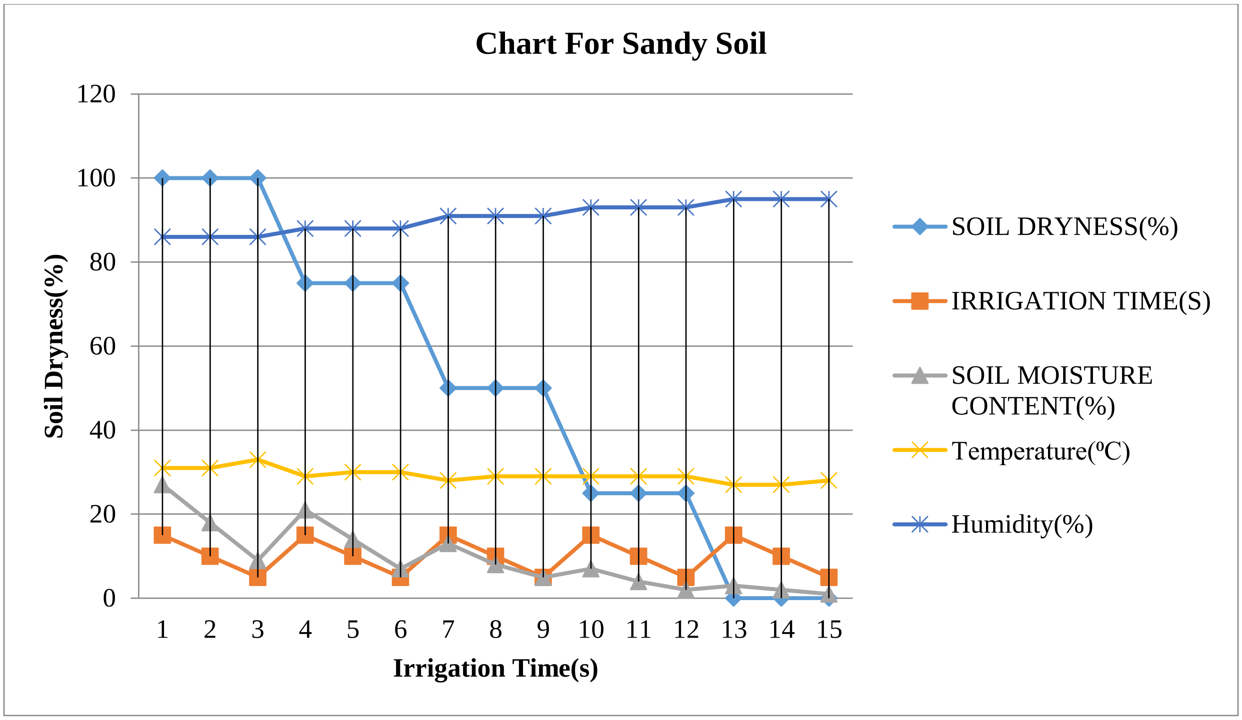

Fig. 7 Graph of irrigation time against soil dryness for Sandy soil

3.1. Comparative Analysis using Results from all soil Types

Comparative analysis was done for three soils and soil surface characteristics, namely moisture content, surface temperature and humidity for clay, loamy and sandy soil samples at different soil dryness and irrigation times. The table values were used to plot the percentage soil moisture content comparative graph.

Table 4. Comparative system performance on soil absorption for all soil types

Soil Sample	Soil Dryness(%)	Irrigation Time(S)	Clay Soil Moisture Content(%)	Loamy Soil Moisture Content(%)	Sandy Soil Moisture Content(%)
C1	100	15	26.5	26.0	12.3
C2	100	10	17.5	17.3	10.3
C3	100	5	8.7	8.6	7.4
C1	75	15	20.2	20.0	11.7
C2	75	10	13.8	13.5	11.4
C3	75	5	7.1	6.4	7.5
C1	50	15	13.4	13.0	9.8
C2	50	10	8.2	7.8	7.3
C3	50	5	5.3	4.5	5.2
C1	25	15	7.3	7.3	7.3
C2	25	10	4.4	4.4	4.3
C3	25	5	2.5	2.2	2.5
C1	0	15	3.8	3.2	3.9
C2	0	10	2.2	2.5	2.7
C3	0	5	1.5	1.0	1.2

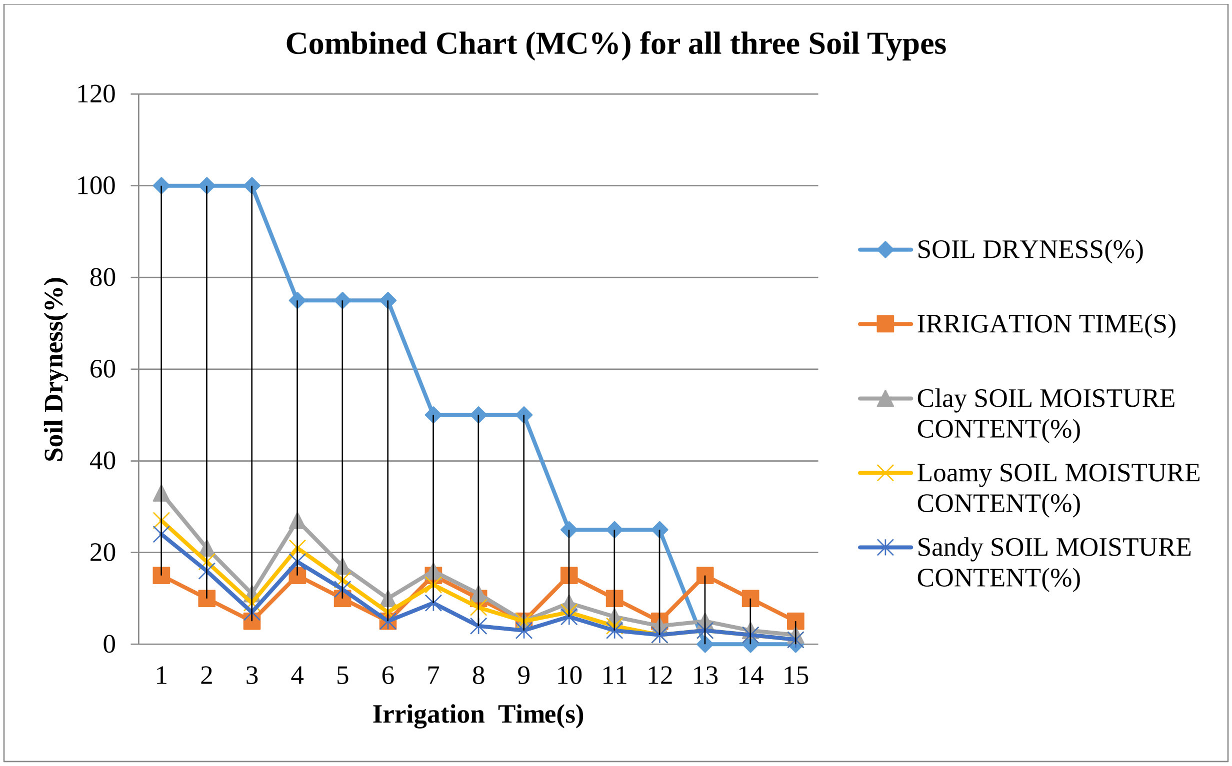

Fig. 8 Comparative graph of irrigation time against soil dryness for the three soil types

4. Discussion

Tables 1 to 3 above represent loamy, clay and sandy soils and the obtained test values are plotted as shown in figures 5 to 7. Soil moisture, temperature and humidity are plotted against varied irrigation times of 5, 10 and 15 seconds for each of the soil samples having varied dryness of 100, 75, 50, 25, and 0 percent accordingly. It was shown from the graphs that, in general, while the soil surface temperature and irrigation time decrease with an increase in humidity led to a drastic decrease in the moisture content of the soils. However, for longer periods of irrigation, it was observed that the change in temperature and humidity will keep decreasing the moisture content of the soil until it becomes constant after a saturated point is reached. At this saturation point, further irrigation will no longer affect either the temperature or humidity, rather observing water wastage [2]. It was also observed that at constant soil dryness, the humidity remains constant, but soil moisture content increases with an increase in irrigation time and decreases the soil temperature in loamy soil samples.

The results also showed that the humidity and temperatures remain constant at constant soil dryness, but soil moisture content increases with an increase in irrigation time in clay soil samples.

The results of sandy soil samples showed that with constant soil dryness and humidity, soil moisture content increases with an increase in irrigation time and decreases the temperature of the soil, as stated by Sanddeep and Deepali (2017).

From the graph (figure 8), it can be seen that the behavior of the percentage moisture content is very similar for all the soil types, namely Clay, Loamy and Sandy soil. However, Clay soil shows a higher tendency to hold more moisture than loamy and sandy soil, keeping other variables constant, according to Flörke et al. (2013). Also, Sandy soil holds the least moisture compared to other soil types. These discoveries can be useful in choosing soil type for a particular crop production depending on the water requirements and absorption capability of the particular crop. It will also help farmers decide when to use sprinkler, drip, surface or sub-surface irrigation methods for crop production.

5. Conclusion

The modified machine uses timed feedback control to measure the soil moisture and turn the valve on demand in regular or preset intervals. Compared to the existing works in this area of study, it can be concluded that this work has added a great deal of improvement to automated irrigation systems by adding the (ability to configure) semi-automated mode, which allows the farmer to set both irrigation duration (valve closure delay) and irrigation interval, thereby adopting the system for a wide range of crop types with varied water requirements.

For example, the system can be configured to meet the water needs of cucumber or cabbage with high water requirements; it can also be configured for sweet corn and lettuce, which have much lower water requirements. This can be achieved simply by adjusting the irrigation timer (valve closure delay) and the irrigation interval. All these are available in the semi-automated mode of the system. This will not only ensure adequate water for crop production, but it will also optimize water resources management by minimizing water wastage.

The system is modified and designed to be adaptable for a wide range of crop types, hence the semi-automated mode of operation where the farmer can set irrigation duration and interval according to the crop water requirements.

It was concluded that the behavior of the percentage moisture content of the soils is very similar for all three soil types. However, Clay soil shows a higher tendency to retain more moisture than loamy and sandy soil at constant temperatures, humidity and increased irrigation time. Also, Sandy soil retains the least moisture compared to other soil types. This system proves to be economically important in improving irrigation for agricultural practices, water conservation, and time of water requirement for different soils and crops. Following the importance of this system and the solution it provides to the major global challenges in global agriculture, It will be very beneficial if funding is provided not only to commercialize this system but also to subsidize the cost further and make the system available to our indigenous farmers.

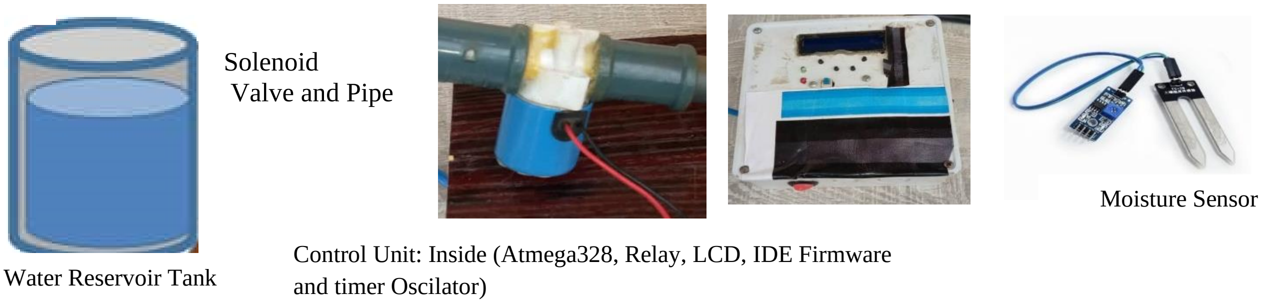

Fig. 9 Components view of automated irrigation system

Fig. 10 Finished time-based automated irrigation system

1. Soil Sample
2. Soil Moisture Sensor
3. Pipe
4. Reservoir Tank
5. Solenoid Valve
6. LCD (Liquid Crystal Display)

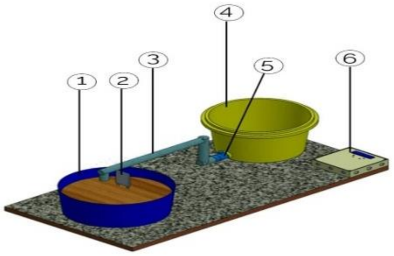

Fig. 11 Isometric View Time-Based Automated Irrigation System

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