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ORIGINAL RESEARCH ARTICLE

DESIGN AND IMPLEMENTATION OF INTERNET OF THINGS BASED IRRIGATION SYSTEM

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ABSTRACT

This work considered the design and implementation of an Internet of things (IoT) based irrigation system that encourages efficient and optimal use of water management practice. The proposed IoT based irrigation system promotes user acknowledgment practice on farmlands by monitoring the soil moisture value and other environmental parameters. This system, which is based on IoT, stores the sensor data, and the water pump can be monitored via the internet using a ThingSpeak channel. Using a micro-controller which coordinates system activities, a wireless fidelity (WIFI) module which transmits the sensed data to the cloud, a motor driver which controls the pump, a digital temperature and humidity (DHT)11 sensor which monitors environmental parameters, and a YL-69 soil moisture sensor, an IoT based irrigation system is implemented. Results obtained showed that the system irrigates the soil based on the defined threshold value of the soil moisture in order to promote efficient and optimal utilization of water management practice. Additionally, farmers can monitor the irrigation processes remotely from a ThingSpeak channel, which gives a graphical representation of the soil moisture value, pump status, temperature and humidity value as well as the flow rate within the environment.

1.0 Introduction

Conventional irrigation system either results in over irrigated or under irrigated land as the water requirement by crops depend on the soil type, crops, and environmental parameters such as temperature and humidity. The growth and development of plants can be prevented due to scarcity of water. Similarly, excessive water has adverse effect on the growth of plants. Under conventional irrigation system, several parts of the irrigated field are either over irrigated or under irrigated due to variability in the water holding capacity of land, water infiltration, and water runoff. Over irrigated areas suffer from poor plant health due to increase in salinity, and excessive water replaces air in pores of the soil. Hence, roots of the plants do not get sufficient air which may lead to leaching. Similarly, under irrigated area suffer from water stress. Accordingly, efficient water management practice plays a key role in agriculture (Patel and Tope, 2016).

On the other hand, Internet of Things (IoT) represents a general concept for the ability of network devices to sense and collect data from the world around us, and then share that data across the internet where it can be processed and utilized for various interesting purposes (Rawal, 2017). IoT collect and process data from series of wireless sensors connected together. Wireless Sensor Networks (WSN) have been the subject of research in various domains over the past few years and deployed in numerous application areas (Roham, 2015). WSN is seen as one of the most promising contemporary technologies for bridging the real and virtual world thus, enabling them to interact. A WSN is composed of a number of sensor nodes which are usually deployed in a region to observe particular phenomena in a geospatial domain (Roham, 2015). Sensor nodes are small stand-alone embedded devices that are designed to perform specified simple computation and to send and receive data. They have, attached to them, a number of sensors gathering data from the local environment that is being monitored (Roham, 2015).

In general, various irrigation techniques to monitor and coordinate effective water management practices have been investigated. In particular, work done in Roham, (2015) proposed a system in agricultural field where various essential climatic factors are monitored for regulation of crop production. This model uses WSNs to trace down the local climatic condition parameters (such as carbon dioxide (CO_2), Temperature, and Humidity) at different locations. Al-omary et al. (2018) proposed a cloud based IoT smart garden monitoring and irrigation system using Arduino Uno. As outlined in Al-omary et al. (2018), the water requirement of a plant can be adjusted by monitoring the soil moisture. Measuring the soil moisture of the plant gives information about if the plant is ideally watered, over watered or under watered. The proposed system in Al-omary et al. (2018) monitors and maintains two quantities of the garden namely; the garden soil moisture content, and light intensity. This is done using soil moisture sensors and light intensity sensor, respectively. The monitored data is sent continuously to ThinkSpeak IoT cloud. In the cloud, the data gathered from the system is analyzed such that when a target threshold of soil moisture is reached, an action is sent accordingly from the cloud to the garden automatic watering system to irrigate the garden. In Al-omary et al. (2018), the Arduino Uno microcontroller is used to implement the system control unit, and IoT is used to keep the garden owner updated about the status of the sprinklers. On the other hand, Srivastava et al. (2018) designed a smart irrigation system that uses a pH sensor, water flow sensor, temperature sensor, and soil moisture sensor for measurement, and based on these measured sensor values, the Arduino microcontroller drives the servo motor and the pump. The Arduino receives the information and transmits with ESP8266 Wi- Fi module wirelessly to the website through the internet. The transmitted information is monitored and controlled using IoT. This enables the remote control mechanism through a secure internet web connection to the user. Users can control water pumps and sprinklers through the internet, and keep an eye on the reference values which will help the farmer increase production with quality crops. Alternatively, Anila et al. (2017) proposed an automated irrigation model for efficient water management and intruder detection system. In particular, soil parameters such as soil moisture, pH, humidity are measured and the pressure sensor as well as the sensed values are displayed on the liquid crystal display (LCD) screen. The intruder detection system is done with the help of passive infrared (PIR) sensor where intruders such as birds are repelled from entering into the field. Through the use of a global system for mobile communication (GSM) module, a communication link between the farmer and the field can be established. The current field status will be intimated to the farmer through short messaging system (SMS). The farmer can access the server about the field condition anytime, anywhere thereby reducing man power and time. A major drawback of the work done by Anila et al. (2017) is that it does not monitor soil nutrient nor forecast any weather parameter.

Various models, systems and methodologies for the irrigation of parcels have been developed. These models made use of an integrated system for automated irrigation management with an advanced novel routing protocol for WSNs, named equalized cluster head election routing Protocol (ECHERP) (Nikolidakis et al., 2015). The proposed system in Nikolidakis et al. (2015) aimed at efficiently managing water supply in cultivated fields in an automated way. The system takes into consideration the historical data and the change in the climate values to calculate the quantity of water that is needed for irrigation. In contrast to existing result, this work considers the novel design and implementation of an IoT based irrigation system that optimizes water management practice for crop production, and promote monitoring practice for user acknowledgment. In particular, this work involves the development of an automatic irrigation system which switches the pump motor ON/OFF on sensing the moisture content of the soil. The advantage of using this novel method is to reduce human intervention and still ensure proper irrigation. This design uses an 8051 series microcontroller which is programmed to receive the input signal of varying moisture condition of the soil through the sensing arrangement. This is achieved by using an operational amplifier (op-amp) as comparator which acts as interface between the sensing arrangement and the microcontroller. Using a microcontroller (Arduino Uno), Android application, sensors, Internet of things, WI-FI Module and Motor Driver to design the IoT based irrigation system, the proposed irrigation system helps in efficient management of water based on the soil moisture, temperature and humidity values, which invariably increases crop production, eliminate human labor as the smart irrigation works with sensors to switch the motor ON/OFF.

The block diagram of the IoT based irrigation system is shown in Figure 1. From the Figure, it is worth noting that the Arduino Uno is the decision maker of the system, it inspects the temperature and moisture value. Primarily, the threshold value of soil moisture must be well-defined. When the sensed moisture value goes below the threshold value, the controller checks for the temperature, and then the user is alerted through an app and irrigation commences only if the sensed soil moisture value is lower than the defined threshold value. This is because crops can withstand dry soil moisture condition if the temperature is moderate, and water use for irrigation would be conserved.

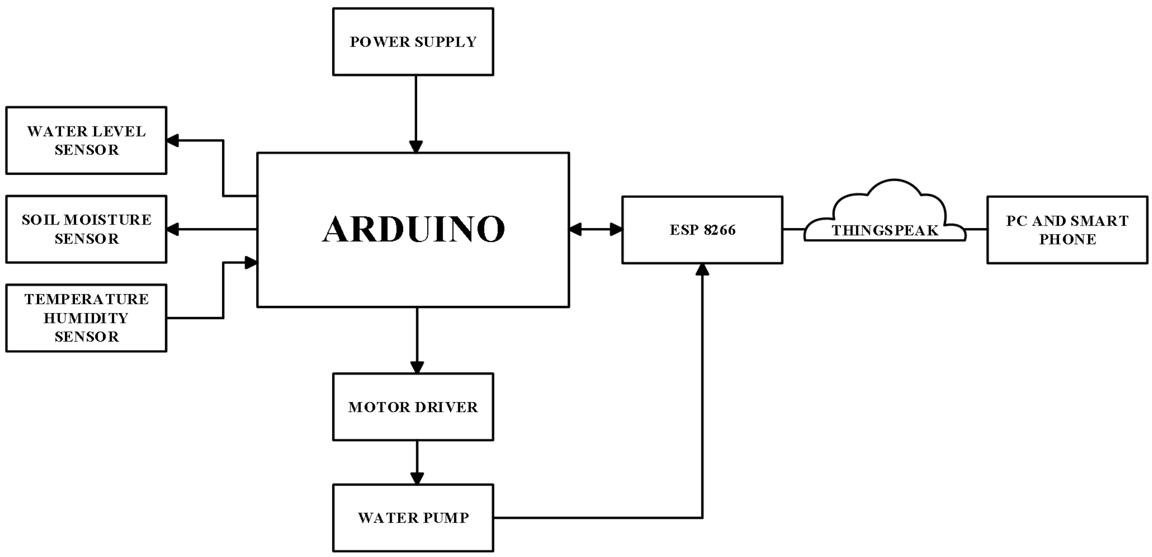

Figure 1: Block diagram of an IoT based Irrigation System

2.0 Materials and Methods

This section considers the system architecture, control and analysis unit as well as the IoT unit.

2.1 System Architecture

The system architecture consists of a simple circuit designed to control irrigation scheme on a farmland. It is designed to monitor, and control irrigation based on a response to real-time status of soil moisture. The system uses a Wi-Fi module to transmit information of the soil moisture, temperature, humidity, water level and pump status data to the cloud. The device performs the action of irrigation management by setting the threshold value of soil moisture. Accordingly, when the sensed moisture value goes below the threshold value, the controller checks for the temperature, the user is alerted, and irrigation will commence only if the sensed soil moisture value is lower than the defined threshold value.

2.2 Parameter Sensing Unit

The sensing unit in IoT consist of a group of sensors that acquire data from the physical world, followed by an embedded system that drives the physical system of the IoT application, the communication network, and the necessary protocol to send the data to the internet, and finally the data analysis. A typical block diagram representation of the process involved in the parameter sensing unit is shown in Figure 2.

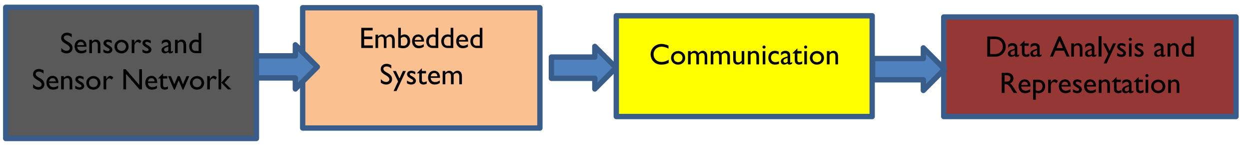

Figure 2: Parameter Sensing Unit

The sensors act as the interface between IoT applications and real physical world. They capture real data from the environment and the IoT system uses these data primarily for functionality. Sensor fusion leverages a microcontroller to fuse the individual data derived from sources to get a more accurate picture of the environment.

2.2.1 Soil Moisture Sensor

The soil moisture sensor as shown in Figure 3 is part of the system sensing unit and it is used to detect the soil moisture content. The soil moisture sensor measures the conductivity and resistivity of the soil. The voltage of the sensor output changes according to the soil water content. When the soil is wet, the output decreases, and when the soil is dry, the output increases. The sensor has an in-built potentiometer for sensitivity adjustment of the digital output, a power light emitting diode (LED) and a digital output LED. The soil moisture sensor considered in this work has a supply voltage of 3.3V to 5V. With this supply, it gives an output voltage of between 0V to 2.3V for the full range of complete dryness to submersion in water. Additionally, the maximum operating current is 15mA.

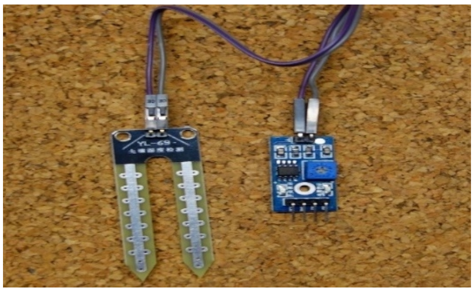

Figure 3: Soil moisture sensor

2.2.2 Digital Temperature and Humidity sensor (DHT11) Sensor

The DHT11 sensor as shown in Figure 4 is the temperature and humidity sensor. Its technology ensures a high dependability and adequate stability. This sensor includes a resistive element and a sense of wet negative temperature coefficient (NTC) temperature measuring devices. It has excellent quality, fast response, anti-interference ability, and high cost advantages. For determining humidity, the humidity sensing module is used. It has two electrodes with moisture holding substrate between them. When humidity changes, the conductivity of the substrate changes or the resistance between these electrodes' changes. This change in resistance is measured and processed by the integrated chip (IC) which makes it ready to be read by a microcontroller (Patel and Tope, 2016). To determine the temperature, these sensors make use of an NTC temperature sensor or a thermistor. A thermistor is a variable resistor that changes its resistance with a change in temperature. These sensors are made by sintering of semi conductive materials such as ceramics or polymers in order to deliver larger changes in the resistance with just small changes in temperature. NTC simply means that the resistance is inversely proportional to the temperature and vice versa (Patel and Tope, 2016).

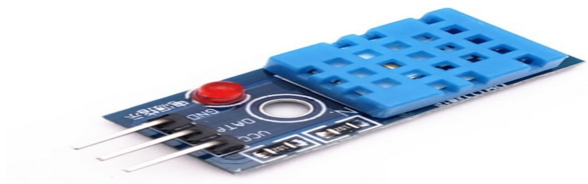

Figure 4: DHT11 Sensor

2.2.3 Water Flow Sensor

There are various methods of measuring water flow. The volumetric calculation includes the following;
Open channel flow with examples like; non pressurized water, river and canal.
Velocity Meter, which include the cross-sectional area and velocity of flow.
Large water flow.
Closed channel flow with example like; pressurized water, mechanical, gear, propeller type.
Hall effect with example like; water flow sensor.
The water flow sensor works with the principle of hall effect. In general, electromagnetic induction is the interaction of magnetism with magnetic conductors. The production of electric current in a magnetic field is proportional to the rate of change of magnetic flux. Hence, a magnetic field is generated when electric current passes through an electrical conductor. Hall-effect is the production voltage differences across an electric conductor, transverse of an electric current in the conductor and then applied perpendicularly to the magnetic field. Hall effect sensors consist primarily of a thin piece of rectangular semiconductor material (Patel and Tope, 2016). A typical water flow sensor is shown in Figure 5.

Figure 5: YF-S201 Water flow sensor

2.3 Control and Analysis Unit

This unit comprises of the Arduino microcontroller, L293D Motor driver, and a direct curren (DC) pump. The microcontroller is the control unit of the system. It is designed to monitor, and control irrigation based on a response to real-time status of the soil moisture. The system uses a Wi-Fi module to transmit information of the soil moisture, temperature, humidity, water level, and pump status data to the cloud.

2.3.1 ESP8266 WI-FI Module

This is a system on chip (SOC) and Wi-Fi networks that have software applications. The TCP/IP protocol is present in it and allows access to the Wi-Fi connection. It is capable of hosting an application or removing all Wi-Fi networking functions from any other application processor. Flash memory can start directly from an exterior move. Built-in cache memory will decrease memory requirement and support upgrade system performance. Additionally, it consists of the wireless internet access that understands the function of the Wi-Fi adapter, it can add to any microcontroller-based design, easy connection due to the SCI / SDIO interface. It is a sophisticated device with a fine processing system and storage capacity. It integrates with GPIO ports sensor and other application on specific machine. ESP8266 require little external circuits due to highly integrated chip. The ESP8266 system supports the following features namely: Bluetooth interference, and Energy saving VoIP applications. The module has 3.3 V input voltage. It has 8 pins namely; 1 TXD and 1 RXD, 2 GPIO pins i.e. GPIO 0 and GPIO 2, RST (Reset), VCC and GND (Ground). This module is inexpensive and transforms the IOT method into a specific version (Srivastava et-al, 2018). The ESP8266 Wi-Fi Module is shown in Figure 6.

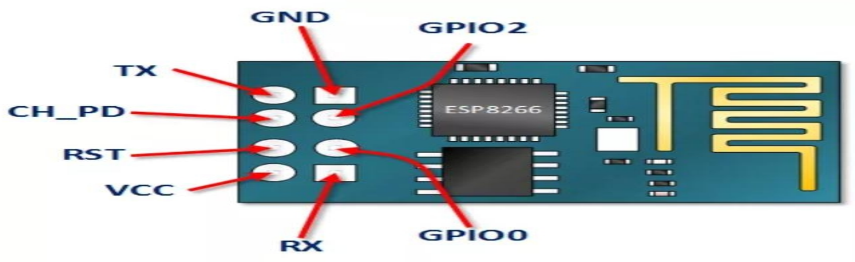

Figure 6: ESP8266 Wi-Fi Module

2.3.2 *Arduino Uno (Microcontroller)*

As shown in Figure 7, Arduino Uno is an open platform microcontroller; it is an electronic platform built on easy to use hardware. Arduino UNO is one of the most easily available low-cost Arduino board. The Arduino is an embedded system. Various pins on the Arduino are used to read or write values onto the system. Arduino holds the following advantage over other microcontrollers:

Inexpensive, cross platform (Linux, Mac OS, Windows), simple clear programming environment.

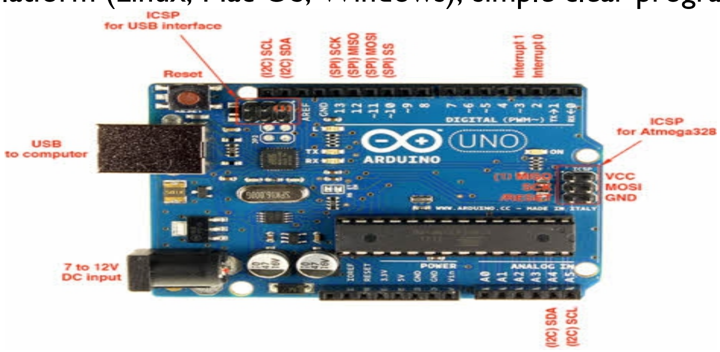

Figure 7: Arduino Uno

2.3.3 *Motor Driver*

A motor driver is an integrated circuit chip which is usually used to control motors. The motor driver used in this work is the L293D motor driver. It serves as an interface between the microcontroller and DC pump. The L293 is the simplest and inexpensive for low current motors as it provides the power required for running the pump. L293D convert the DC electrical power to mechanical power which in turn drives the DC pump. The shaft rotates at a particular revolution per minute (rpm) based on the voltage provided.

2.4 IoT Unit

The IoT unit is used for data storage and representation. It makes use of an IoT app called ThingSpeak. ThingSpeak app is an open data internet of things platform that allows a user to aggregate, visualize, collect and store data in the cloud by using the HTTP protocol over the internet via a local area network. It includes a channel where data to be stored are sent to. Each channel includes 8 field for any type of data, 3 location fields, and 1 status field. Once there is an available ThingSpeak channel, data can be sent to the channel. The ThingSpeak interface is shown in Figure 8.

Figure 8: ThingSpeak API Interface

2.4.1 *Gateway and Network Layer*

The network and gateway layer manages the connectivity of the network to the cloud. Nearly every IoT system needs some way to connect sensors/devices to the cloud so that data can be sent back-and-forth between them. IoT gateways can be essential in making this connection possible because gateways act as bridges between sensors/devices and the cloud. Many sensors/devices will "talk" to a gateway and the gateway will then take all that information and "talk" to the cloud.

2.4.2 *Application Layer*

IoT application layers cover "smart" environments/spaces in fields such as: Transportation, Building, City, Lifestyle, Retail, Agriculture, Factory, Supply chain, Emergency, Healthcare, User interaction, Culture and tourism, Environment and energy.

2.5 Circuit Schematics

The circuit schematics are shown in Tables 1 to 3.

Table 1: Circuit Connection of Wi-Fi Module, Moisture Sensor and L293D Motor Driver with Arduino Uno

Component 1	Pin	Pin Description		Pin	Pin Description	Component 2
Arduino Uno	A0	Analog Read	→	A0	Analog data	YL-38 Soil Moisture Sensor Module
	5V	Vcc		Vcc	-	
	GND	Ground		GND	Ground	
Arduino Uno	8	Digital I/O	→	Tx	Input 2	L293D Motor Driver connected to water pump
	GND	Digital I/O		Rx	Input 1	
	5V	3.3V		Vcc	Enable	
	GND	3.3V		CH_PD	Ground	
Arduino Uno	3 (Rx)	Receiver	→	Tx	Transmitter	ESP8266
	4 (Tx)	Transmitter		Rx	Receiver	
	3V3	3.3V		Vcc	-	
	3V3	3.3V		CH_PD	Chip Enable	
	GND	Ground		GND	Ground	

Table 2. Circuit Connection of DHT11 Sensor and Wi-Fi Module with Arduino Uno

Component 1	Pin	Pin Description		Pin	Pin Description	Component 2
Arduino Uno	10	Digital I/O	→	DATA	Serial Data	DHT11 Sensor
	5V	Vcc		Vcc	-	
	GND	Ground		GND	Ground	
Arduino Uno	3	Digital I/O	→	Tx	Transmitter	ESP8266
	4	Digital I/O		Rx	Receiver	
	3V3	3.3V		Vcc	-	
	3V3	3.3V		CH_PD	Chip Enable	
	GND	Ground		GND	Ground	

Table 3. Circuit Connection of YF-S201 Water Flow Sensor, L293D Motor Driver With Arduino Uno

Component 1	Pin	Pin Description		Pin	Pin Description	Component 2
Arduino Uno	2	Digital I/O	→	D0	Data	YF-S201 Water Flow Sensor
	5V	Vcc		Vcc	-	
	GND	Ground		GND	Ground	
Arduino Uno	3 (Rx)	Receiver	→	Tx	Transmitter	ESP8266
	4 (Tx)	Transmitter		Rx	Receiver	
	3V3	3.3V		Vcc	-	
	3V3	3.3V		CH_PD	Chip Enable	
	GND	Ground		GND	Ground	

The flow chat for the IoT based irrigation system is shown in Figure 9 while the system circuit design is shown in Figure 10.

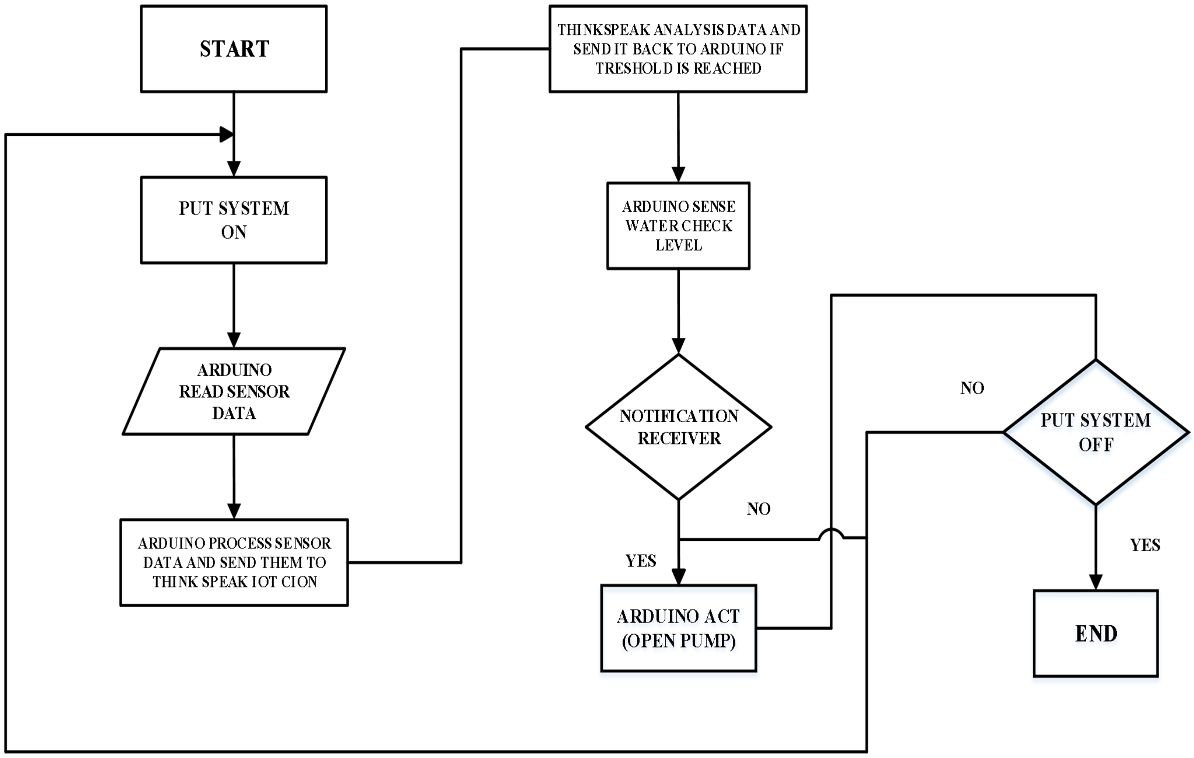

Figure 9: System Flowchart

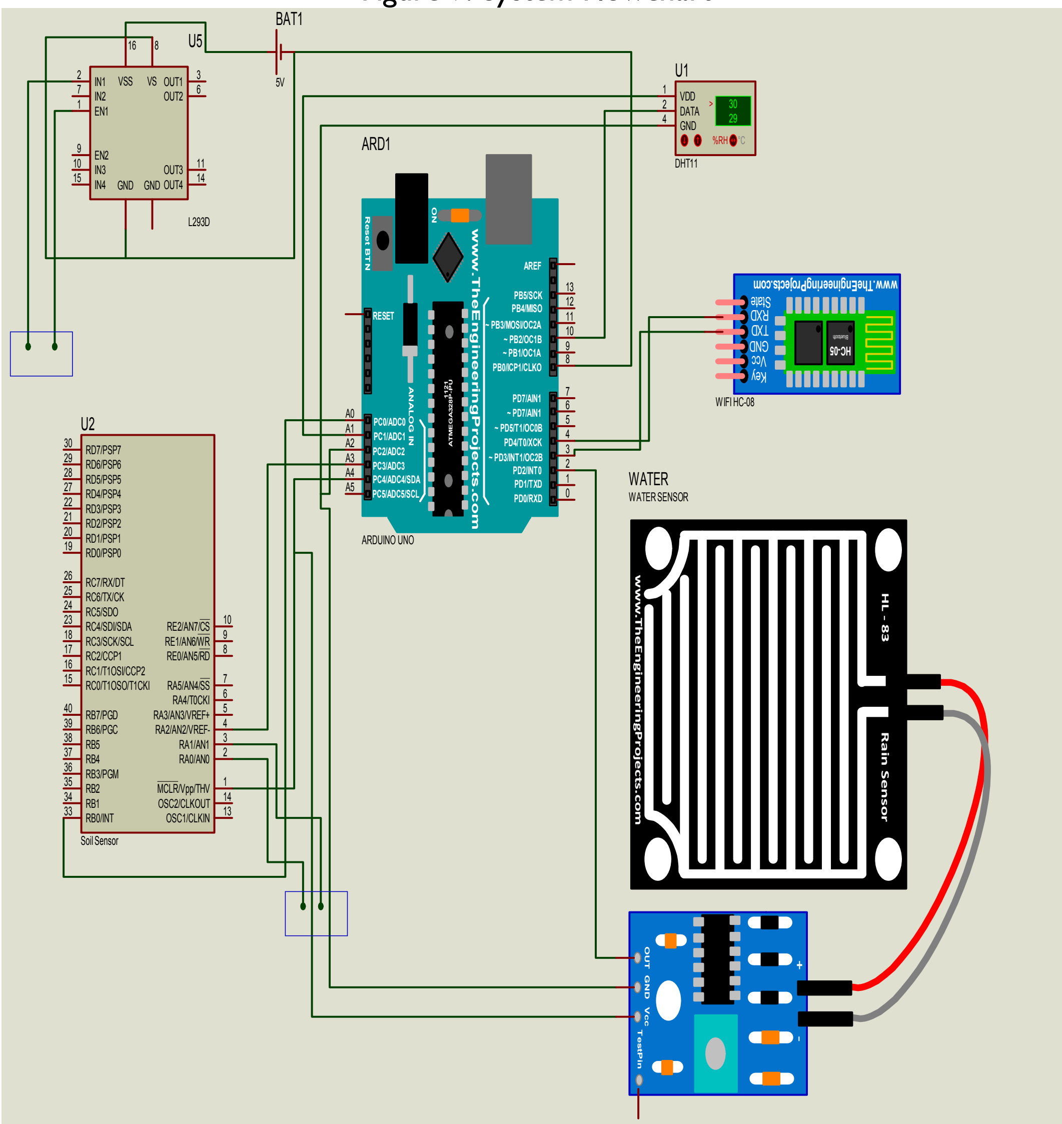

Figure 10: System Circuit Design

3.0 Results and Discussion

In this section, results and discussion, using the prototype of the proposed system as shown in Figure 11, are presented. In particular, the performance of the proposed system with regards to the soil sensor, temperature sensor, and humidity sensor is investigated. Accordingly, the overall aim of this section is to monitor the irrigation processes at different depth level of the probe in the soil.

The prototype of the proposed system comprises of the connection of the pump tube, water flow sensor, battery, L273D motor driver, Arduino Uno, ESP8266 WiFi module, soil sensor probe, DHT11 sensor and the soil moisture sensor.

Figure 11: Prototype system

To monitor the irrigation processes in loamy soil at different depth level of the probe, Table 4 presents the soil moisture value, temperature and humidity readings obtained using the prototype system in Figure 11.

Table 4: Readings from Prototype System of Soil moisture value, Temperature and Humidity of a Loamy soil.

Dry Soil value			
Depth (cm)	Soil Moisture Value (cm^3)	Temperature °C	Humidity %
4	11	27	93
3	9	27	94
2	6	27	95
1	4	27	95
Wet Soil Value			
4	62	27	94
3	60	27	94
2	56	27	94
1	46	27	94

Also, to monitor the irrigation processes in sandy soil at different depth level of the probe, Table 5 presents the soil moisture value, temperature and humidity readings obtained using the prototype system.

Table 5. Readings from Prototype System of Soil moisture value, Temperature and Humidity of a Sandy soil

Dry Soil Value			
Depth (cm)	Soil Moisture Value (cm^3)	Temperature °C	Humidity %
4	26	25	95
3	14	25	95
2	15	25	95
1	9	25	95
Wet Soil Value			
4	36	25	94
3	30	25	94
2	24	25	94
1	16	25	94

Using the ThingSpeak channel, the graphical representation of the sensor value at different time interval is shown in Figure 12.

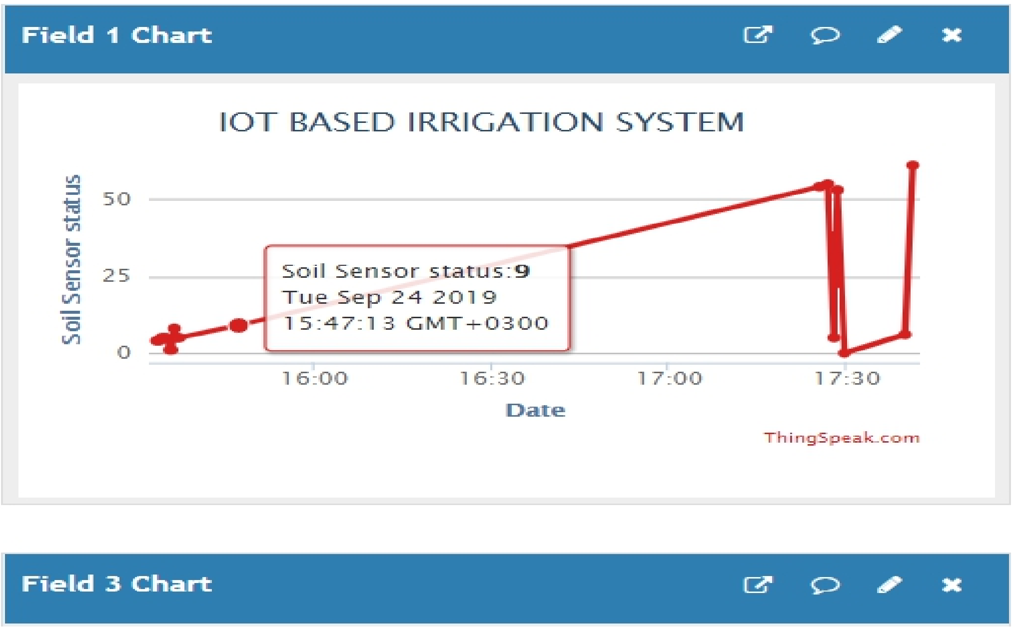

Figure 12: Soil Sensor Graph

Figure 12 shows the soil moisture value from the YL-69 at every 30 seconds interval of time which is transmitted to the ThingSpeak application. Irrigation takes place when the soil moisture value is below the defined threshold value of the soil. The value obtained from the soil moisture sensor enables the pump to switch ON and OFF. Thus, a farmer can remotely monitor the process of irrigation on the farm land.

4.0 Conclusion

The proposed system was designed to promote user acknowledgement practice for farmers. The system irrigates the soil based on the defined threshold value of the soil moisture in other to promote efficient and optimal application of water management practice. The farmers monitor the irrigation processes remotely from a ThingSpeak channel, which gives a graphical representation of the soil moisture value, pump status, temperature and humidity value within the environment and the flow rate. To increase the efficiency, effectiveness and reliability of the system, the following recommendation can be put into consideration; Due to inefficient power supply in Nigeria, a solar panel can be incorporated into the power supply unit, to provide alternative power source. Option of controlling the pump remotely can be giving to the farmers i.e. farmers can switch ON/OFF the pump during the process of irrigation. A crop surveillance unit can be incorporated to ensure crop safety from animal and man. The IoT unit can be improved by incorporating a GSM/GPRSSIM900A module to alert the farmers on the irrigation process via SMS, the GPRS can alert the farmers on the specific location on the land that needs to be irrigated. This would reduce human intervention in farming activities.

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