Enhancing Agricultural Production Using Wireless Sensor Network

C.A. NWABUEZE[1], S.A. AKANEME[2], R.I. NWABUEZE[3]
[1, 2]*Dept. of EEE, Chukwuemeka Odumegwu Ojukwu University, Uli Campus, Nigeria*
[3]*Dept. of EEE, Federal College of Education Technical Umunze, Nigeria*

Abstract* - Agriculture is an important sector for economic growth of any nation. Although the sector has a lot of challenges especially in developing countries, the application of Information and Communication Technology (ICT) with emphasis on wireless sensor network (WSN) indicates enhanced productivity. In this work, wireless sensor network was applied in conjunction with GSM technology and was used to monitor and control various environmental factors. The model monitored temperature, humidity, soil moisture and water level which were evaluated to activate or deactivate the designed irrigation system with set threshold values. The threshold value for soil moisture was 65% and temperature range was 0 - 35°C (F). For temperature within the threshold range and soil moisture sensor indicating Low, the irrigation pump will come ON and stays ON as long as the sensor reading is LOW. The irrigation pump goes OFF when the temperature is out of range even when the moisture level is LOW. Results obtained showed that the system has an advantage of robustness, reliability in data transmission, but energy consumption was one of the most challenging aspects of the networks at various stages. Consequently, network lifetime was shortened. Hence there is improved agricultural yield with effective and efficient application of wireless sensor network technology.

Indexed Terms - Wireless Sensor Networks, RF module, Moisture, Irrigation, Agriculture, and Temperature

I. INTRODUCTION

Water is a basic component of all known life on earth, hence water can both sustain life in correct quantities and threaten life when it is not available or in excess. If too much water is applied to crops, problems arise resulting in runoff, erosion, leaching, waste of water, threat to plant, etc. If inadequate water is applied, different problems equally arise such as turf burnout, hence the need to control the quantity of water supplied to crops. To this effect, mankind has continued to figure out how best to irrigate large areas of foliage through the use of automated irrigation systems. Irrigation control started as far back as the Egyptians along the River Nile about 5000 BC. The Chinese had irrigation by 5100 BC. By 5200 BC elaborate irrigation systems were widely used.

Now, irrigation is practiced in all parts of the world where rainfall does not provide enough ground moisture such as in Borno State, North-East, Nigeria. Irrigation is maintained from the time a crop is planted to the time of harvest. Among the early devices used for irrigation include, lifting water from streams to higher lying fields which is a bucket set on one end of counter weighted pole(Caruthers, 2008, Richard et al, 2006). The Archimedes screw used for the same purpose is a cylinder containing a wide threaded screw turned by hand. The cylinder was set on an incline with the stream, and as the screw was turned, it lifted water to a higher level.

Irrigation control system has witnessed tremendous growth from time to time in line with prevailing technological advancement. These trends are moving or changing from Mechanical to Electronic technology. The rapid development of sensing, computing and information technologies has introduced wireless sensor networks (WSN) as a new concept in the management and control of irrigation systems. The development of WSN in irrigation control has indeed turned the fortunes of irrigation especially in optimal water useage and increase in crop yield. Recently wireless sensor network has become the centre of attraction for researchers due to wide application areas with low or no cost of maintenance after deployment in a targeted area. Sensor nodes are expected to remain in operation for a long time without human intervention, making sensing and reporting automatically.

Definitely a smart farm system which deploys this technology will surely enhance agricultural production, which directly means increase in the gross domestic product (GDP) of the nation. The economic growth of every developing country of the world directly depends on this all important sector: agriculture. Also this sector is not without challenges like climate changes, drought, flooding to mention but a few. These result in poor yield of agricultural products. This work developed a robust smart system to enhance both irrigation and flood monitoring and control, leveraging on Wireless Sensor Networks (WSNs) to boost agricultural production. Significantly, the irrigation monitoring and control system reduced involvement of irrigation operators in day to day irrigation management activities.

In Zhejiang (2013), several wireless nodes were introduced to monitor and control the Green House parameters such as humidity, water PH, Light intensity and temperature. In the work, mesh topology was deployed as the structure of the network. From the result, data acquisition and remote management of the system showed satisfactory performance. Resultsequally showed that the system has an advantage of robustness, reliability in data transmission, but energy consumption was one of the most challenging aspects of the networks at various stages. Consequently, network lifetime was shortened.

Mitchel et al (2013), developed a node power optimization protocol called 'Energy-Efficient Medium Access Control Protocol for Wireless Sensor Networks. The main objective of the work was to minimize the power consumption of the node. In the work, a node module was configured to wake up at every 45 minutes interval for 5minutes just to transmit data to the base station. The work failed to test the extra energy required for the transitions and moreover, the sleep duration of the nodes was too long. Despite the contributions, the power consumed by WSN node was still relatively high and network disconnection among the nodes was sometimes observed.

Purnima (2012) designed a Remote Monitoring and Control System with Automatic Irrigation System using GSM-Bluetooth'. This system has simple features designed with the objective of low cost using sensors for remote monitoring and controlling devices which are controlled via SMS using a GSM module. This system has an advantage of using both GSM and Bluetooth technology thereby eliminates the cost of network usage to a great extent by using Bluetooth when in the range of few meters with the devices. The downside of it is that the systems rely majorly on the services from public service providers (GSM) thereby making it uneasy to be deployed to remote areas where there is no network coverage.

An Effective Method for Crop Monitoring Using Wireless Sensor Network' was designed and implemented by Sakthipriya (2014) as an autonomous solution to enhance agricultural technology. The work was centred on deployment of star network topology to minimize the power consumption during data transmission within the WSN nodes. In deploying the star topology, it was however noticed that power depletion of the node was moderate but the system was not robust as there was lack of versatile communication network. Equally, data transmission was not reliable and transmission distance was limited.

This work developed a robust smart system to enhance both irrigation and flood monitoring and control, leveraging on Wireless Sensor Networks (WSNs) to boost agricultural production.

II. BASIC IRRIGATION CONTROL CONCEPTS

A control system is a device or system that maintains or alters the operation of a process. The whole system consists of: (i) the process being controlled; (ii) the sensing system (to measure the process response if feedback is required); and (iii) the controller (which incorporates both the software and hardware required to control the process). Control systems may be either open-loop or closed-loop: an open-loop control system uses known relationships between the process input and output to adjust the controller parameters, while a closed-loop control system measures the output of the process and adjusts the controller parameters to minimize the 'error signal' which is the difference between the input and the measured output (Hill, 1996; Merriam & Keller, 1998). However, there are two basic irrigation control strategies: open loop control systems and closed loop control systems. The difference between these is that closed loop control systems have feedback from sensors, make decisions and apply decisions to the irrigation system. On the other hand, open loop control systems apply a preset action, as is done with irrigation timers. Since the controller is the brain behind irrigation control system, the type of controller used determines the irrigation control system.

- Irrigation Control Components:

Standard automated irrigation control system comprises though not restricted to the following components or features; - sensors, controller(s), timers, relays, water pumps, personal computers, software component, WSN, communication gadgets (i.e system modem, phone, etc), water reservoir, etc. Broadly, sensors can be grouped into two: continuous sensors and discrete sensors. Continuous sensors: Continuous sensors produce a continuous electrical signal, such as, current, voltage, capacitance, conductivity, or any other measurable electrical property (Herschede, 2006). Discrete sensors are switches, mechanical or electronic, that indicate whether an ON or OFF condition exists. Discrete sensors are useful for indicating thresholds, such as the opening and closure of devices (vents, doors, alarms, valves, etc.). They can also be used to determine if a threshold of an important state variable has been reached.

Sensors many at times do not react directly to the variable being measured. For example, when a mercury thermometer is used to measure temperature, temperature is not being measured; rather, a change in volume due to a change in temperature is measured. Because there is a unique relationship between the volume and the temperature the instrument can be directly calibrated to provide temperature readings. The ideal sensor responds only to the "sensed" variable, without responding to any other change in the environment. It is important to understand that sensors always have a degree of inaccuracy associated with them and they may be affected by other parameters besides the "sensed" variable.

A controller is a computer-on-a-chip or a single-chip computer that contains the processor (the CPU), non-volatile memory for the program (ROM or flash), volatile memory for input and output (RAM), a clock and an I/O control unit. The term ‘controller’ tells that the device might be used to control objects, processes or events, measure, store or display information. The largest single use for microcontroller in automobiles-car manufactured today includes at least one microcontroller for engine control and more to control additional systems. In desktop computer, one may find microcontrollers inside keyboards, modems, printers, and other peripherals. In test equipment, microcontrollers make things easier to store measurement, to create and store user routines, and to display messages and waveforms. Consumer products like cameras, video recorders, compact-disk players, and oven. And they are so many applications where we use microcontrollers. In contrast, microcontrollers are a single chip computer because it contains memory and I/O interfaces in addition to the CPU (Bautista & Clemmens, 2006).

Irrigation timers are simple controllers consisting of clock units capable of activating one or more subunits of the irrigation system at specified times. Several designs are commercially available with many different features and over a wide range of costs.

Since computer systems work internally with numbers (digits), the electrical signals resulting from the sensors must be converted to digital data. This is done through specialized hardware referred to as the Analog-to-Digital (A/D) interface. Discrete signals resulting from switch closures and threshold measurements are converted to 0 and 1. Continuous electrical (analog) signals produced by the sensors signals are converted to a number related to the level of the sensed variable.

Actuator as applied to irrigation control system is made up of relays, motors, water pumps, valves and other devices that play complementary roles. A relay is an electromechanical device which allows power circuits to switch relatively high current/voltage ON/OFF. It is usually actuated by an electrical current. The current flowing in one circuit causes the opening or closing of another circuit. Relays are like remote control switches and are used in many applications because of their relative simplicity, long life, and proven high reliability. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal (Hall, 1992; Horowitz, 2001).

A wireless sensor network is a collection of sensor nodes interconnected by wireless communication channels. A wireless sensor node is a small wireless device that encompasses a microcontroller, a radio transceiver, an antenna, a power source, and one or more sensors. A lightweight operating system enables a node to function and provides features such as sensor polling, data manipulation, wireless communication, and remote access.

III. METHODOLOGY AND SYSTEM DESIGN

Bottom-up approach was used to realize the aim of this work. First, a general overview of high level description of the wireless sensor network based smart farm system for irrigation and flood monitoring as well as control for the enhancement agricultural products was given before detailing the individual blocks that make up the system. Next, the priority components or blocks in the wireless sensor network system unit (WSNSU) as well as that of remote control system unit (RCSU) were considered and identified. This was followed by the detailed design of WSNSU and RCSU before flow chart modelling of functional behaviour of the individual electronic components that make up the priority blocks leveraging on the data sheets of the components. Intelligent algorithm for WSNSU and RCSU of the wireless sensor network based smart farm system for irrigation and flood monitoring system were then developed using the behavioural flow charts of the priority components (PC). The software implementation of the developed WSNSU and RCSU were done using embedded c language. The testing of the both units were done and data collected. The Data collection was achieved by leveraging on the GUI capability of the arduinouno integrated development environment (IDE). Figure 1 shows the methodology flow chart.

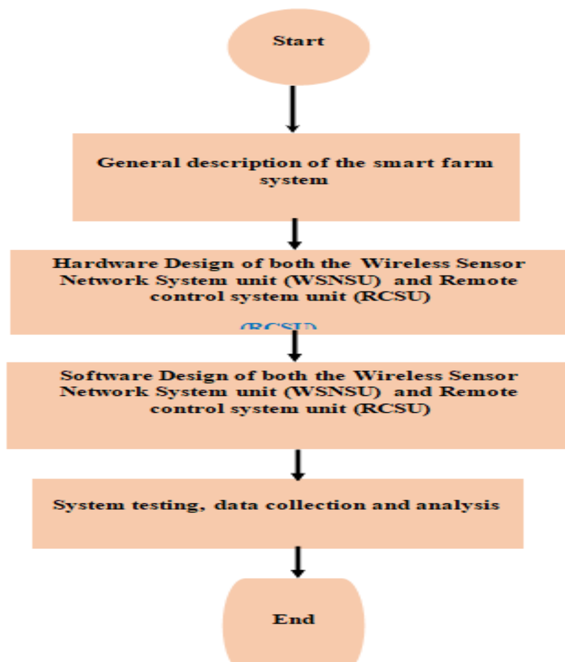

Figure 1: Methodology flow chart

IV. GENERAL DESCRIPTION OF THE WIRELESS SENSOR NETWORK BASED SMART

3.1 Farm System for Irrigation and Flood Monitoring As Well As Control System for the Enhancement Agricultural Products

The figures 2 and 3 show the block diagram of both the wireless sensor network system unit (WSNSU) as well as that of remote control system unit (RCSU). The description of the various units are also given below

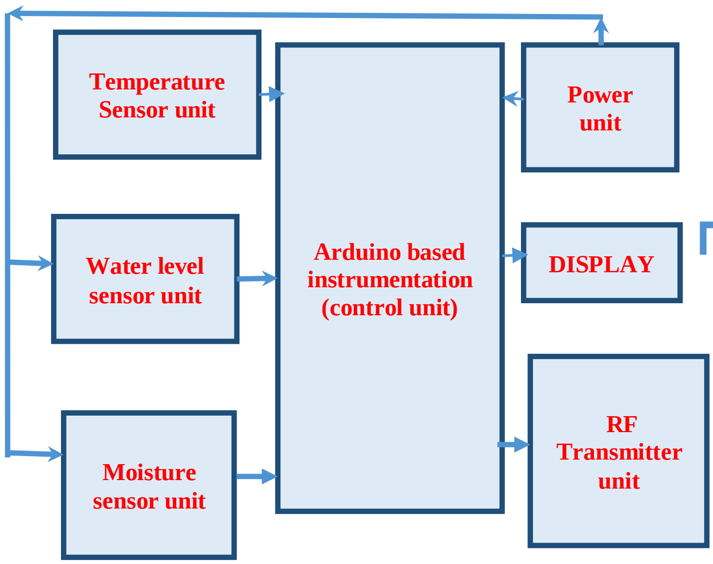

Figure 2: Wireless Sensor Network System unit (WSNSU) Network (WSN) UNIT

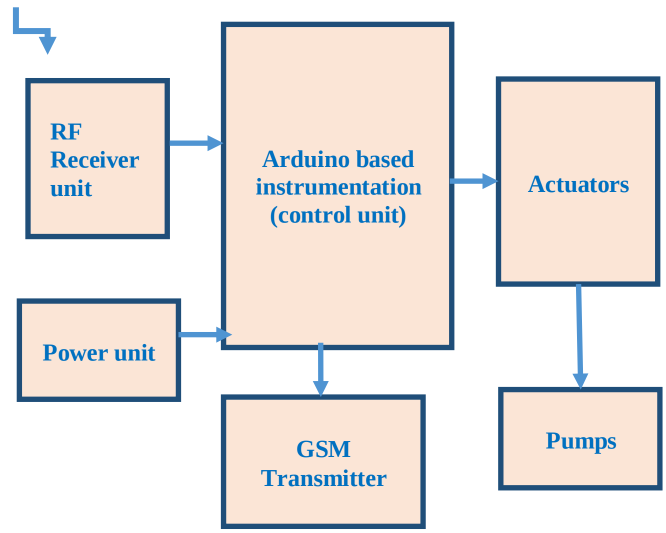

Figure 3: Remote control system unit (RCSU)

Temperature sensor unit was used to sense the ambient temperature of the farm so as to know the right time to irrigate the farm. In this work thermistor was used as the temperature sensor for the monitoring of the ambient temperature of the farm.

Moisture sensor unit senses the moisture level of the soil to ascertain if the soil is dry or wet. In this work it was configured to operate in the digital mode giving an output reading of either HIGH or LOW.

Water level sensor unit senses the water level of the farm, to ascertain when the farm is flooded. This sensor was configured using probes, transistor and resistors. It was designed in such a way that its output reading is either HIGH or LOW.

Arduino based instrumentation (control unit) was used to process the received signal from the sensors and then give a corresponding output.

RF Transmitter unit transits an encoded signals corresponding outputs from the Arduino board (control unit) wirelessly to the base station. This unit is made up of an encoder (HT12E), RF transmitter (FS100A) and a resistor (1.1 MΩ).

Display does the displaying of all activities of the system, making the system user friendly. In this work Liquid Crystal Display (LCD) was used.

Power unit is consist of a 9v battery and a regulator, it is responsible for the supply of 5v required by the system.

RF Receiver unit receives the encoded signals from the wireless sensor network system unit (WSNSU) and relays them to the control unit of the RCSU. This unit is made up of RF receiver, Decoder (HT12D), LED and resistors.

Arduino based instrumentation receives signals from the Receiver unit, processes them and then gives a corresponding output (switching ON & OFF of irrigation and drainage pump).

Actuators were used to switch the pumps ON and OFF. This unit is made up of two (2) relays and a driver (ULN2003).

Pumps were used for either irrigation or draining of water from the farm land.

GSM Transmitter is responsible for the sending of sms to a predefined phone number relaying the current state of the farm. The GSM transmitter is a modem based on sim900 chip which operates within the frequency band of 900MHz. This was selected for this work because it is compatible with arduinouno. The Sim900 module is an important part of the system responsible for communication between the arduinouno board and the mobile phone. AT commands are instructions used to control a module. AT is the abbreviation for ATTENTION commands. Every command line starts with “AT”, that is why module commands are called AT commands. Starting the command line with AT informs the module that a command is coming, AT commands are used to interface the module as well as to configure it.

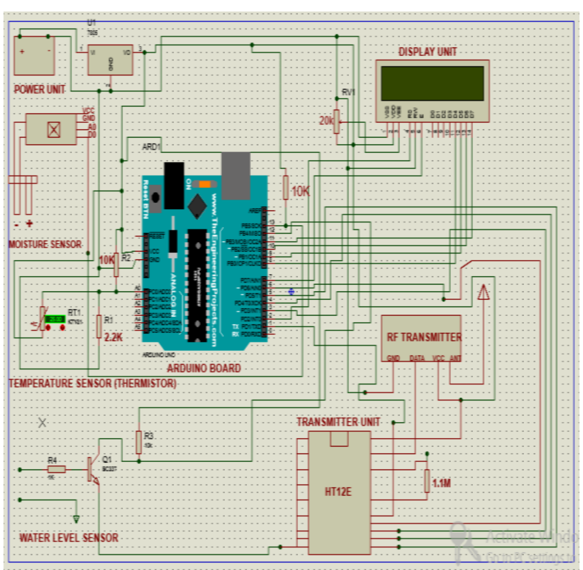

Figure 4: The schematic design of Wireless Sensor Network System unit (WSNSU)

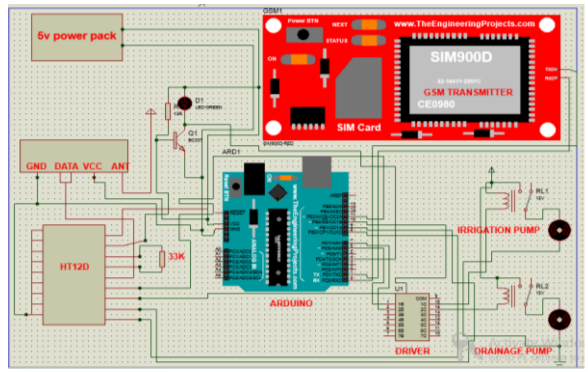

Figure 5: The schematic design of remote control system unit (RCSU)

i. Design Description Of The Wireless Sensor Network System Unit (WSNSU):

Temperature Input: Thermistor was used to measure the temperature of the farm. The output of the thermistor serves as an analog input, A1 of the on board analog to digital converter (ADC) of the controller (Arduino board). In determining the biasing resistor for the thermistor, the following values were gotten from the data sheet of the thermistor in use:

$$V_{RT} = 3.3\text{v}, I_B = 0.77\text{mA} \qquad (1)$$

But

$$\text{Vcc} = 5\text{v}, V_{RB} = \text{voltage across the biasing resistor} = 5\text{v} - 3.3\text{v} = 1.7\text{v} \qquad (2)$$

$$V_{RB} = I_B R_B \qquad (3)$$

$$R_B = V_{RB} / I_B \qquad (4)$$

$$R_B = \frac{1.7 \; X \; 103}{0.77}$$

$$R_B = 2.2\text{k} \qquad (5)$$

$therefore$ this was used as biasing resistor.

Moisture sensor Input: The moisture sensor input is connected to the pin 13 with a pull up resistor of 10kΩ as a recommended value of pull up resistor for Arduino controller.

Water level sensor Input: The water level sensor input is connected to the pin 12 with a pull up resistor of 10kΩ as a recommended value of pull up resistor for Arduino controller. In other to properly biase the transistor used for the sensor, a proper calculation of the based resistor must be known. From the transistor data sheet;

Base − emitter Voltage

$(V_{BE}) = V_B - V_E$ (6)

Where V_B = base voltage, and V_E = emitter voltage.

Given that $V_B = 5V$ and $V_E = 0V$ (7)

$V_{BE} = V_B - V_E = 5 - 0 = 5V$

Minimum current required to turn the transistor on is given by $I_B = 0.5mA$

Hence,

$R_B = \frac{V_B}{I_B} = \frac{5X10^2}{0.5} = 10000\Omega = 10K\Omega$ (8)

Therefore 10KΩ was used as the biasing resistor for the transistor used in the water level sensor design.

RF Transmitter unit: In the transmitter unit 1.1MΩresistor was connected to pin 15 and 16 of the encoder (HT12E), which is connected to enhance frequency selection which is in accordance with the manufacturer specification.

Design description of the remote control system unit (RCSU)

The remote control system unit (RCSU) which can also be seen as the base station unit, as explained above this unit is responsible for the switching ON and OFF of both the irrigation and drainage pump. It has a control unit, RF receiver, GSM transmitter, pumps, actuators and its own power supply unit. The control unit (arduino based) receives the sensor node (WSNSU) transmitted data via the RF receiver and decodes the message. The functions of the control unit are defined by the control program embedded into its ROM memory. It will continue to sample the received data and measure them against predefined thresholds. The microcontroller would energize or de-energize the relay depending on the threshold values, which would in turn start or stop the irrigation and drainage processes.

RF receiver unit: In the transmitter unit 33KΩ resistor was connected to pin 15 and 16 of the encoder (HT12D), which is connected to enhance frequency synchronization with the RF transmitter (HT12E), which is in accordance with the manufacturer specification.

Led limiting resistor: This is used to limit the current flowing through the LED

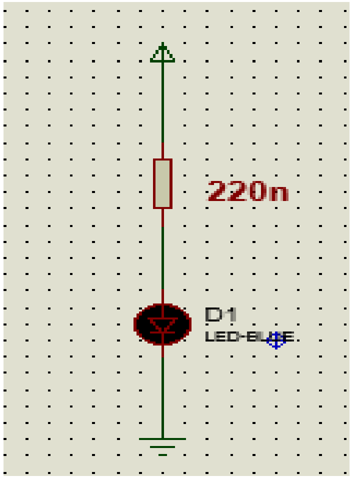

Figure 6: limiting LED resistor arrangement

$V = IR,$

Allowing a current of 20mA to flow through the LED which is ok as designed by the manufacturer, and V = 5v. Therefore,

$5 = 20\ X\ 10^{-3}\ X\ R$ (9)

$R = 5/20\ X\ 10^{-3}$ (10)

$R = 250\Omega$

But the closest value in the market is 220Ω. Therefore 220Ω was used.

ii. The Software Design Of The Proposed Wireless Sensor Network Based Smart Farm System For Irrigation And Flood Monitoring As Well As Control System For The Enhancement Agricultural Products.

The Intelligent Algorithm (software) for Wireless Sensor Network System unit (WSNSU), shows the development of the intelligent algorithm (software) for the wireless sensor network system unit. Figure 1.7 shows the flowchart diagram of WSNSU.

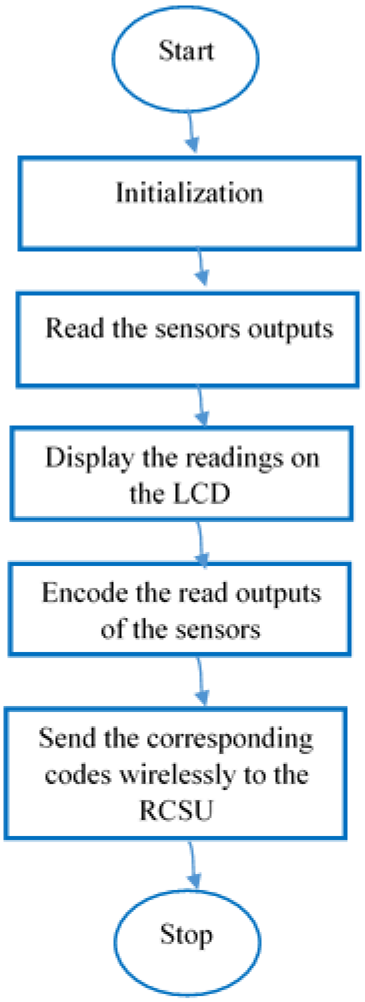

Figure 7: The flowchart diagram of WSNSU

iii. The Intelligent Algorithm (Software) For Remote Control System Unit (RCSU)

This section shows the development of the intelligent algorithm (software) for the remote control system unit, figure 8, 9 and 10 shows the flowchart diagram of RCSU.

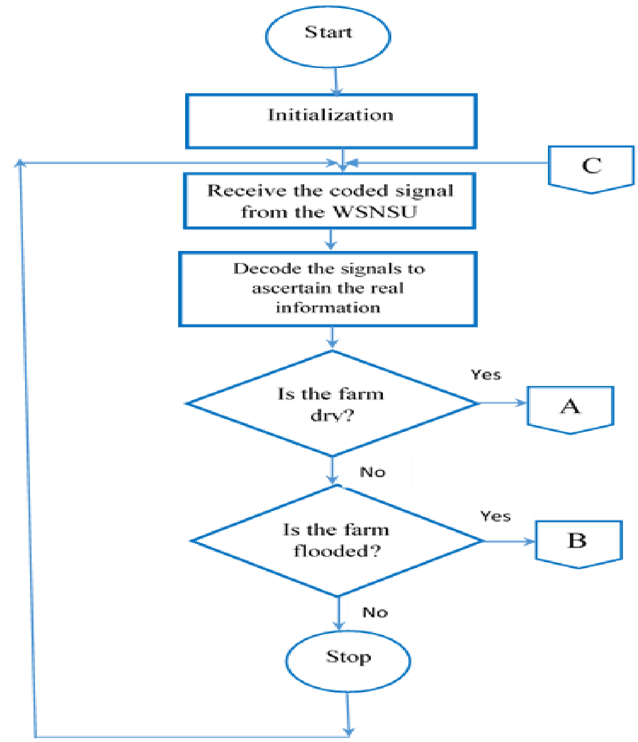

Figure 8: Flowchart diagram of RCSU.

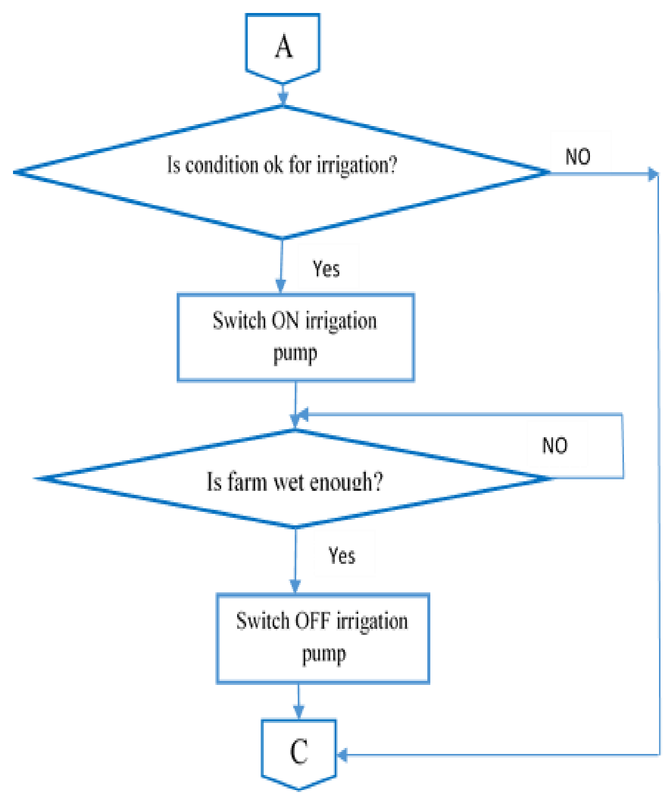

Figure 9: Flowchart diagram of RCSU.

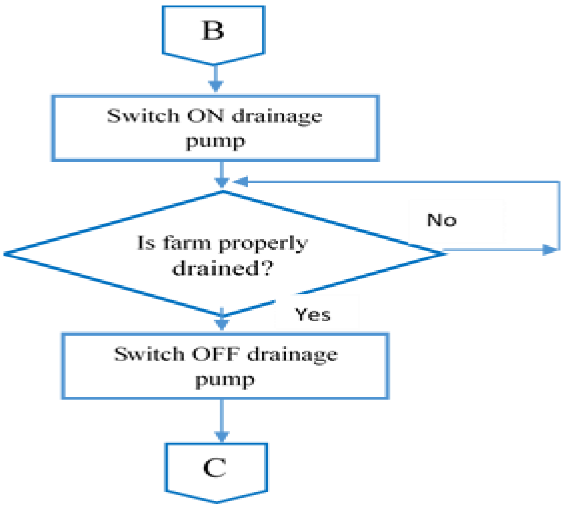

Figure 10: Flowchart diagram of RCSU

V. RESULTS

The designed system was used to monitor and control the environmental activities in the farm with the aim of enhancing production of agricultural products. The basic operation of the Remote Control System Unit (RCSU) is the control of pumps by the on board microcontroller through the driver relay arrangement, which would be energized via the codes written for the control and stored in the microcontroller.

The recorded data was exported to Microsoft Excel for evaluation and analysis, using the information in appendix C, D, E and F to plot graphs showing the system's response to variation of environmental features like soil moisture, water level and temperature of the farm.

Figure 211 shows a graphical representation of the behaviour of the system when the soil is dry and the temperature is conducive for irrigation. Four (4) different temperature readings with their corresponding moisture level and water level values as well as irrigation and drainage pump state from the captured data of data_1 were used in the plotting of the graph, this is because using all will make the graph clumsy. From the graph it shows that as long as the temperature value is within range (00C - 350C) and the soil moisture sensor indicating low soil moisture, the irrigation pump comes ON and stays on as long as the sensor reading is indicating that the soil moisture level is low.

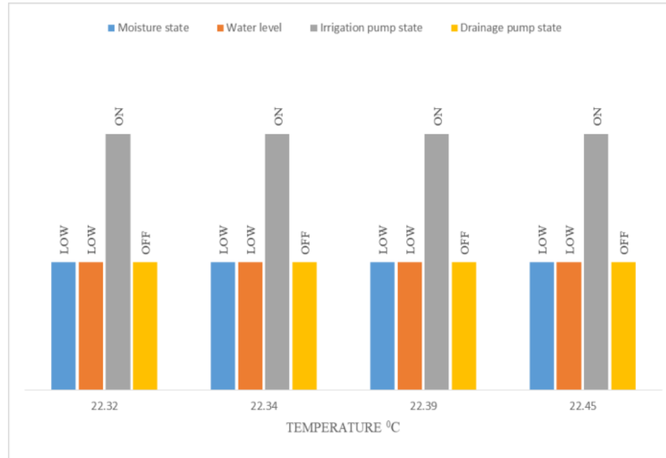

Figure 11: Graph showing the behaviour of the system when the soil needs to be irrigated and the temperature is conducive.

In figure 12, it shows a graphical representation of the behaviour of the system when the soil is dry and temperature is not conducive for irrigation. Five (5) different temperature readings with their corresponding moisture level and water level values as well as irrigation and drainage pump state. From the graph it shows that as long as the temperature value is not within range (0^0C - 35^0C), even when the soil moisture sensor is indicating low soil moisture, the irrigation pump remains OFF until it the temperature falls within range.

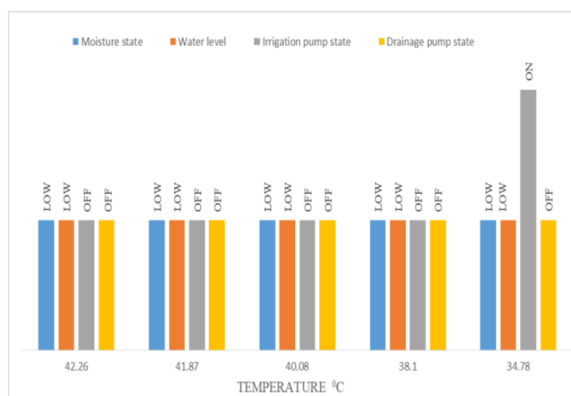

Figure 12: Graph showing the behavior of the system when the soil needs to be irrigated and the temperature is not conducive.

In figure 4.8 it shows a graphical representation of the behaviour of the system when the soil moisture is ok, water level low, which means no flooding has occurred. Four (4) different temperature readings with their corresponding moisture level and water level values as well as irrigation and drainage pump state were used in the plotting of the graph. From the graph it shows that as long as the soil moisture sensor is indicating high soil moisture, which means it is ok and water level sensor not indicating that flooding has occurred, both the irrigation pump and the drainage pump will remain OFF.

In figure 2.3 it shows a graphical representation of the behaviour of the system when the soil moisture is ok, water level low, which means no flooding has occurred. Four (4) different temperature readings with their corresponding moisture level and water level values as well as irrigation and drainage pump state were used in the plotting of the graph. From the graph it shows that as long as the soil moisture sensor is indicating high soil moisture, which means it is ok and water level sensor not indicating that flooding has occurred, both the irrigation pump and the drainage pump will remain OFF.

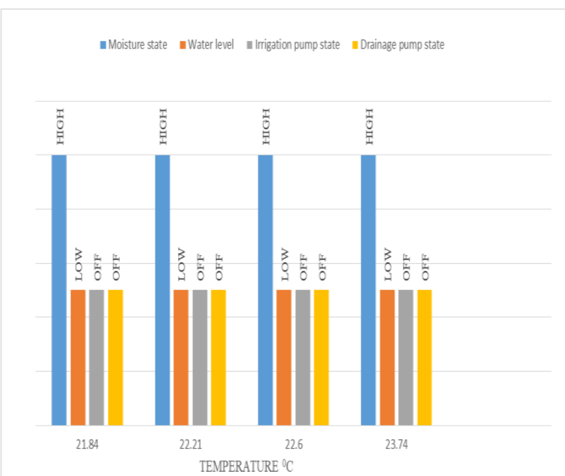

Figure 13: Graph showing the behaviour of the system when the Soil is moist (high but ok) Soil with no flood detection.

Finally figure 14 shows a graphical representation of the behaviour of the system when the soil moisture is high and the water level is high indicating occurrence of flooding. Four (4) different temperature readings with their corresponding moisture level and water level values as well as irrigation and drainage pump state were used in the plotting of the graph. From the graph it shows that the drainage pump only comes ON when the soil moisture sensor is indicating high soil moisture level as well as the water level sensor indicating high water level. The drainage pump will remain ON until the water level sensor's output goes LOW indicating that the flood has been taken care of.

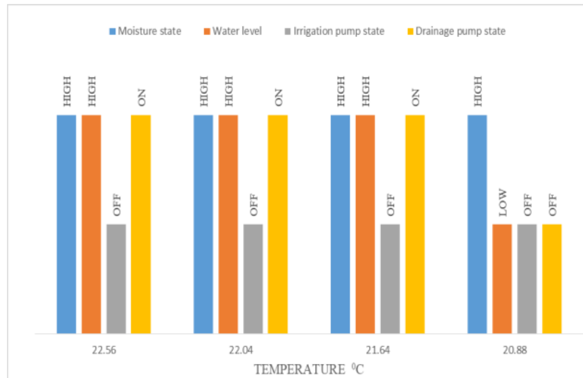

Figure 14: Graph showing the behaviour of the system when the Soil is moist (high) and the water level is high indicating occurrence of flooding.

From the figures above, this work has shown that the designed system was able to monitor and control the specified environmental factors within the experimental test bed region to enhance agricultural product. In addition to that, this system relays information about the farm status to the owner through the GSM transmitter leveraging on AT commands, keeping the farmer informed of the happenings in the farm.

CONCLUSION

During the course of the review of related works, it was discovered that most projects on WSN in agriculture are research oriented. Equally, literature reviews indicate lack of research on use of mobile phones and WSNs technologies to enable middle-scale farmers in the country monitor and control their farm field. For this reason, the researcher conducted this research which demonstrated the practical ways of using mobile phones in conjunction with WSNs to enable farmers in Nigeria monitor and control their farm and hence increase their productivity. Furthermore, the research work will serve as a platform to motivate the possibility of extensive researches in the area of WSN and mobile phone technologies; and the role this could play on improvement of agricultural methods in the context of developing country like Nigeria.

REFERENCES

[1] Caruthers L.M. (2008), Irrigation and food security in 21stcentury, pp (34-41)

[2] Hall, Douglas V, (1992), "Microprocessors and Interfacing" 2nd edition McGraw Hill.

[3] Herschede, R. (2006), "Microcontroller Foundations for Mechatronics Students," master's thesis. Pp (l 7-19)

[4] Hill D. R., (1996), "A History of Engineering in Classical and Medieval Times" London: Routledge. p. 143. ISBN 0-415-15291-7.

[5] Horowitz P. (2001) "The Art Programming" Cambridge University press.

[6] Merriam J. L., and Keller, J., (1998), "Farm irrigation system evaluation: a guide for management." Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah.

[7] Mitchel P., Anieke J.I, Seun M. O (2013) "Energy-Efficient Medium Access Control Protocol for Wireless Sensor Networks". International Journal of Engineering & Technology IJET- IJENS Vol: 09

[8] Purnima, S.R.N., (2012), 'Design of Remote Monitoring and Control System with Automatic Irrigation System Using GSM-Bluetooth'. International Journal of Computer Applications Volume 47, No. 12, pp888

[9] Zhejiang L. M. (2013), "Green House Management Using Wireless Sensor Networks". International Journal of Distributed Sensor Networks Volume 2, Issue 2, pp 11-19

[10] Sakthipriya, N. (2014), 'An Effective Method for Crop Monitoring Using Wireless Sensor Network,' Middle-East Journal of Scientific Research, IDOSI Publications. Pp 1127.