An Application of Industry 4.0 in Agriculture in Nigeria

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Abstract

The evolution of industry 4.0 in the agricultural sector is the emerging technology in vogue. Wireless Sensor Network (WSN) applications are technological innovations used in monitoring, sensing, reading of attached devices, in order to detect physical phenomena. WSN is said to be the key technology of IoT. The system developed is mainly for agricultural precision, which involves real-time monitoring of climatic as well as the environmental properties of farmland is been monitored and adequate decisions are taken in respect to the sensed variables to amend the unpalatable conditions on the farmland. The developed WSN system uses a mesh topology structure to achieve scalability for monitoring environmental variables that affect crop productivity. The system design incorporates the Global System of Mobile (GSM) technology into it, to give the farmer real-time information about the environmental conditions of the farm, thus providing real-time monitoring for better decision making. The designed system is energy efficient, reliable and relatively simple, the system credibility was validated by testing it in a real farm environment in Ekiti State, Nigeria. The gateway node used in the design successfully collects the sensed data using the environmental conditions of the farmland and afterward forwards the report to the farmer.

Keywords: Agriculture, Industry 4.0, IoT, Sensors, Microcontroller, WSN

1.0 Introduction

The quest to achieve food security has been a major agenda for developing nations of Africa over the last two decades. This is because Africa's population is geometrically increasing which in turn causes a continuous demand for food. However, there has been a continuous decline in the levels of agricultural production over the years.
Nigeria is a nation which is blessed with abundant land and water resources. According to statistics from the Federal Ministry of Trade and Investment, 40% of Nigeria's land mass is made up of arable land. However, due to incessant deforestation, bush burning practices and indiscriminate application of fertilizer, a lot of the arable land, which is fragile has become unusable for farming (NTWG 2009). Food and Agriculture Organization of the United Nations (FAO) reports showing that Nigeria's arable farmland has reduced from 41.17% in 2007 to 39.53% in 2011.

Conversely, the Nigerian agricultural sector has the tendency to increase its productivity, yet, its productivity has maintained an all-time low over the past five years. According to statistics from the Federal Ministry of Agriculture, the turnout of the agricultural sector has experienced a high setback. Its growth rate was recorded to be 3.3% in the early 1990s which later increased to 6% between 2003 to 2007. According to statistics, about 38% of Nigeria's landmass, which is about 33.7 million hectares are used for farming while others are underused.
Due to the country's climatic situation, which is highly diverse in nature, this places the country at a high advantage to be able to virtually cultivate all agricultural products that can survive both in tropical and semitropical regions. The Nigerian government has encouraged commercial farming through the introduction of intervention funds for commercial farmers, farming support tools and many other farming incentives that can aid their productivity. The country is blessed with water and nice climatic conditions as well as large areas of arable land. However, even with all this natural endowment, the country still faces some setbacks in its agricultural productivity owing to low soil fertility in most of the areas and also the methods adopted in the cultivation of farmlands is still another issue.

A lot of factors have affected the level of productivity in the nation. Climate change has caused deleterious effects, such as disordered seasonal cycles, the desired water supply is interrupted, and this has adverse effects on the environment.

This causes a low food production. Agricultural production is anticipated to be brutally bastardized by climate inconsistency and changes. The country's agricultural system solely depends on climate because water and light are the sources of food for crops. In addition, farmers are experiencing an increase in the incidence of pests and diseases arising from climate change.

The Nigerian agricultural sector needs to deploy modern technology in addressing some of these challenges, especially climatic issues affecting agricultural productivity in the country.

Adoption of modern technology in carrying out their agricultural production is very key for achieving high productivity in the agricultural sector. Enhanced commitments in research and development, use of modernized equipment and the introduction of irrigation practices, financial support to the farmers, as well as providing infrastructural development that will aid the easy access to farmlands, markets are also essential to quicken and sustaining the development of the countries agricultural sector.

Ecological issues such as temperature, humidity, soil moisture, light, pest, weeds, and others are the factors that affect crop growth and productivity (Al-Aubidy, Ali, Derbas & Al-Mutairi, 2014:1-7). Adoption of industry 4.0 in the agricultural sector through the use of wireless sensor technology will give room for continuous monitoring of farm environmental variables in real-time to enable real-time dissemination of information to a farmer for better monitoring of the farm even from distant locations. This will help the farmer to have a clear knowledge of the factors responsible for low growth rate for him to take the necessary steps to ensure utmost crop productivity and in addition, accomplish outstanding energy savings. Knowing the climatic conditions of the farmland enables farmers to know the exact quantities of agricultural inputs such as water through irrigation schemes and fertilizers to be applied (Sahota, Kumar & Kamal, 2011a:1628-1645).

In recent times, wireless technology is being actively used for in agriculture for better monitoring of farm status. A WSN for agricultural purposes is a network of sensor nodes distributed all over an area (field) with the ability to periodically collect soil statistics and transmit the acquired soil statistics to an information processing center. The soil statistics acquired through this network is suitable for ascertaining the best measures of the agricultural inputs such as soil nourishments, irrigation, to be applied at various farm sites and at diverse periods in the field (Sahota, Kumar & Kamal, 2011b:1628-1645).

The advancement in the use of Wireless technology in recent times has really increased. Several wireless technologies have been developed, ranging from the traditional Infrared Data Association (IrDA), that employs the use of infrared light in its application, though its limited to short range as well as point to point (P2P) communications, to wireless personal area network (WPAN) which is also limited to short range, but has point-to-multipoint communications capabilities, such as Bluetooth and ZigBee unlike the infrared, to wireless local area network (WLAN), which has a mid-range access, multi-hop facility for long-distance cellular mobile systems, for example GSM/GPRS and CDMA.

In this study, we have designed and implemented a WSN for smart agricultural applications. To achieve this, we have developed a system utilizing ZigBee wireless protocol for the implementation of the WSN and the Internet/GSM technology connecting the sensor network (SN) to the farmer. Internet connectivity adds the ability to predict weather conditions and will help in connecting customers to farmers effortlessly.

2.0 Overview of Wireless Sensor Networks

A WSN can be defined as a network of devices comprising of radio frequency (RF) transceivers, microcontrollers, sensors, and power sources (Chen, Wan & Li, 2012:, The 15th APT Wireless Group Meeting 27 – 30 August 2013, September 2013:).

Wireless sensor technology is attractive and progressively increasing in demand from a wide range of commercial, research and to local applications. Due to this development, the cost of sensors are relatively cheap and affordable as the numbers of sensor manufacturers and suppliers increase daily due to high demand. A relatively small investment in this capability could potentially save large plant maintenance, generate more revenues and create a better farming environment.

The Global System for Mobile Communication (GSM) technology and the internet are effective tools for monitoring and prompt notification of devices from any location [5]. This is advantageous in agriculture, as farmers can have access to the farm from any location. These technologies with the aid of remote control sensing technology can assist the farmer to locate crop zones that require water, adequate nutrients as well as other reasonable attention. Development of a broader range of these devices would momentously bring about advancement in the agricultural sector. Usually, Sensor networks (SNs) has been found suitable for incorporating spatiotemporal order or drifts in climates, such as pressure and soil moisture, broadcasting superlative management choices to the farm manager. Adopting Sensors that allow farmers to recognize quality and real-time arrangement of farm products will subject them to competitive advantage in terms of price and quality (Valada, Kohanbash & Kantor, 2010:13-28). Countless varieties of sensors can be unified into the sensor node, which makes it useful for other applications. To fully create very robust smart farming techniques, a lot of environmental factors will need to be considered, the sensor node should be able to accommodate for new sensors.

A sensor network (SN) is composed of several nodes which are deployed densely in close proximity to the phenomenon to be monitored [7]. Each of these nodes collects data and route this information back to the control center. The network must have a self-organizing ability since the positions of individual nodes are not predetermined.

Many different wireless communication technologies are interfaced with the internet and use protocols which are established for sensors through several manufacturers. To easily control a group of wireless nodes, the IoT technology has been adopted for industry 4.0 in various studies. In [8], a survey of recent trends in IoT was presented and in [9], [10], the authors have presented a review of the state of the art and future trends in industry 4.0. In addition, authors in [11], presented a review of WSN applications in agriculture. The authors also highlighted some of the challenges with the use of WSN in various applications. Furthermore, authors in [12], [13] have in addition highlighted some challenges of WSNs generally.

IoT combined with WSN provides a network with a group of nodes which cooperate together to disseminate information gathered in their vicinity to the users [14]. In addition to the sensing capability of wireless sensors, they also have onboard processing, communication, and storage capabilities. When many sensors cooperatively monitor large physical environments, they form a WSN. Each SN node (or more) typically consists of several parts. The main parts being (i) a radio transceiver, (ii) a CPU, (iii) an electronic circuit interfacing with the sensors and (iv) an energy source [15]. Many WSNs also include actuators which allow them to directly control the physical world. Fig. 1 shows an overview of a WSN.

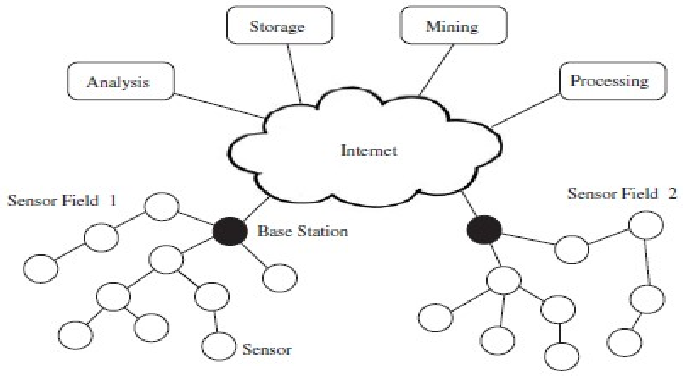

Fig. 1. A Wireless Sensor Network (WSN).

2.1 Farm Factors

The smart farming system has nodes which can measure the following different parameters:

a. Temperature

Climatic temperature greatly influences the survival or growth of a crop. Every crop has its own temperature survival range called cardinal temperatures. As temperature increases, respiratory reaction rates also increase, using more of the photosynthetic compounds manufactured in a day. Thus, an increase in the respiratory reaction will require more water for the plant to cope with the requirement and if it is not controlled, it will lower farm yield. In many crops (such as wheat, sugar beet) low temperatures are required for flower initiation. Usually, high temperature promotes the growth of weeds, insects, and pathogens.

b. Humidity

This is an important climatic factor which is an important tool to prevent the spread of plant diseases on farmlands. Normally, for healthy growth of agricultural crops, the range of relative humidity for the plants is from 50% to 70%.

c. Soil Moisture

An accurate measurement of soil moisture and water content of the soil is greatly needed to determine the need for a supply of resources such as fertilizer and water to the plants. Soil moisture is important in agriculture to help farmers manage their irrigation systems more efficiently. With low water supply to grow a crop, they are able to increase yields and the quality of the crop through better management of soil moisture during critical plant growth stages.

d. Light Intensity

Light is very important to drive the photosynthetic process and also for crop production. Plant growth and development is greatly affected by both the quantity and quality of the light it receives. The evapotranspiration calculation for irrigation employs solar radiation as a key variable. It is important that farmers understand this important variable in order to efficiently produce quality plants. Light greatly affects photosynthesis, an increase in the intensity of light will result in an increase in photosynthesis. Deficient light tends to reduce plant growth, development, and yield. Excessive light intensity should be avoided as it scorches the leaves and reduces crop yield. All these factors mentioned above are been measured by sensor nodes placed at strategic locations on the farm.

2.2 IEEE 802.15.4 and ZigBee

The ZigBee wireless device is a very useful wireless technology for WSNs. The ZigBee Association was founded in 2002 by an alliance of several companies. Their target is to develop and design products that are dependable, which is going to be cost effective, energy efficient and have the capability to be networked wirelessly by means of uncluttered global standard. The Institute of Electrical and Electronics Engineers, together with the ZigBee Association in the agreement concluded that the technology would be called ZigBee. The network layer below this technology which supports its advanced features is known as IEEE 802.15.4 standard. Potential applications of this standard include WSN's, remote controls, home automation, and interactive toys [16].

The IEEE 802.15.4 standard is a set of standards that define power management, addressing, error correction, message formats, and other P2P specifics necessary for proper communication to take place from one radio to another. ZigBee explains 3 software layers, which are on the physical (PHY) and MAC 802.15.4 layers. These are network layers, security layers as well as the application layer, this is shown in Fig. 2. A ZigBee Network consists of three types of nodes namely: (a) Coordinator/gateway: which is responsible for forming the network, handing out addresses, and managing the other functions that define the network, securing it, and keeping it healthy, (b) Routers: A router is a full-featured ZigBee node. It can join existing networks, send information, receive information, and route information. Routing means acting as a messenger for communications between other devices that are too far apart to convey information on their own. Routers communicate with the coordinator and other routers to reduce functions of end devices and provide a path for the end device to communicate data to the base station or coordinator, (c) End device: End devices ensures the interfaces to the physical world. It senses the parameters for which it has been designed and communicates with the coordinator through the desired routing protocol and forwards signals to the base station. ZigBee networks may have any number of end devices. In fact, a network can be composed of one coordinator, multiple end devices, and no routers in some cases. The network layer supports star, mesh and cluster tree topologies.

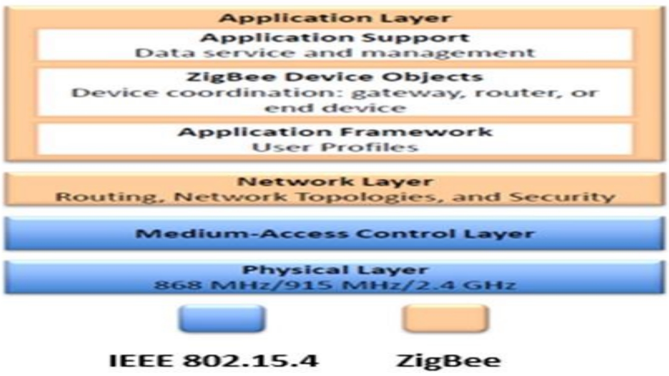

Fig. 2. IEEE 802.15.4 and ZigBee layer.

2.3 Network Topology

Communications networks consist of a number of different topologies for radio or wireless communication. A brief discussion of the network topologies that apply to WSNs are discussed in (a), (b), (c) and are shown in Fig. 3.

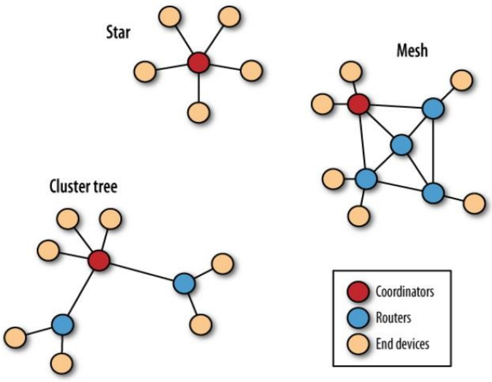

Fig. 3. ZigBee Star, Mesh, and Cluster tree topologies.

a. Star Network (Single point-to-multipoint)

A star network is an arrangement of nodes to a central hub where a single coordinator sends and receive messages from a number of remote nodes. The remote nodes can only send or receive a message from the single coordinator; they are not allowed to send or receive messages from each other. The advantage of this type of network for WSNs is in its simplicity and its ability to keep the remote node power consumption at a minimum. The disadvantage of such a network is that the coordinator must be within the radio transmission range of all the individual nodes and this makes it not to be as robust as other networks, because of its reliance on a sole node to operate the network.

b. Mesh Network

Mesh Network is designed to accommodate any node within the network, this enables it to convey data to every other node within its radio transmission radius. This process enables multi-hop communication. This means when a node interacts with another node which is outside of its network radius, there are possibilities of using an intermediary node to convey the information to the desired node. There is a high advantage in this type of network topology, it gives room for redundancy and scalability. In a case of single node failure, the remote node has the capability to interact with other nodes within its range, which can subsequently transmit the information to the preferred destination. The radius covered by the network is not restricted to the range in between single nodes, this can be extended by acquiring more nodes to the system. The shortcoming of this kind of network is that it's not energy efficient in terms of the nodes power consumption, unlike the nodes that don't have this capability. This limits battery life.

c. Hybrid Star (Mesh or Cluster tree network)

This type of network is a combination of the star as well as a mesh network. It offers a strong and useful communications network while sustaining the capability to make the wireless sensor node energy efficient. This network topology provides low energy sensor nodes which are not empowered with the capability to transmit messages. This gives a steady minimal power consumption. However, other nodes on the network are enabled with multi-hop capability, allowing them to forward messages from the low power nodes to other nodes on the network. Generally, the nodes with the multi-hop capability have high power and are often plugged into the electrical mains.

3.0 Methodology

The design and developmental processes carried out in this study involved a number of stages and processes. This section introduces our method for agricultural monitoring using WSN technology. To optimize the growth of ornamental plants, farm crops and to improve crop yield, we irrigated the plants at the precise time. The system is configured to monitor farm factors which are important to farm growth and better farm production. The system is in addition equipped with a GSM/GPRS module that allows communication between farmers using the GSM SMS technology because of lack of access to the internet. This helps to give them information about the status of the farm. The farmer or a farm customer can also send a message to the farm system in form of an SMS (Short Messaging Service) to either make the farm system do some farm automation or to ask the farmer for information related to the farm.

Adoption of the Wireless communication technology in this study was deployed primarily to collect the measurements, that is, the soil variables and to transmit it to the farmer who may not be in any way close to the farm environment.

The WSN architecture is shown in Fig. 4.

3.1 Wireless Network System Architecture

The design of the WSN carried out in this study is based on mesh network topology. In the design architecture considered as shown in Fig. 4, each sensor node is made up of a microcontroller circuit and equipped with a wireless transceiver that allows it to communicate with the gateway node and other sensor nodes. The microcontroller also interfaces with the farm sensors that monitor the farm factors like the soil temperature, air temperature, humidity, and light intensity. Also the sensor node is capable of controlling an irrigation system around, such that if the area covered by this sensor node requires water, it can switch on the control valve of the irrigation system to allow for water to reach the area, and when the water level for that area has reached its optimum level, the sensor node can also switch off the irrigation control valve.

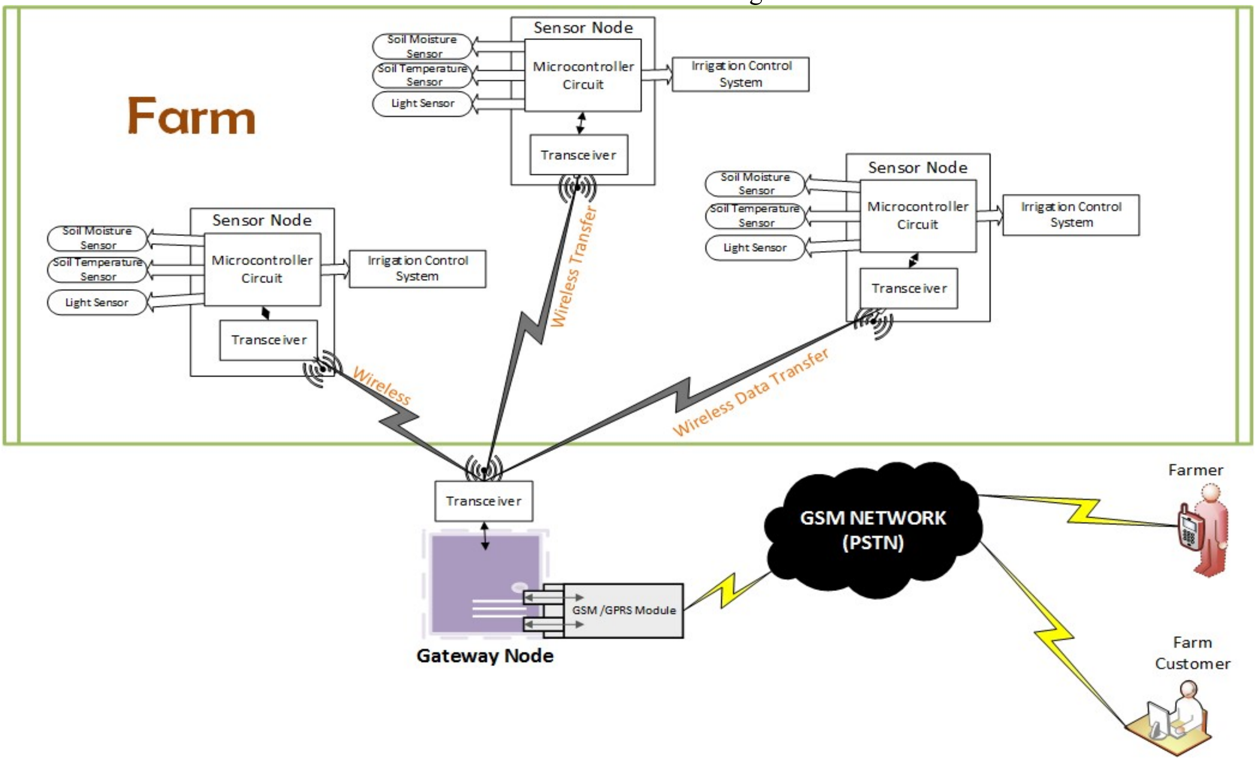

Fig. 4. The WSN Architecture.

The gateway node serves as the server of the system. The gateway node is a crucial part of the WSN system as it is used to create the network at the initial stage and also maintain the network subsequently. Thus, it will need to be powered at all times. The gateway node has a wireless transceiver that allows it to communicate with the sensor node stationed in the farm, also attached to the gateway node is the GSM/GPRS module. This module gives the gateway ability to interact with the outside world through the Internet and the GSM network. The information from the nodes can be sent to the interested party through the internet and the GSM network.

3.2 System Design

a. Hardware Description

The microcontroller sensor node acts as the end device by interfacing with the physical world, that is, it interfaces to the farm sensors to read the farm data like soil temperature, soil moisture, and others.

Each of the sensor nodes is an autonomous sensor processor (SP), usually, the selection of self-regulating sensors might be attached. The SP freely accesses several other sensors attached directly to the node, gathers the data from those sensors. The node has added to it a radio module that it uses to communicate with the gateway or with other nodes in the network. A node can be situated in any field location if it can communicate to the gateway via the radio module. Each node gathers data intermittently from its private group of sensors and conveys back the data to the gateway. The internal structure of the sensor node is shown in Fig. 5.

The sensor node is based on the Atmega 328P microcontroller and the Xbee Series 2 Wire. An antenna which acts as the wireless transceiver.

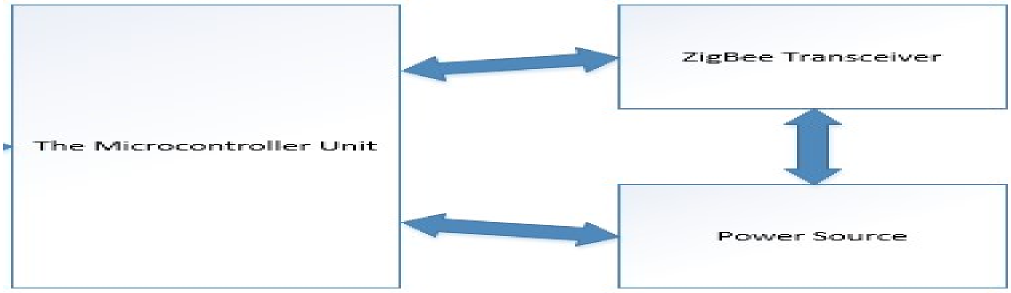

Fig. 5. Internal Structure of the Sensor Node.

Fig. 6. The Internal Structure of the Gateway.

b. Operational Principle of the Sensor Node

The developed circuitry for the microcontroller sensor node is shown in Fig. 7. From the circuitry, the microcontroller Atmega 328P communicates with the Xbee Transceiver using the universal synchronous/asynchronous receiver/transmitter (USART) communication interface. Both the microcontroller and the transceiver both have USART ports embedded in them.

From the circuit, the transceiver is powered by 3.3V, it gets its 3.3V from a 3.3V regulator. The Atmega 328P is powered by 6V AA battery regulated down to 5.3V by the diode. A filter capacitor C3 is placed for filtering purpose. The lightning emitting diode is attached to one of the digital input and output pin of the microcontroller.

The LED is attached to the microcontroller to serve as the node indicator. The wireless transceiver is connected to the USART port of the microcontroller. The transmitting part of the USART port of the microcontroller outputs 5V, but the transceiver is a 3.3V sensitive device. Anything higher than 3.6V will damage it. A resistive potential divider circuit is added to give an output of 3.3V from the 5V input. The microcontroller is controlled by a 16MHz crystal oscillator. The sensors get their power from the transistor which is switched on and off by the microcontroller which is designed such that power consumption is reduced during the power saving mode. The FTDI JI is a jumper cable which an FTDI cable is plugged in to allow for the programming of the microcontroller. An FTDI cable is a USB to Serial Converter device, it allows for serial communication with a serial device like a microcontroller, computer, and others. The use of the FTDI cable programming method is possible as a result of a boot-loader running in the microcontroller. A boot-loader is a software that runs on the memory of the microcontroller which allows for programming of the device through the USART interface. The FTDI cable communicates with the microcontroller through the USART interface. The sensors are attached to the microcontroller communication interface, and the node sample data at a rate of 1 sample per 10 minutes, then transmits the sensor data to the gateway node before entering a sleep mode. This mode is a very low power saving mode, it helps to prolong the battery life of the node.

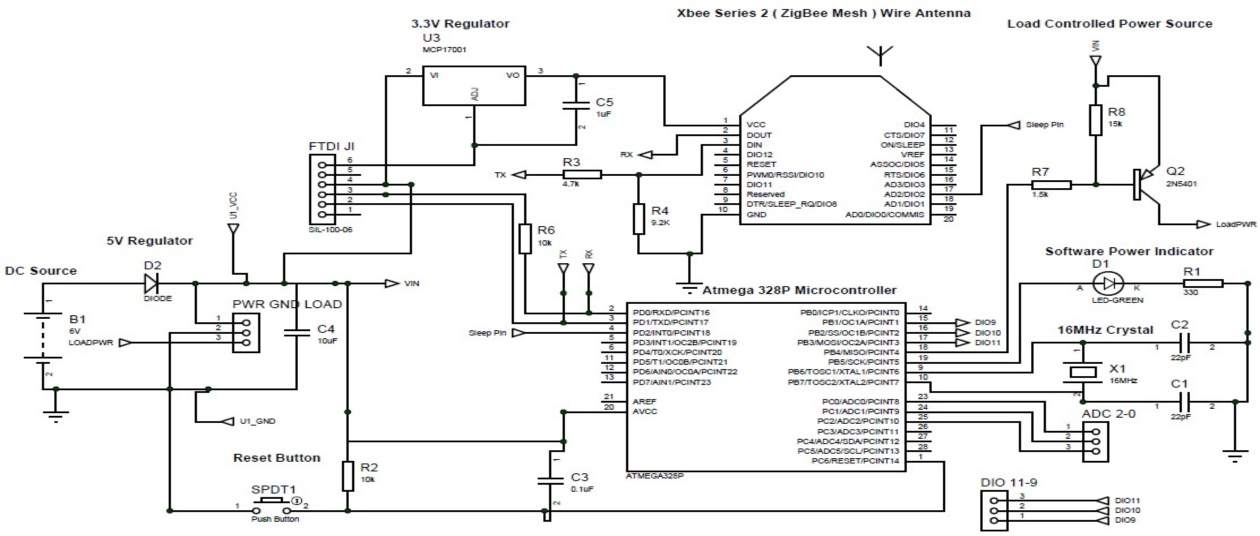

Fig. 7. The Sensor Node Circuit including the Microcontroller and the Wireless Transceiver.

c. The Gateway Node Design

The Gateway node performs supervisory control of the network, creation of the WSN and it is responsible for long-term storage of all data collected from the nodes. It also performs post-processing of the data received from the individual nodes and interprets it into a form that is understandable. The Gateway node is powered by a renewable source of energy because the gateway device needs to be on always, and powering down of the gateway will lead to a collapse of the whole network. The Gateway consists of a wireless transceiver, an Atmega328P microcontroller, a storage card for storing of node data and a SIM900 GSM/GPRS module. The internal storage of the Gateway is shown in Fig. 6. The SIM900 GSM/GPRS module allows the gateway to interact with the physical world, it allows the farmer to interact with the network.

d. Operational Principle of the Gateway Node

The Gateway receives data from the nodes through its wireless transceiver and then processes the data. The gateway analyzes the sensor readings from each node and then outputs a readable form of information to the farmer by sending out a periodic Short Messaging Service (SMS) message. Also, the farmer can interact with the Farm system by sending it an SMS.

When the message gets to the Gateway, it takes a decision and then acts on it. The Gateway node is equipped with a programmer that allows for the programming of the device and also for interfacing it with a computer system for collection of data or debugging purpose. The circuit diagram of the programmer is shown in Fig. 8. An FTDI cable is plugged into the board which also has a male header which is plugged into the node for programming and interfacing with a computer system.

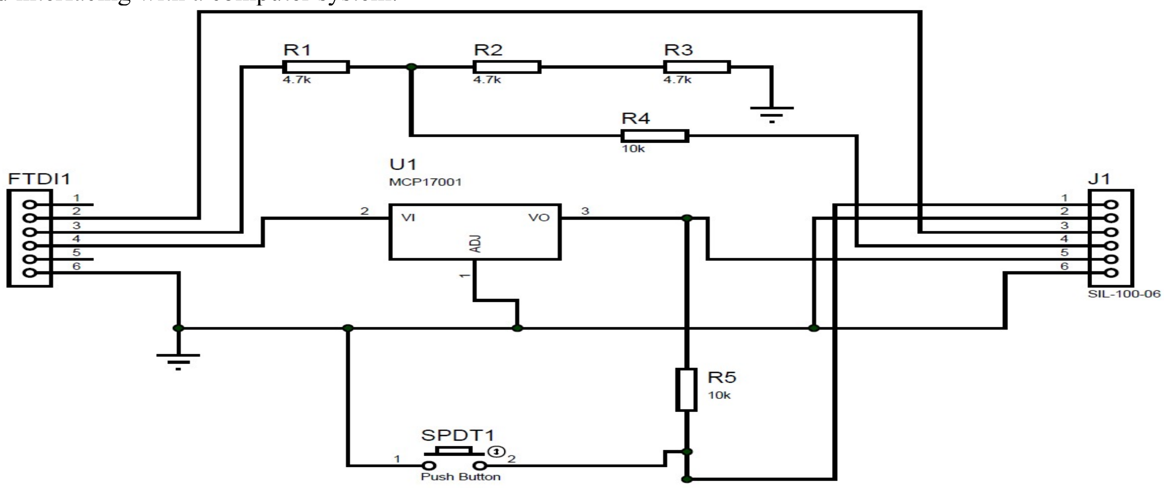

Fig. 8. Circuit Diagram of the Programmer.

3.3 Programming Methods

This section emphases on the rooted code within the sensor nodes and the gateway node. The programming language for the node is based on the popular C programming language. A modified version of the C language is used. The integrated developer Environment IDE used is the Atmel Studio 6.2 IDE. The Atmel Studio is an IDE design for programmers developing programs for Atmel microcontrollers. This IDE is based on the popular Visual Studio 2010.

a. Software Design for the Sensor Nodes

The working principle of the node is presented in (i), (ii) and (iii). The node is programmed to follow this working principle shown in the flowchart of Fig. 9.

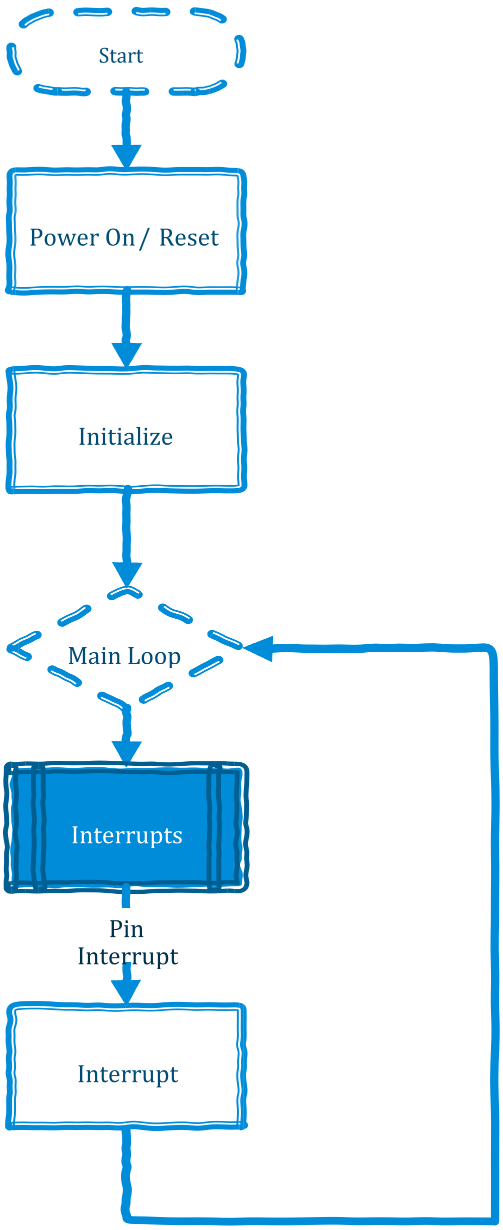

Fig. 9. Node Main Process Structure.

i. Node Main Process Stage

Fig. 9 shows the main process flow of the sensor node. First, the least level routine is initialized which enhance the core processor to interrupts. An Interruption motivated threads are formed and are energetic when the interrupt initializes them. Immediately an interruption occurs, at the completion of its cycle, the thread dismisses until there is a sequence of another interruption. The aim of employing the interrupt is to enable the processor to be woken up during sleep mode.

ii. Node Initialization Routine

The initialization routine is illustrated in Fig. 10 below. At the initialization stage, all the outward pin functions are defined, initial values, as well as internal registers and startup parameters, are set up here. The next stage after the initialization is the main loop execution stage which is discussed in (iii).

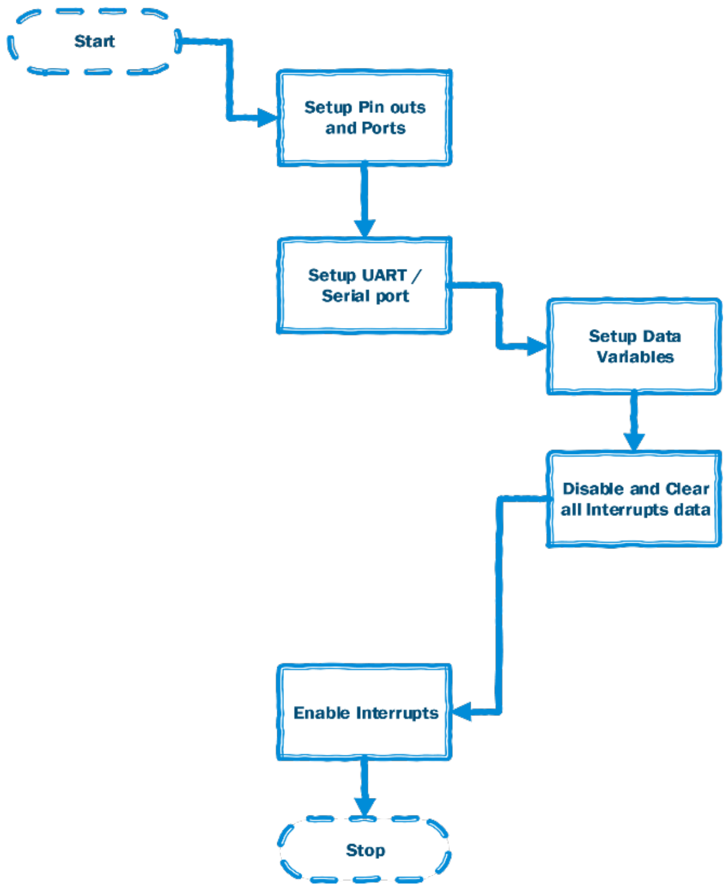

Fig. 10. Node Initialization Function.

iii. Main Loop Thread

In this stage, the control enters the main loop after initialization. Fig. 11 shows the control flow within the main loop. The node at this stage checks the UART for any data from the wireless transceiver. The wireless transceiver uses the UART protocol to communicate with the microcontroller. If data is found, it processes it to determine what kind of data it is. The data could be a configuration data, control data, or data requests. The node carries out a sensor scan to fetch data from its sensor. After data has been collected from the sensors it is compiles and the sends this out through the UART ports to the wireless transceiver for onward transmission. The node then determines if it is to carry out control actions by checking its control variable parameters.

After this, it goes to sleep mode. At sleep mode, the node is not active at all. This mode helps to conserve power usage. The node is woken up by interrupts. Interrupts from as a result of data present from the wireless transceiver or interrupts, as a result, the time has reached to send data again. Time duration used is 10 minutes.

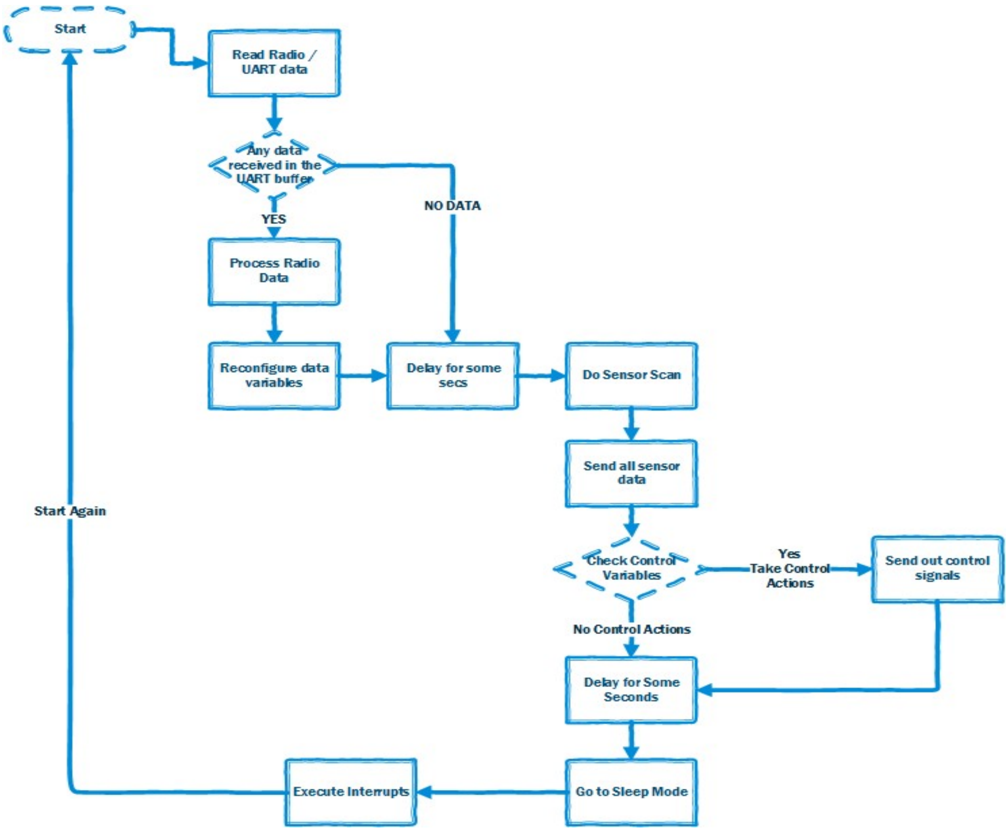

Fig. 11. Node Main Loop.

b. Node DO Sensor Scan

The Node Do sensor performs cyclic gathering of sensor data. After the gathering of data, it performs a scan which originates from the Main loop. Sensor pins are all initialized. Multiple samples of data are taken by each sensor and an average of these samples is calculated. All the sensor data are processed and combine together for easy transmission and decoding as shown in Fig. 12.

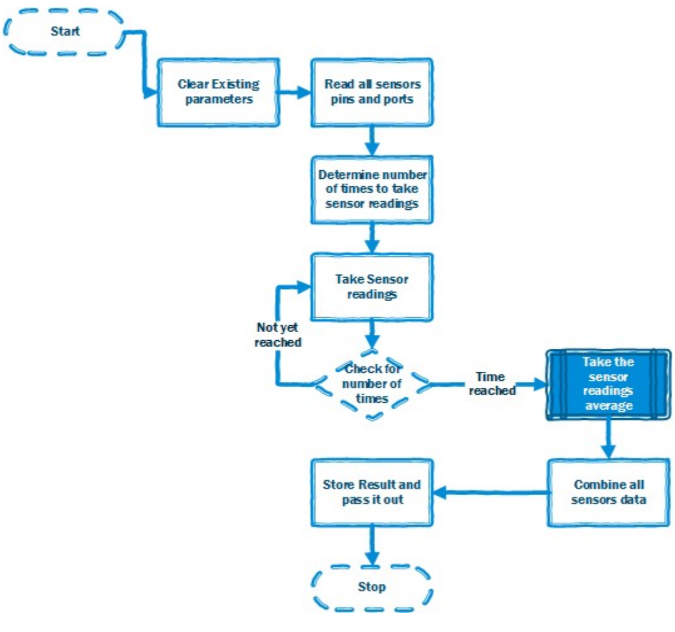

Fig. 12. Node Do Sensor Scan.

c. Node Sleep Mode Process

The Go to Sleep Mode is called from the Main loop and shown in Fig. 13. It performs the sleeping task of the microcontroller. A specific sleep mode is chosen. The Atmega 328P supports 6 sleep modes, each with its own advantages. The Sleep mode SLEEP_MODE_POWER_DOWN is chosen because it allows the device to enter the most energy saving mode during sleep. Before entering sleep mode the interrupt is disabled in order to avoid disruption of the sleep configuration and re-enable after the sleep configuration. The node is then put to sleep. The node is woken up only when interrupts occur.

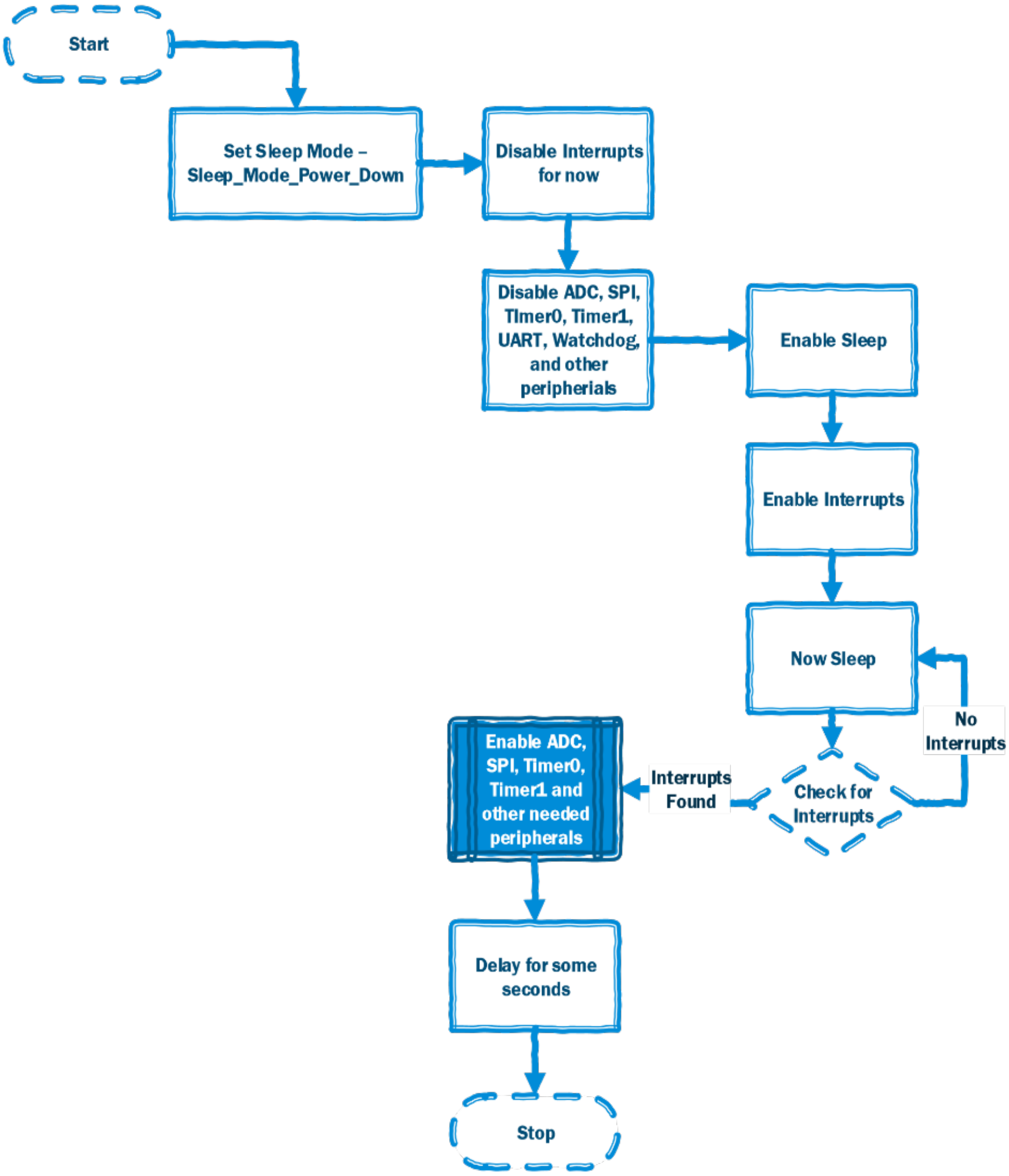

Fig. 13. Node Sleep Mode Process.

d. Software Design for the Gateway Node

The working principle of the gateway node is programmed to follow the stages in the flowchart in Fig. 14.

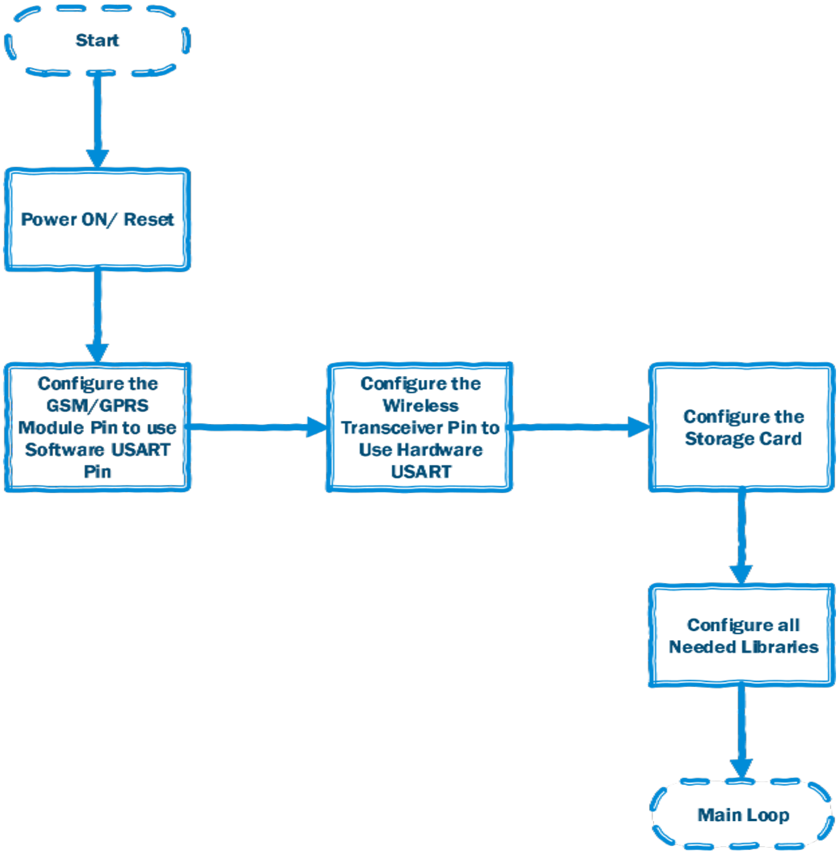

Fig. 14. Gateway main process stage.

e. Gateway Main Process Stage

The most crucial stage of the gateway node is shown in Fig. 14. It is at this stage that the gateway starts up and configures all required hardware and calls necessary libraries.

Firstly, the node starts up and configures the GSM/GPRS module attached to the board. The GSM/GPRS module is a chip made by SIM900 Company and it has support for the serial communication. The inbuilt USART port of the GSM/GPRS chip is connected to the USART pin of the ATmega 328P microcontroller. The ATmega 328P microcontroller has only one USART port but the GSM/GPRS module and the Xbee wireless transceiver also requires USART for communication.

In order to be able to accommodate the two different modules, SoftUSART where used. SoftUSART is a way of configuring other digital input and output pins for USART communication with a little degradation in speed. Since the GSM part of the work is not speed critical it was connected to the SoftUSART port. GPIO pins 2 and 3 of port A of the Atmega 328P was used for the SoftUSART. The Xbee transceiver is configured to use the hardware USART port of the microcontroller GPIO pin 0 and 1 of port A. The SD Card, attached to the board is used for data storage purpose. The SD Card communicates using Serial Peripheral Interface (SPI) to the microcontroller SPI interface. SPI is a synchronous protocol that allows a device to initiate communication with a slave device. Data is transferred between these devices. It is easy to implement and allows for serial communication between two or more devices at a high speed. Lastly, some libraries were used and were initialized at this stage. The next stage after the initialization is the main loop execution stage.

f. Gateway Main Loop Execution Stage

After the main processing stage, control enters the main loop. Fig. 15 shows the control flow of the main loop. The node at this stage checks the UART for any data from the wireless transceiver. The wireless transceiver uses the UART protocol to communicate with the microcontroller. If data is found, it proceeds to determine what kind of data it is and where the data is coming from, since there are so many nodes sending different data to the gateway. After processing of the data, it stores the data into temporary memory which is the RAM (Random Access Memory). The gateway will now check if the expected number of data from the nodes has been reached. If false, it checks for any new SMS before continuing, in case the farmer wants a request during the time the gateway is still reading data from the nodes, if a new SMS is found, it goes to check the SMS stage. If no new SMS message is found it rechecks for new data from the USART port and after receiving the expected data, it stores all data from the temporary storage to the storage card for analysis and freeing up the flash memory of the microcontroller. It recalls data from the storage card where all the data are processed and analyzed. It checks for abnormal farm conditions from the processed data, and if any abnormal condition is found that needs reporting to the farm, e.g. if an intruder was detected or farm conditions are poor it will send an SMS to the farmer about the current development. If no abnormal conditions were found, the system will check if it is time to send normal farm status message to the farmer about the current status. It sends SMS daily to notify the farmer. If the time has not reached, the system checks for any new SMS from the farmer and determines what type of message it is before going back to restart the whole execution loop again.

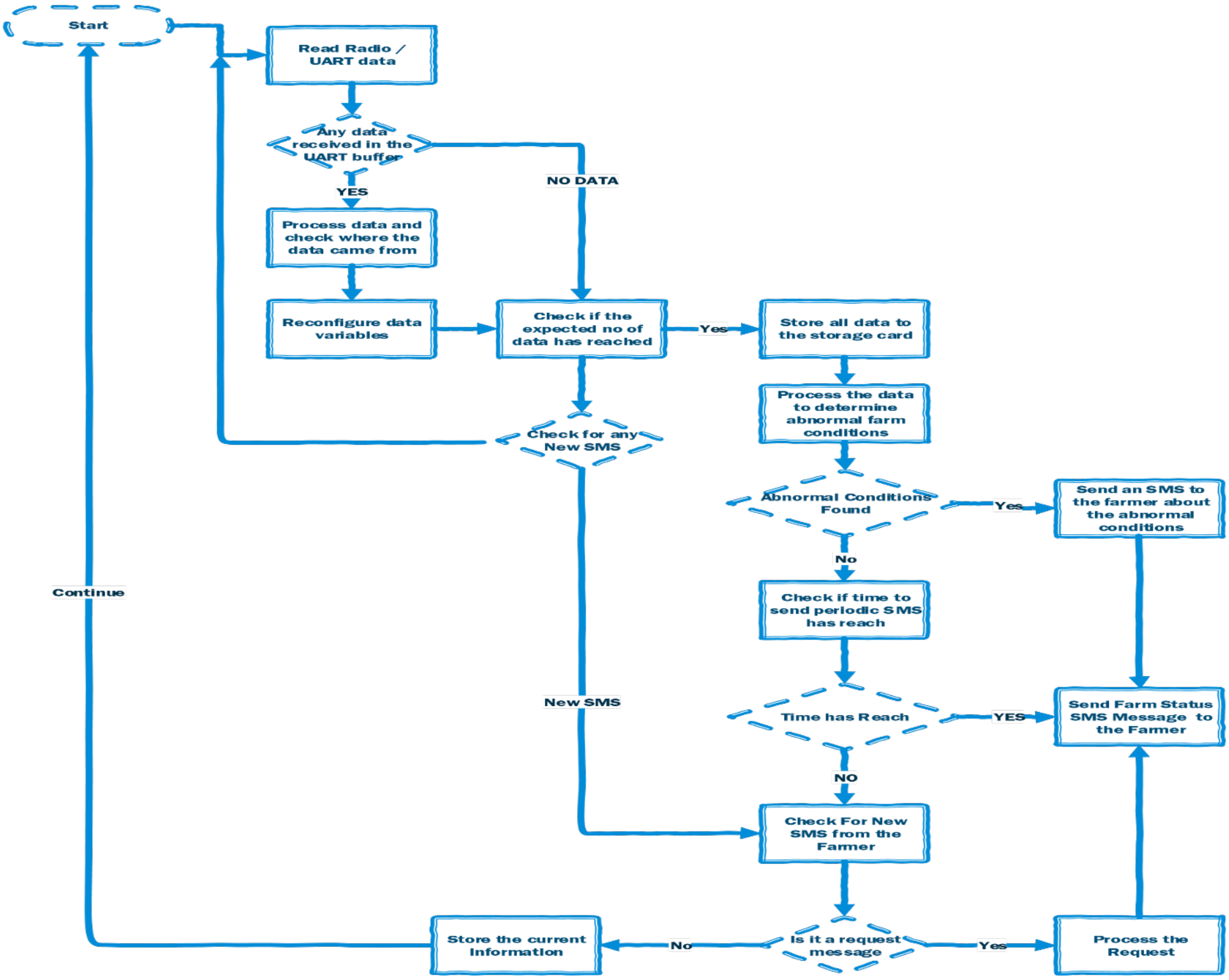

Fig. 15. Main loop execution stage.

3.4 Construction Work

The gateway is a development board from Small Iteadstduio called Gboard. The GSM/GPRS module, wireless transceiver port, storage card slot, and the Atmega 328P microcontroller are all embedded on one board. This board is used due to the high cost of making one that has all the features needed. The construction of the sensor nodes was carried out in three stages explained in (a) and (b).

a. Simulation using a CAD Software

The first stage of the design software was carried out using Proteus 8.1 simulation software. It is a Computer Aided Design software that can be used for simulating the node operation in a controlled environment. This also helped to determine how feasible and workable the design of the project would be, so as to make necessary corrections where needed.

b. Construction using Bread Board

The simulated circuit functioned as desired. Design of the system was moved to a breadboard to be able to determine the real operating conditions of the design. It was found necessary to carry out some modification on the modeled circuit.

c. Transfer to Printed Circuit Board

After confirming the design is working in the real world, a PCB (printed circuit board) was fabricated using manual means of fabrication instead of using a PCB machine. The method used involving first printing the PCB layout of the circuit to a glossy paper then using pressing iron to transfer the print out to a copper board before finally etching the board using an acid solution HCL. After the etching process, the completed board was drilled and the components were placed and then soldered on it. The board was tested to confirm if there was an error in the design process.

4.0 Results and Discussion

Wireless Sensor Network Test

We carried out Tests on the implemented WSN system to asses its performance. The performance test was carried out in an outdoor environment clustered around small classroom buildings. Fig. 16 shows the network layout that was used. The nodes are represented in boxes and the gateway is represented as a triangle. The results of the test and a short analysis are given in (a).

The tests were conducted.

i. Node coverage test
ii. New node's joining the network after network setup
iii. Network setup time
iv. Power consumption test and battery lifetime
v. Communicating through SMS

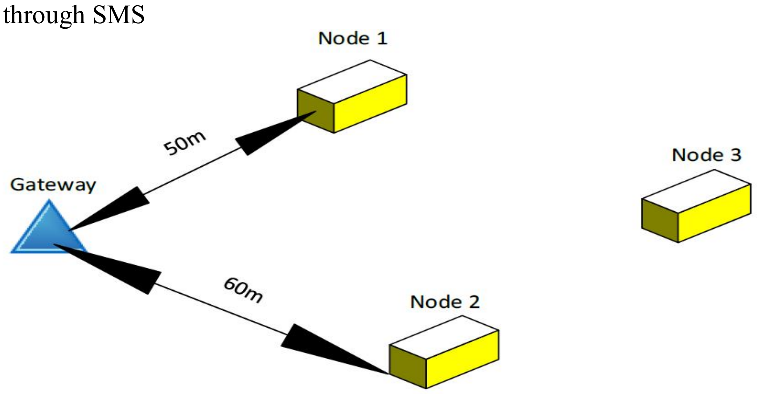

Fig. 16. Network layout with no support for multi-hop capability.

a. Node Coverage Test

Fig 16 below demonstrates the network layout which was adopted for this test. Because of the obstructions of buildings, the network's gateway node coverage range is about 80 meters. Node 1 was deployed at roughly 50 meters distance from the gateway. Node 2 was deployed within the coverage range of the gateway of about 60 meters. Node 3 was placed such that it was out of the coverage range of the gateway both Node 1 and Node 2 were configured as end devices and not as routers. Node 3 was unable to communicate with the gateway and the network. When Node 1 and Node 2 are reconfigured as routers, the network range increased, thus allowing Node 3, which was out of the radio coverage range of the gateway to be able to communicate with the other two nodes that forward the data to the gateway as shown in Fig. 17.

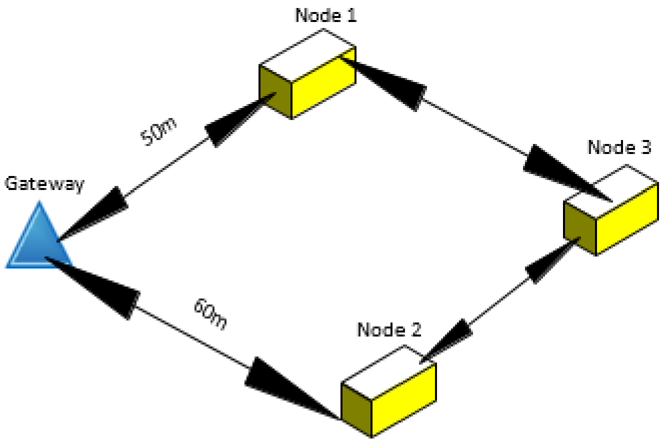

Fig. 17. Network Layout with support for multi-hop capability.

b. New Nodes Joining the Network

When new nodes were to join the network and the node was placed within the coverage range of the gateway, it starts communicating with the gateway directly and when the node was placed out of the coverage range of the network, it was unable to communicate with the gateway.

c. Network Setup Time

The change in the network setup time is shown in Fig. 18. The variation in the number of nodes in the network can be seen from the graph in Fig. 18. When the number of nodes in the network increase, the time for the network setup also increases. The network setup time here is the time the gateway node uses to configure all the nodes at full startup.

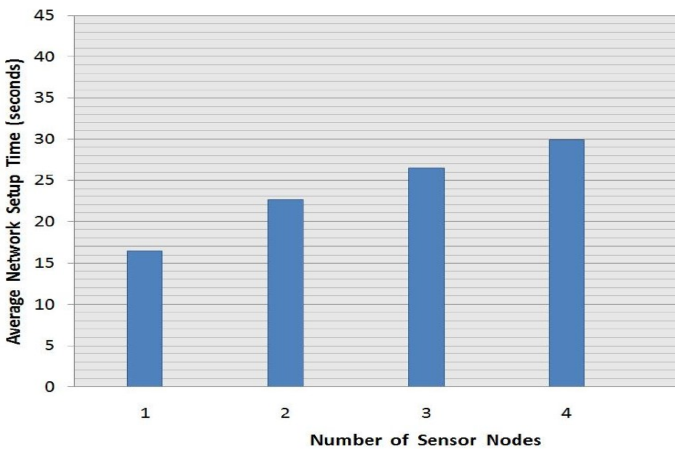

Fig. 18. Network Setup Time.

d. Power Consumption and Battery Lifetime

The power consumption for the sensor nodes is an important factor that will help to determine the performance of the network, the probability of failure of the node and the battery lifetime of the node. The energy source for the sensor node uses four 1.5 volt AA batteries with a capacity of 6000mAh. Power consumed by the sensor node during operation is 80mA and power consumed by the node when sleeping is 1mA. The sensor node is active for about 1 second and sleeping for about 10 minutes which is equivalent to 600 seconds.
Based on this observation, the average current drain is given in Eq. (1) and (2).

$$\frac{80\times 1+1\times 600}{600+1}=\frac{680}{601}=1.2mA\ per\ 601s\ =\ 1.2mA\ per\ 10mins \tag{1}$$

The battery lifetime calculation is shown below,

$$\frac{\frac{6000 \times 60 \times \frac{1}{60}}{\frac{1.2}{10}}}{24hr/day} = 2083\ days\ =\ 5.76\ yrs \qquad (2)$$

The ideal life for the sensor node using the 6000mAh battery is about 5.76 years. The estimated value does not include battery discharge rate and other factors that will normally affect battery life, but with all factors included the lifetime for the sensor node can be estimated to about 3-4 years before replacing the battery.

e. Communication through SMS

After the WSN was created by the gateway node. The gateway was able to collect readings from the sensor nodes, also it was able to send an SMS message to the farmer about the current farm development.

5.0 Conclusion

This paper presents a WSN system for the purpose of agricultural monitoring that is supported by the ZigBee network protocol technology. The designed WSN system is compatible with other sensor nodes. These sensor nodes are able to monitor farm environmental parameters such as soil moisture, humidity, air temperature, and light intensity. Its compatibility with other sensor nodes allows more sensors to be conveniently attached to it and to control the irrigation system through its output port. A communication link between the farmer and the farm system was established by employing the GSM communication technology, where the farmer can request for information about the farm and the farm system can notify the farmer about the farm development.

Future research efforts will focus on reducing the size and cost of the sensor nodes. Surface mounted components can be used instead of the through hole components used for making the sensor node. This will significantly reduce the size. In addition, a low-cost wireless transceiver e.g. the CC300, nRF24L01 module, can be used instead of the XBee module used in this work. This will reduce the cost and size of the sensor nodes. Mass production of the sensor nodes will also reduce the SNs.

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