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Agriculture Data Logger Using GPS Equipped Wireless Sensor Network: A Model to Support Ghana Planting for Food and Jobs Program

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Abstract
The Government of Ghana's agenda to maximize food production in agriculture requires the need for the design and development of innovative agricultural systems. Due to the high demand for land for farming which will likely cause deforestation and global warming, coupled with restricted access to some farmland due to distance or pandemics such as COVID-19, there is the need to use technology to optimize farming through precision farming. This paper proposes a model of an agricultural data logger using a wireless sensor network for agricultural parameters collection. The system logs soil temperature, moisture, humidity, and light intensity, transmits and stores the data in a central server for decision making. The wireless sensor network constitutes two nodes and a base station. Each node is a standalone system with sensors; temperature sensor, soil moisture sensor, humidity sensor, and a light sensor. The base station receives information from the various nodes through its network-equipped system. The network system is well secured through proper encryption of data. Global Positioning System is deployed in the proposed system to generate the longitudes and latitudes of the individual nodes. The soil data collected is display on a website and a database is incorporated in the website design to keep records of previously collected data for analysis and better farming decisions. The system consumed low power through the use of a low-powered microcontroller, NodeMCU, and the implementation of the wake and sleep mode of the sensor nodes.

Keywords
Base station; Node; Wireless Sensor Network; Global Positioning System; microcontroller; precision farming

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Contents

1 Introduction 8
2 System Design 10
3 Test and Results 11
3.1 Design Architecture 12
3.2 Battery Efficiency 13
3.3 System Test 13
4 Conclusion 13
5 Acknowledgement 13
References 13

1. Introduction

Agriculture is the backbone of the economy of major developing countries in Africa and the world as a whole. Due to the high demand for food, many efforts have been put in place to maximize agricultural productivity. The Ghana Planting for Food and Jobs (PFJ) Program is a government of Ghana program which was launched in 2017, to serve as a transformational tool in the agricultural sector to increase food production, improve food security and create job opportunities. This program has improved the agricultural sector of the country and this can be sustained by providing support through the design and development of innovative agricultural systems (Ministry of Food and Agriculture, Republic of Ghana, 2017). In recent times, technology has enhanced the standard of living by improving and sustaining life. Agriculture has been improved tremendously through innovative technologies such as precision farming and the use of advanced farming machinery. Wireless sensor network (WSN) has been a vital tool for the design and implementation of innovative agricultural systems.

In (Sathish and Thilagavati, 2013; Culibrina and Dadios, 2015) a ZigBee based WSN is implemented to monitor environmental conditions such as soil moisture content, soil temperature, weather, and soil fertility. The system deploys a wireless network that is energy efficient and incorporates a website that provides farmers with a view of the status of their farmlands in relation to environmental conditions. The data transmission rate of the system is very low with an unsecured network due to Zigbee network technology deployed. Authors from (Zu et al. 2015), designed a farmland environmental monitoring system for simultaneous monitoring of environmental parameters, which includes: soil temperature, moisture, humidity, illumination intensity, pH value, and CO2 concentration. Also, real-time acquisition, transmission, and predictive analysis of the information on crop growth are implemented. A tree network topology is deployed in the system. A major setback of the system is its higher probability of network failure. This is the result of the interconnection of the sensor nodes, hence a failure in one sensor node causes an entire network failure. In (Shinde and Siddiqui, 2018; Vincent et al. 2018), environmental parameters are monitored and the values are recorded. The system deploys a Raspberry Pi 3 as a central unit for logging, hosting, and uploading onto the internet, where any web-based devices can access these data for analysis. The system also constitutes an Arduino Uno-based sensor node and a transceiver. The Raspberry Pi 3 makes the system flexible, however, the design is expensive and lacks analog to digital converters.

An agricultural data logger called WiField is designed in (Brinkhoff et al. 2017; Paul and Chattopadhyay, 2016). The system is designed to gather and upload agricultural parameter data to cloud services in real-time. The data logged is analyzed through interactive graphs. The microprocessor is programmed using Squirrel programming language, to process the collected data. The system incorporates several Field Effect Transistors (FETs) for switching on the sensors and controlling the solar charging of the power supply (batteries) for better power optimization. The WiField device tends to be costly due to its components. In (Yong, 2010; Bhanu et al. 2014), agricultural parameters like humidity, light, and temperature are monitored. The data are collected and recorded for analysis, using a WSN system. The system's base station provides storage capability to data received from the sensor nodes. An agricultural data model called AgriLogger is designed in (Ladaresta et al. 2020). The AgriLogger model developed is capable of monitoring, collecting, and storing environmental data (temperature and relative humidity). This model is deployed in remote areas where the telecommunication network is low, hence it incorporates a drone for the data gathered from the farmland to the base station. The major setbacks of the system are the limited number of agricultural parameters it can monitor, and the very expensive due to the use of drones.

A design and conduction of a data acquisition system are discussed in (Tagle et al. 2018; Guico et al. 2019). This system provides the capability of logging many farmland parameters such as water level, relative humidity, pH level, air temperature, and light. In (Devi et al. 2019), a wireless network system is designed to monitor farmland parameters (temperature, light, and humidity). The system provides security features through theft detection. A GPS is developed in the system for easy location of farmlands. A web-server is created to host the data, with an android app developed to access information about the condition of farmlands (Han et al. 2017).

The deployment of WSN can be adapted for a more specific environmental condition or specific crop as done by (Majone et al. 2013) in their design and implementation of a WSN in an apple orchard. They aimed to check the soil dynamics suitable for the apple plant growth. They use a multi-hop wireless mesh topology that comprises many homogeneous sensor nodes. The mesh topology has the disadvantage of high processing power consumption due to the multipath communication as compared to the star topology employed in this paper. A solar-powered energy source was employed to provide power to the WSN which is problematic in a farm set up as the wiring of the whole network gets complex. In this paper, a WSN model is used to develop a data logger for data acquisition of agricultural parameters to aid in agronomical decision-making to enhance productivity. These parameters are soil temperature, moisture, humidity, and light intensity. The basic component of WSN model includes sensors, microcontroller, a transceiver, power source, and GPS. A Base station is developed to store information relayed from the various nodes. A subnetwork is created in the model, where each node is assigned a fixed IP address for easy data acquisition at those nodes and also easy routing of data packets. This design uses Wi-Fi technology for the transmission of data which provides a secured and high transmission rate. Also, a NodeMCU that incorporates an RF transceiver and an ADC is implemented in the system for easy transmission of data. A star network topology is used in this proposed system to ensure reliability.

The motivation behind this Agriculture Data Logger using GPS equipped wireless sensor network is to maximize food production through modern innovative agricultural systems like precision farming. The use of transducers and Wi-Fi technology to make analytical decisions on the farm to maximize crop yields is the main focus of this research. Organizations and research firms have invested a lot to increase food production across the globe to alleviate hunger and starvation. Researches have been made in areas such as pest control, fertilizer production, precision farming, food storage, biotechnology, and monitoring technologies for maximum crop yields. The application of technology in farming has however been on the low side mostly because of lack of knowledge and local technology infusion in farming processes. The United Nations Development Programme (UNDP) as part of their Sustainable Development Goals (SDG) has come up with an initiative called leaving nobody behind. As part of these goals is a zero hunger which aims to end all forms of hunger and malnutrition by 2030 (The United Nations Strategy Beyond, 2015). Promoting sustainable agricultural practices will be needed to achieve this. The Covid-19 pandemic has also impacted the agriculture sector by restricting the movement of goods and services through the measures put in place to curb the spread such as self-isolation, quarantine, lockdown, and social distancing. All these measures hinder farmers from visiting their farms regularly which can affect their productivity. Modern farming practices such as precision farming can help farmers in such situations to still monitor the progress of crops remotely from the comfort of their homes.

2. System Design

The proposed agricultural data logger system is described in Figure 1 and Figure 2 by a block diagram and flow chart respectively. It constitutes a base station and two sensor nodes. The various sensor nodes are equipped with GPS modules that generate coordinates of the nodes. The individual nodes are connected wirelessly to the base station. A backup unit is connected to the base station to keep records of the transmission of data from the two sensor nodes to the base station for future purposes. The web application displays the agricultural data parameters of the various nodes stored in the base station.

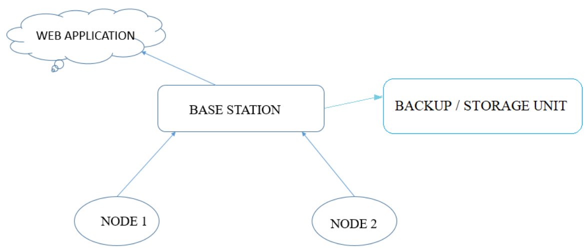


Figure 1. Block diagram of the system

The node shown in Figure 3 is made up of four units in its architectural design which includes sensing, processing, communicating, and a power supply unit. The sensing unit monitors the agricultural parameters. The data read by the sensing unit is collected and processed by the processing unit and transmitted to the network by the communication unit. The power supply unit has the purpose to supply energy to the node.

The sensors' data are relayed to the NodeMCU controller where the data is processed and stored on an SD card. The base station operating as a server creates a Local Area Network where the various nodes join using their already assigned IP addresses. A webpage is developed to serve as an interface that displays the environmental parameters to the user. The GPS module in the system generates longitude and latitude coordinates which help to determine the location of the individual nodes. The sensing unit detects the agricultural parameters from the environment. It comprises a light sensor, humidity sensor, temperature sensor, and soil moisture sensor.

A soil temperature sensor is an electronic device that measures an analog signal/value and converts it into a digital value. The proposed system has one temperature sensor on each node. An LM35 temperature sensor is employed to detect the ambient temperature and convert it into an electrical voltage which is directly proportional to changes in temperature. Thus, for a temperature change of 1°C, an output voltage change of 10mV is obtained. The humidity sensor measures the amount of water in the atmosphere and converts it to a corresponding electrical signal. It detects the relative humidity of the immediate environment in which it is placed. The Soil moisture sensor measures the amount of water content in the soil at a given time. The design uses a capacitor-based soil moisture sensor, which operates by using the capacitance of the device to measure the dielectric permeability of the surrounding medium. It has two pads that serve as probes for the sensor, to measure the moisture content in the soil. The soil moisture is expressed as LOW (for dry soil) or HIGH (wet soil). A light sensor measures the intensity of light and converts the photons detected to electrical energy. The light sensor in the design is a Light Dependent Resistor (LDR). The LDR works on the principle of photoconductivity. The light intensity is expressed in lumens.

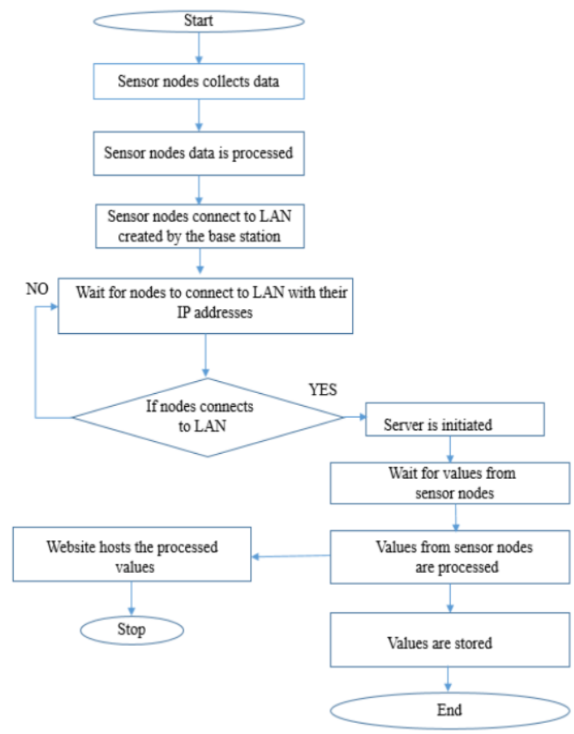


Figure 2. Flow chart of the proposed system

The base station is the central unit of a WSN shown in Figure 4. It acts as a server where all data collected from the two nodes are stored and hosted. Also, the base station creates a local area network, where the nodes connect to and forward data packets. The communication unit is equipped with an RF transceiver for receiving data from the various nodes through wireless means. A Local Area Network is created in the design, where an IP address is assigned to the base station with the creation of subnets for the various nodes. The IP address assigned enables a user to access all information via the internet. Finally, for future analysis and the possibility of a loss of data packets during transmission to the user, a backup unit is created to store all data processed by the base station. The backup unit makes the system resilient to failurs. The user can receive data from the sensor nodes directly after being processed by the base station or from the backup unit which already has the processed data. This makes the system more reliable.

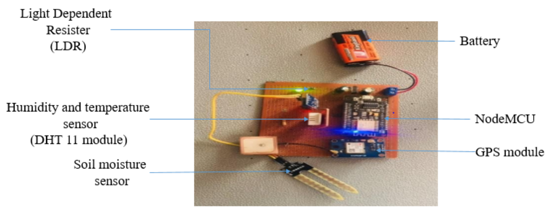


Figure 3. Structure of Node

The base station receives the data packets from the nodes and hosts the data packets for easy access. The Agriculture data logger presented is simple but robust. The system is well optimized concerning power consumption and size, hence very portable and easy to install. The Agriculture data logger features a cost-effective microcontroller, NodeMCU which is programmed using Arduino IDE software for the operation of the system. Wi-Fi technology is used for the transmission of data, providing data security and a high transmission rate. The transmission of data in this system is very secure and reliable due to the deployment of a star network topology, where a breakdown of one node does not affect the entire system operation.

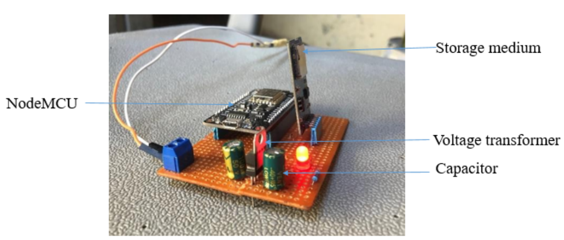


Figure 4. Structure of base station

3. Test and Results

The proposed system is tested with two nodes place in two soil samples with different soil conditions as shown in Figure 5. The base station is wirelessly connected to the nodes through its transceiver to collect the data at five seconds intervals. Node 1 is mounted on 'Soil Sample A' and node 2 on 'Soil Sample B'. The various sensors collect temperature, humidity, sunlight, and soil moisture.

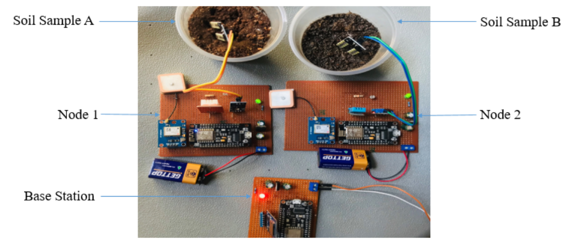


Figure 5. System test on soil samples

The system acquires soil samples data and displays it on the webpage interface call AGRITECH in this work to show the various environmental parameters. AGRITECH GH has a login page shown in Figure 6 which provides access to all nodes' current states and database of previously collected data shown in Figure 1 to 9.

Figure 6. Login display

The dashboard displays the status and records the data of the nodes. The status shows the current condition of the farmland, thus the temperature, soil moisture, light, and humidity values in real-time as shown in Figure 8. The records show the parameter data collected over a period shown Figure 10.

A range of 0-200 lumen shows a low light intensity, 200-500 lumen shows a medium light intensity and any value above 500 lumen shows high light intensity.

Figure 8 shows the current condition of soil sample A. The results show that the soil has high soil moisture,

Figure 7. Dashboard display

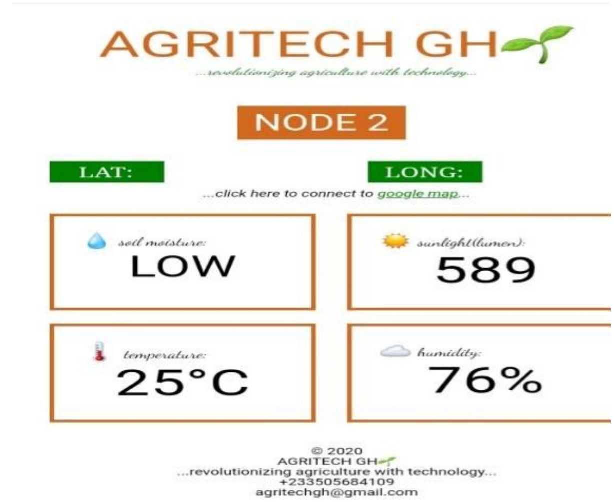


Figure 9. Status display of node 2

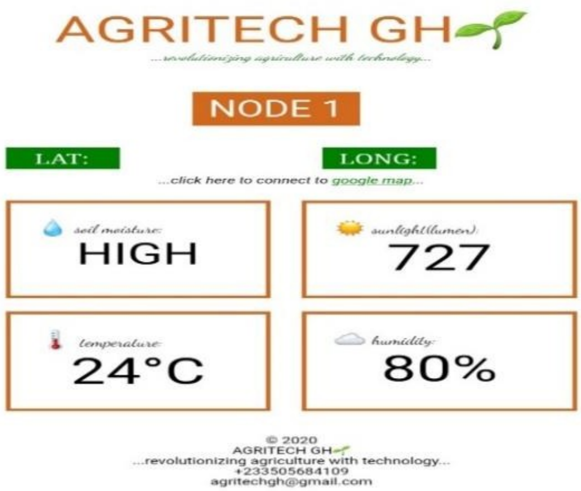
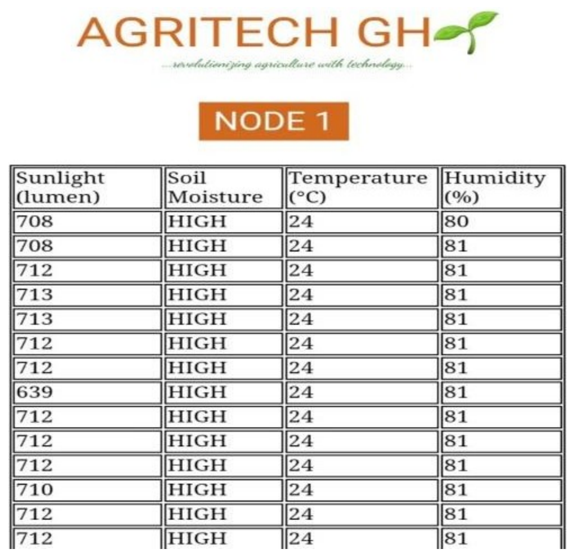


Figure 8. Status display of node 1



Sunlight (lumen)	Soil Moisture	Temperature (°C)	Humidity (%)
708	HIGH	24	80
708	HIGH	24	81
712	HIGH	24	81
713	HIGH	24	81
713	HIGH	24	81
712	HIGH	24	81
712	HIGH	24	81
639	HIGH	24	81
712	HIGH	24	81
712	HIGH	24	81
712	HIGH	24	81
710	HIGH	24	81
712	HIGH	24	81
712	HIGH	24	81

Figure 10. Database of node

727 lumens of light, 24°C temperature, and a humidity of 80%. Soil Sample B data is shown in Figure 9.

3.1 Design Architecture

The star single-hop topology use in (Tongtong et al. 2011; Shaikh et al. 2010) have the advantage of reliability due to the simple structure of the architecture that ensures easy fault tracing. It also ensures reduce energy consumption in processing due to it not using multipath communication as is the case of the mesh topology in (Majone et al. 2013; Vellidis et al. 2013) where information transmission happens between all nodes as each node becomes an information relay to the base station. The cluster topology incorporates two or more star topology as in (Sudha et al. 2011; Peng and Liu 2012) to cover a larger area with reduced transmission power compared to if each sensor node was transmitting to a distance base station (Anisi et al. 2014). The cluster system also maintains the simplicity of the star topology. The cluster stem that can be employed in this work is been adapted for large-scale farming of multi-farm farm system that is separated by long distance.

3.2 Battery Efficiency

Sensor nodes' performance duration is dependent on the power supply specifications and availability. Batteries and solar are the common use power supply. The connection to the solar power supply may not be convenient for a farm setting. The xx batteries are used in this work. Due to the difficulty presented in power supply and or sensor replacement when they exhaust their lifetime, there is, therefore, the need for efficient energy usage and employing methods that conserve energy. This work uses the sleep and wake method where sensors are not always active but come alive only to take measurements and go back to sleep. This helps preserve the battery life. The simplicity of the topology use also implied reduce processing in finding nodes or communicating with a base station which reduces power consumption. The average current consumed by the sensor node can be calculated using the formula, (Koushik, 2021) average sensor calculation approach.

Conservation of power was achieved using the sleep mode functionality of the microprocessor. After the collection of data, the base station processes these data and enters into sleep mode waiting for the next scheduled collection of data from sensor nodes. Power consumption is high at the base station because it almost continuously transmitting data packets. The solar panel can be installed alongside the battery at the BS to increase the efficiency of the system (Pierce and Elliott, 2008).

3.3 System Test

The whole system setup was put to test in a laboratory. Two soil samples A and B were used to determine the performance of the sensor nodes. Each NodeMCU collects data from the sensors and stores the data on an SD card. Wifi technology was used for the transmission of data. Subnetting technique was also used for individual sensor NodeMCU to establish wireless communication with the base station. Data transmitted from sensor nodes were encrypted to stop intruders and provide security. The next field test would be to evaluate the collection of data in two different seasons as deployed (Mohamed, 2020). The challenge with such a WSN system is power supply, faulty sensor detection, and replacement in the system. There is also the education of usage of technology in farming in Ghanaian society and financial backing for scalability.

4. Conclusion

The significance of the farm to Ghana's economy and sustenance cannot be downplayed as Agriculture accounts for 19.7% of Ghana's Gross Domestic Production (GDP) (Ghana Statistical Service, 2019) and major sector for Ghana employed population. As the Ghanaian population is increasing, so is the dependency on agricultural produce. This has brought the need for more land for farming than when not manage will become a serious national and global crisis because more forest will be cleared for farming purposes which would aid global warming and adversely affect the environment. The need to optimize farm processes through the use of technology to increase farm yield for the minimum resources available is necessary. This proposed system provides log data using a wireless sensor network, equipped with a GPS module. The system is capable of collecting agricultural data parameters by the sensor nodes. An RF transceiver that transmits the collected data to the base station. The base station provides a storage system where data is kept for some time. The system can be adapted for remote monitoring of conditions of farmlands that may be difficult to visit on daily basis to make better decisions on suitable crops (seeds) to grow at a particular season based on the environmental conditions. The database design in the proposed system provides vital environmental parameter data collected over time, which can be analyzed to make better agronomical decisions. The incorporation of a GPS module also aids in the location of farmlands by generating longitude and latitude coordinates of sensor nodes, for easy access to environmental parameter data. The proposed system if adopted will help in the implementation of PFJ which will increase the sustainability of the agricultural sector by providing data for decision making in precision farming. The challenge of financial backing to scale the system can look at in future works with other sensors to track other environmental parameters, animal and plant health within a locality to facilitate policy and decision making in things that have to do with plant and animal health especially seasonal diseases and pests. Also, a nationwide synchronization of various WSN systems backed by privacy policy could be implemented to facilitate national planning and decision-making in agriculture and environmental wellbeing.

5. Acknowledgement

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