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IMPLEMENTING SMART FARMING USING INTERNET TECHNOLOGY AND DATA ANALYTICS: A PROTOTYPE OF A RICE FARM

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Precision Agriculture which includes the implementation of smart farms is gradually becoming commonplace in our present world. The Internet of Things (IoT) and also Analytics techniques are useful tools for the actualization of smart farms as they allow for information dissemination to rural farmers and also serve as a platform for monitoring farm activities. When farm activities are properly monitored, food production is optimized. As the world's population grows, there is a greater challenge of the availability of food. The combination of IoT and data analytics has not been fully explored for Smart farming especially in developing economies. This paper proposes a FarmSmart Application using an IoT-based mobile monitoring system that combines sensors, and data analytics to manage irrigation processes and broadcast Agricultural information to farmers. The FarmSmartApp was implemented on the IntelliJ IDE using C++ and MongoDB.Python and Excel were used for the data analytics. The effectiveness of the proposed system is examined on a real-world dataset harvested from the mounted sensors. Also an initial evaluation of the system is done by stakeholders. Simple Analysis of Variance of light, moisture and temperature led to the rejection of the null hypothesis of no significance difference in mean effect among the variables since fcalc is greater than fcrit justified by p value less than 0.05. On the system evaluation, 97 % of the examined stakeholders agreed that the system delivered on the agreed functionality .The system therefore has the capacity to provide farmers with useful Agricultural information to guide irrigation procedures and Agricultural decision making

Keywords: smart farming, internet of things, irrigation, information broadcasting, and data ingestion

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1. Introduction

Smart farms have become a popular farming alternative in our digitalized world and they have come to stay. The Internet and also Analytics techniques are useful vehicles in the implementation of smart farms as they allow for information dissemination to rural farmers and serve as a platform for monitoring farm activities. These lead to increased food production. In spite of advances in technology and other human endeavours, humans and other living species need energy in order to live, work and survive in our immediate environment, which is guaranteed only by food. According to the United Nations' (UN) Food and Agriculture Organization (FAO), the global population is expected to surpass 9 billion people by 2050. To produce enough food for the given population, Agricultural production volumes have to increase by 70 % [1]. With an expanding population currently at 190 million in Nigeria, it is obviously evident that it is necessary to embrace innovative ways of implementing best practices in Agriculture that would increase food production to cater for the teeming population.

The absence of mechanization is a major challenge as it limits the progress of farming activities, which stagnates development. Since large-scale Agriculture is not common; Agricultural holdings are small and scattered, and farming is carried out with simple tools. Also, uncertain weather conditions and subsequently climate change determine to a large extent Agricultural crop yields. Farmers in Nigeria depend majorly on the natural God-given weather conditions. Consequently, farmers do not only wait until the rainy season before planting crops, but also completely depend on the sufficiency of the rain to take the crops to yielding stage. Sometimes the farmers may experience low yields possibly because the rain is too much or because it is too small depending on the type of crop that a particular farmer may plant [2]. Variability in weather conditions negatively affects farm productivity if weather forecast is not enabled through scientific and technological support to reduce the risks and losses [3]. Little or no use of Internet-of-Things (IoT) and Mobile Technology on farms makes it difficult for farmers to continuously monitor their farms, reduce manual labour and manage moisture content for specific soil types and specific crops [4]. Most farmers do not know the particular soil type they are farming on and also do not have at their disposal the right information on the right seed variety to get optimum yield on a particular soil type. The difficulty in transforming rain-fed farming into more productive and sustainable systems to support national populations that depend on them is a major challenge in agricultural development [5]. Decision makers (government) not having access to information on farms causes them to make faulty decisions regarding agricultural interventions.

With Smart Farming, farmers are able to implement weather tracking applications to help them take precautions against adverse weather conditions. Tracking applications could predict high or extremely sunny weather for farmers and enable them make provision for irrigation to prevent plant from dryness. With IoT-based Smart Farming, farmers could have access to Geo-Positioning System (GPS), soil scanning, data management, and IoT technologies. By precisely measuring changes within a field using sensors, farmers can greatly increase the effectiveness of irrigation activities while being more accurate about it. This means that the cooperative farmers would be able to use IoT and Mobile Technologies to inform interested and registered farmers when to irrigate their farms at the right time with the right quantity of water. Thereby, maintaining the essential moisture level in the soil. Therefore, research devoted to the development of a broadcast application using a combination of Internet of things and Data Analytics is relevant.

2.Literature review and problem statement

Smart Farming is not only possible, but has become increasingly pervasive due to the introduction of IoT in farming methods and processes. This pervasiveness is because of the increasing availability of various building blocks that constitute IoT such as sensors, software, network components and other electronic devices including smartphones. With IoT, every object that has the capacity to generate data can be assigned an IP address so that it can transfer data over a network [4]. It was reported that by the end of 2016, there will be 30 % rise in the count of connected devices compared to 2015 with this count further increasing to 26 billion by 2020 [6]. In fact, it has been projected that the Smart Agriculture market, by 2022, is expected to reach a value of $18.45 billion at an annual growth rate of 13.8 %. It was also projected that by 2020, 75 million IoT devices will be shipped for Agricultural uses. These projections point to the need for the adoption of Smart Farming for the present and the future. The paper [7] outlined the recent applications of Wireless Sensor Networks (WSNs) in agriculture research as well as classified and compared various wireless communication protocols, and the taxonomy of energy-efficient and energy harvesting techniques for WSNs that can be used in agricultural monitoring systems. The paper in its review also compared early research works on agriculture-based WSNs. While this study was helpful in so many ways including demonstrating how WSNs could drive Smart Farming and agriculture research it did very little in demonstrating how the farmer could interface with the system and get real-time updates regarding farm situations The paper also stated that "Smart Farming permits the association of crop data, which includes crop performance, environmental, soil, irrigation, and fertilisation data, and related data analysis results with specific crop varieties such as plant genes and phenotypes". They pointed out that the association of all this information will revolutionize food production worldwide.

An executive summary presented by Food and Agriculture Organization [8] showed that Smart Farming in some contexts is also referred to as precision Agriculture, which is an all-encompassing term as it brings smart metering and smart cities on board as well. It was explained in the study that Smart Farming makes it possible for farmers to rely on the presentation of a wide variety of information regarding soil and crop behaviour, machine status, storage tank status emanating from remote sites so as to take appropriate actions at the right time. The study went further to list Sensing Technologies, Data Analytics Solutions, Hardware and Software Systems, Telematics, Positioning Technologies, Communications Systems, and Software Applications as the different types of technologies that constitute Smart Farming.

In a research study, [4] focused on the role of Internet of Things (IoT) in agriculture as a way of arriving at Smart Farming. The study explained key reasons why Smart Farming is the way to go for Agricultural production today and in the future. It stated that enhancing efficiency, productivity, global market and other essential features to living standards such as minimum human intervention, time and cost were listed as essential reasons for embracing Smart Farming. The study predicted thatIoT will play a significant role in driving Smart Farming to minimize human efforts and simplify farming techniques if the use of smartphones and that IoT devices can be encouraged in various aspects of Agricultural production. However, it did not provide insights into possible techniques and technologies that will enable farmers and other relevant stakeholders interact with the IoT devices and their smartphones.

The paper [9] aimed at characterizing the scientific knowledge about Smart Farming contained in global scientific literature as well as describing current Smart Farming prospects in Brazil from the perspective of experts in the same field. While the research study provided the perspective of experts regarding Smart Farming in Brazil, it was not enough to understand possibilities of Smart Farming with regards to the Nigerian environment. However, the methodology adopted for the study was considered to be useful in conducting a research that will help to understand how Smart Farming can be implemented in Nigeria. This was demonstrated in the decision to conduct semi-structured interviews with market and research experts in Brazil using a bibliometric survey methodology with the help of a data mining software The paper showed that there was a challenge of integrating the different available Smart Farming systems on the market and the challenge of lack of education, ability and skills of farmers. .

A research study [10] discovered that the yield of Agriculture is decreasing day by day, but with the right implementation of an IoT based Smart Farming system, production will increase while extra man power efforts will significantly reduce. To conduct this study, the paper developed a remote sensing and control irrigation system that uses distributed WSN in full to achieve variable rate irrigation, real-time field sensing, and control in a site-specific precision irrigation system. This maximized productivity with minimal use of water.

In 2016, a study [7] was conducted to present the design and implementation of SmartFarmNet, an IoT-based platform. It is considered to be the largest system in the world in terms of the number of sensors attached, crops assessed, and users supported, that provides crop performance analysis and recommendations. It was developed to automate the collection of environmental, soil, fertilisation, and irrigation data; automatically correlate the data and filter out invalid data from the perspective of assessing crop performance as well as compute crop forecasts and individualized crop recommendations for any specific farm.

A good number of research works have been conducted to figure out ways of implementing Smart Farming technologies to help address the issues of economy diversification, food security, and low levels of Agricultural exports in Nigeria. [11] discussed the application of IoT technologies and Data Analytics in agriculture and presented the benefits and challenges of deploying IoT and Data Analytics. The study showed how IoT is deployed in Plant Farms using a company called Libelium in Columbia as a case study, who installed several IoT kits to control the conditions of the soil. With IoT technology deployed humidity, temperature, soil moisture, radiation, and leaf wetness information was received. The study also reviewed how the MilkTrack app is to monitor the milking process of cow by providing data on the temperature, yield and conductivity of the milk. The paper went further to demonstrate how analysis of the data acquired can be used to inform the farmer of the health state of the cows. identified and discussed the application of IoT and Data Analytics to solve these issues. The paper proposed IoT and Data Analytics methods used in developing countries that can be adopted in Nigeria to solve Agricultural issues. The MilkTrack app, which monitors the milking process of cows by providing data such as the temperature, yield, and conductivity of the milk was discussed. Analysis of the data generated informs the farmer of the health state of the cows. This application has been deployed in Kenya and Nepal.

The paper [12] examined the Precision Agriculture concept applied to agricultural production as a way of managing natural resources and realizing modern sustainable development of agriculture using Information Technology. Technologies considered in this study included Geographic Information System, Satellite Remote Sensing, and Global Positioning System (GPS). This study helped to demonstrate how Nigeria has been able to harness these technologies to implement Precision Agriculture in order to open up much more opportunities for local farmers. Even though the study did not demonstrate how these technologies could be designed, modelled and implemented for deployment by stakeholders such as farmers, it provided a basis for such a research project to be conducted. A method of approach was presented that detailed the technical phases required for the deployment of any Precision Agriculture technology and stated some of the benefits of Precision Agriculture. One of them is the fact that different levels of farm inputs can be administered to a specified area of land within a region depending on the various yield potentials of the crops in that particular area of land. This is because precise data about the soil types and the most viable crops on those soil types is made available for the farmers. Another benefit pointed out in the study was the fact that Precision Agriculture makes it possible to significantly reduce the risk of environmental pollution from agrochemicals applied at greater levels than what is required. Also, operations can be scheduled appropriately based on available data on weather and soil characteristics.

The paper [13] presented an affordable single-board computer-based system that could be plugged into any traditional office or home to convert it into a smart, automated and remote-controlled environment. This research study did not demonstrate how IoT could be adopted by farmers to implement Precision Farming. This was majorly because involving the farm as a work environment was not considered to be a part of the aim and scope of the research study.

The literature reviewed demonstrated that there were unresolved issues regarding how an IoT-based Smart Farming application can be designed and implemented to help the farmer make good use of the volume of data captured by the various sensors deployed. The reason for this gap could be traced to the absence of Software Engineering techniques and procedures in the research studies conducted. Another reason for this challenge is the scarcity of software development skillset required to implement according to Software Engineering standards that can be appreciated in an academic research study. A way to overcome this challenge was to study and identify an appropriate software development model that satisfies the system requirements identified for the research study. A research study [14] that proposed a model-driven approach to ease the modelling and realization of adaptive IoT systems identified the Agile Model-Driven Development (AMDD) model to be suitable for this research study. All this suggested that it was advisable to conduct a study on the development of a FarmSmart application that employs IoT to capture real-time data that can be interpreted for the farmer using a broadcast system and data analytics.

3. The aim and objectives of the study

The aim of the study is to propose a FarmSmart Broadcast Application using an IoT-based mobile irrigation system that gathers the data generated from sensors, which is eventually used for simple analytics – analysis of variance and regression analysis on captured variables.

To achieve this aim, the following objectives are accomplished:

– interviews were conducted with stakeholders (farmers) to gather requirements for the system design;

– farm parameters such as water level, light, humidity and temperature were monitored using sensors;

– an IoT system was built using the Raspberry Pi microcontroller;

– a FarmSmart application was developed for monitoring and managing irrigation processes and the FarmSmartApp tool was evaluated using a questionnaire prepared on Google Forms and Google Sheets;

– data analytics was carried out on the sensor data generated from the developed system.

4. Materials and methods

4. 1. The agile model-driven development model

The Agile Model-Driven Development (AMDD) model was adopted for the development of this IoT-based system due to the specified design models derived from system requirements and the manner in which the models capture the system functionality and adaptations [15]. This development model, as an agile model, used various models to determine the specifications of the application and enabled the transformations of those models to get the source code with speed and more cost efficiency [16]. There are four (4) major modelling and specification activities as shown in Fig. 1 below.

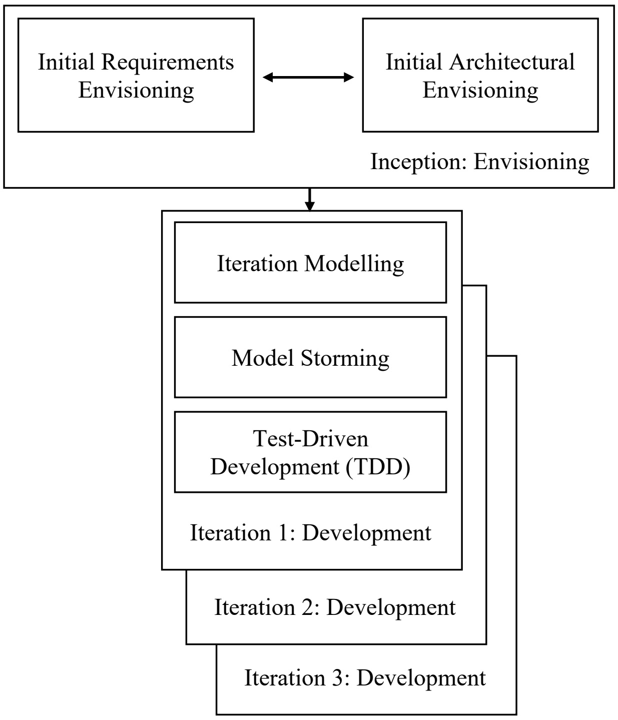


Fig. 1. The Agile Model Driven Development (AMDD) lifecycle for a project [17]

Envisioning: the scope and user requirements of the FarmSmartApp system were identified.

Iteration Modelling: the requirements identified for the system were converted into various models.

Model Storming: specific issues to be resolved by the proposed system were identified and quickly explored and addressed by a small team in 'model storming sessions'.

Test-Driven Development (TDD): specific test cases or tasks that a user is expected to carry out on the system were first of all outlined so that production codes were then created to fulfil these test cases written.

4. 2. System analysis and architecture

Findings from the initial requirement gathering and literature review conducted in this study inspired the system architecture that was selected for this project. For the purpose of this research study, the current system of farming was analysed with respect to the expected outcomes of farming products.

Interaction with farmers in the Middle Belt zone brought to light the fact that farmers simply decide what crops to plant at any time of the year based on a simple hunch they have rather than making their decisions based on relevant data and facts concerning the soil they intend to farm with and the prevailing weather conditions within the area. In most cases, the farmer chooses the crops to cultivate based on its personal expertise, its experience over the years, farming traditions in the family, and the value of the crops in the market per time. A research conducted by [18] presented a conceptual framework that suggests that both environmental and socio-cultural factors are the key factors that contribute to the beliefs responsible for the dynamics and outcomes of traditional Agricultural systems. This means that environmental factors such as weather, soil, and crop production levels over time create mental models of how farmers practice farming. In addition, certain community norms and expectations determine the information farmers focus per time. Research has shown that these factors do not serve as a dependable approach to determining the level of production that the farmer will achieve after cultivation. Farmers can only maximize production levels by precisely monitoring key factors such as the moisture and nutrient level of the soil, light, temperature and humidity levels, watering periods on the farm as well as the type of crops selected for cultivation with respect to the soil types for cultivation. Fig. 2 presents how the conceptual framework explained relates with the current system of farming before the development of the FarmSmartApp system.

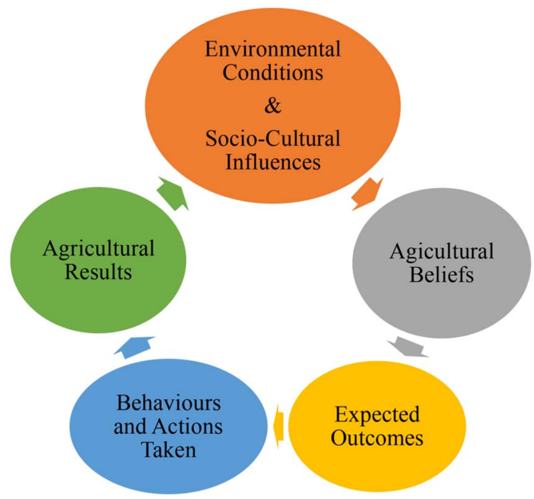


Fig. 2. The Current Farming System

A system architecture of the FarmSmartApp platform is shown in Fig. 3.

Fig. 3 describes diagrammatically how sensor data from the farm sensors get to the users of the FarmSmartApp.

This approach to the study helped to make the following contributions:

– a FarmSmart Broadcast Application using an IoT based mobile irrigation system that combines sensors, GPS and data-analytics to manage irrigation processes;

– an alert mechanism that broadcasts Agricultural information to farmers for timely intervention;

– a Smart Farm Prototype that can be mounted in the farm;

– analytical results showing the Analysis of variance between farm variables and regression between pairs of related variables;

– evaluation reports by stakeholders on the application.

The implementation and deployment were done for a rice farm in Ber Agbum Local Government Area, Benue State as a prototype. The sensors used were moisture level, light, temperature and humidity sensors. Data to be collected from the field excluded soil nutrient levels. Data visualization on the IoT-based application was only made available via a web browser and not an installed mobile application to only farmers assigned to the particular farm that are registered on the application.

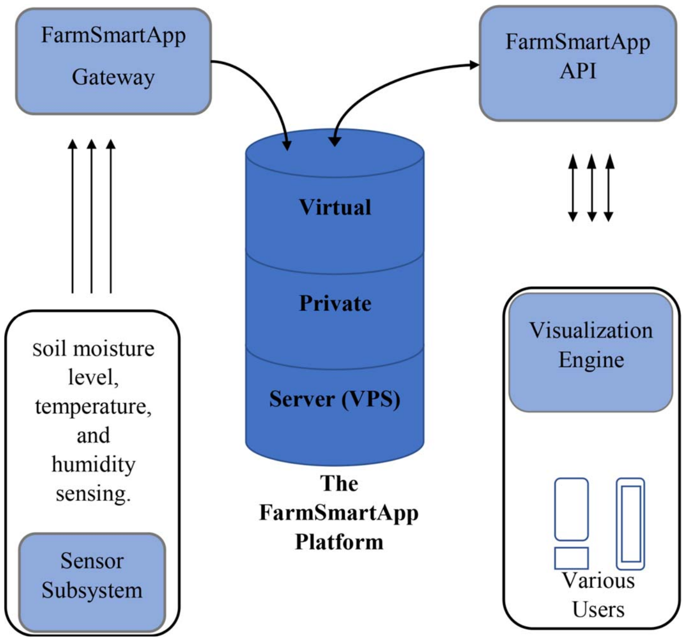


Fig. 3. The system architecture of the IoT-Based smart farm platform

4. 3. System features

The features of the system developed for this research study have been categorized as shown below on a functionality basis.

4. 3. 1. Farm sensing

The FarmSmartApp being developed in this research study includes an IoT device powered with a Raspberry Pi microcontroller. The sensors used are:

– soil Moisture Sensor;
– light Sensor;
– temperature and Humidity Sensor.

The Soil Moisture Sensor as shown in Fig. 4 is made to penetrate the soil so as to sense the amount of moisture in the soil.

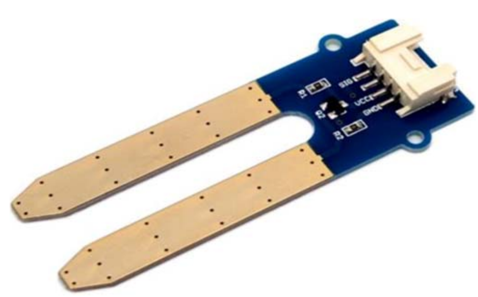


Fig. 4. Moisture level sensor

The Temperature and Humidity Sensor for the sake of this research study is pinned to the housing of the Raspberry Pi microcontroller so that the atmospheric temperature and humidity can be sensed. The time function inherent in the Operating System is included in the programming of the application.

The farm data gathered by the Raspberry Pi microcontroller has to be transmitted to the FarmSmartApp virtual private server (VPS) for the FarmSmartApp to be able to make sense of it and to be able to make the data useful to the farmers. The Raspberry Pi microcontroller transmits the data collected on the field to a VPS for monitoring through a gateway node via the Internet with the help of an application programming interface (API) as demonstrated in Fig. 5, 6.

The FarmSmartApp gateway makes data transmission possible from the farm sensors to the VPS. The real-time nature of the FarmSmartApp system, the heterogeneous nature of the data generated by the various sensors as well as the large volume and high velocity of these data required that an efficient method was utilized in the network as a means of constraining energy and resources [19].

The FarmSmartApp receives large streams of time-series data from different sensors. This means that the data from the sensors were collected at successive equally spaced points in time. In order to limit the volume of data that came into the FarmSmartApp's database, the time interval for values recorded was increased from one second to fifteen (15) minutes. This meant that temperature values for instance were recorded and sent to the server after every 15 minutes. The charts below in Fig. 7, 8 demonstrate how the various readings were taken.

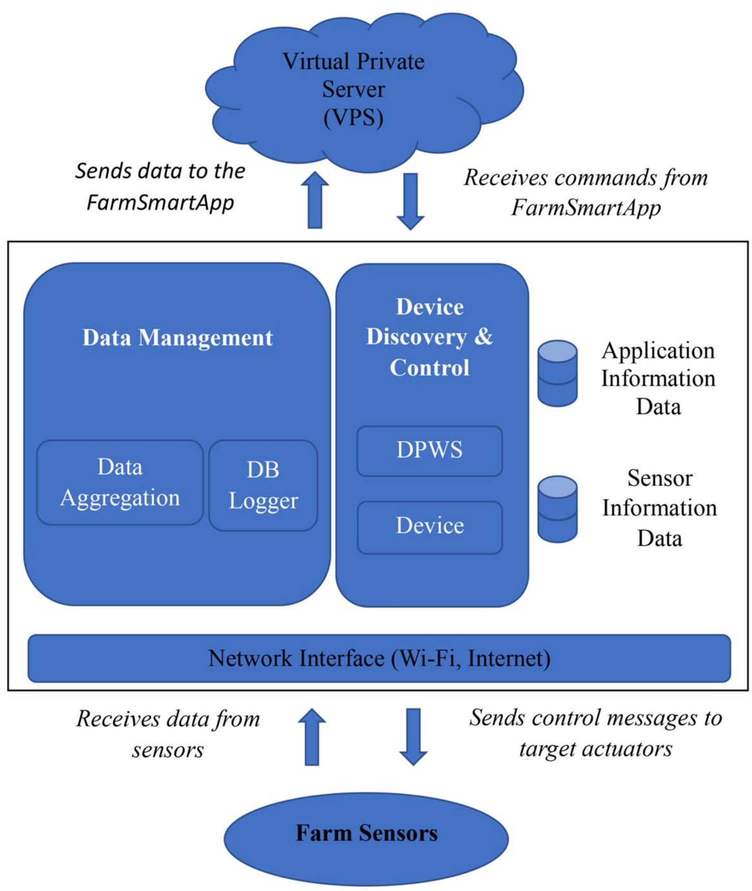


Fig. 5. The role of the FarmSmartApp gateway

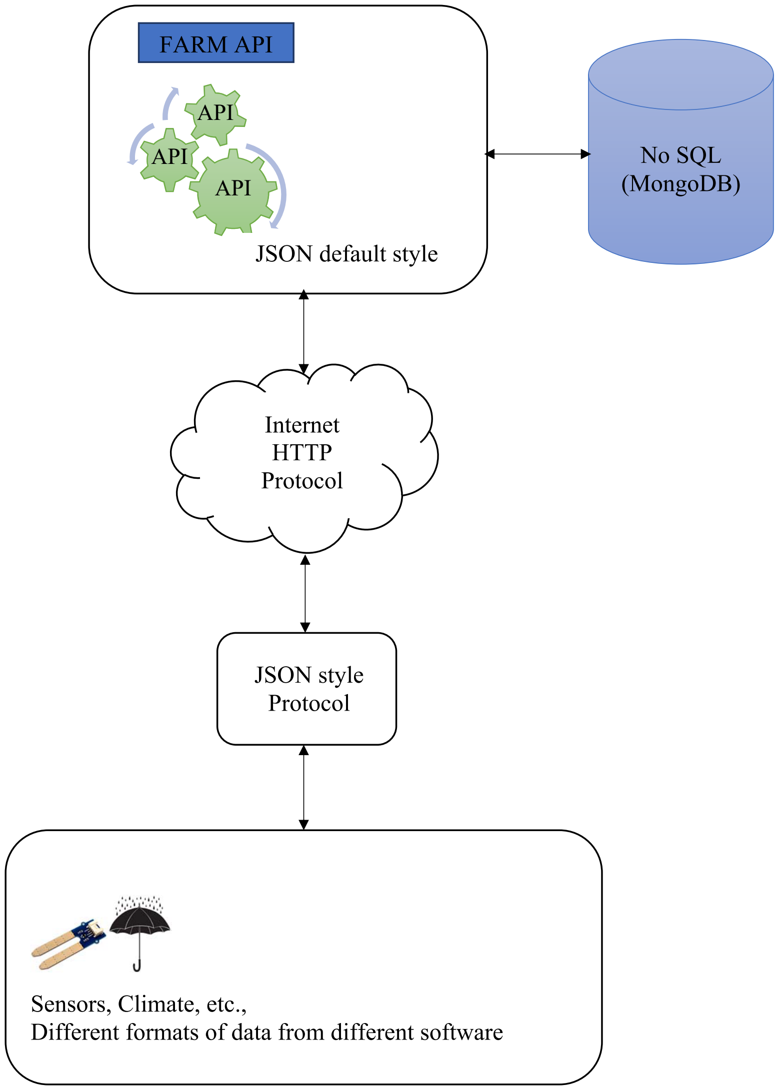


Fig. 6. The role of the FarmSmartApp Application Programming Interface

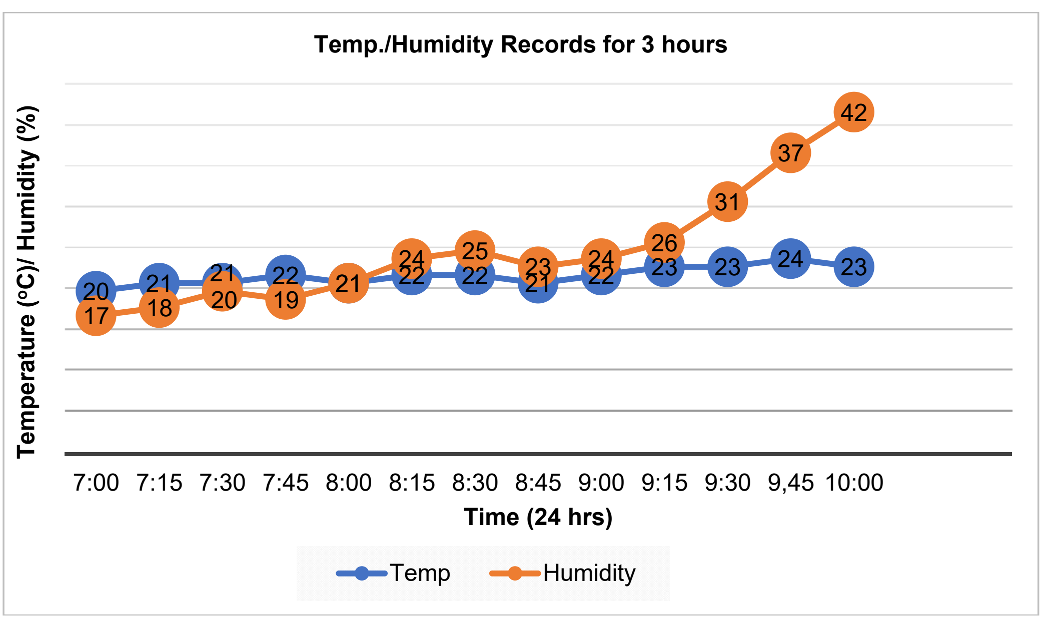


Fig. 7. Temperature and Humidity Records taken from 7 am to 10 am Friday 5th July, 2020

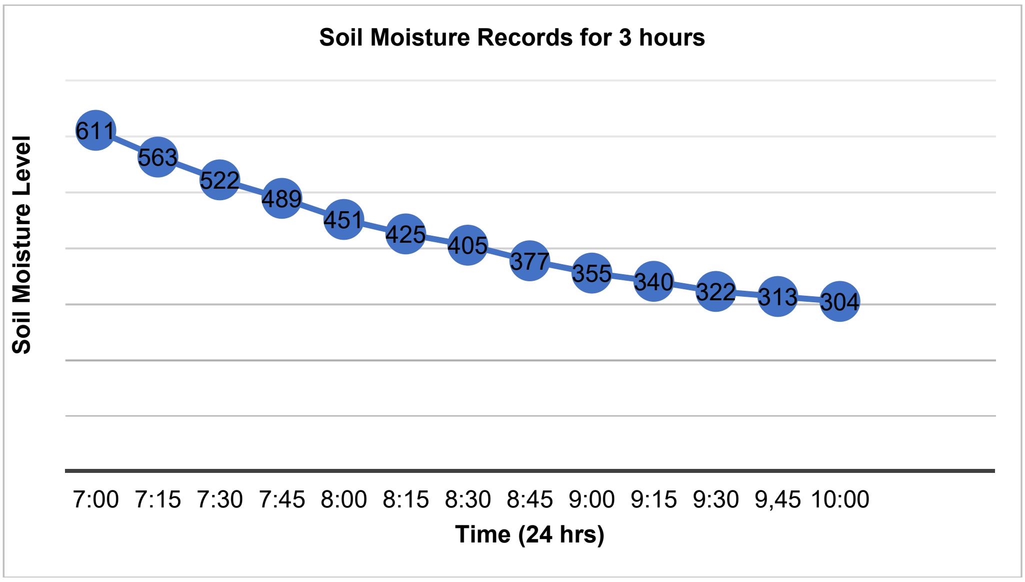


Fig. 8. Soil Moisture Level Records (7 am to 10 am)

The data acquired from the sensors is ingested for timely use by farmers.

4. 3. 2. Farm data analysis

The data transmitted to the VPS is received by the FarmSmartApp for data processing in the form of data visualization. This is where some form of data analysis takes place. Farm data is collected from the farm sensors in a programmed fashion such that the farm parameters are sensed after a selected time interval. A specific threshold value is defined for soil moisture level along with the temperature and humidity threshold values. Once the soil moisture value is less than the defined threshold value, while the temperature and humidity value is favourable, information is broadcasted by the FarmSmartApp to farmers who have been registered via SMS or email to resume irrigation. The farmer then decides the time of the day that is favourable for irrigation to begin to prevent the water from being heated by the sun while irrigation goes on. These functions are handled by the visualization engine as shown in Fig. 9.

The ability of the FarmSmartApp system to help farmers make timely agricultural decisions based on farm data acquired by the sensor subsystem makes it a decision support system (DSS). As a DSS, it depends on the farm data stored in the FarmSmartApp VPS provided by the farm sensors to formulate its decisions and presents its conclusions on the FarmSmartApp website. The FarmSmartApp system decides that the soil is dry when the soil moisture level goes below a specified value. Also, the FarmSmartApp system decides that the environment is appropriate enough for irrigation to take place. This was done using conditional statements such that if moisture level is low then irrigation should take place and if moisture level is satisfactory then irrigation can stop. The information requesting irrigation to take place is shown on the visualization pane of the FarmSmartApp system and is also sent as a broadcast to all registered farmers on the platform. The sensor data are further tested using python.

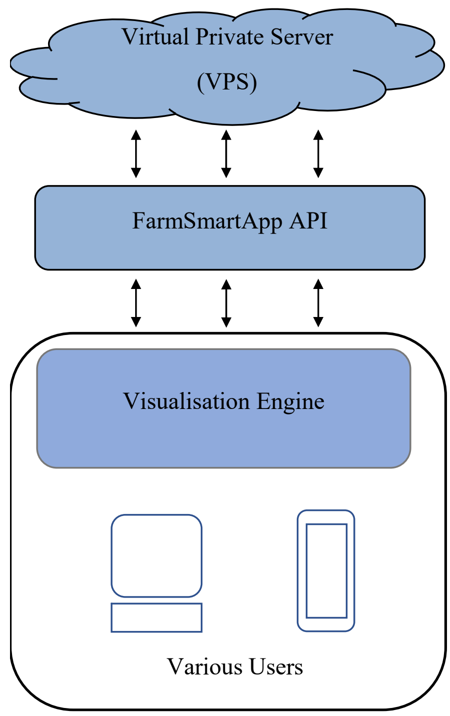


Fig. 9. The role of the visualization engine

4. 3. 3. Information broadcasting

The FarmSmartApp admin ensures that a broadcast via short message service (SMS) or email is sent from time to time to registered farmers with timely advice on what to do on the farm. The SMS API enabled the FarmSmartApp system, which serves as the client, to communicate with the platform of an SMS vendor. The Twilio SMS API, which was the SMS API selected for this project. A new program was created that integrates the FarmSmartApp to the SMS vendor. Setting up the email broadcasting service on the FarmSmartApp system, instead of using an API, a simple mail transfer protocol (SMTP) was used.

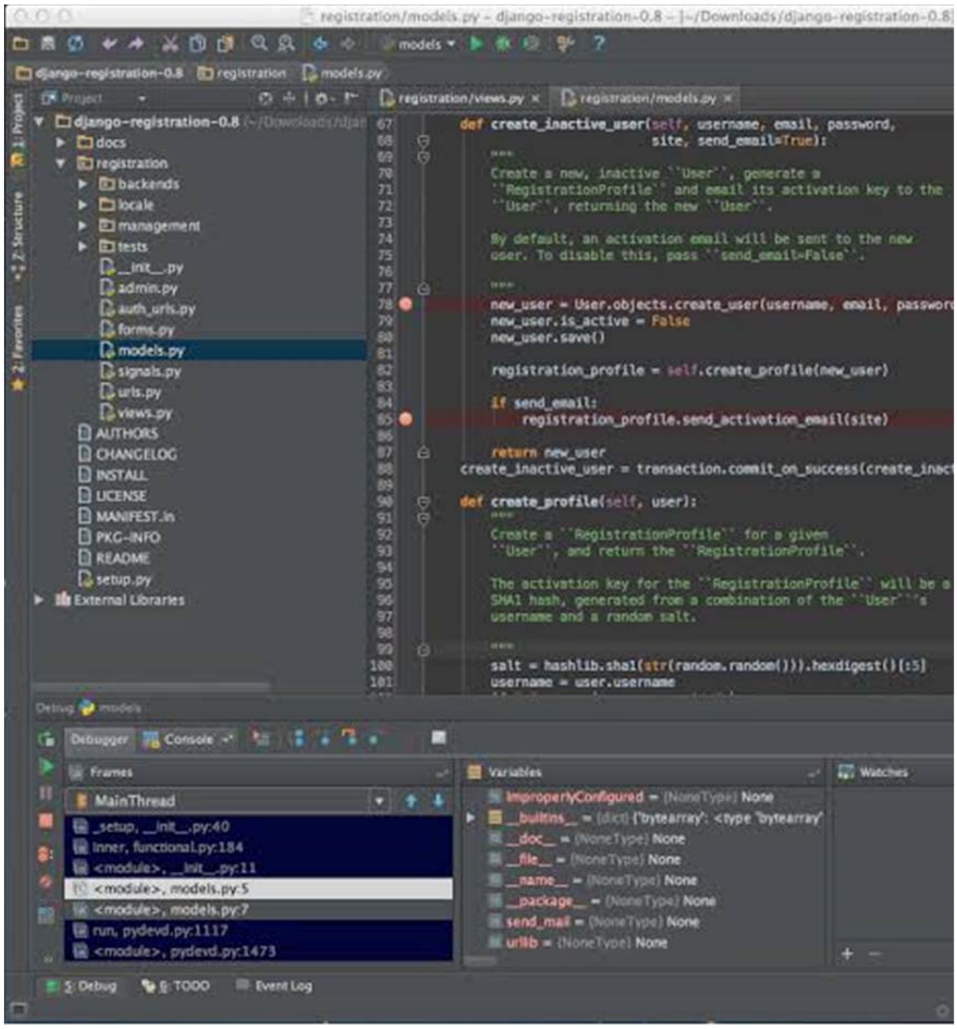


Fig. 10. A screenshot of the IntelliJ IDEA IDE in use

This protocol provided the set of procedures and rules required for the FarmSmartApp to create and send emails to any email address. The broadcast platform was also designed to handle a large farm scenario. For example, for a farm of four (4) acres, the farm can be divided in four equal parts such that each farm has separate sensor readings sent to the FarmSmartApp for analysis and broadcast. In that case, the broadcast platform sends information to the farmers based on the moisture level at a specific acre of the farm. The farmer who receives the SMS is also informed of the particular acre the information is referring to.

4. 4. Programming Tools

The Raspberry Pi microcontroller was used in this project to house and control the various sensors involved in the operations of this IoT-based system. This microcontroller made it possible for the sensors to be controlled by the application on the client-end. The challenge with using an Arduino Uno microcontroller was that it has a very limited processing capacity that is not suited for the varied data gathering required for this project. The Raspberry Pi microcontroller helped to address this challenge as it works with a 32-bit ARM processor that processes at a speed of up to 1 GHz instead of the 8-bit ATmega processor that processes between 8 and 16 MHz. Thus, with the Raspberry Pi microcontroller all data sensed from the various sensors were gathered and processed simultaneously with much more ease.

The IntelliJ IDEA Integrated Development Environment (IDE) was used to provide a conducive environment for implementation. Fig. 10 is a screenshot of the IntelliJ IDEA IDE when in use.

MongoDB, a NoSQL database program, is the database management system used for the development process of this research study. It helped the virtual private server being deployed in the cloud in managing large volumes of unstructured data that will be generated over time. Running the application on NoSQL data models ensured more flexibility and very low downtime and to incorporate spatial functionalities by adding the PostGIS extension.

Python, running on Jupiter Notebook 6.3.0 was used for further analysis of sensor data.

5. Results of farm smart application development

5. 1. Report on personal interview with farmer

A face-to-face personal interview was conducted with a rice farmer who owns acre of rice farm to understand the prevailing conditions it deals with in ensuring maximum yields, especially with respect to monitoring water levels and climatic conditions and ensuring that the best conditions are ensured for high crop productivity. Notes were taken while the farmer was interviewed.

These are some excerpts from the interview.

What are the major challenges farmers face in ensuring high productivity?

Response: Moisture level in the soil is very difficult to monitor and control and that makes it difficult to maintain the required moisture level for high productivity of crops like rice.

How can farmers who are not conversant with Information and Communications Technology (ICT) deal with the introduction of new ICT tools for farming?

Answer: These farmers have co-operative societies that provide support to member farmers. These societies can provide a central point that serves these farmers with new ICT tools.

Do these challenges pointed out affect the entire Middle Belt zone in Nigeria?

Answer: To a large extent the answer is yes. This is because of the similarity in climatic conditions and the type of soil in this subregion.

How can we ensure that a broad spectrum of farmers in a sub-region can benefit from the system if newly introduced?

Answer: The new system if created can be controlled by the co-operative society while a broadcast feature can be incorporated to the system to enable member farmers receive instructions as messages via SMS on what to do per time.

5. 2. Sensor Data from the IoT System

Data generated by the sensors employed in the prototype system was captured and presented in its raw state as shown in Table 1.

Table 1

Table presenting data as collected from sensors

Id	version	Time	moisture	light	status	temperature
1	0	1.62E+09	0	705	ON	29.19
2	0	1.62E+09	0	705	ON	29.29
3	0	1.62E+09	0	709	ON	29
4	0	1.62E+09	0	708	ON	29.27
5	0	1.62E+09	0	707	ON	29.23
6	0	1.62E+09	0	700	ON	29.22
7	0	1.62E+09	0	709	ON	29.01
8	0	1.62E+09	0	701	ON	29.29
9	0	1.62E+09	0	703	ON	29.08
10	0	1.62E+09	0	706	ON	29
11	0	1.62E+09	0	705	ON	29.26
12	0	1.62E+09	423	704	OFF	29.21
13	0	1.62E+09	490	704	OFF	29.13
14	0	1.62E+09	494	702	OFF	29.19
15	0	1.62E+09	349	707	OFF	29.27
16	0	1.62E+09	613	705	OFF	29.25
17	0	1.62E+09	658	708	OFF	29.13
18	0	1.62E+09	668	702	OFF	29.21
19	0	1.62E+09	679	707	OFF	29.09
20	0	1.62E+09	677	706	OFF	29.05
21	0	1.62E+09	674	705	OFF	29.25
22	0	1.62E+09	673	708	OFF	29.29

The Status column in Table 1 refers to the status of the water pump in the IoT system controlled by the Raspberry Pi microcontroller. The water pump comes on when the moisture level as shown in the 4th column is at zero (0) level.

5. 3. The IoT System Using a Raspberry Pi Microcontroller

The FarmSmartApp was tested using a prototype scenario of a farm where dry and wet soils are created for sensing by the soil moisture sensor, and a housing for the Raspberry Pi board as well as the temperature/humidity and light sensors as shown in Fig. 11.

The prototype scenario as shown in Fig. 11 is made of the Raspberry Pi microcontroller responsible for controlling the moisture level sensor dipped into the soil kept in the plastic container. There is also a plastic container containing water serving as a reservoir that makes irrigation possible. A message is sent to the pump to start irrigation once the sensor data indicates that the water content has gone below a determined value.

Fig. 11. The Raspberry Pi Board being used for System Testing

5. 4. Evaluation Results of the FarmSmart Application

Table 4 displays the corresponding frequency distribution for the responses generated from participants in Table 2. Fig. 12 displays the graphical presentation of the frequency distribution in Table 4.

Table 2

Lists the participants of the system evaluation

Respondents	Role	Date Tested
Respondent 1	Admin	23rd November, 2020
Respondent 2	Admin	23rd November, 2020
Respondent 3	Admin	23rd November, 2020
Respondent 4	Admin	23rd November, 2020
Respondent 5	Admin	23rd November, 2020
Respondent 6	Admin	23rd November, 2020
Respondent 7	Admin	24th November, 2020
Respondent 8	Admin	24th November, 2020
Respondent 9	Admin	25th November, 2020
Respondent 10	Admin	25th November, 2020

Table 3

Frequency distribution

Response	Functionality	Interface	Usability	Overview
Yes	28	21	29	30
Uncertain	0	2	1	0
No	2	7	0	0

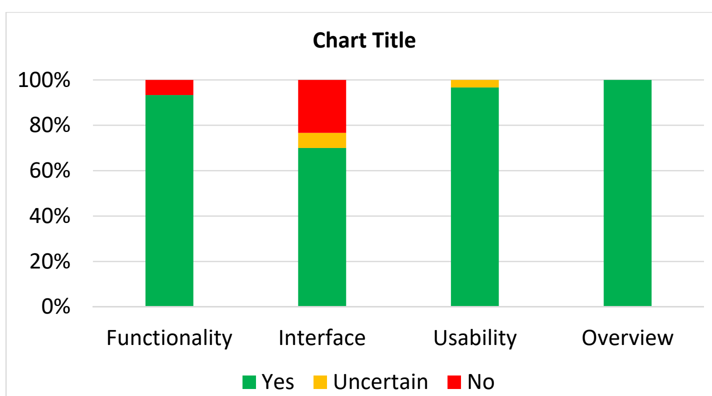


Fig. 12. Evaluation results of the overall performance of the FarmSmartApp tool

Table 2 is made up of three columns representing the respondents, their roles and the dates testing was conducted. Table 3 shows in numbers how the respondents score the FarmSmartApp system tested while Fig. 12 describes Table 3 in a chart.

Fig. 13 shows the Login page of the FarmSmartApp. Fig. 14 shows the Homepage of the FarmSmartApp. Fig. 15 shows what the Manage-User Form looks like on the FarmSmartApp. The SMS page and the Email Page are shown in Fig. 16 and 17 respectively.

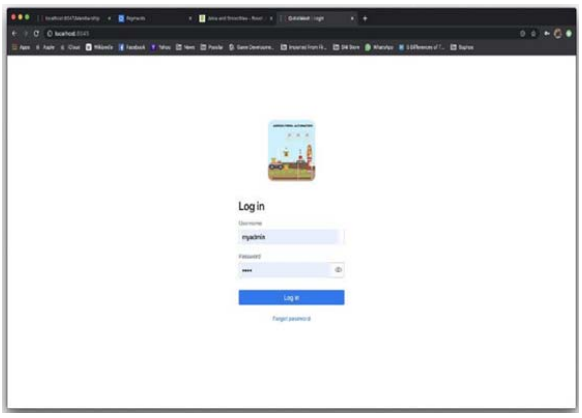


Fig. 13. The Login Page of the FarmSmartApp

Fig. 14. The Home Page of the FarmSmartApp

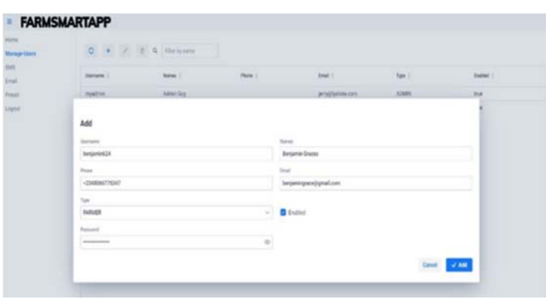


Fig. 15. The Manage-User form of the FarmSmartApp

Fig. 16. The SMS page of the FarmSmartApp

These screenshots presented in Fig. 13–17 show segments of the app developed in this paper.

Fig. 17. The Email Page of the FarmSmartApp

5. 5. Data analytics of the sensor data

The sensor data are further tested using Excel and Python. Steps employed for this analysis include:

– normalization of the data using the log10 function;

– ANOVA – single factor analysis of temperature, moisture and light data;

– regression analysis of light and temperature data;

– regression analysis of moisture and temperature data.

The data gathered from the developed device were further analysed. In order to put the data in a form amenable for further analysis, the comma separated variable data were normalized using the log10 function in Excel. The light, moisture and temperature features were normalized.

Analysis of Variance (ANOVA) – Single factor Analysis of Temperature, Moisture and Light data was carried out. Results are shown in Tables 4, 5.

Table 4

Analysis of Variance (ANOVA : Single Factor)

Groups	Count	Sum	Average	Variance
Moisturelog10	102	224.9202	2.2051	1.281237
Temperaturelog10	102	149.4019	1.464724	1.78E-06
Light	102	290.4996	2.848035	2.79E-06

Table 5

ANOVA

Source of Variation	SS	Df	MS	F
Between Groups	97.75239	2	48.8762	114.4426
Within Groups	129.4054	303	0.427081	–
Total	227.1578	305	–	–

Fig. 18 shows a snaphot of the sensor data.

Fig. 19 shows the plot of light and the normalized temperature:

a) Regression analysis of light and temperature data.

Fig. 20 shows a plot of moisture and the normalized temperature plot:

b) Regression analysis of temperature and moisture data.

On the regression light and temperature the model is:

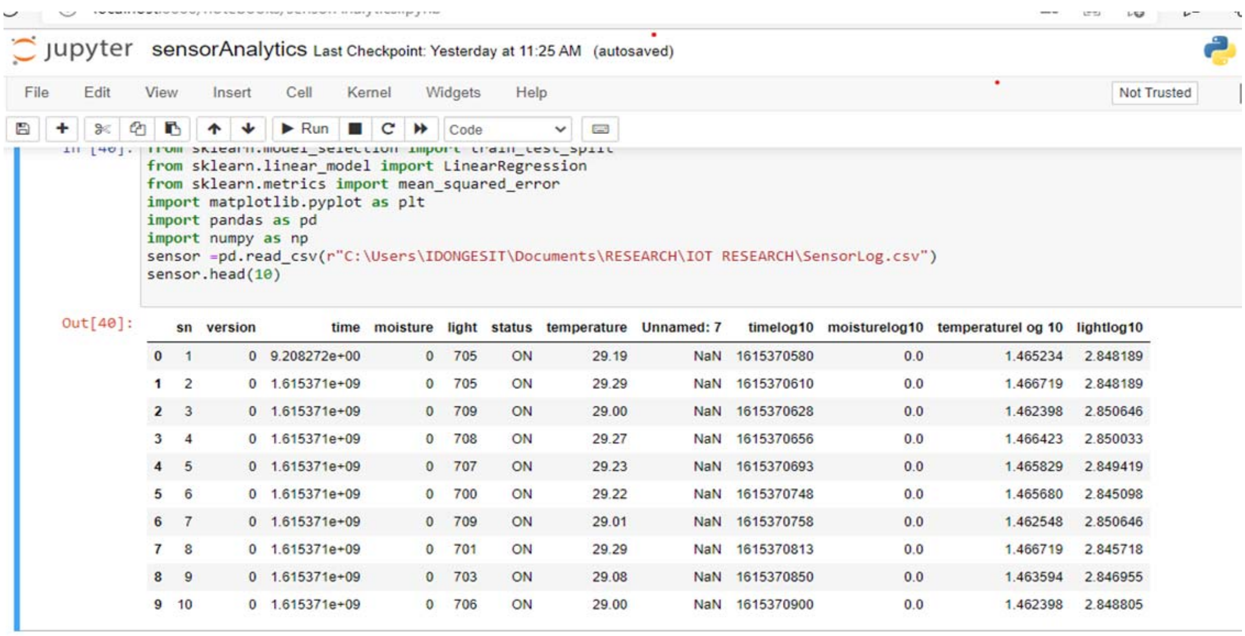
$$Temp=1.3045+0.056*light,$$

0.056 unit increase in light brings about one unit increase in temperature. The distribution of the also shows that further increase in light causes not much increase in temperature.

While on the regression between moisture and temperature, the derived model is

$$Moisture=167.049-112.5*temp.$$

These models can be used for predictive purposes. For instance, given a particular value for temperature, the moisture level can be estimated by substituting the value for temperature.




```
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error
import matplotlib.pyplot as plt
import pandas as pd
import numpy as np
sensor =pd.read_csv(r"C:\Users\IDONGESIT\Documents\RESEARCH\IOT RESEARCH\SensorLog.csv")
sensor.head(10)
```

Out[40]:

	sn	version	time	moisture	light	status	temperature	Unnamed: 7	timelog10	moisturelog10	temperaturel og 10	lightlog10
0	1	0	9.208272e+00	0	705	ON	29.19	NaN	1615370580	0.0	1.465234	2.848189
1	2	0	1.615371e+09	0	705	ON	29.29	NaN	1615370610	0.0	1.466719	2.848189
2	3	0	1.615371e+09	0	709	ON	29.00	NaN	1615370628	0.0	1.462398	2.850646
3	4	0	1.615371e+09	0	708	ON	29.27	NaN	1615370656	0.0	1.466423	2.850033
4	5	0	1.615371e+09	0	707	ON	29.23	NaN	1615370693	0.0	1.465829	2.849419
5	6	0	1.615371e+09	0	700	ON	29.22	NaN	1615370748	0.0	1.465680	2.845098
6	7	0	1.615371e+09	0	709	ON	29.01	NaN	1615370758	0.0	1.462548	2.850646
7	8	0	1.615371e+09	0	701	ON	29.29	NaN	1615370813	0.0	1.466719	2.845718
8	9	0	1.615371e+09	0	703	ON	29.08	NaN	1615370850	0.0	1.463594	2.846955
9	10	0	1.615371e+09	0	706	ON	29.00	NaN	1615370900	0.0	1.462398	2.848805

Fig. 18. Screenshot of sensor data – captured and normalized

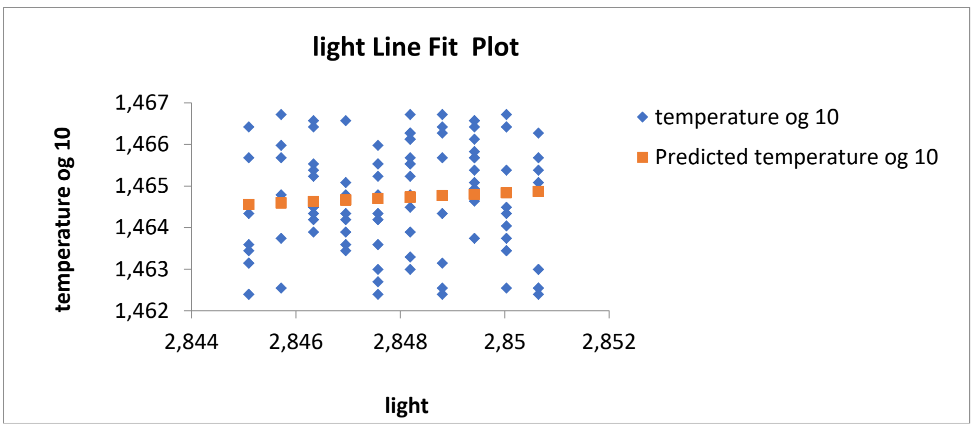


Fig. 19. Temperature-light plot

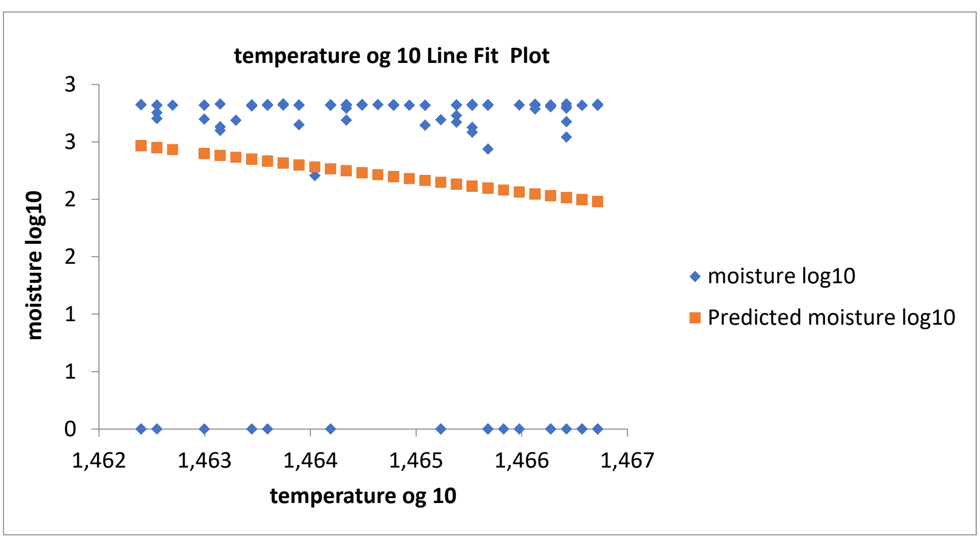


Fig. 20. Moisture – temperature plot

6. Discussion of system testing results

Notes taken while interviewing the farmer as shown in Section 5.1 explained how that in rice farming ensuring optimal water levels was a priority in rice production as too much water could be a problem just as too little water could be a problem. In other words, it was saying that ensuring that right moisture level was identified and maintained was very essential. When asked how these conditions are ensured it explained that it has been quite difficult to consistently maintain the right moisture level as rainfall is unpredictable and that even where irrigation methods are used it is virtually impossible to maintain the right conditions throughout the entire day on day-to-day basis. The farmer was asked if the use of sensors that can monitor the moisture level, humidity level as well as sunlight levels to decide when it is start irrigating and exactly when to stop irrigating. Its response was in the affirmative and it went further to suggest possible ways such a project could be conducted to help a community of rice farmers in a particular farmers' community in Ber Agbum Local Government, Benue State. Its suggestions provided system requirements that led to the modelling for the system that was developed.

The status column of Table 1 presented in Section 5.2 refers to the status of the water pump in the IoT system controlled by the Raspberry Pi microcontroller. The water pump comes on when the moisture level as shown in the 4^{th} column is at zero (0) level. Fig. 11 shows the prototype that was developed in this research. This was tested and all features functioned as intended. Section 5.4 discusses results from the Application developed to work with the hardware.

Feedback was gathered from participants through a system evaluation questionnaire that was prepared on Google Forms and distributed to participants via WhatsApp. The questionnaire was prepared to assess the usability and fitness of the system for its purpose. The research objectives and description of how the system works were presented to the participants before system testing commenced. To enable participants to test the system properly, a list of specific tasks was laid out for the participants who were to play the role of the Admin of the FarmSmartApp. Each participant was expected to complete the tasks outline and afterwards fill the system evaluation questionnaire based on their observations while using the FarmSmartApp tool. The responses from participants were analyzed and used to assess the FarmSmartApp tool.

All participants were presented with the same questionnaires via Google Forms to give their individual opinions based on their experiences with the FarmSmartApp tool to boost the broadcast of agricultural information.

An analysis on the results obtained from the FarmSmartApp tool evaluation was carried out to determine the feedbacks from users with regards to the effectiveness and usability of the system as shown in Table 3 and Fig. 12. As explained earlier, the system evaluation questionnaire was divided into three sections namely Functionality, Interface, Usability and General Overview respectively. The first three sections were made up of three questions each while the last section (General Overview) was made up of just one question, making the total number of questions ten in all. Since this portion of the study focused on the experience of the user and the ability of the system to satisfy the objectives of the research study, only the results based on these sections in the overall evaluation of the FarmSmartApp tool have been discussed. Table 4 shows the results of the evaluation of the system by stakeholders. 93 % agree that the system carried out the intended functionality, while 97 % supported that the system was useful. This clearly shows that the system was assessed to be useful by the intended users.

In testing the FarmSmartApp, the Admin opens the FarmSmartApp website via a web browser, and expected to log in to the site via a log in page as shown in Fig. 13. The Admin is required to enter his username and password to log in.

After the Admin has been successfully logged in, the home page of the application is opened granting the Admin access to the FarmSmartApp's data dashboard. On the home page as shown in Fig. 14 the Admin is able to view readings of the light, temperature and humidity at the farm as well as moisture level of the farm soil. The Admin is able to view these readings because the FarmSmartApp has been able to track the readings received from the sensors on the field, analyzes them into key performance indicators (KPIs) that are useful to farmers.

The Admin manages user as shown below by filling the form shown in Fig. 15. On the SMS page, the dashboard displays a graphical summary of recent SMS activity on the system and enables the Admin to send a single SMS or multiple SMS messages by choosing any of the icons shown in Fig. 16.

On the email page, the dashboard displays a graphical summary of recent email activity on the system and enables the Admin to send a single email or multiple emails by choosing any of the icons shown in Fig. 17.

This study was conducted with the aim of developing an IoT-based application that will enable farm data gathering and broadcasting to farmers within the rice farm in Ber-Agbum, Benue State. This application was developed in the form of the FarmSmartApp.

The Testing was carried out in two phases:

1) testing the FarmSmartApp by stakeholders;

2) analysis on sensor data.

Feedback was gathered from participants through a system evaluation questionnaire that was prepared on Google Forms and distributed to participants via WhatsApp. The questionnaire was prepared to assess the usability and fitness of the system for its purpose. The research objectives and description of how the system works were presented to the participants before system testing commenced. To enable participants to test the system properly, a list of specific tasks was laid out for the participants who were to play the role of the Admin of the FarmSmartApp.

Each participant was expected to complete the tasks outline and afterwards fill the system evaluation questionnaire based on their observations while using the FarmSmartApp tool. The responses from participants were analysed and used to assess the FarmSmartApp tool.

The results obtained were generated from the system testing procedure conducted after the development of the FarmSmart Broadcast Application which used an IoT-based mobile irrigation system that combines sensors, GPS and data-analytics to manage irrigation processes. The screen shots shown above demonstrates the alert mechanism that broadcasts Agricultural information generated from the FarmSmart application that was mounted in the farm while the analytical results above in Table 1 show the analysis of variance between farm variables and regression between pairs of related variables and finally an evaluation report by stakeholders on the application.

The features of the system developed for this research study have been categorized as shown below on a functionality basis:

– farm sensing;
– farm Data Transmission;
– farm Data Analysis;
– information Broadcasting.

In order for farmers to assess the conditions of the farm including the atmosphere and the soil they depend on their ability to observe and monitor the field without their physical presence every now and then. The need to regularly and often observe the farm environment informed the need for remote sensing technology, which provides the means to assess farm conditions without the physical presence of the farmer. The FarmSmartApp being developed in this research study includes an IoT device and powered with a Raspberry Pi microcontroller that is made up of three different sensors to make remote sensing possible for farmers who need regular updates on farm conditions. With the help of a Raspberry Pi microcontroller, the different sensors are able to constantly gather a large volume of farm data such as soil moisture level, soil temperature, and humidity level from the farm. This feature makes it possible for farmers to appreciate the precise state of their farming environment which is not the case presently in most developing countries. Sensing devices pretty much work the same way in previous works but here, these results are communicated in a timely manner to the affected farmers.

The farm data gathered by the Raspberry Pi microcontroller has to be transmitted to the FarmSmartApp virtual private server (VPS) for the FarmSmartApp to be able to make sense of it and to be able to make the data useful to the farmers. To make this possible the Raspberry Pi microcontroller transmits the data collected on the field to a base station for monitoring through a gateway node via the Internet. The base station in this case is the virtual private server (VPS) hosted in the cloud. However, transmitting of the data to the VPS of the system is not a straightforward one as data is generated from several different sensors. A major difference between this system and others is its capacity to make communication flow between the server and the dashboard seamless and smooth.

At this level, the data transmitted to the virtual private server is received by the FarmSmartApp for data processing in the form of data visualization. This is where some form of data analysis takes place. Farm data is collected from the farm sensors in a programmed fashion such that the farm parameters are sensed after a selected time interval. A specific threshold value is defined for soil moisture level along with the temperature and humidity threshold values. This means that once the soil moisture value is less than the defined threshold value while the temperature and humidity value is favourable then an information is broadcasted by the FarmSmartApp to farmers who have been registered via SMS or email to resume irrigation. The farmer then decides when the time of the day is favourable for irrigation to begin to prevent the water from being heated by the sun while irrigation goes on.

The ability of the FarmSmartApp system to help farmers make timely agricultural decisions based on farm data acquired by the sensor subsystem makes it a decision support system (DSS). As a DSS, it depends on the farm data stored in the FarmSmartApp VPS provided by the farm sensors to formulate its decisions and presents its conclusions on the FarmSmartApp website. To help the FarmSmartApp system arrive at its decisions, the data acquired from the sensors is monitored with specific values for different parameters signifying the need for specific actions. This means that the FarmSmartApp system decides that the soil is dry when the soil moisture level goes below a specified value. Also, the FarmSmartApp system decides that the environment is appropriate enough for irrigation to take place. This was done using conditional statements such that if moisture level is low then irrigation should take place and if moisture level is satisfactory then irrigation can stop. The information requesting irrigation to take place is shown on the visualization pane of the FarmSmartApp system and is also sent as a broadcast to all registered farmers on the platform. This feature made it possible for the system to stand out as the analytics conducted is easy to use and simple to interpret even by rural farmers.

This is an essential section of the FarmSmartApp as it ensures that relevant information prepared by the FarmSmartApp is conveyed to concerned farmers. The FarmSmartApp admin ensures that a broadcast via SMS or email is sent from time to time to registered farmers with timely advice on what to do on the farm. To introduce the SMS service into the FarmSmartApp system, an SMS API service was employed. The SMS API enabled the FarmSmartApp system, which serves as the client, to communicate with the platform of an SMS vendor. The Twilio SMS API, which was the SMS API selected for this project. created a new program that integrates the FarmSmartApp to the SMS vendor. The broadcast platform was designed such that an SMS can be sent to selected recipients or to all registered recipients on the platform. Setting up the email broadcasting service on the FarmSmartApp system, instead of using an API, a simple mail transfer protocol (SMTP) was used. This protocol provided the set of procedures and rules required for the FarmSmartApp to create and send emails to any email address. The broadcast platform was also designed to handle a large farm scenario. For example, for a farm of four (4) acres, the farm can be divided in four equal parts such that each farm has separate sensor readings sent to the FarmSmartApp for analysis and broadcast. In that case, the broadcast platform sends information to the farmers based on the moisture level at a specific acre of the farm. The farmer who receives the SMS is also informed of the particular acre the information is referring to. For us this is a major advantage of this method over existing ones.

On the analysis of the sensor data in Table 1. The ANOVA between the variables light, moisture and temperature conclude that the null hypothesis of no significance difference in mean effect is rejected since f_{calc} is greater than f_{crit} justified by p value less than 0.05.

It is important to evaluate the relationships between the variables obtained by the sensors in order to make useful decisions that would maximize crop production. For example, the relationship between temperature and moisture could inform the farmer on the proper time to water the crops in the future using past records of temperature and the moisture level.

Two major limitations of this study include:

1. The need for Internet Connectivity.

2. The need for unlimited power supply so that farmers can have their mobile devices powered up to receive notifications and alerts for the broadcasting system.

Major disadvantages of the systems would be the following:

1. For very large farms, setting up all the hardware, software and data expectations may be capital intensive at first, but subsequently the implementation cost would reduce.

2. For proper and more precise analytics to be carried out, it may take a couple of years to gather all the needed and relevant data as proper analytics thrives with big data.

3. Expertise with setting up the systems and carrying out analytics requires a lot of skillsets.

7. Conclusions

1. The informal interview with the farmers resulted in the system requirements of the system. These requirements formed the basis for the development of all the components of the system.

2. The monitored farm parameters – water level, light, humidity and temperature–that were monitored from the sensors served as the basis for decisions taken by the analytics feature of the entire system. Timely reports were sent to the farmers as a result of these sensed values.

3. The IoT system that was built using the Raspberry Pi microcontroller served as the base physical component of the entire system. The board of connected sensors can take essential readings from the farm and make them available through the FarmSmartApp gateway to the Virtual Private Servers (VPS) in the cloud for access by the end-user of the FarmSmartApp.

4. The FarmSmart application that was developed for monitoring and managing irrigation processes was fully tested and deployed. A very important aspect of this study was the broadcasting capacity of the FarmSmartApp to send timely SMS and emails to other beneficiaries who have been registered on the database by the system Admin and the analysis of initial data harvested from the farm. The App was tested by stakeholders who included basically the farmers. On the system evaluation, 97 % of the examined stakeholders agreed that the system delivered on the agreed functionality.

5. Simple analysis of variance (ANOVA) of light, moisture and temperature was carried out using the sensor data that was harvested from the developed system. The result of the analysis led to the rejection of the null hypothesis of no significance difference in mean effect among the variables since f_{calc} is greater than f_{crit}. This was justified by p value being less than 0.05.

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