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Environmental Parameters Monitoring And Control System In Horticulture Greenhouse Using The Internet Of Things Case Of: IPRC Musanze

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Abstract – Efficient management of greenhouse farming is a challenge to ensure high yield production. This is a great challenge to farmers who do not have a reliable mechanism to ensure the optimum environmental conditions for their crops. Farmers are opting to look for solutions from technologies such as Machine to Machine and Internet of Things. This paper proposes a wireless sensor network architecture for real-time greenhouse environmental parameters monitoring to achieve technology- based farming at a low management cost. Uncontrolled temperature, humidity, light intensity and soil moisture content, are among the major parameters that contribute to the deterioration of plants in the green house. The system employs the temperature and Humidity sensor DHT11, a light sensor LDR and soil moisture sensor to detect the environment parameters inside the greenhouse. A low-cost Wi-Fi microchip, with built -in TCP/IP networking software called as ESP8266, has been used to help connect the microntroller with the internet wirelessly. Sensed data is monitored on-site using a Liquid Crystal Display. The ThingSpeak Cloud platform has been used to assure the remote monitoring of the sensed data, and further analytics can be done through it. Actuators namely the solenoid valve, cooling fan, and heating bulb are immediately triggered in case the limit level of the environmental parameters been sensed, has been exceeded. The Global System for Mobile Communication has been used to provide notification to the farmers cell phone farmers in case of critical conditions. The results of the system are provided in form of waveforms observed through the ThingSpeak for the sensed parameters, others are in form of notification through LCD and GSM, and the actions performed by the solenoid valve, cooling fan and Heating bulb in case the sensed environment data goes beyond the required level.

Keywords – Environmental Parameters Monitoring, Control System In Horticulture Greenhouse,Internet Of Things.

1.1 GENERAL INTRODUCTION

1.1.2. Background to the Study

A greenhouse is a structure that is covered with a transparent material, such as a plastic bag or glass, and is used to grow plants that require regulated climatic conditions (Drakes, 2008). Additionally, greenhouse management is in charge of the everyday activities involved in growing plants for both scientific and commercial purposes. This includes selecting and sowing seedlings, maintaining greenhouse infrastructure, coaching and supervising staff, and keeping records.

In a bid to address issues of low agricultural production partly caused by very small farms, Rwanda has embarked on growing some crops in greenhouses and hydroponics – technologies acclaimed to enhance farm output. The country seeks to establish greenhouses and hydroponic facilities with a cost of Rwf8.28 billion by 2023/2024. Greenhouses (mainly for the growing of vegetables and flowers) are expected to cover over 1,274 hectares by 2023/2024 financial year (Newtimes.co.rw)

According to Yayici (2015), Information and communications technology (ICT) applications in agriculture are becoming more and more significant Yayici, E. (2015). Today, it ensures productivity by implementing wireless and cloud-connected devices that aid in yield maximization, automating day-to-day agricultural activities, and delivering real-time monitoring data that enables sound decision-making.

Agricultural quality is increased and a more favorable environment for low-cost crop production is created by greenhouse climate management and monitoring. You might conceive of greenhouse farming as the utilization of modern technology and research to boost agricultural productivity. Wireless sensor networks (WSN) are the primary impetus behind the development of greenhouse monitoring. The main driving force behind the growth of greenhouse monitoring is wireless sensor networks. Multifunctional, highly communicative sensors may now be built and produced at low cost and with little power usage thanks to recent advancements in wireless communication and electronics. These sensors are portable (compact in size) and feature a short-range communication capability Borozan, V. (2015). Affordable connected smart sensors via wireless links and installed/connected in large numbers, offers colossal opportunities for automatic monitoring and control of homes, industries, cities and environment Borozan, V. (2015) and Vieira& da Mata, J. M. (2003, September). As a modern technology, wireless sensor networks can explore the possibilities of sensors, control, network transmission, data processing, and storage. Ghosal, D. (2008). Thanks to the advancement of WSNs in system platforms for data collection, authentication, processing, and display, it is possible to boost agricultural productivity at a fair cost.

Using a network of dispersed measuring sensors, several quantifiable environmental parameters can be monitored and recorded during the growing season. These environmental elements might include soil moisture, humidity, and temperature. These environmental elements could include temperature, humidity, and soil moisture. In close to real-time, WSNs are successfully able to provide, capture, and store measured environmental parameters. Using the captured and stored data, tools or models for monitoring and managing the production of agricultural crops might be created. Additionally, the gathered data might be examined to learn more about how the environment affects agricultural production, how to reduce production risk, and how to modify crop production methods. Consequently, utilizing wireless sensor networks significantly increases agricultural output Despite being practiced for centuries, greenhouse farming has only recently gained significant attention. Greenhouse farming is a comprehensive technique for maximizing the production of agricultural products in a controlled environment. They could be either permanent or temporary constructions covered in glass or plastic, often eliminating simple high or low tunnels, shade houses, and others from the permanent construction requirement with temperature controls, and "with automated watering systems." In addition to protecting plants from pests and extreme weather, greenhouses also provide protection from dust storms and blizzards. Sun, D.C. (2009) & Westar. (2019). Marginal settings' food production is improved through greenhouses, which can convert unarable soil into arable land by controlling humidity and temperature.

Moreover, the Tomato and cucumber are reportedly the major crops grown in a greenhouse at IPRC Musanze. The diversity of plants in the greenhouse have been carefully chosen. This ensures disease resistance, good crop performance under specific ideal environmental conditions, and other crop traits like storage, aesthetically pleasing appearance, flavor, etc.

The ideal daily average temperature for growing cucumbers in greenhouses is 1524°C (65–75°F). The best conditions for growth are around 18°C at night and around 28°C with lots of light during the day. To ensure that the rate of photosynthesis is optimal, light between 400 and 700 nm (nanometers) is needed. The ideal relative humidity range for crops is between 60 and 80 percent to guarantee they don't run the risk of contracting diseases or having their growth stunted by a lack of oxygen. To maintain purity and precise concentration control for photosynthesis, the ideal liquid carbon dioxide application is between 400 and 700 ppm during the day or any time of the night. They often thrive in a wide pH range (5.5-7.5), although it is widely agreed that the ideal pH for both mineral and organic soils is between 6.0 and 6.5. Harvesting begins 45–55 days after planting, and the cucumber crop takes 40–50 days to reach maturity (Parker, James, Jarvis & Parks, 2010).

The ideal temperature for growing tomatoes in a greenhouse is 25° C, whereas the ideal conditions for seedling growth are 18° C at night and 27° C during the day. The crop's quality is improved by accelerating its growth rates when the needed carbon dioxide concentration is between 800 and 1000 ppm. The ideal pH range for soil is 5.8 to 6.8. To ensure that the plant transpires freely during photosynthesis, the recommended humidity range for tomato plants should be between 65 and 75 percent at night and 80 to 90 percent during the day. To guarantee that photosynthesis is actively occurring, 625-700nm of light is advised for this plant. When the crop is grown under the ideal environmental parameters stated, it takes a crop roughly 5-7 weeks to produce (Larsen, Kim & Theus, 2009).

1.1.3. Statement of the Problem

The greenhouse horticulture industry in Rwanda is still in its infancy, and there are little resources and specialists in this area. As a result, we were motivated to develop greenhouse management and monitoring systems for the IPRC Musanze greenhouse for horticulture. This is not to imply that technical advances won't occur in the future; in fact, they may be feasible, depending on the economic environment (particularly changes in product costs and quality) and level of knowledge.

Rwanda seeks to establish greenhouses and hydroponic facilities with a cost of Rwf8.28 billion by 2023/2024, and according to the conducted research, most of greenhouses found in Rwanda especially in Musanze District 99% are not technological based. In Kinigi there is one greenhouse of SOPYRWA which is semi-automated and it is reserved for seeds multiplication, so this is a big problem that my research has to sort out. From the above information or facts, I have been decided to conduct this research.

Due of the unexpected weather changes, agricultural technologies used in greenhouse farming are ineffective at monitoring environmental conditions. Additionally, they don't capture the environmental factors in real-time, which should be monitored, which reduces productivity in greenhouse farming. In order for farmers to practice precision and profitable greenhouse farming, technology must be used (Zhao et al., 2010).

A greenhouse farm's production efficiency and sensor-based remote monitoring are both guaranteed when environmental conditions are managed. An Internet of Things (IoT) prototype can assist in monitoring the environmental conditions in a greenhouse and further ensure that the information is analyzed and distributed to the appropriate end users, such as farmers (Fangli, 2015). In this study, I'll build a working prototype of the Internet of Things that monitors environmental conditions in a greenhouse. Those criteria have also to be looked at and swiftly given to IPRC Musanze and farmers in order to guarantee that their productivity is higher.

Purpose of the study

Most greenhouse systems use manual systems for monitoring the temperature and humidity and other environment parameters which can cause discomfort to the worker as they are bound to visit the greenhouse every day and manually control them. Also, a lot of problems can occur as it affects the production rate because the temperature and humidity must be constantly monitored to ensure the good yield of the plants. Internet of Things is one of the latest advances in Information and Communication Technologies, providing global connectivity and management of sensors, devices, users with information. So the combination of IoT and embedded technology has helped in bringing solutions to many of the existing practical problems over the years.

1.1.4. Objectives

1.1.5. General Objective

The main objective of this study is to develop an IOT-based real-time monitoring and control system of environmental parameters in horticulture greenhouse.

1.1.6. Specific Objective

1. Determining the existing IOT system techniques challenges posed to the greenhouse farming for horticulture greenhouse real-time monitoring and control.
2. To examine the models, frameworks, and architectures used in greenhouse farming.
3. Create an efficient a IOT prototype based on the real-time monitoring and control system for horticulture greenhouse.
4. Evaluate the proposed IOT prototype against the existing approaches

1.1.7. Research questions

1. What are the existing IOT system techniques challenges posed to the greenhouse farming for horticulture greenhouse real-time monitoring and control?

2. What are the models, frameworks, and architectures used in greenhouse farming?

3. How an efficient IOT prototype based on the real-time monitoring and control system can be created for horticulture greenhouse?

4. What are the proposed IOT prototype contributions against the existing approaches?

1.1.8. Scope

This study concentrated on greenhouses, with IPRC Musanze Greenhouse serving as the case study. Farmers and their employees have to be involved. The types of crops that have been focused on are vegetables; cucumber, tomato. Integration of technology with the greenhouse farming is limited to IoT and M2M technologies.

1.1.9. Significance of the Study

According to Warwick (2015), the IoT could be a key enable to transform the agricultural industry and to increase food production by 70% by 2050 Warwick (2015). It enables smart farming which means preparing the soils, planting and harvesting at the best time.

Farmers are the primary beneficiaries of this study, which enables them to practice smart farming by improving their understanding of monitoring environmental conditions and thus increasing farm productivity. The system also benefits greenhouse managers greatly because it provides them with a remote monitoring tool for the farms.

The demand for food is always rising as the world's population rises, placing further pressure on already overworked land to boost its productivity. Residents with low incomes do not have easy access to affordable fresh food. Due to the difficulties people have keeping up a balanced diet, this has a significant impact on poverty and poor health. Precision agriculture, which maximizes the use of small amounts of land in farming, is one of the new farming methods being used to try to solve this issue.

This study sought to understand how farmers use M2M and IoT to easily incorporate farming into their daily lives, such as by monitoring irrigation and environmental conditions. Moreover, to offer workable methods so that farmers may simply get environmental analysis and reporting.

1) Providing favorable crop growing conditions
2) Protecting IPRC Musanze crops from unfavorable weather and various pests
3) Contributing to attaining sustainable development goals (SDGS) related to zero hunger.

1.2 RESEARCH METHODOLOGY

1.2.1. Introduction

This research aims to design and implement IoT-based Real-Time Monitoring and Control System of environmental parameters in horticulture Greenhouse to prevent crops disease. In order to achieve this aim; the different methodology approaches have been used. This chapter illustrates how the research project was conducted. It purifies the method used to collect all data, the analysis of the existing system as well as of the proposal of the new system. Data collected are also analyzed within different chapters and the conclusion gives the better performance of objectives of the research.

1.2.3. Research Design

In this study, an applied research design will be employed. The research design includes determining the product's market need(s), designing a product that could satisfy those needs, creating a prototype, and evaluating if the prototype satisfied those needs in terms of cost, environmental impact, and profitability when it was released onto the market.(Marder, 2011). In addition, the researcher will conduct a thorough system analysis, design, and development using the Structured Systems Analysis and Design Method (SSADM). Entity event modeling, logical data, and data flow were all included. (Sarstedt & Mooi, 2003). A cross-sectional study was carried out using a sample of constituents from an interest population at a particular moment. The study will focus on a sampling of the population's components. Conclusions will be reached after analyzing the data.

1.2.4. Data collection techniques

Techniques of investigation are data collection techniques that are used for deeply understanding of the requirements and the problem domain.

The researcher made use of both primary and secondary data. Primary data was useful in getting first-hand and new information from the various stakeholders. This data was collected by administering questionnaires and face-to-face interviews to the farmers and mangers of the greenhouse farms. The main strength of questionnaires was that a large number of questions was asked about a given topic and gave flexibility to the analysis. Secondary data was used to understand IoT technologies deployed in greenhouse farming and selecting one that was appropriate to design an IoT system that would enable recording of environmental conditions, analyze them and display them to various end-users such as farmers. This data was collected by reviewing literature. In addition, the secondary data was used to identify ways of developing future works such automating processes in the greenhouse such as irrigation and lighting.

1.2.5. Observation

Observation is the gathering of primary data by investigator's own direct observation of relevant people, action and situations without asking from the respondent. This method requires to the investigator to get into about any event. In observation, the researcher goes to place where the events are taking place and records finding. For this case, I visited IPRC Musanze greenhouse

1.2.6. Interview

More sorts of interviews exist than most people realize. When conducting a qualitative interview, open-ended questions are typically used to engage participants in conversation and obtain information about a topic. Most of the time, the interviewer is a subject-matter expert who seeks to understand the thoughts of the respondents through a carefully thought-out and executed series of questions and responses. When it comes to gathering data from the target market, interviews are similar to focus groups and surveys, but they operate very differently. Focus groups are limited to a small group of people, whereas surveys are quantitative in nature. Employees of IPRC Musanze who work in greenhouses for horticulture are those who will be interviewed in this case.

1.2.7. Documentation

Sometimes you can collect a considerable amount of data without asking anyone anything. Document and records-based research used to collect secondary data by using existing data for a study. Attendance records, meeting minutes, and financial records are among examples of this type of research.

Since you are mostly using already-completed research, using documents and records can be effective and affordable. Documents and records, however, can be an unreliable data source because the researcher has less control over the outcomes. As mentioned in chapter two, we used books, journals, reports, and websites for our research.

1.2.8. Data Processing

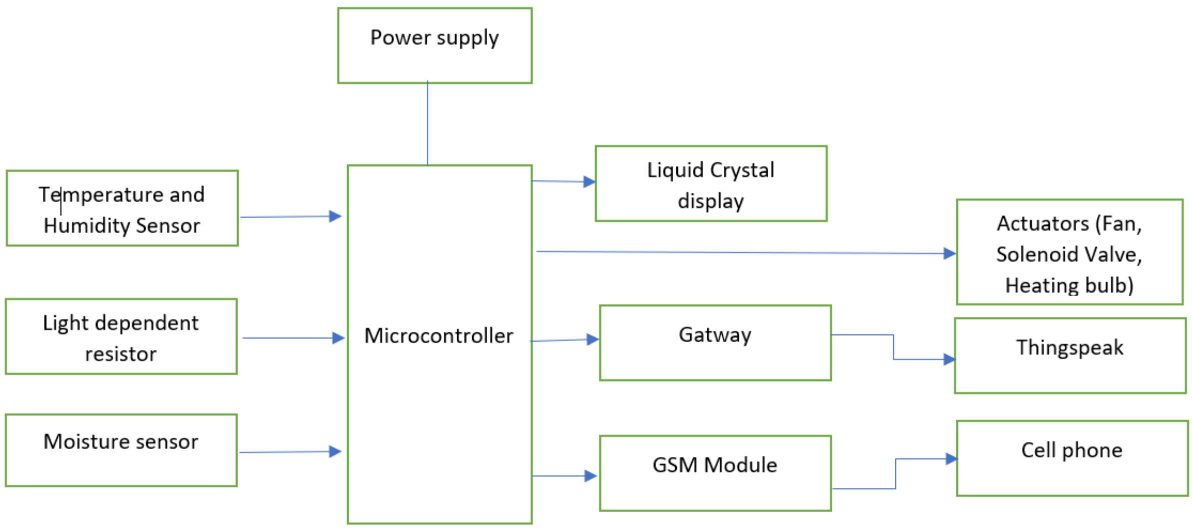

Figure 1: Data Processing

Here a farmer will get notifications through his/her mobile phones but also he/she will have access to Thingspeak foe remote monitoring, Arduino will be programed using Arduino IDE software or Python.

1.2.9. Development methodology

(Matthew M, 2022) The prototype will be produced, tested, and refined until it achieves the intended prototype, according to the prototyping model used by the researcher. Additionally, this model functions best when the specifics of the project's requirements are uncertain. It is an iterative, trial-and-error process that involves the client and the developer.

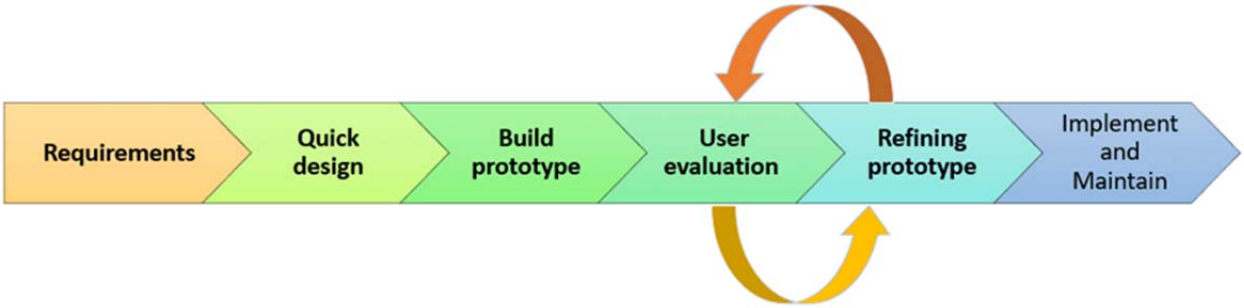

Figure 2: Prototype model phases (Matthew M,2022)

- ✓ **Requirements gathering and analysis:** This is the first phase which involves requirements analysis and helps for defining requirements of the system.
- ✓ **Quick design:** This is the second phase for beginning design or a quick design. The creation of a simple design of the system is done in this stage. Note that this stage is not the final because it gives to users a summary of the system. The quick design helps in developing the prototype.
- ✓ **Build a Prototype:** In this phase, the desired prototype is designed and developed basing on the collected information from previous phase. It will be a small working model of the required system.
- ✓ **Initial user evaluation:** this stage involved the presentation of proposed system. From this, strength and weakness of the developed model are identified. Comments, suggestion are collected for improvements; the proposed system will be presented. It helps to find out the strength and weakness of the working model. Comment and suggestion are collected.
- ✓ **Refining prototype:** this stage help to refine the developed prototype basing on feedback and suggestions provided by the user if she/he is not happy with the current prototype.
- ✓ **Implement Product and Maintain**: this is the final phase from which the developed prototype is being tested and deployed. It involves also the maintenance of produced product for correcting some failure and improving performance.

1.2.10. Hardware requirement

- ✓ **NodeMCUESP8266**

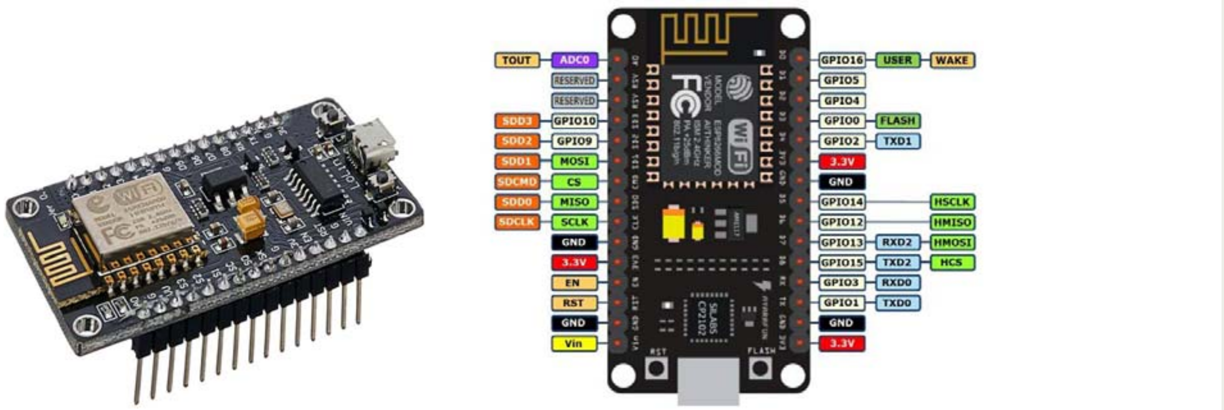

Figure 3: NodeMCUESP8266 (Electroniclinic, 2020)

NodeMCU is an open-source Lua based firmware and **expansion board** to be used specifically for IoT based Applications. It includes firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. (Electroniclinic, 2020)

NodeMCU Development Board Pinout Configuration

NodeMCU Development Board Pinout Configuration

Pin Category	**Name**	**Description**
Power	Micro-USB, 3.3V, GND, Vin	**Micro-USB:** NodeMCU can be powered through the USB port **3.3V:** Regulated 3.3V can be supplied to this pin to power the board **GND:** Ground pins **Vin:** External Power Supply
Control Pins	**EN, RST**	The pin and the button resets the microcontroller
Analog Pin	A0	Used to measure analog voltage in the range of 0-3.3V
GPIO Pins	GPIO1 to GPIO16	NodeMCU has 16 general purpose input-output pins on its board

SPI Pins	SD1, CMD, SD0, CLK	NodeMCU has four pins available for SPI communication.
UART Pins	TXD0, RXD0, TXD2, RXD2	NodeMCU has two UART interfaces, UART0 (RXD0 & TXD0) and UART1 (RXD1 & TXD1). UART1 is used to upload the firmware/program.
I2C Pins		NodeMCU has I2C functionality support but due to the internal functionality of these pins, you have to find which pin is I2C.

NodeMCU Pin layout description.

- ✓ **Arduino Uno**

Figure 4: Arduino Uno

Arduino/Genuino Uno is a microcontroller board of the type of the ATmega328P which has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.

It contains all components needed to support the microcontroller; where it is connected to a computer via a USB cable or power it with a AC-to-DC adapter or battery to get started. You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again.

"Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform.(Arduino, 2021).

- ✓ **Bread board**

A breadboard is a construction base for prototyping of electronics. Originally it was literally a bread board, a polished piece of wood used for slicing bread. In the 1970s the solderless breadboard (AKA plugboard, a terminal array board) became available and nowadays the term

"Breadboard" is commonly used to refer to these. "Breadboard" is also a synonym for prototype". Because the solderless breadboard does not require soldering, it is reusable. This makes it easy to use for creating temporary prototypes and experimenting with circuit design. For this reason, solderless breadboards are also extremely popular with students and in technological education. Older breadboard types did not have this property. A stripboard (veroboard) and similar prototyping printed circuit boards, which are used to build semipermanent soldered prototypes or one-offs, cannot easily be reused. A variety of electronic systems may be prototyped by using breadboards, from small analog and digital circuits to complete central processing units (CPUs).

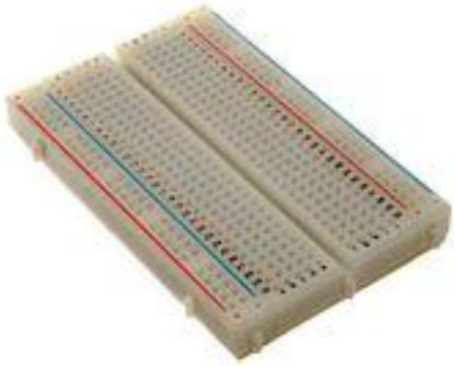

Figure 5: Bread board

A modern solderless breadboard consists of a perforated block of plastic with numerous tin plated phosphor bronze or nickel silver alloy spring clips under the perforations. The clips are often called *tie points* or *contact points*. The number of tie points is often given in the specification of the breadboard. The spacing between the clips (lead pitch) is typically 0.1 in (2.54 mm). Integrated circuits (ICs) in dual in-line packages (DIPs) can be inserted to straddle the centerline of the block. Interconnecting wires and the leads of discrete components (such as capacitors, resistors, and inductors) can be inserted into the remaining free holes to complete the circuit. Where ICs are not used, discrete components and connecting wires may use any of the holes.

- ✓ **Jump wires**

Jump wires (also called jumper wires) for solderless breadboard can be obtained in ready-to-use jump wire sets or can be manually manufactured. The latter can become tedious work for larger circuits. Ready to- use jump wires come in different qualities, some even with tiny plugs Attached to the wire ends. Jump wire material for ready-made or homemade wires should usually be 22 AWG (0.33 mm2) solid copper, tin-plated wire - assuming no tiny plugs are to be attached to the wire ends. The wire ends should be stripped 3⁄16 to 5⁄16 in (4.8 to 7.9 mm). Shorter stripped wires might result in bad contact with the board's spring clips (insulation being caught in the springs). Longer stripped wires increase the likelihood of short-circuits on the board. Needle-nose pliers and tweezers are helpful when inserting or removing wires, particularly on crowded boards.

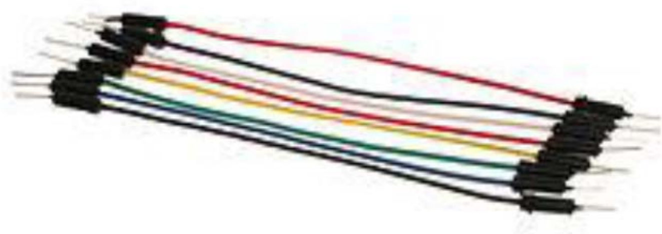

Figure 6: Jump Wires.

Differently colored wires and color-coding discipline are often adhered to for consistency. However, the number of available colors is typically far fewer than the number of signal types or paths. Typically, a few wire colors are reserved for the supply voltages and ground (e.g., red, blue, black), some are reserved for main signals, and the rest are simply used where convenient.

✓ **Temperature and Humidity sensor DHT11**

The DHT11 is a basic, ultra-low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed). It's fairly simple to use, but requires careful timing to grab data. You can get new data from it once every 2 seconds, so when using the library from Adafruit, sensor readings can be up to 2 seconds old. It Comes with a 4.7K or 10K resistor, which you will want to use as a pullup from the data pin to VCC.

Main specifications of DHT11

- 3 to 5V power and I/O
- 2.5mA max current use during conversion (while requesting data)
- Good for 20-80% humidity readings with 5% accuracy
- Good for 0-50 °C temperature readings +-2 °C accuracy
- No more than 1 Hz sampling rate (once every second)
- Body size 15.5mm x 12mm x 5.5mm
- 4 pins with 0.1" spacing

✓ **Liquid crystal display**

A 20x4 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.

A 20x4 LCD means it can display 20 characters per line and there are 4 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. This is standard HD44780 controller LCD.

Main specifications of LCD (20*4)

- 20 Characters x 4 Lines
- Built-in HD44780 Equivalent LCD Controller
- Works directly with ATMEGA, ARDUINO, PIC and many other microcontroller/kits.
- 4- or 8-bit data I/O interface
- Low power consumption

✓ **Soil Moisture Sensor**

The soil moisture sensor is one kind of sensor used to gauge the volumetric content of water within the soil. As the straight gravimetric dimension of soil moisture needs eliminating, drying, as well as sample weighting. These sensors measure the volumetric water content not directly with the help of some other rules of soil like dielectric constant, electrical resistance, otherwise interaction with neutrons, and replacement of the moisture content.

The relation among the calculated property as well as moisture of soil should be adjusted & may change based on ecological factors like temperature, type of soil, otherwise electric conductivity. The microwave emission which is reflected can be influenced by the moisture of soil as well as mainly used in agriculture and remote sensing within hydrology.

✓ **Soil Moisture Sensor Pin Configuration**

The FC-28 soil moisture sensor includes 4-pins

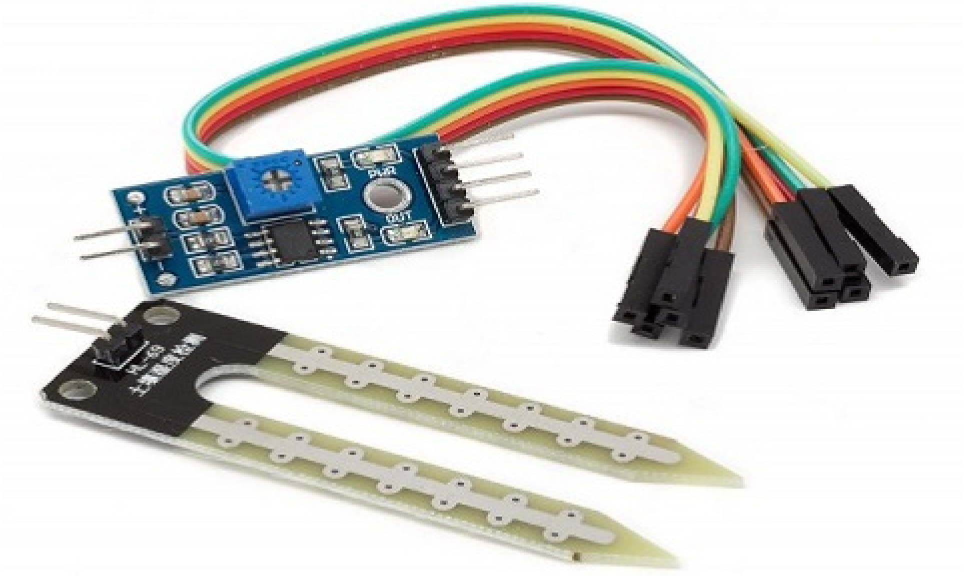

Figure 7: Soil Moisture Sensor

- VCC pin is used for power
- A0 pin is an analog output
- D0 pin is a digital output
- GND pin is a Ground

This module also includes a potentiometer that will fix the threshold value, & the value can be evaluated by the comparator-LM393. The LED will turn on/off based on the threshold value.

✓ **GSM SIM 800L (**Global System Mobile**)**

SIM800L is a miniature cellular module which allows for GPRS transmission, sending and receiving SMS and making and receiving voice calls. Low cost and small footprint and quad band frequency support make this module perfect solution for any project that require long range connectivity.

Figure 8: GSM (Global System Mobile)

- ✓ **Light Dependent Resistor (LDR) sensors**

An LDR or light dependent resistor is also known as photo resistor, photocell, photoconductor. It is a one type of resistor whose resistance varies depending on the amount of light falling on its surface. When the light falls on the resistor, then the resistance changes. These resistors are often used in many circuits where it is required to sense the presence of light. These resistors have a variety of functions and resistance. For instance, when the LDR is in darkness, then it can be used to turn ON a light or to turn OFF a light when it is in the light. A typical light dependent resistor has a resistance in the darkness of 1MOhm, and in the brightness a resistance of a couple of KOhm.

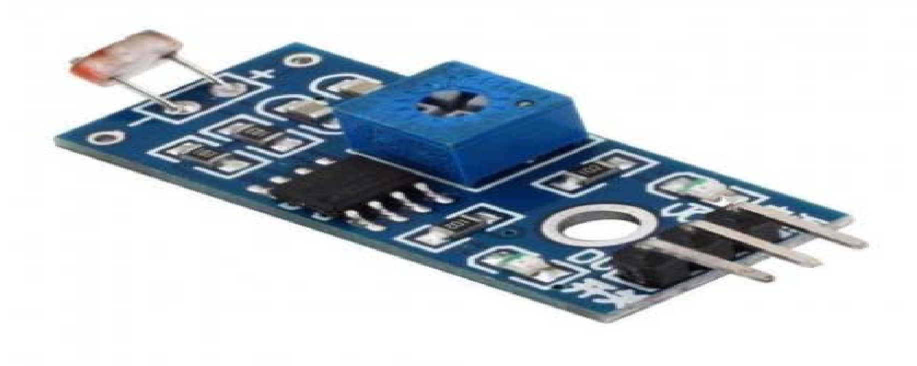

Figure 9: Light Dependent Resistor (LDR) sensors

- ✓ **Solenoid pump**

Solenoid pumps are a class of positive displacement pump which use a diaphragm and solenoid assembly to displace the fluid into the discharge line. The solenoid assembly consists of an electromagnet and spring. When current is applied to a solenoid the electromagnetic core moves a diaphragm into the discharge position.

Figure 10: Solenoid pump

1.2.11. Software Requirement

- ✓ **ThingSpeak Platform**

ThingSpeak is an open-source software written in Ruby which allows users to communicate with internet enabled devices. It facilitates data access, retrieval and logging of data by providing an API to both the devices and social network websites. ThingSpeak was originally launched by ioBridge in 2010 as a service in support of IoT applications.

ThingSpeak is an open-source software written in Ruby which allows users to communicate with internet enabled devices. Features of ThingSpeak include real-time data collection, data processing, visualizations, apps, and plugins. At the heart of ThingSpeak is a ThingSpeak Channel. A channel is where you send your data to be stored.

- ✓ **Arduino IDE**

Figure 11: Arduino IDE (NodeMCU(wikipedia, 2019).

The Arduino Integrated Development Environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in functions from C and C++. It is used to write and upload programs to Arduino compatible boards, but also, with the help of third-party cores, other vendor development boards like NodeMCU(wikipedia, 2019).

1.2.11. Limitations

This research combines machine-to-machine and Internet of Things (IoT) technologies, which requires expensive hardware equipment. The apparatus is made up of microcontrollers, sensors, and actuators. The project also necessitates a thorough understanding of M2M, IoT, and data storage technology, and I won't go through every greenhouse parameter here.

1.2.12. Ethical considerations

Since this study involves human responders, various ethical concerns have been taken into account and handled. In order to protect the participants' privacy, it is crucial to take these ethical concerns into account. Consent and secrecy are two ethical concerns that need to be taken into account.

3.1. DESIGN AND IMPLEMENTATION

3.1.1. Introduction

Constant monitoring and control system of environmental parameters by using intelligence systems in horticulture green house could be ready to us for smart agriculture in Rwanda and Contributing to the reduction of environmental hazards associated with infections and diseases in farms, by monitoring vegetables and fruits in greenhouses, thus mitigating the threat to future generations. In order to achieve these, research has been conducted on **IoT based real-time monitoring and control system of environmental parameters in horticulture greenhouse.** In this chapter focuses on the design and implementation of a research solution prototype, this prototype is able to detect temperature, moisture, light and humidity needed for a better growth of vegetables especially tomatoes.

3.1.2. Prototype system Design

3.1.3. Circuit diagram

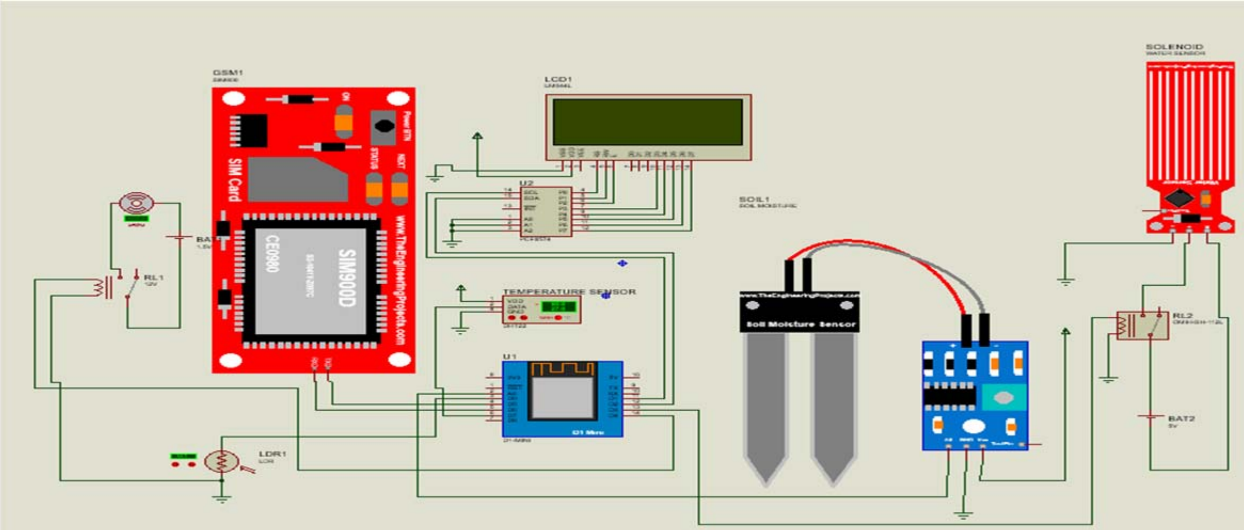

Figure 11: Circuit diagram

3.1.4. Working principle

In this prototype, I have designed a simple system by using nodeMCU, moisture Sensors, LDR sensor and DHT11 sensor, where DHT 11 will be measuring temperature and humidity once temperature is to high the cooling device will work here I mean fan and if the temperature is too low, alerting message will be sent to the farmer via phone the same to humidity and for the moisture sensor when the estimation of volumetric water content is low the solenoid pump react by irrigating. Other environmental parameters have to be analyzed through Thingspeak means that a farmer can check environmental parameters by using it.

3.1.5. Prototype system implementation

3.1.6. Hardware implementation

The prototype has been implemented and it works according to its working principle. The following figure is the part of sensors where three sensors (LDR, Moisture and DHT11) used.

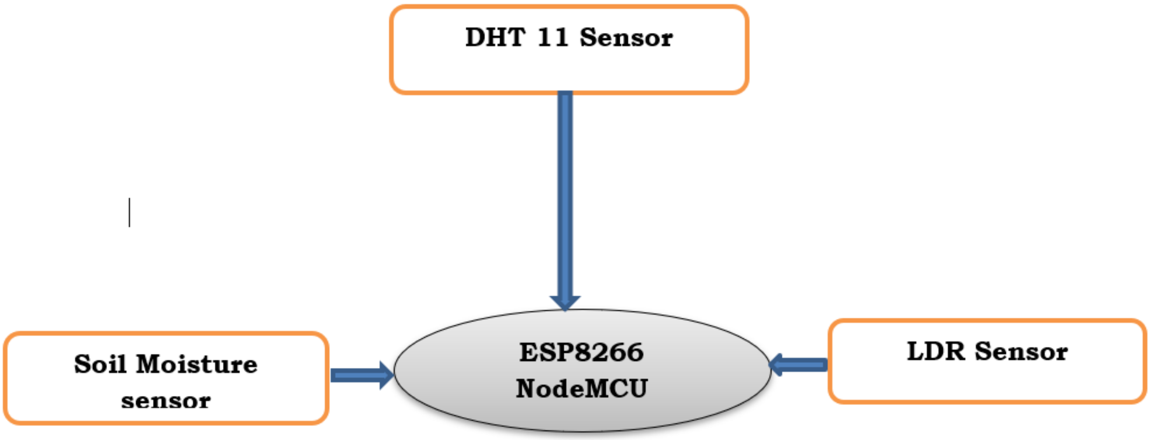

Figure 12: Sensing part

The sensed data through jumper wires reach to microcontroller boards composed by NodeMCU for data processing.

3.1.7. 3.3.2 Software implementation

- ✓ **ThingSpeak communication**

Figure 13: ThingSpeak Communication

In addition to the monitoring from the cloud platform, the system sends SMS notifications using GSM to the responsible person and coordinates on temperature, humidity, and light changes.

3.1.8. Data visualization

- ✓ **On-site monitoring**

```
Current humidity = 21.00%  temperature = 23.00C
Current light:57.00
```

Figure 14: On-site monitoring

✓ **Remote monitoring using ThingSpeak**

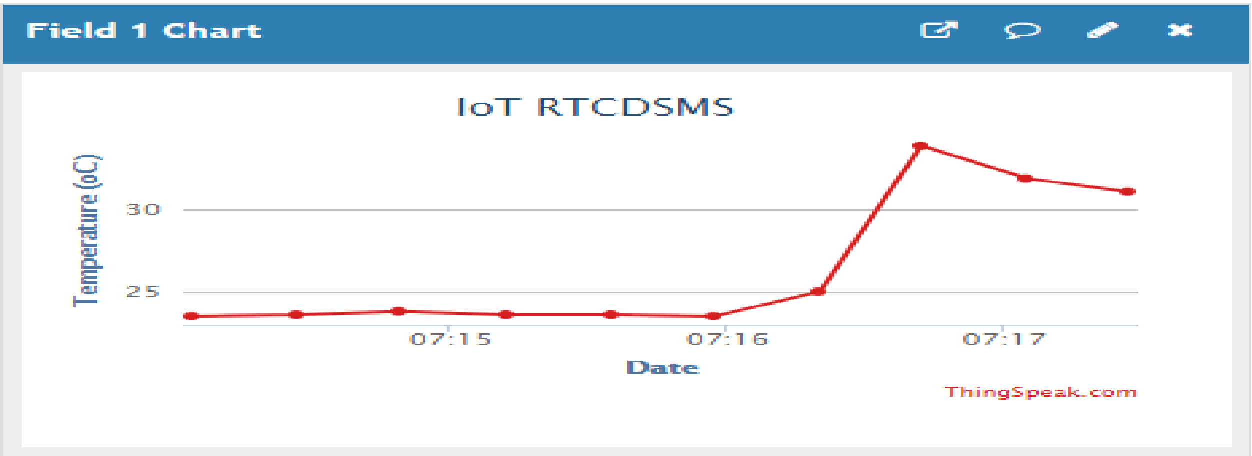

Figure 15: Remote monitoring using ThingSpeak(Temperature parameter)

The above figure shows how temperature is monitored using ThingSpeak and this should be analyzed by farmer day per day

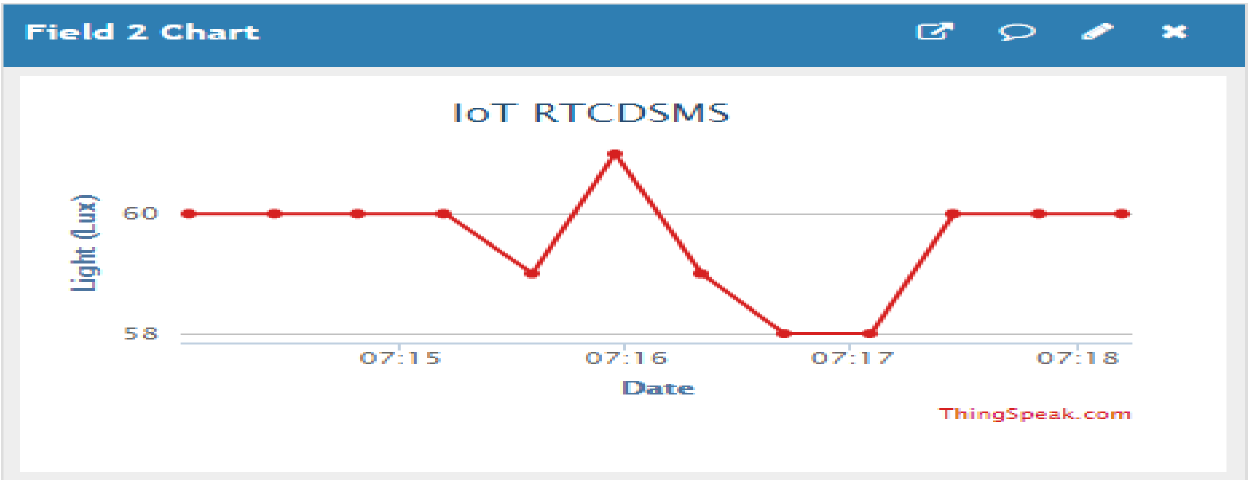

Figure 16: Remote monitoring using ThingSpeak (Light parameter)

The above figure shows how light is monitored using ThingSpeak and this should be analyzed by farmer day per day to know if light is needed or not depending to the plant

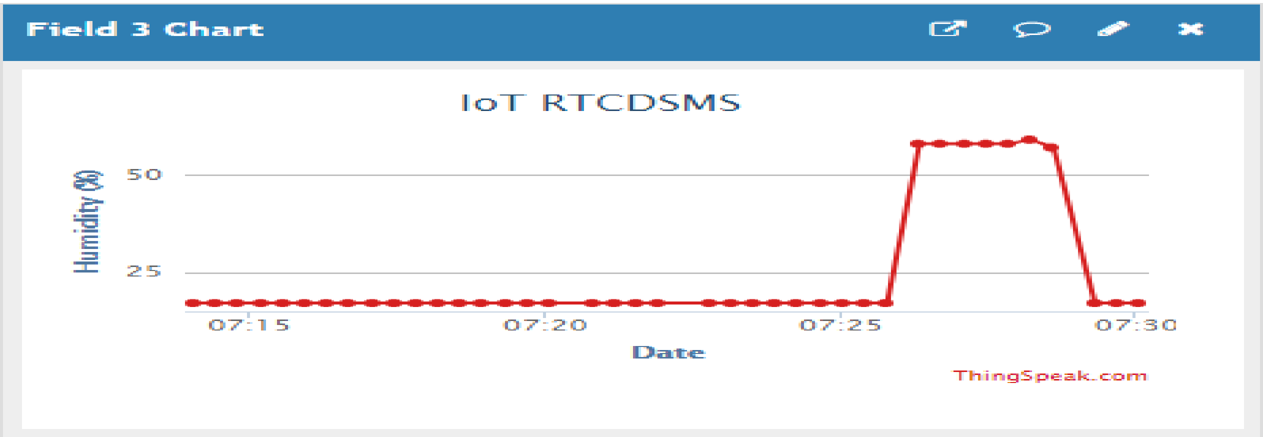

Figure 17: Remote monitoring using ThingSpeak (Humudity parameter)

The above figure shows how humidity is monitored using ThingSpeak and this should be analyzed by farmer day per day.

3.1.9. Calculation

Soil moisture sensors measure or estimate the amount of water in the soil. These sensors can be stationary or portables such as handheld probes. Stationary sensors are placed at the predetermined locations and depths in the field, whereas portable soil moisture probes can measure soil moisture at several locations.

A better understanding of the basic principles, definitions, and terms behind the soil-water-plant relationship is essential to effectively utilize soil moisture sensors.

Volumetric water content (VWC) soil moisture sensors

Volumetric water content is the volume of liquid water per volume of soil. It is usually expressed as a percentage. For example, 25% volumetric water content (VWC) means 0.25 cubic inch of water per cubic inch of soil.

When compared with the maximum amount of water that the soil can hold or field capacity, volumetric water content (VWC) measurements can be used to measure soil water deficit for irrigation scheduling:

Soil water depletion/deficit (inches) = soil water content at field capacity (inches) - current soil water content (inches)

Note: %Soil water content measurements must be multiplied by the depth of the root zone to give total water in that soil depth.

For example:

- If a 12-inch soil profile has a VWC of 9%, then
  - Total water in a 12-inch profile = 0.09 x 12 inches = 1.08 inches water
- If field capacity is 18%, then
  - Soil water depletion/deficit = (0.18 x 12 inches) - 1.08 inches = 1.08 inches

3.1.10. Soil water deficits and crop stress

For irrigation scheduling, it's important to understand the soil water content at which a crop begins to experience stress. In general, most crops begin to experience stress when soil water depletion/deficit is 30-50% of available water holding capacity (AWC). This is called management allowable depletion (MAD) or irrigation trigger point.

MAD can vary depending upon crop, growth stage and an irrigation system's pumping capacity. For more information. Irrigation should be triggered when the % soil water depletion is equal or close to the % MAD.

Volumetric water content (VWC) can be used to calculate %soil water depletion using the following formula:

$$\% \, Soil \; Water \; Depletion = \left[1 - \left(\frac{Sensor \; VWC(\%) - PWP(\%)}{FC(\%) - PWP(\%)}\right)\right] * 100$$

Where PWP is permanent wilting point and FC is field capacity.

Field capacity can be measured very easily in the field using soil moisture sensors. The VWC measurements provided by the soil moisture sensor after 12-24 hours of heavy irrigation or rain is the field capacity of the soil.

3.1.11. Summary of Findings

After testing the IoT Based real-time Monitoring and control environmental parameters prototype in a greenhouse located in IPRC Musanze and analyzing the results, the application ensures solving gaps identified in the environmental. The tested mains parts of the system have attained to the following goals:

(a) **Monitoring:** on-site monitoring (LCD), Remote monitoring (ThingSpeak platform)

(b) **Control**: solenoid valve, cooling fan, heating bulb.

4.1. CONCLUSION AND RECOMMENDATION

4.1.1. Introduction

A majority of greenhouses in Rwanda have deployed technology to assist them in higher agricultural activities. However, integration of agricultural activities with Internet of Things is yet to be realized. This type of solution appeals to the farmers due to automation of greenhouse farming activities and hence improves production yield. This section focuses on the conclusions and recommendations for the research. The researcher developed a prototype for monitoring and controlling environmental conditions and did an analysis of the challenges faced in greenhouse.

4.1.2. Conclusion

The main challenges of greenhouse farming in small-scale farms in Rwanda are; operation expenses (electricity, machinery and employees), pests and diseases, lack of quality water sources and lack of training on appropriate technological advancements in agriculture sector such as use of Internet of Things. However, the key challenge they face is monitoring.

The researcher's key objective was to identify the optimum environmental conditions in a greenhouse and the best technology to monitor the parameters. To accomplish the set objectives, the research made use of both primary and secondary data. Primary data was used to identify the optimum environmental parameters in a greenhouse and challenges faced in greenhouse farming. It was found out that the main environmental parameters are temperature, humidity, light and moisture.

Moreover, there was an even distribution of challenges faced in greenhouse management where environmental conditions were observed as the most important factor. It was important for the farmers to record the environmental conditions accurately to ensure higher yield productions. Secondary data was used to compare various greenhouse management architectures deployed and to determine the most appropriate technology to be deployed in the greenhouses at IPRC Musanze.

4.1.3. Recommendation

Environmental conditions have been observed as a key requirement to ensure greenhouse farming is running effectively amongst other factors. Therefore, this implies that Internet of Things architectures should be deployed to monitor and control the various environmental parameters. Based on the analysis of strengths and weaknesses of various architectures deployed in greenhouses, the use of NodeMCU as a microcontroller and grove system, as the sensors, was found to the most appropriate architecture for greenhouse farming management. This because the architecture can be integrated with a cloud-platform(Thingspeak) for analysis and storage due to its wi-fi enabled feature. Greenhouses in IPRC Musanze should adopt this design to ensure high and quality yields. In addition, real-time predictive analysis will improve decision making which will optimize agricultural processes in the greenhouse. The farmers should be technologically equipped and trained to harness ICT skills to ensure efficiency in their production.

Areas for further research

Almost all environmental variables (temperature, humidity, amount of light in common and individual spectral regions, atmospheric pressure and air quality) in the greenhouse system can be used as sensed data. Due to the specific requirements of the greenhouse experiment, different types of environmental variables need to be monitored, and thus different values of sensors need to be measured Many different combinations are sampled based on experience and experimental parameters: Temperature, humidity, CO2 concentration, illumination, illuminance (limited to a specific part of the spectrum). Other sensors include barometric pressure, specific gas concentration (oxygen, nitrogen, ozone)

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