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Internet of Things for Monitoring Environmental Conditions in Greenhouses: A Case of Kiambu County

Kanake James Maina

Submitted in partial fulfillment of the requirements for the degree in Master of Science in Information Technology at Strathmore University



Faculty of Information Technology

Strathmore University

Nairobi, Kenya

MAY, 2016

Declaration

I declare that this work has not been previously been submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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KANAKE JAMES MAINA

Date.....

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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. Machine to Machine Communication refers to solutions that allow communication between devices of the same type and a specific application through wired or wireless communication networks. Moreover, Internet of Things is a connection of physical things to the internet which makes it possible to access remote data and control the physical world from a distance. These types of solutions allow end-users to capture data about events and transfer it to other devices but they do not allow broad sharing of data or connection of the devices directly to the Internet. In this thesis, the researcher investigated the use of machine to machine communication by having small electronic devices equipped with sensors that when deployed in a farm they can record the environmental conditions and communicates the information to the farmers. Moreover, the different types of crops grown in greenhouses at Kiambu County. Thereafter, the information was analyzed and sent to relevant end users such as the farmer and a metrological department that will enable them to monitor and adapt to the environmental conditions. The research used applied method of research, interviews and questionnaires to gather data. Therefore, an IoT prototype was developed to gather the critical environmental conditions in a greenhouse. The recorded data was transmitted by wireless networks using machine to machine (M2M) technologies from the sensors to the cloud platform, Intel IoT analytics dashboard, for real-time predictive analysis of the environmental parameters. An email notification was sent to alert the farmers when the parameters exceeded the threshold which were preset. This IoT prototype was used in small to large commercial indoor operations as well as small personal gardens.

Acknowledgements

I greatly acknowledge the guidance given by Dr. Vitalis Ozianyi in the research orientation and study of the subject. He has been very instrumental in understanding the topic and implementation of the prototype. Also to my classmates Master of Science in Information Technology class of 2014 for their academic support.

I also acknowledge the Faculty of Information Technology (FIT) for giving me an opportunity to pursue a Masters in Information Technology course (MSc.IT) and the thesis seminars that were guided by Professor Ismail Ateya to help us achieve quality work.

Lastly my acknowledgements go to my parent Miss Margaret Kanake for her support and encouragement.



Abbreviations/ Acronyms

- **3GPP**-Third Generation Partnership Project
- **ETSI**-European Telecommunication Standards
- **GIS**-Geographic Information System
- **GPS**-Global Positioning System
- **ICT-Information Communication Technology**
- **IoT**-Information of Things
- **IPv6**-Internet Protocol Version 6
- M2M-Machine to Machine Communication
- MQTT- Message Queuing Telemetry Transport
- NIST-National Institute of Standard Technology
- PA-Precision Agriculture
- RFID-Radio Frequency Identification
- SMS-Short Message Services
- TIA-Telecommunications Industry Association
- UC-Ubiquitous Computing
- WSN-Wireless Sensor Networks

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Chapter One: Introduction

1.1 Background to the study

A greenhouse is a structure that is covered with a transparent material, such as plastic bag or glass, in which plants requiring regulated climatic conditions are grown (Drakes, 2008). In addition, greenhouse management oversees the daily operations that cultivate plants for research and commercial use. This involves choosing and planting seeds, maintain greenhouse facilities, train and supervise employees and maintain records.

The introduction of greenhouses in Kiambu County heralds what could be a major shift from open pollinated farming to hybrid high yielding methods, which could lead to massive improvements in crop production, output, incomes and ultimately self-sufficiency in food production. In addition, there has been a marked uptake of improved planting materials in the county, a sign that farmers are keen to adopt new products and technology (Nelson, 2011).

According to Patel (2007), if technology is widely embraced in the greenhouses, the county could start enjoying year-round supply of crops, such as tomatoes and kales, which currently get damaged during the wet seasons, pushing prices through the roof. Therefore, growing crops under greenhouses has many advantages, among them the ability to produce huge quantities on a small piece of land and continuous harvesting.

According to Agarwal (2000), Internet of Things refers to creating a network of objects that communicates with each other, via the internet, integrating embedded sensors, actuators, computers, RFID, mobile phones etc. These objects will have unique addresses to verify their identities and to be able to exchange and process information according to defined tasks and send reports to end users. Therefore, IoT is a network of Internet enabled objects that interacts with the web services. The technology is an evolution from Machine-to-machine communication where the objects would exchange data but do not interact with the Internet.

Machine-to-Machine communication refers to solutions that allow communication between devices through wired or wireless communication networks (Holler, Tsiatsis, Mulligan, Karnouskos & Avesand, 2014). This type of solution allows end-users to capture data about events and transfer it to other devices but they do not allow broad sharing of data or connection of the devices directly to the Internet. Radio Frequency Identification (RFID) is a simple and cost effective system that allows devices such as sensors and smart phones interconnect with large databases and the Internet. This how the data about things is collected and processed. Sensor technologies will facilitate data collection which will happen in real time to detect any changes in the environment. The embedded devices will form a network that will basically have information processing capabilities. A combination of all of these developments will create an Internet of Things that connects the world's objects in both a sensory and an intelligent manner.

The basic idea of the IOT is that virtually every physical thing in this world can become a computer that is connected to the Internet. This means devices can be tagged with tiny computers to do smart things such as share, store and analyze information (Zhao, Zhang, Feng &Guo, 2009).

Advancements in technology have led to E-agriculture which focuses on enhancing agricultural development through improved information and communication processes. E-agriculture embraces the use of Internet of Things which involves conceptualization, design, evaluation and application of innovative ways to use technology in the field of agriculture.

In agriculture, IoT has been used to minimize crop damage of plant eating pests by having sensors monitors in the fields. They are able to monitor the fields by capturing real time data of the pest's movement and relay the information to famers of any attack on their crops before they spread widely (Naorem & Chanu, 2011).

IoT in agriculture has been deployed to aid in prevention for theft of livestock. The animals are fitted with radio frequency identifiers (RFIDs) that enable tracking of the animal. The RFID chips and readers are placed at various agricultural monitoring centers. Through data that is transmitted wirelessly to agricultural centers, the animals can always be tracked (Maumbe & Okello, 2013).

Technology has also been deployed in agriculture in the sector of aquaculture where satellite light radiation sensors detect water pollution in large water bodies which have a problem of flooding in the river basins. The sensors have the ability to see what happens throughout the river basin and the real time information is fed to a website which can predict weather patterns. This information saves a lot of lives in agricultural communities including their plants and livestock. The IoT technologies can also support precision agriculture, a form of agriculture whose goal is to maximize return on investment in agriculture. This is usually used in green houses where they deploy water and soil detection sensors that relay information wirelessly to farmers on water reserve points and when to irrigate. Moreover, the farmers can then adapt automated drip irrigation in areas where water is scarce (Patrikakis & Okello, 2013).

The researcher developed an IoT monitoring prototype in application of agriculture for greenhouse farming. The prototype uses embedded computers to collect real time critical information for greenhouse production such as temperature, humidity and soil pH by the use of Intel Edison module and Grove sensors. The information collected was transmitted by wireless networks through machine to machine (M2M) support platform for cloud storage and management. Then finally the real-time data of greenhouse production environmental conditions was sent to a farmer using email alerts on the production of greenhouse farming.

National Institute of Standard Technology (NIST), defines cloud management as a model for enabling convenient, demand network access to a shared pool of configurable computing resources that can be accessed with minimal management effort or service provider interaction (Mell&Grance,2011).

NIST claims cloud computing is about moving data to offsite location which is a centralized facility. By making data available in the cloud, it can be more easily accessed, often at much lower cost, increasing enabling opportunities for enhanced collaboration, integration and analysis on a shared common virtual platform.

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1.2 Problem Statement

Agricultural systems deployed in greenhouse farming are not effective for monitoring environmental conditions due to the unpredictable weather changing conditions. In addition, they do not record real-time information, the environmental parameters, which ought to be monitored and as a result it causes loss of productivity in green house farming. There is need of use of technology to enable farmers to have precision and profitability in greenhouse farming (Zhao et al., 2010).

Managing environmental conditions in a greenhouse farm will ensure production efficiency and ensure distant monitoring of the farms by using sensors. An IoT prototype can help monitor the environmental conditions in a greenhouse and further ensure there is analysis and dissemination of the information to the relevant end-users such as farmers (Fangli, 2015).

The researcher built an IoT prototype that recorded environmental conditions in a greenhouse. In addition, have the conditions analyzed and sent to the farmers in a timely manner to ensure their production is higher.

1.3 Research Objectives

The general objective for the research was to monitor environmental conditions in a greenhouse to increase productivity for farmers. In addition, the research intends to cover a number of objectives among them:

- i. To identify the optimum environmental conditions required for greenhouse farming
- ii. To understand the challenges facing greenhouse farming management.
- iii. To review the models, frameworks and architectures that have been used in greenhouse farming management.
- iv. To design an IoT prototype.
- v. To test the IoT prototype.

1.4 Research Questions

- i. What are the optimum environmental conditions for greenhouse farming?
- ii. What are the challenges faced in greenhouse farming management?
- iii. What are the models, frameworks and architectures that have been used in greenhouse farming management?
- iv. How will the IoT prototype be designed?
- v. How feasible and scalable is this technology in solving the proposed solution?

1.5 Justification

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

Farmers will be the main beneficiaries of this study which will enable them to practice smart farming by having a better understanding of monitoring environmental conditions which will improve productivity in the farms. The greenhouse managers will also benefit greatly from the system mainly because they will have distant monitoring tool of the farms. An increase in the world population is continually pushing for greater food demands on land that is already being pushed to the limits to achieve more productive capacity. Low-income residents do not have easy access to cheap and fresh produce of food. This greatly contributes to poverty and poor health because of the challenges the face for maintaining a balanced diet. New farming techniques are trying to address this problem by practicing precision agriculture, which makes the most efficient use of small pieces of land in farming.

This research aimed to identify how farmers will use M2M and IoT to easily integrate farming into their day-to-day lifestyles such as monitor environmental condition and irrigation. Moreover, to provide practical solutions on how farmers can easily have analysis and reporting of the environmental conditions.

1.6 Scope

This research focused on greenhouses and the case study was on Kiambu County. It involved the farmers and their administrative staff. The types of crops that were focused on were vegetables; cucumber, tomato, capsicum and kales. Integration of technology with the greenhouse farming was limited to IoT and M2M technologies.

1.7 Limitations

The research requires hardware equipment to integrate machine-to-machine (M2M) and IoT technologies which are costly. The equipment are microcontroller, sensors and actuators. In addition, the research requires good understanding of M2M, IoT and could storage technologies to ensure a successful implementation.

Chapter Two: Literature Review

2.1 Introduction

According to Yayici (2015), the application of Information and Communications Technology (ICT) in agriculture is increasingly becoming more important. Today, it is ensuring productivity by deploying wireless and cloud-connected systems that aid in maximizing yields, automating day-to-day agriculture operations and providing real-time monitoring information that enables smart decision making.

ICT deployment in agriculture has facilitated E-agriculture which is the application of innovative ways to use information and communication technologies primarily to enhance productivity. Technology has taken a big leap in developing new small devices (such as mobile phones and sensors) and infrastructure (such as telecommunication networks and cloud computing facilities) which increases farmers' accuracy of acquiring weather conditions and access of markets for their produce.

Introduction of mobile phones has led to great changes in the agriculture sector which has resulted into efficiency and profitability. Farmers can market directly their produce without having a middleman by having an Unstructured Supplementary Service Data (USSD) which is provided by mobile operators. This has increased profitability of the farmers by opening their markets widely.

According to Patrikakis and Maumbe (2013), using technology such as Global Positioning System (GPS) and Short Messaging System (SMS) farmers are able to get notifications of where their animals are by tagging them with devices that send messages where the animals are roaming.

Geographic Information Systems (GIS) have extensively been deployed in the field of agriculture to aid in decision making such as what and where to plant using historical sampling and data. This done by mapping land digitally, topography and other statistical data which makes it easier for farmers to do soil analysis of different regions before farming (Saravanan, 2010)

2.2 Greenhouse Management in Kiambu County

The international community faces great challenges in the coming decades to ensuring food security for the growing population due to global climate changes. Changes in the agriculture sector are essential to addressing these challenges. Agriculture provides the main source of livelihood for the poor in developing countries, and improving agricultural productivity is critical to achieving food security as well as most of the targets specified under the Millennium Development Goals (Rosegrant et al. 2006).

Countries in Sub-Saharan Africa are particularly vulnerable to climate change impacts because of their limited capacity to adapt. The development challenges that many African countries face are already considerable, and climate change will only add to these.

In Kenya, where the poverty rate is 52 percent and 70 percent of the labor force depends on agricultural production for its livelihood. Poor farmers are likely to experience many adverse impacts from climate change. Therefore, efforts to facilitate adaptation are needed to enhance the resilience of the agricultural sector, ensure food security, and reduce rural poverty (FAO 2009).

Greenhouses can reduce the impact of climate change, adaptation to climate change will be essential to ensure food security and protect the livelihoods of poor farmers. They will increase the resilience of poor farmers to the threat of climate change and also offer co-benefits in terms of agricultural mitigation and productivity.

Greenhouse management practices that increase agricultural production and reduce production risk also tend to support climate change adaptation because they increase agricultural resilience and reduce yield variability under climate variability and extreme events, which might intensify with climate change.

In Kiambu County, where annual average precipitation volumes are expected to increase with climate change, the greatest impacts on agricultural production are expected from changes in rainfall variability, such as prolonged periods of drought and changes in the seasonal pattern of rainfall. Therefore, adaptation strategies that reduce yield variability during extreme events, such as droughts or floods, or because of erratic rainfall or changing patterns of rain will provide the greatest benefit to farmers (Herrero et al. 2010).

According to Herrero et al. 2010, there exists synergies and tradeoffs between greenhouse agricultural adaptation, mitigation and productivity impacts. Table 2.1 discusses the greenhouse management practices and adaptation benefits used by farmers in Kiambu County and elsewhere in Sub-Sahara Africa to ensure farm productivity, profitability and climate adaptation.

| Management Practice | Productivity Impact | Climate Adaptation |
|-------------------------------|--------------------------------|---------------------------------|
| | Troductivity impact | Benefits |
| Improved crop varieties or | Increased crop yield and | Increased resilience against |
| types (early-maturing, | reduced yield variability. | climate change and |
| drought resistant, etc.) | | variability. |
| | | Increases soil carbon storage. |
| Changing planting dates. | Reduced likelihood of crop | Maintained production under |
| | failure. | changing rainfall patterns, |
| | | such as changes in the timing |
| | | of rains or erratic rainfall |
| | | patterns. |
| Improved crop rotation with | Increased soil fertility and | Improved soil fertility and |
| Legumes | yields over the medium to | water holding capacity |
| | long term due to nitrogen | increases resilience to climate |
| | fixing in soils. | Change |
| | | x 1 1 1 |
| Appropriate use of fertilizer | Higher yields due to | Improved productivity |
| and manure | appropriate use of | increases resilience to climate |
| | fertilizer/manure | change with frequent |
| | | droughts. |
| Soil and water management | Higher yields due to | Reduced production |
| by constructing terraces, | increased soil moisture and | variability and greater |
| mulching and grass strips | greater intensity of land use. | climate resilience when |
| | | systems are well designed |
| | | and maintained |

Table 2.1 Greenhouse Management Practices in Kenya (Herrero et al. 2010)

Therefore, while there appear to be many practices available to farmers that provide multiple benefits, farmers face a tough challenge in making farm decisions based on the unpredictable climatic changes. They must consider adopting new farm practices or technologies which require domain knowledge and experience in the field of Information Communication and Technology. Farmers who have access to information about the environmental parameters may experience greater yield variability in the short term as they experiment with the new practice.

2.2.1 Optimum Environmental Conditions

According to Herrero et al. (2010) the main crops grown in a greenhouses located at Kiambu County are tomato, capsicums and chilies, cucumber and kales. There is a careful selection of the variety of plants in the greenhouse. This to help assure disease resistance, good crop-performance in certain optimum environmental parameters and other crop qualities such as storage, visual aesthetics, flavor etc.

Greenhouse cultivation of cucumber requires optimum daily average temperature is 15-24°C (65-75°F). Optimum temperatures for growth are at night, about 18°C, and during the day, about 28°C accompanied by high light intensity. The light requirements are 400-700nm (nanometers) to ensure the rate of photosynthesis is optimum. The optimum relative humidity is 60-80% to ensure the crop does not have risks of neither developing diseases nor stunting growth due to lack of adequate oxygen. The optimum liquid carbon dioxide applied is between 400 and 700 ppm during the day or any time of the night to ensure purity and accurate concentration control for photosynthesis. They generally grow quite well in a wide range of soil pH (5.5-7.5), but a pH of 6.0-6.5 for mineral soils and a pH of 5.0-5.5 for organic soils are generally accepted as optimum. Cucumber crop matures within 40-50 days and harvesting starts 45-55 days after planting (Parker, James, Jarvis & Parks, 2010).

Growing of capsicum in a greenhouse requires optimum temperatures are 18-24°C, but for night temperatures are 21-24°C while day temperatures are 18-21°C to ensure optimum development. This ensures quality seed development and fruit maturity. The crop grows best on loam or sandy-loam soil which has pH of 5.5-6.8. This to ensure the soils are properly drained. The optimum required humidity is between 60-65%. The required light requirement is between 500 and 600nm to optimize photosynthetic active rate (PAR). The optimum required carbon dioxide concentration is between 340 and 1000ppm to ensure optimum photosynthesis (Russo, 2012).

Tomatoes are grown in a greenhouse with optimum temperatures of 25° C, while seedling growth is optimal at 18°C night-time minimum and 27°C day-time maximum. The required carbon dioxide concentration is 800-1000ppm which increases the crop's quality by increasing its growth rates. The required soil pH is between 5.8 and 6.8. The ideal humidity level for tomato plants should be between 65 to 75 percent during the night and 80 to 90 percent during the day to ensure

the plant transpires freely during photosynthesis. The recommended light requirement for this plant is 625-700nm to ensure there is active photosynthesis. The production time for the crop is about 5-7 weeks with the discussed optimum environment conditions (Larsen, Kim & Theus, 2009).

The production of kales in a greenhouse house require optimum temperatures of 18-29°C, day-time 16-27°C and night-time 13-15°C. They grow best in moist and fertile soil, with a pH between 6.0 and 7.5 which are mixed in application of a balanced organic fertilizer. The light requirements are between 625 and 700nm to ensure the crop has an effective photosynthesis active rate. The carbon dioxide concentration ought to be 600-1000ppm to enhance the crop's growth through photosynthesis. The optimum humidity requirement is 60-75% to ensure the crop is well resistant to pests and diseases (David, 2014).

2.3 Machine to Machine Communication (M2M)

Machine-to-Machine communications (M2M) refers to technologies that allow devices to communicate with other devices through both wired and wireless systems. M2M deploys sensors to record weather conditions, which are relayed through a wired or wireless network to an application software program. The recorded data is analyzed and is translated, into meaningful information which will be relayed to the end user (Boswarthick, Elloumi, & Hersent, 2012).

The technical standards for M2M are developed by various standards bodies such as Institute of Electrical and Electronic Engineers (IEEE), European Telecommunication Standards Institute (ETSI), Third Generation Partnership Project (3GPP) and Telecommunications Industry Association (TIA).

ETSI drafts standards of the structure of an M2M network which consists of five components: (i) smart devices capable of sending data and replying to requests (ii) a gateway that provides interconnection and interworking between the devices (iii) M2M area network that furnishes connections between the smart devices and the gateway (iv) communication networks that provide connections between the applications and gateway and (v) application software that records and analyzes data and passes it to other applications.3GPP defines the requirements and features for Machine Type Communications (MTC). ETSI specifies a common set of functions required by the various M2M applications. IEEE standardizes the air interface and related functions associated with wireless area networks (Boswarthick, Elloumi, & Hersent, 2012).

M2M has been deployed in various sectors of the economy such as health where it is being used for remote patient monitoring to obtain heart rate and glucose levels; it uses Bluetooth connectivity between of a monitoring device and a mobile phone. In the transport sector, a sensor that uses mobile communications is embedded in the vehicle and it is used in various functions such as; fleet management by ascertaining location of vehicles, theft prevention by locating lost cars and navigation which provide video map information to the vehicle. In the energy sector, home applications are deploying smart meters which allow automatic collection of information such as consumption or diagnostic which is then communicated to devices such as consumer cell phones in terms of meaningful information such as billing, analysis of usage and troubleshooting (Boswarthick, Elloumi, & Hersent, 2012).

The key drivers for adoption of M2M solutions are diminishing costs of devices, communication and widespread deployment of the internet globally. Advances in radio technologies and wide area communication protocols have led to falling communication prices therefore fostering growth of M2M deployments. Internet has become the standard network for network communications making most communication service providers in the world to deploy IP networks at a national and international level. The use of the same networking technology globally has simplified deployment of M2M applications due to the ease of various applications and devices to access the Internet (Misic & Misic, 2015).

2.3.1 Issues and Challenges of M2M Communications

According to Ganchev, Curado and Kassler (2014), M2M is still a new field, so the technology is faced with several challenges such as:

- Exchange of information between the smart devices and sensors needs to be secured.
 This is because it is possible to extract information from sensors and actuators such as
 RFIDs. Therefore, M2M deployments need to be done in a safe mode of operation.
- ii. Deployment of M2M applications will require to be integrated with cloud computing to further improve data analysis and storage of the recorded data.
- Energy management techniques need to be ensured in each node, in the deployment of M2M applications, where they should be small in size, with low complexity and low energy consumption.

iv. External interference needs to be addressed as it occurs frequently due to link reliability issues. There is need for using Medium Access Control (MAC) and routing protocols that will ensure the channel will not be prone to failure or error.

2.4 Internet of Things

The Internet of Things (IoT) is formed by networking interconnections of everyday objects through configuring wireless networks of sensors which send information to other objects and to people. It is a dynamic global network infrastructure based on interoperable and standard communication protocols where physical things have identities and attributes, using intelligent interfaces, and are seamlessly integrated into the global information network. IoT enables "smart objects" in our environment to be active participants in business and information processes where they are capable of recognizing events and changes in their surroundings, share information with other objects or people by exchanging data and react autonomously to the environmental events with or without direct human intervention (Vermessan & Friess, 2011).

2.4.1 Internet of Things Architecture

IoT needs an open architecture to maximize interoperability among distributed and heterogeneous systems. Architecture standards should consist of well-defined interfaces and protocols, abstract data models and neutral technologies, such as Xtensive Markup Language (XML), to support a variety of programming languages and operating systems (Vermessan & Friess, 2011).

The IoT architecture should be designed to be resilient to disruption of the physical network and ensure the nodes use various communication protocols to connect to the IoT since they may have intermittent connectivity. IoT nodes should form peer networks with other nodes through a decentralized approach to the architecture with support for discovery and peer networking.

IoT requires prototyping of embedded devices such as the Arduino Chip, which combine the RAM, processor, networking and storage capabilities onto a single chip which makes them more specialized. The chip also runs on low power and is programmable to tailor it to developer specifications (McEwen & Cassimally, 2014).

Due to the large volumes of data that will be generated, there is need for routing, processing and storage of the information remotely in the cloud. This will enable effective caching, synchronization, updates and data flows in the architecture. According to Vermessan and Friess (2011), IoT has the following key initiatives and drivers (refer to Table 2.2) that has enabled it grow from research and innovation to market deployment.

| IoT Initiatives | Description | Objective |
|--|-----------------------------|--------------------------------|
| GRIFS | Global RFID Forum | To maximize global |
| | | interoperability and |
| | | collaboration of RFID |
| | | standards |
| CASAGRAS | Coordination and | To develop a |
| | Support Action for Global | framework for international |
| | RFID related activities and | development and issues |
| | Standardization-Embracing a | concerning RFID and IoT in |
| | fully inclusive range of | regards to standards and |
| | EDGE technologies | regulation |
| W3C | World Wide Web | Ensure a semantic web |
| | 1 27 | that will allow you to find |
| ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ | | share and analyze information |
| 24 | | more easily. |
| ROLL | Routing Protocols for | Improvement in the |
| | heterogeneous low power and | Quality of Service for |
| | lossy networks | heterogeneous networks |
| RACE | Raising Awareness | Dedicated to creating |
| | and Competitiveness in | international cooperation |
| | Europe for Networked RFID | about RFID |
| M2M | Cost effective | M2M |
| | solutions for M2M | communications is a key |
| | communication | driver for IoT applications |
| | | with better Quality of Service |
| | | (QoS) |

 Table 2.2: Key Drivers and Initiatives for IoT (Vermessan & Friess 2011)

2.4.2 Challenges facing Internet of Things

According to Chandra (2014), IoT has the following challenges when it comes to its deployment:

- i. For each and every IoT application there is need for a reliable bandwidth connectivity to ensure interaction of the various devices, exchange of information, storage, analysis and reaction to the real world events.
- ii. IoT should not be viewed only as a technical system only but should be considered as social system that has a human-centered approach. Therefore, it is necessary to expand smart objects beyond software and hardware to include human interaction.
- iii. IoT faces a challenge of scalability that arises from the number of objects that will be connected to the internet. This is due to the various protocols used across various applications and their integration which is very complex.
- iv. Security and privacy is also an issue in the deployment of IoT applications. The information can be intercepted at various levels such as at the nodes when they are exchanging information or even when sending or retrieving information in the cloud or at the cloud storage.
- v. For IoT to be implemented successfully IPv6 addresses need to be adopted at a faster rate to support the infrastructure because it has a large addressing capacity.
- vi. There is need for data storage investments to control flow and storage of data of the IoT infrastructure.
- vii. The IoT devices signaling and sending data between one another require low power consumption to make connections and allow large data communications.

2.5 Precision Farming Framework

Blackmore et al. (1994), claimed that a Wireless Sensor Network (WSN) system can be designed to increase the quality of agricultural yield by, properly monitoring soil and the environment. They also observed that, in early stage of WSN, farmers were reluctant to deploy it, because of its high cost.

However, technological development and deployment costs have reduced over the years. There has been advancement in digital electronics and telecommunications infrastructure over the last decade that has made faster, cheaper and smaller computers. This has led to development of embedded devices equipped with network interfaces.

According to Lowenberg-DeBoer (2010), technological progress in communication has led to development in Precision Agriculture (PA) technologies such as Global Positioning Systems (GPS), remote sensing and Geographic Information Sensing (GIS) to manage large scale farming.

The GPS is used to determine a farmer's exact geographic position in the farm and perform operations such as soil sampling, yield monitoring and field mapping. The GIS is a software application which enables farmers to computerize maps and display land topography. With such information they are able to record soil characteristics for example temperature, acidity and various soil types. Sensing technologies are used to record information about the crop and soil conditions by having a sensor in the farms or by having remote sensing using satellite imaging to detect pest manifestation.

Precision farming technologies are mainly used to help farmers in making informed decisions. Farmers also have access to historical data, from the multiple layers of information recorded from the maps, which improves quality of management decisions and recommendations. However, effective decision making depends on accuracy and timeliness of the data recorded (Lowenberg-DeBoer, 2010).

Figure 2.1 below depicts Precision Agriculture where a self-steering robotic tractor that records data through a crop sensor and transmits it via the Internet. The recorded data is sent to a Geographical Information System (GIS) which accumulates the recorded data such as topography, contour and soil fertility which would help farmers in decision making.



Figure 2.1: Precision Farming Overview (Lowenberg-DeBoer, 2010)

- 2.5.1 Strengths of the Precision Farming Framework
 - i. It gives a platform for a wireless sensor network which enables access of farm data efficiently.
 - ii. Increases the quality of agricultural yield, due to enhanced monitoring, which results into higher profit margins.
- iii. The topography, contours and soil characteristics can be mapped into a GIS and stored in a cloud service. The historical data can be used for analysis and prediction for future farming activities.
- iv. It enables better management of the farm through the use of high input mechanism such as sensors that record environmental conditions and the use of GPS that allows farms to be surveyed easily.

v. Precision farming is an environment friendly farming practice due to its greening impact that decreases the use of agrochemicals.

2.5.2 Weakness of the Precision Farming Framework

- i. High investment and deployment costs for farmers. The income from most of the farms does not correlate with the adoption of precision farming technology.
- ii. The system requires a high reliance of Internet connectivity due to the interconnection of various systems; sensors, GIS and GPS.
- iii. The system is very complex to integrate and deploy it for example combination of realtime and mapping systems such as GPS.
- iv. It may take years to fully implement this system because of the amount of time required in collecting and analyzing the data needed.
- v. Adoption rates are poor in developing countries due to low awareness levels among farmers in regards to technological developments.
- vi. Compatibility of the various heterogeneous systems also might be a challenge.

2.6 Ubiquitous Computing Framework

Ubiquitous Computing (UC) is a concept in computer science which allows computing to be done anywhere and everywhere, in any format and location, in contrast to desktop computing which occurs using a device. The primary name behind this innovation, Ubiquitous Computing, is Mark Weiser and his main aim was to achieve smart device collaboration (Polad, 2009).

According to Cunha et al. (2012), ubiquitous computing envisions the transfer of physical spaces into active information spaces. The ubiquitous smart spaces will consist of various ubiquitous objects (devices and applications) and their collaborations that provide intelligent services to users. This implementation has become technically feasible thanks to rapid progress of network technologies and mobile communication devices. Therefore, due to this concept of making a digital environment that is responsive to people there emerged the concept of Internet-of-Things. Consequently, this now allows the manufacturing of extremely small and inexpensive low end computers.

Ubiquitous Computing has six main key enabling components namely; sensor technology, microelectronics, communication technology, localization technology, machine-to-machine

communication (M2M) and human-to-machine interface. The integration of these components enhances computer usability by placing the devices in the environment to gather information, store and process it to meet user's various needs.

Sensors are the central component of the Ubiquitous Computing technology. They record external physical aspects of the external environment, such as light, temperature, humidity, motion and moisture, and relay it as a digital signal. Microelectronics ensures efficient design of integrated circuits, capacitors, resistors and inductors for microprocessors.

Communication technology plays a fundamental role in UC to ensure strong and reliable communication networks. The adoption of IPv6 will enable a huge addressing pool for every device to have its own routable Internet Protocol address and mobile IP for mobile communication. This ensures communication is everywhere due to full deployment of wireless and mobile devices.

Localisation technologies make it easy to locate data and objects mainly through wireless transmissions and satellite positioning systems such as GPS. They have a precision of 1 meter indoors and 10 meters outdoor respectively.M2M communication allows both wireless and wired systems of similar type of devices to communicate. This allows efficient flow of data from the various IoT nodes to meet various user needs.

Ubiquitous Computing also requires a good human-machine interaction which can be achieved by appropriate user interface such as touch screens and keypads. This enables users to instruct the infrastructure efficiently either to retrieve information or to react to an environment change.

In conclusion, UC envisions a world where computers, sensors and digital communication technologies are inexpensive and available everywhere. It will provide users with an informational environment by integrating computational and physical infrastructures. This environment will have thousands of computing devices and sensors that will provide various specialized functionalities, from interaction among the users and devices, which will boost productivity (Miles, Flanagan & Cox 2012).

2.6.1 Strengths of the Ubiquitous Framework

According to Miles, Flanagan and Cox (2012) Ubiquitous Framework has the following strengths;

- i. UC allows data storage and exchange of information anytime, anywhere and at a high speed. This ensures faster communication between the various components and nodes in the framework.
- ii. It provides architectures for the design of real-time and embedded systems.
- iii. UC enables a huge computational power and storage. This includes having virtual operating systems and basic services; storage, database and signaling. Therefore, it merges computational power and storage in a dynamically scalable infrastructure.
- iv. Allows for Human-computer interaction which enables a user friendly framework
- v. The advancement in communication technologies, that is use of IPv6, ensures intelligent and autonomous communicating objects

2.6.2 Weakness of the Ubiquitous Framework

According to Miles, Flanagan and Cox (2012) Ubiquitous Framework has the following weakness;

- i. Internet centered approach where there is too much reliance on Internet connectivity to undertake the various functions of peer-to-peer communication. Poor Internet connections may not achieve ubiquitous computing.
- ii. Data privacy, trust and security are key issues in UC where information is stored in third parties and transmitted across public networks. The lack of authenticity means it's highly vulnerable to viruses and hacking.
- iii. Due to high level of wireless communications, ensuring high level energy management might be a challenge. There is need to ensure battery saving mode where individual applications switch to modes of operation of lower energy demand under operating system control.
- iv. Loss or theft of a device in the architecture will lead to interruption of data flow and therefore loss of productivity of the architecture.

2.7 Wireless Sensor Network Models

A Wireless Sensor Network (WSN) consists of distributed autonomous sensor nodes used to monitor and control environmental conditions, such as temperature and light intensity, at different locations cooperatively. The recorded data is passed through the network to a main location where it is further analyzed and/or stored (Gavin, 2014).

Beckwith, Tiebel and Bowen (2004), worked on a Wireless Sensor Network (WSN) in a vineyard on a very large scale design and deployment. Their research was mainly driven by trying to understand how ubiquitous computing can be useful in agriculture and help in climate monitoring of a farm. They also intended to provide a solution for managing workers, work done and the tools they use through the network they intended to build.

Their research was based on ethnographic research, which involves observing target users in the real-world rather than in an artificial environment such as a laboratory. The aim of such a research is to gather insights on what they do, what they require and how they use resources in their everyday professional life. They collaborated with agricultural researchers, who are the domain experts, to create awareness and have a better understanding of climate data (Beckwith, Tiebel & Bowen, 2004).

Climate monitoring was the central part of their project and they were specifically focused on temperature and humidity which are the two weather conditions that affect grape farming. Recording low temperatures would help them to predict crop damage while heat unit accumulation (temperatures summed over a period of time) would help predict fruit maturity (Beckwith, Tiebel & Bowen, 2004).

They successfully implemented a WSN in a vineyard to collect real-time data on environmental conditions in the vineyard by deploying sensors which were recording temperature variations in a vineyard. The information was recorded from all the sensors and a synchronized signal was sent to a terminal which showed the various temperatures recorded for each node and the average temperature. However, they were able to collect temperature values only and did not manage to record pH data (alkalinity or acidity of soils) which is also very key in grape farming (Beckwith, Tiebel & Bowen, 2004). The information collected helped the farmers in key decision making areas for the grape farming such as picking decisions and segregation of the fruits for fermenting. However, their research and deployment was only a specific application due to lack of sufficient domain knowledge in IoT to develop a successful network design that would lead to monitoring of all environmental conditions in agriculture (Beckwith, Tiebel & Bowen, 2004).

Baggio (2005), designed a crop management system, through a Wireless Sensor Network, for the Lofar Agro project, in Europe. In this project, he focuses on monitoring micro-climates in a farm to ensure effective field crop production. He aimed to develop a Decision Support System (DSS) for farmers in different aspects of agriculture such as monitoring crops, soil and climate in a field. He specifically focused on proper application of pesticides and fertilizer in real time environmental changes.

In his research, he investigates how to fight phytophtora in a potato field using wireless sensors. Phytophtora is a fungal disease which can enter a field through a variety of sources. The development and associated attack of the disease depends strongly on the climate conditions within the field which are humidity and temperature. The main aim for monitoring the conditions is to reveal when the crop is at risk of developing the disease and inform the weather stations who would advise farmers on how to treat the field (Baggio, 2005).

He creates a WSN in a potato field by deploying sensors which record temperature and humidity. For energy-efficient considerations the sensors record data once every ten minutes and the data sent across the network is minimized by delta coding. To prevent loss of data, he used a global sequence number per sensor and the MintRoute routing protocol which maintains reliability of the WSN by ensuring good links between the sensors (Baggio, 2005).

The data collected was transferred via WiFi to a personal computer (PC) at their project center. The information collected from the wireless network is relayed to a weather station for purposes of controlling crop diseases through an SMS. The recorded information did not only include environmental conditions, humidity and temperature, but also included signal strength, battery level, error rate in transmission and reception (Baggio, 2005).

However, his key challenge was that he was not able to collect other environmental conditions, such as light intensity and carbon monoxide. This is because the project aimed at

collecting both environmental conditions and wireless sensor network information such as mint route routing table, signal strength, link quality measurements, battery level, error rate in reception and transmission. Moreover, he lacked a proper system for analysis for this information which meant data was sent as raw data to the weather stations and hence took time to synthesize the information before it is sent to the farmers (Baggio, 2005).

2.7.1 Strengths of the Wireless Sensor Network Models

According to Langendoen et. al (2013), wireless sensor networks have the following strengths;

- i. Wireless Sensor Networks measure climate conditions at a finer scale by the use of sensors which are able to record accurate weather conditions.
- ii. Using wireless sensor networks, enables farmers to access information from their fields in real-time using a computer, smart phone, tablet or any other device connected to the internet.
- iii. Farmers can set up alerts to be sent via text message or email letting them know when an event occurs such as when temperatures drop below a specific target.
- iv. WSN can be a useful tool in preventing loss of data and statistics by the use of MintRoutemultihop routing which keeps routs for each sensor and removes bad quality links from the routing table.
- v. WSN can provide other important information such as battery level and signal strength. This information is valuable to the network designer to ensure energy and network efficiency is managed.
- vi. WSN infrastructure requires very little wiring, it's flexible, can be accessed through a central monitoring location and can accommodate new devices at any given time.

2.7.2 Weakness of the Wireless Sensor Network Models

According to Langendoen et. al (2013), wireless sensor networks have the following weakness;

- i. They require high level expert domain knowledge so as to design an effective system that meets the various user needs.
- ii. A wireless sensor network is application specific, user needs are met my specific applications which makes it challenging for a researcher to determine how the deployment of the network will be.

- iii. Setting up the various connections and configuring a WSN is challenging and requires high technical expertise to ensure the architecture is effective and well set-up.
- iv. The sensor nodes are battery powered therefore maintaining a WSN for longer periods of time might be challenging due to constraints of energy management of the sensor nodes.
- v. A WSN is prone to data transmission challenges due to noisy channel, errors in transmission and time varying wireless channel.
- vi. The WSN might have challenges in scalability due to lack of a proper network protocol design which will meet needs for the different network sizes.
- vii. A WSN is faced by hardware challenges; cost of sensor nodes, robustness and fault tolerance, while the software challenges are; security and privacy of data.
- viii. A WSN is not fully efficient in terms of management of recorded data, storage, analysis and dissemination; therefore it requires to be integrated with other technologies such as cloud technology to improve the overall efficiency of agriculture.

2.8 Greenhouse Monitoring using Amtel Architecture

Greenhouse monitoring projects use microcontrollers and relays to monitor and control environmental conditions such as humidity, temperature, PH and moisture of soil. The parameters are set as per the vegetables or fruits to be grown inside the greenhouse.

In this Amtel architecture, the engineers chose temperature and light as the parameters to be monitored. Therefore they used the respective sensors, temperature and light (Atarah, Bagchi &Yao, 2012).



Figure 2.2: Greenhouse monitoring using Amtel Architecture (Atarah, Bagchi & Yao, 2012).

The project uses Amtel microcontroller to monitor and control environmental parameters. Monitoring involves reading environmental conditions which are in analog values in milivolts. Therefore, it needs to have an amplifier which will convert the milivolts to volts for the values to be digitalized.

The Analog to Digital Converter (ADC) converts the analogue environmental parameters read by the sensors to digital values which the microcontroller can perform its actions.

The controlling action is done when these parameters surpass the set level by the Amtel microcontroller. The controlling devices used are motor drivers. At the output of motor drivers are used as buzzers to notify users.

The Liquid Crystal Display (LCD) is used to display the results of the microcontroller at a specific point such as the values which have been converted from analog to digital and the instructions passed to the motor drivers.

2.8.1 Advantages of Greenhouse Monitoring using Amtel Architecture

According to Barret and Pack (2012), the advantages of the Amtel Architecture in greenhouse monitoring are as follows:

- i. There is automation of the data acquisition process of the environmental conditions that govern growth of various plants grown in a greenhouse such as flowers, vegetables and fruits.
- ii. This architecture reduces the human effort significantly required to monitor and control the environmental conditions and parameters.
- iii. The architecture can be applied as Agriculture Management System (AMS) in greenhouse to monitor and control the environmental conditions of the various plants.

2.8.2 Disadvantages of Greenhouse Monitoring using Amtel Architecture

According to Barret and Pack (2012), the disadvantages of the Amtel Architecture in greenhouse monitoring are as follows:

- i. The architecture monitors very few environmental conditions, which are temperature and light, and does not factor in more important conditions such as humidity, PH levels of soil etc.
- ii. Amtel microcontroller is not a strong microcontroller this is because it operates on very low power therefore the need of a 12-bit Analog to Digital Converter (ADC). Moreover, it has a low integration with other components such as sensors therefore it cannot support many sensors.
- iii. It requires a lot of technical training and support for successful implementation of the system.

2.9 Greenhouse Monitoring using Arduino Architecture

In this architecture, many parameters are measured to monitor and control quality of the plants grown in greenhouses. They are temperature, humidity, light intensity and soil moisture as illustrated below in figure 2.3 (Wang et. al., 2013).


Figure 2.3: Greenhouse monitoring using Arduino Architecture (Wang et. al., 2013)

The arduino microcontroller is the heart of this architecture. It constantly performs the analogue to digital conversion of the various sensors, verifies them and checks if there is need for any corrective action is to be taken at that instant of time. Therefore, this is how the arduino microcontroller achieves its monitoring and controlling functions.

When the temperature exceeds the defined level, the arduino microcontroller turns on the relay for temperature control which in this case is a fan. Also when the temperature falls to normal range it is automatically turned off.

The humidity levels read by the sensors are also monitored by the arduino microcontroller and when the humidity of the environment is below the defined levels, the motor for moisture which sprays water is automatically turned on and then off when the desired level is achieved.

When light intensity is lower than a defined level, the arduino microcontroller automatically turns on light bulbs, and when the light intensity comes down to optimum range a motor automatically turns off the light bulbs.

A GSM Modem has been incorporated in this architecture to send a notification to the owner of the system whenever the arduino microcontroller automatically turns on or off the respective motors to control the environmental conditions.

2.9.1 Advantages of Greenhouse Monitoring using Arduino Architecture

According to Barret (2012), the advantages of using Arduino architecture to monitor greenhouses are as follows:

- i. Low cost system, power consumption, maintenance and provides automatic data acquisition by using sensors that have high sensitivity and easy to handle.
- ii. Malfunctioning of any sensor or motor will not affect the whole system but just a single function of the system.
- iii. User is sent updates, through the GSM Modem, for any changes done by the motors which are controlled by the Arduino microcontroller.
- iv. The response of the motors, which are activated by the Arduino microcontroller, is fast therefore protecting greenhouse from lack of the optimum environmental conditions.

2.9.2 Disadvantages of Greenhouse Monitoring using Arduino Architecture

According to Barret (2012), the disadvantages of using Arduino architecture to monitor greenhouses are as follows:

- i. There is no internal system to detect malfunctioning of sensors or motors.
- ii. Requires uninterrupted power supply to function fully which might therefore result to one having an external source of power such as batteries.
- iii. Complete automation in terms of an agricultural management system cannot be fully achieved. An example is pest and insect detection and eradication maybe a challenge to achieve.
- iv. It requires technical training to adopt and successfully implement the system.

3.0 Summary

The literature review started by exploring some of the key words in the research. These are Machine to Machine Communication (M2M) and Internet of Things (IoT).

The main aim of IoT deployment is to monitor and control not only environmental conditions but also smart objects via the Internet interconnecting objects and sensors. Internet is a key technology and is the backbone of creating the infrastructure of IoT.

It was evident that there are technologies are available to deploy an IoT infrastructure in the agriculture sector. Moreover, it can make tremendous difference for farmers in terms of monitoring conditions, conserving resources, controlling costs and improving overall efficiency.

Chapter Three: Research Methodology

3.1 Introduction

This chapter contains the approaches that were used to carry out the research. This includes the research design used, target population of the study, the sample design, method of data collection and the data analysis and presentation.

3.2 Research Design

An applied research design was used in this study. The research design included identifying market need for the product, design a product with the potential to meet the need (s), build a prototype and test whether the prototype meets desired functions with respect, cost, environmental consequences and profitability when it is brought to the market (Marder, 2011).

Moreover, the researcher used Structured Systems Analysis and Design Method (SSADM) for a rigorous system analysis, design and development. It involved logical data, data flow and entity event modelling (Sarstedt & Mooi, 2003).

A cross-sectional study was conducted involved a sample of elements from a population of interest at one point of time. The study was concerned with a sample of elements from the population. Such data was analyzed and conclusions were drawn.

3.3 Population Target

The research population dealt with greenhouse farming and the target population was greenhouse farmers in Kiambu County. According to Justus and Danlin (2014), Kiambu County has twenty three (23) commercial greenhouse farms following the spatial distribution of commercial greenhouses in Kenya.

USAID (2013), states that in Kiambu small scale greenhouse farm has 36 employees who are distributed as shown in table 3.1.

| Role of Employee | Number |
|-------------------|--------|
| Managers | 2 |
| Employed(Finance, | 19 |
| Marketing, Sales) | |
| Grounds men | 15 |
| Total | 36 |

Table 3.1: Employees at Small-Scale Greenhouses

3.4 Population and Sampling Design

The population that was used in this research was eight hundred and twenty eight (828). This constituted the total number of employees who work in greenhouses in Kiambu County. The researcher arrived to this number by multiplying the total number of employees in a small-scale greenhouses by the total number of greenhouses in Kiambu County. According to Calmorin and Calmorin (2007), for a population more than 100 sampling is a must and the formula is as shown below:

Ss=NV+[Se(1-p)] N=Population Size, V=Std Value (2.58), Sampling error=0.01

NSe+[V*p(1-P)] P=Largest possible proportion (0.50)

Therefore the sample size is 240.

The researcher applied stratified sampling techniques to the study mainly because of the different information provided by the different strata (Calmorin & Calmorin, 2007).

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3.5 Data Collection Tools

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.

3.6 Data Analysis

Inferential statistical analysis was used to analyze the gathered data where the model which analyzed the primary data was ANOVA. The analyzed data was the optimum environmental conditions required in a greenhouse, types of crops grown and challenges faced in greenhouse farming. Mathematical models were applied to the data and provide a basis for the analysis. Moreover, Microsoft Excel and SPSS software was used for statistical analysis to analyze, tabulate and compare the primary qualitative data.

3.7 Data Presentation

Data was represented using tables and pie charts. This is because they are helpful in giving summaries in areas that are being addressed (Odhiambo, 2009).

3.9 Research Quality

The research aimed to have a high level of precision by the use of the small coefficient of variation, which is 1 percent, indicates the estimates could vary slightly due to small sampling error margin provided. The researcher also aimed to improve the coefficient of variation by increasing sample size.

Construct validity was used to ensure the study will focus on the relevant variables in regard to greenhouse management. The researcher interviewed the experts in the domain of agriculture to ensure the variables intended to be studied were valid. In addition, parallel forms reliability was used by administering different versions of assessment tools, which were face-to-face interviews and questionnaires, to the same group of individuals.

The research thoroughly explored the implications of the findings and examine where old and new knowledge are in harmony and where they are not. Moreover, the research also recommended appropriate course of actions from the findings that were observed.

3.8 Ethical Considerations

This study required the participation of human respondents therefore certain ethical issues were considered and addressed. The consideration of these ethical issues was important for the purpose of ensuring privacy of the participants. The ethical issues that were considered include consent and confidentiality. In order to secure the consent of the selected participants, the researcher relayed all important details of the study. The confidentiality of the participants was ensured by not disclosing their names or personal information in the research. Only relevant details that helped in answering the research questions were captured and recorded.



Chapter Four: System Analysis and Design

4.1 Introduction

This chapter contains the data analysis of the data collected from the target respondents who were farmers and greenhouse managers. The analyzed data was largely used for system analysis and design of the prototype development.

4.2 Optimum Environmental Conditions for Greenhouse Management

The research had its first objective to find out the optimum environmental conditions for greenhouse management. Primary data was used to provide an insight into this by administering questionnaires to both farmers and managers of the greenhouses. The most important environmental conditions that need to be controlled for optimal greenhouse climate are temperature, light, humidity, water and carbon dioxide.

Temperature is the most important condition in greenhouse farming operations which plays a significant role in plant growth and development. Typical small-scale greenhouse temperatures should be maintained at around 16 to 30 degrees Celsius during the day and 13 to 18 degrees Celsius during the night. When the temperatures are too low plant growth is limited whereas too high temperatures result to wilting and death of the plants.

Humidity control is also vital to ensure plants growth. The optimum relative humidity has a range varying between 50 and 70 percent. When the humidity is too low it slows down the growth of plants whereas too high humidity encourages growth of mold which causes plant diseases.

The CO2 concentration in a greenhouse greatly influences the plant growth rate through the photosynthesis process where plants combine it with water to produce oxygen and sugars. The optimum CO2 concentration is about 1000 ppm (parts per million) for most plants but due to photosynthesis can bring it down to 200ppm which is low enough to impact the growth of plants negatively.

Water is also a key requirement for plants in a greenhouse mainly for irrigation which enables transpiration and photosynthesis to take place. Transpiration is the loss of water from plants in form of vapor. This process is important for plants to ensure they do not wilt on hot and sunny weather. Photosynthesis is the process where the plants make food. Water is important in this process because it goes through the plant's stem and further moves to the leaves where photosynthesis takes place.

Light is also an important environmental condition, they usually acquire their energy from sunlight, to ensure they carry out photosynthesis. Without light, plants would not be able to produce the energy it needs to grow.

Therefore, with this information I was able to define a threshold for which the prototype will be monitoring the environmental parameters. Table 4.1 depicts the threshold that was set for the various crops grown in Kiambu County greenhouses.

| Plant | Temperatures | Light | Humidity | Carbon | Soil PH |
|-----------------------|--------------|-----------|----------|-------------|---------|
| | | (PAR) | | Dioxide | |
| Cucumber | 19-24° C | 400-700nm | 60-80% | 400-1000ppm | 5.5-7.5 |
| Tomato | 18-27°C | 625-700nm | 65-70% | 800-1000ppm | 5.8-6.8 |
| Capsicum & Chilies | 18-24°C | 500-600nm | 60-65% | 340-1000ppm | 5.5-7.0 |
| Kales | 18-29°C | 625-700nm | 60-75% | 600-1000ppm | 5.8-6.5 |

Table 4.1: Optimum Environment Parameters for Greenhouse Monitoring

4.3 Challenges Faced in Greenhouse Management

The research had its second objective to identify the challenges faced in greenhouse management in small-scale greenhouses located in Kiambu County. A questionnaire was administered to the managers of the greenhouse, where deductions were made, which was prepared by the researcher (See Appendix A).

According to the greenhouse managers, the main challenges of greenhouse farming in smallscale farms in Kenya are: operation expenses (electricity, machinery and employees), monitoring and controlling environmental conditions, lack of quality water sources, pests and diseases and lack of training on appropriate technological advancements in agriculture sector such as use of Internet of Things.

The biggest challenge of management when it comes to small scale greenhouses in Kiambu County is to manage environmental conditions required for good yield production. Greenhouse farming always requires constant humidity and temperature to be managed properly at all times. Small scale greenhouses are prone to overheating when it is too hot and condensing when temperatures to drop. Light is also an important environmental parameter which needs to be managed by the type of material that covers the greenhouse and the different sources of light when there is no sufficient sunlight. In addition, one has to get advice from an agronomist on the type of soil they require before they start farming. This will help the farmer to know what type of crops the greenhouse can grow and also the soil moisture required.

Operational costs are mainly incurred when it comes to erecting the greenhouse structure. In Kiambu County, small-scale greenhouses cover a ¹/₄ acre and below whereas larger greenhouses occupy a ¹/₄ and above. The two main types of greenhouses built are; wooden greenhouses which are built from fabricated wood and polythene bags and metallic greenhouses which are made of steel rods and polythene bags. Wooden greenhouses last about two years and one has to build a new one due to wear and tear of the wooden poles. Moreover, farmers need to treat the poles against termites often. Metallic greenhouses are more robust because they can last for more than 10 years. For both greenhouses, the polythene bags have to be replaced from time to time while ensuring ventilation has to be looked into and managed properly because the greenhouse farming is being practiced in a region where temperatures can easily go beyond the optimum and destroy the yield. There are other small operational expenses which farmers incur such as having casual laborers, fertilizing and weeding produce before it goes to the market.

There is lack of quality water resources in the country, including Kiambu County which is deficient of good water resources such as boreholes or rivers. Moreover, the available water is contaminated because it is chlorinated or could be saline which causes bacterial wilt hence the yield is of poor quality. Irrigation in this county is usually done Therefore water is a scarce resource which ought to be managed with effective mechanisms which water the plants only when the soil has dried up.

Pests and diseases is also a difficult challenge in greenhouse farming in Kiambu County. This is because of the type of crops planted which are mainly kales, green peppers, tomatoes, cucumber, avocado and red chilies. Pathogens and insects get established very fast in a greenhouse that grows such type of crops. However, they use ultraviolet-absorbing plastics which reduce the insects and pests.

There is also lack of proper training for the farmers in regards to the technological advancements, in the agriculture sector, for what the farmers can apply in the greenhouses to effectively manage

the greenhouses. They do not have the appropriate training on how to use the devices such as sensors and microcontrollers, such as Amtel or Arduino, which could control various functions in their farms such as monitoring environmental conditions and controlling functions such as irrigation.

The figure 4.2 indicates the distribution of greenhouse farming challenges facing greenhouse farming from the sample which was analyzed.



Figure 4.1: Distribution of Greenhouse Farming Challenges

4.4 Analysis of Greenhouse Monitoring using Amtel Architecture

This analysis of greenhouse monitoring was done by reviewing literature to understand how the features of Amtel architecture address the challenges faced in greenhouse management. The architecture is weak as depicted in the table 4.2 and therefore necessity for a stronger architecture.

| Challenges facing | Characteristic of Amtel | Does system characteristic |
|----------------------------|-------------------------------------|----------------------------|
| Greenhouse Management | Architecture | address the challenge? |
| | | (YES/NO) |
| Monitoring and controlling | Monitors and controls only light | NO |
| environmental conditions | and temperature which does not | |
| | cover for other important | |
| | parameters such as humidity and | |
| | soil moisture. In addition, the | |
| | system does not report the | |
| | information to farmers remotely. | |
| High Operational Costs | It's a costly system which requires | NO |
| | the Amtel Microcontroller, | |
| | Analog-to-Digital Converter, LCD | |
| | screen and motor drivers which act | 7 |
| 22 | as actuators. | |
| Pests and Diseases | Does not have a sensor that | NO |
| | identifies movement of pests | |
| Water Scarcity | Does not have a sensor that | NO |
| | efficiently monitor water flow | |
| | which carries out irrigation | |
| | system. | |

Table 4.2: Analysis of Greenhouse Monitoring using Amtel Architecture

| Lack of training on | Technology requires a lot of | NO |
|--|---|----|
| technological advancements in Agriculture sector | training and support for its successful implementation. | |
| | 1 | |

4.5 Analysis of Greenhouse Monitoring using Arduino Architecture

This analysis of greenhouse monitoring was done by reviewing literature to understand how the features of Arduino Architecture for greenhouse monitoring address the challenges faced in greenhouse management. The architecture is weak as depicted in the table 4.2 and therefore necessity for a stronger architecture.

| Challenges facing | Characteristic of Arduino | Does system characteristic | | | |
|----------------------------|---|----------------------------|--|--|--|
| Greenhouse Management | Architecture | address the challenge? | | | |
| | 1999 - 199 | (YES/NO) | | | |
| Monitoring and controlling | Monitors and controls | YES | | | |
| environmental conditions | environmental parameters such as | | | | |
| | temperature, humidity, light | | | | |
| 2 | intensity and soil moisture. In | | | | |
| | addition, the system sends SMS | | | | |
| | alerts to farmers remotely. | | | | |
| High Operational Costs | It's a costly system which requires | NO | | | |
| | theArduino Microcontroller, | | | | |
| | sensors, LCD screen, GSM Modem | | | | |
| | and motor drivers which act as | | | | |
| | actuators. | | | | |

Table 4.3: Analysis of Greenhouse Monitoring using Arduino Architecture

| Pests and Diseases | Does not have a sensor that neither | NO |
|-------------------------------|-------------------------------------|----|
| | identifies movement of pests nor | |
| | encroachment of bacteria on the | |
| | plants | |
| Water Scarcity | Does not have a sensor that | NO |
| | efficiently monitors water flow for | |
| | carrying out an effect irrigation | |
| | system. | |
| Lack of training on | The technology requires a lot of | NO |
| technological advancements in | training, in regards to IoT and | |
| Agriculture sector | | |
| | M2M, for its successful | |
| | implementation. | |
| | Y SS | |

4.6 System Structure of Intel Edison Greenhouse Monitoring

The greenhouse system will compromise of a sensor unit, microcontroller unit, middleware and an end user mobile application. The grove sensors that were deployed were for light and temperature.

The microcontroller unit converts the analog to digital values which are sent to the middleware for analysis. The middleware that was implemented was Intel IOT Analytics which is an open standard cloud platform for performing data analytics and storage. The data is sent through Message Queuing Telemetry Transport (MQTT) protocol which is a light weight messaging protocol for sensors and mobile devices. The information is also stored in a database for historical data.

The end users, farmers and greenhouse managers, can view analytics which are graphs on the trends of the recorded environmental parameters. In addition, when the parameters surpass the set

threshold, alerts are sent periodically to their email accounts to notify them which environmental parameters have surpassed the limit.

Figure 4.2 and 4.3 depict the system structure and use case scenario respectively:



Figure 4.2: System Structure of Intel Edison Architecture



Internet of Things for Greenhouse Monitoring Use Case

Figure 4.3: Use Case Diagram of the Greenhouse System

The system has three main functionalities which are data recording, facilities control and notifications. The main actors who interact with the system are farmers and greenhouse managers.

Data recording functionality is where the sensors carry out data abstraction in real time. The sensors record temperature, light, humidity and soil ph. The values are converted from analog to digital values. This functionality is achieved by the Intel Edison module with the assembled sensors.

Context-aware service is a function that specifies numerical values which is set as the threshold for certain data recorded such as temperature or light. The function activates the respective actuators which control the greenhouse optimum conditions.

Event-processing service functionality involves having IoT analytics where the greenhouse manager can view the trends of the environmental parameters. In addition, they also receive e-mail notifications when the parameters surpass the set threshold.



Figure 4.4: Sequence Diagram for the Greenhouse system

Figure 4.4 depicts the process of data being recorded by the sensors, converted to digital values which are then sent to the middleware for analysis. The end user is sent email notifications to make the greenhouse monitoring process possible. The analyzed information is also stored in the database server for historical data analysis and prediction.

Chapter 5: System Implementation and Testing

5.1 Analysis of the IoT Prototype Implementation

The IoT prototype is composed of an Arduino Uno board, which accepts the Intel Edison module, as the microprocessor and the Grove system which is a modular toolkit that consists of a base shield, sensors, liquid-crystal display (LCD) screen and standardized connectors. The prototype will also be integrated with a GSM module to send alerts to the farmers.

5.2 Strengths of this approach

Intel Edison module provides a platform for embedded systems for specialized or small applications that require low power consumption.

The prototype uses a base shield which in comparison to a breadboard; it allows easy connection with any microprocessor output or input from the different types of the Grove sensors.

Intel Edison module and Grove system are easier to learn, than the complicated breadbroad and other microcontroller such as Amtel, because they come as packaged ready to use tool kit for engineering applications.

Intel Edison module has integrated with features such Bluetooth and Wi-Fi which increases the communication options with 3rd party applications. The architecture can work even with a poor internet infrastructure in the greenhouse due to the integrated features such as Wi-Fi and Bluetooth. In addition, alerts are sent mainly through email notifications.

The Grove system has different types of sensors such as environmental and physical monitoring. Environmental sensors record temperature, light, humidity whereas physical monitoring sensors record water, electricity and moisture.

The GSM Module has been used as a reporting tool which sends alerts, to the farmers and managers of the greenhouses, periodically on the updates of the changes in the greenhouse.

Based on the strengths above, the researcher found the use of Intel Edison on an Arduino board with Grove System the most suitable to design an IoT prototype. Moreover, the strengths counter the challenges faced in greenhouse farming management. In addition, the IoT prototype is cost effective where the Grove system costs \$10 and the Intel Edison with an Arduino board costs \$50.

5.3 IoT Prototype Architecture

The prototype runs on Linux operating system, Debian Ubuntu installed on a laptop or desktop machine. The steps below are used to set up the Arduino board:

Step I-Assembling the Intel Edison board with the Arduino expansion board

Place the Intel Edison module on your expansion board. Line up the holes on the module with the screws on the expansion board. Tightly fix the screws on the module to secure it to the expansion board. Insert screws in all four corner holes and attach their plastic spacers.

The board can be powered on by a direct current (DC) power supply or a USB port. The DC power supply is the preferred way to power the board and should have 7-15 volts. To activate the USB port, we switch the microswitch down towards the micro-USB ports. When powered on a green LED lights up. When the board is ready and initialized, the computer mounts a new drive on your computer.



Figure 5.1: Assembling and Powering Intel Edison module on Edison board (Ramon, 2015)

Step II- Installing the libraries and integrated development environment.

The libraries required to be installed are MRAA I/O and UPM sensor library. MRAA makes it easy for sensor manufacturers to map their sensors and actuators on supported hardware and allows high-level languages to control low-level communication protocol. UPM is a high-level repository for sensors written in C++ and utilize MRAA library.

- To install the MRAA and UPM libraries the instructions are as follows:
- Establish a serial communication session with your board.
- To ensure that you have the latest versions of the MRAA and UPM libraries, run the following commands in the serial communication terminal

echo "src mraa-upm http://iotdk.intel.com/repos/2.0/intelgalactic" > /etc/opkg/mraa-upm.conf

opkg update

opkg install libmraa0

opkg install upm

The integrated development environment (IDE) that was used is Arduino which is an open source C++based programming environment. The Arduino IDE was convenient because the Intel Edison module is Arduino-pin compatible and it's easy to add sensor code.

Step III Flashing the Intel Edison module

Download the Flash Tool Lite by running this command:

sudo gdebi name_of_flash_tool_lite.deb

Download the FlashEdison.json file which is used as the latest firmware for the Intel Edison module. Click browse and then select the file.

Under the Flash file section, a drop down list automatically displays the name of the .json file when the Flash Tool Lite is ready to flash the module.

Connect only one data cable and the second one only after you have started the flashing of the Intel Module.From the Configuration drop down, choose CDC for Linux and click Start to Flash as illustrated on the figure 5.2:



Figure 5.2: Flashing the Intel Edison Module (Ramon, 2015)

Step IV: Set up a serial terminal

Serial communication with the Intel Edison module gives one access to the board's operating system which is Yocto-built Linux. In addition, you can set up a Wi-Fi connection, change username and password of the Intel Edison module.

Below are the sequential steps for installing and configuring the terminal:

- Open a new Terminal window. Enter the command: *sudo apt-get install screen*
- If prompted, enter your laptop or desktop password.
- Enter the command below to connect to the board:

sudo screen /dev/ttyUSB0 115200

- If prompted, enter your laptop or desktop password to continue.
- At the login prompt, type root and press Enter. When prompted for a password, enter your laptop or desktop's password.

Step V: Setting up a network access to the Intel Edison board

The network connection was done over Wi-Fi to obtain an IP address for the board with the following steps:

- Establish a serial communication session with your board.
- To configure enable Wi-Fi connection to the board, enter the command: *configure_edison --wifi*
- When prompted if you want to set up Wi-Fi, type *Y* and press Enter.
- The board will scan for Wi-Fi networks for approximately 10 seconds and when it is done, a list of available wireless networks will be displayed.
- Choose awireless network you by typingits corresponding number from the list, and press Enter. To confirm your entry, type *Y* and press Enter.
- Enter the password for the wireless network and the board will attempt to connect to the network. When it is successfully connected, a done message will be displayed and the board has connected to the Wi-Fi network and obtained an IP address as shown in figure 5.3:



Figure 5.3: Connecting Intel Edison module over WI-FI (Ramon, 2015)

5.4 Integrating with the Intel Edison Board with Sensors

The Grove system is a tool set that houses the Base shield, various sensors ranging from physical, motion sensing, and wireless communication to environmental monitoring type of sensors and standardized connectors. The Base shield included in the set allows for easy connection of any microcontroller input or output from the Grove sensors which pick different signals based on their functionalities. The modules that are found in the Galileo Grove system includes: temperature sensor, light sensor, buzzer, rotary sensor, button, sound sensor, RGB LCD display, connectors, base shield, Ethernet connector and 2 USB connectors

To interface the following devices for connection to the microcontroller board, the Base Shield is the electronic component that is used. This offers a better alternative of connection compared to the use of Breadboard which has a more complex approach of connecting the sensors, power devices and other I/O devices such as comparators, potentiometers, LCDs and LEDs.

The sensors that were deployed were temperature, humidity (or a combination of temperature and humidity sensor), light and GSM module. In order to have these modules working synchronously, connectors were used to link them to the Base shield which is fit to the Intel Edison's microcontroller GPIO pins. The grove system used in this project is the Grove Starter Kit for Intel Edison as shown in the figure 5.4.



Figure 5.4: The Grove system connected to the Arduino board (Ramon, 2015)

5.5 Integrating Intel Edison Board with the Intel IoT Cloud Analytics

This section of the prototype is where there's connection to the Intel cloud-based analytics for real-time analysis and storage. The Intel Edison Module must be able to access the internet so that it can connect to the cloud. Networks with firewalls or blocked ports may see difficulty in connectivity.

Secure information transmission was a critical issues to ensure system reliability of the IoT prototype. Hybrid encryption technique was applied to ensure security with the cloud-platform. The researcher mainly used digital signature of hybrid key algorithm based on DES and DSA algorithm, on the shell-based node.js. This provided the benefit of the symmetric and asymmetric key performance which enabled strong security and low computational complexity. The hybrid algorithm ensured confidentiality of the sensor information recorded and integrity of the process of information transmission to the Intel IoT Analytics cloud platform.

Below are the steps to setting up an IoT analytics account and then proceeding with connectivity and sensor activation.

5.5.1 Setting up an IoT Analytics Account

Create an account on the Intel IoT analytics website; https://dashboard.us.enableiot.com /ui/auth#/login. I signed up by using an existing Google account, using your username and password.

Accept the Terms and Conditions of Use by selecting the I agree to the Terms and Conditions of Use check box. Click Send confirmation email. Click the activation link in the email to confirm the gmail address. After the confirmation, one can log in to the IoT Analytics site using your gmail address and password.

5.5.2 Activating the Intel Edison Module in the Intel Cloud

On the IoT Analytics website, click the menu icon Menu icon in the top left. Select Account. On the Details tab, locate the activation code which is displayed in the Activation Code field. If the code is expired, click the refresh icon to obtain a new code.

In a serial communication window, enter the following command: iotkit-admin activate "activation_code" to enable the Intel Edison module to send values to the cloud platform. The Intel Edison Module device is associated with the account that the activation code was generated from and provided with security credentials.

On the IoT Analytics site, click the menu icon in the top left. Select Devices. The My Devices page opens with a list of all the IoT devices you have created and activated with this account as shown in figure 5.5.

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Figure 5.5: Created and Active Device in the Intel IoT Account

5.5.3 Registering the Light and Temperature Sensors

The sensors have a component type which is defined and created on the Intel IoT Analytics, such as temperature.v1.0 or humidity.v1.0. Component types are templates that define the types of time series and actuators used by the Intel Edison board to send values to the cloud for analytics in real-time shown in the figure 5.6.



| IoT Analytics Dashboard - Mozilla Firefox | | | | |
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Figure 5.6: Component definition in Intel IoT Analytics

Once the components have been defined on the Intel IoT Analytics cloud platform, run the below commands on a serial command terminal to register the temperature and light sensors respectively:

Iotkit-admin register temp temp.v.1.0 && iotkit-admin register light light.v.1.0

5.5.4 Performing the analytics and defining threshold values

The prototype can now send values to the Intel IoT cloud platform for analysis. Run the command below on the serial terminal window: *iotkit-agent start*. The figure 5.7 and 5.8 depict the real time graphs for temperature and light in real-time.



Figure 5.7:Real Time Monitoring of Temperature Values

The graph above depicts the real-time values obtained from the temperature sensor. The Y axis is the measurement of the temperature values in degrees Celsius while the X axis is the time when the values were recorded. The green line depicts the maximum temperature values while the red line depicts the minimum temperature values recorded. The greenhouse managers can quickly derive meaning conclusion of how this parameter is performing in the greenhouse.



Figure 5.8: Real Time Monitoring of Light Values

Figure 5.8 depicts the real-time recorded values for light parameter. The X asis is the time, in seconds, while the Y axis is the measurement unit when light was measured in.

The threshold values are set in the Intel IoT analytics by clicking the Dashboard menu and then Rules tab. Enter the temperature minimum value as 20°C while the maximum value as 25°C. The light minimum value is 400nm while the maximum value as 700nm.

The threshold values are set on a time-based condition for 3 seconds as the duration the Intel-IoT cloud platform to send email alerts when the set values are surpassed. However, the time-based condition can be increased or reduced to the preferred time duration to send alerts.

Figure 5.9 shows alerts sent to a greenhouse manager in-form of an e-mail alert. The managers also have an option of clicking a link which takes them to the analytics dashboard and view the real-time analytics.



Figure 5.9: Email notification to the greenhouse managers

5.6 System Performance and Testing

The prototype testing strategies that were deployed were agile methods where testing was done concurrently with programming. The project had two phases where Phase 1 was developing the machine to machine communication while phase two was integrating with Intel IoT Analytics cloud-platform. The respondents of the research, farmers and greenhouse managers, were actively involved in each phase where testing was done in every iteration and they validated each phase.

Phase 1 of the prototype development was setting up the board and sensors for data abstraction of environmental parameters. Development for this phase was done by programming the Intel Edison board in C++ using Arduino software version 1.6.8. The testing of phase one was done in the greenhouses by farmers to test efficiency of the machine-to-machine communication between the sensors and the Intel Edison board. The metrics for this phase were task time and success, the rate at which the sensors were recording environmental parameters and efficiency which was tested by the number of steps required to set up the board.

Phase 2 of the prototype was integration with the IoT Analytics cloud-based platform for data analytics and storage. Development for this phase was done by shell-based Node.Js on a terminal. This was used mainly because it's secure and robust for sending data from devices to web-based applications. The testing of phase two was mainly done by greenhouse managers to ensure they

can view and understand the real-time analytics of the environmental parameters. In addition, they were to test if the e-mail notifications were timely and relevant. The metrics for this phase were error-ratio, of the data recorded from the sensors and the analytics graph, and efficiency of time based e-mail notifications.

This Internet of Things prototype had the following strengths which make it a stronger architecture to be deployed in greenhouses:

Monitoring environmental conditions in real-time which also enables real-time analysis to improve decision making by the greenhouse managers. This also optimizes agricultural processes in the greenhouse.

There is reporting through e-mail notification where a farmer or greenhouse manager receives alerts when the set values as threshold have been surpassed. The alerts are sent in a time-based condition where they are sent periodically on a daily basis.

The prototype allows for inter-operability where different devices and technologies to interconnect creating an embedded system. The systems inter-connected are Intel Edison module, Grove Sensors and Intel IoT Analytics cloud platform.

The prototype also achieves scalability through cloud computing where a farmer or a greenhouse manager can have distant monitoring of the environmental parameters via data management and analytics.

The prototype achieves security functions by use of Message Queue Telemetry Transport (MQTT) which is a light weight messaging protocol used on top of TCP/IP protocol. The protocol ensures the values sent from the sensors to the cloud analytics is not susceptible.

Chapter 6: Conclusion and Recommendations

6.1 Introduction

A majority of greenhouses in Kiambu County 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 environmental conditions and did an analysis of the challenges faced in greenhouse management.

6.2 Conclusion

The main challenges of greenhouse farming in small-scale farms in Kiambu County 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 carbon dioxide.

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 Kiambu County. Intel Edison architecture was found to be the most appropriate to monitor and control environmental parameters in greenhouses.

6.3 Recommendations

Environmental conditions have been observed as a key requirement to ensure greenhouse farming is running effectively amongst other factors which include water resources, operational

costs, pests and diseases. 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 Intel Edison 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 for analysis and storage due to its wi-fi enabled feature.

Greenhouses in Kiambu County should adopt this design to ensure high and quality yields from their farms. 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.

6.4 Future Works

An android mobile application to access the Intel IoT analytics would be of benefit to the greenhouse managers. They would make access of analytics and reports be easier because they would not have to go to a browser to view both analytics and notifications.

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An integration of more sensors to enhance monitoring of other environmental factors such as humidity and soil Ph to make the prototype robust. This would be of great beneficiary to the farmers by reducing their operation costs in a greenhouse farm and also provide a platform towards full automation of greenhouse activities.

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Appendices

Introduction

This section contains the questionnaire that was administered to farmers and greenhouse managers to assist in prototype development. The questionnaire focused mainly on optimum environmental conditions, crops grown in the greenhouses, challenges faced in greenhouse management and the best reporting tool for the farmers.

APPENDIX A

The following questionnaire is part of a study being conducted to design an Internet of Things (IoT) prototype for managing environmental conditions in greenhouses at Kiambu County. The focus of this questionnaire is to identify the size of greenhouses, crops grown in the greenhouses and optimum environment conditions in a greenhouse.

Choose the answer which best explains your preference and circle the letter(s) next to it. Leave blank any question that does not apply.

1. What is your age?

- A. Between 20-30 years
- B. Between 30-40 years
- C. 40 and above years
 - 2. What sex are you?
- A. MALE
- B. FEMALE
 - 3(a). Which crops do you grow in your greenhouse?

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- A. Vegetables
- B. Fruits
- C. Flowers

3 (b). Kindly specify the type of vegetables, fruits or flowers grown in your greenhouse?

4. What are the optimum environmental conditions for the different crops grown in the greenhouse?

- A. Temperature
- B. Humidity
- C. Soil Moisture
- D. Carbon Dioxide
- E. Light

5. What is your total area of your greenhouse?



Interview Guide for the Greenhouse Farmers

This phase of the survey will look what the users of the system prefer and how they would want to interact with the system. It will mainly focus on the requirements of the Internet of Things prototype which will be used to design the system.

Choose the answer which best explains your preference and circle the letter(s) next to it. Leave blank any question that does not apply.

- 1. What are the challenges faced in greenhouse management?
- A. Operation expenses (electricity, machinery and employees)
- B. Monitoring and controlling environmental conditions
- C. Pests and Diseases
- D. Lack of quality water sources
- 2. Have you used greenhouse automation systems before? If yes, what are your key challenges when engaging with IoT applications?
 - A. Internet Connectivity
 - B. Complexity of the system
- C. Security and Privacy Concerns
- D. Lack of proper data analysis
- 3. Should the standard threshold for measuring environmental factors be calibrated by an expert or individual (farmer)?
- 4. What would be the most efficient way of relaying the data from the sensors to the farmer?
 - A. Graphs (Application)
 - B. Alerts (Email or SMS)
- 5. How frequent should the alerts be?
 - A. After every 6hrs
 - B. Daily
 - C. Weekly
 - D. Monthly
- 6. What would be the most convenient method to do remote controlling of the greenhouse?
- A. Actuators
- B. Receive a notification then notify your workers
- C. Have workers always in the greenhouse to be advised on instructions

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APPENDIX C

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Interview Guide for Greenhouse Management Administrators

This phase of the survey depicts how greenhouse farms are managed and the various costs they incur to run their farms from the different locations they might be:

Choose the answer which best explains your preference and circle the letter(s) next to it. Leave blank any question that does not apply.

- Date of Interview: Organization:
- Title:

Job Responsibility:

- 1. Does your organization have a greenhouse management system?
- 2. What is the greenhouse management system used at your farm?
- 3. Research shows that majority of the greenhouses in Kiambu County do not have a greenhouse management system. What are the reasons why greenhouse management systems are not incorporated in greenhouse farming?
- 4. In your opinion, which greenhouse management system would be appropriate to be integrated with the greenhouse farming operations in your organization? Why?
- 5. How many part-time workers does your greenhouse employ?
- 6. How many full-time workers does your greenhouse employ?
- 7. What are the main expenses does the greenhouse have?
 - a. Electricity (lighting, fans and heating)
 - b. Employees
 - c. Crop Expenses (pesticides, fertilizers, pollination and irrigation expenses)
 - d. Operating Expenses (machinery, agricultural equipment, land taxes, interest rates, packaging and insurance