Wireless ICT Monitoring for Hydroponic Agriculture

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WIRELESS ICT MONITOTRING FOR HYDROPONIC AGRICULTURE

By

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Declaration of Authorship

I, Loic Andre Stephane Ndame, declare that this dissertation titled, 'Wireless ICT Monitoring for Hydroponic Agriculture' and the work presented in it are my own. I confirm that:

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- Where I have consulted the published work of others, this is always clearly attributed.
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"It is the greatest of all mistakes to do nothing because you can only do little - do what you can."

Sydney Smith

Abstract

It is becoming increasingly evident that agriculture is playing a pivotal role in the socio-economic development of South Africa. The agricultural sector is important because it contributes approximately 2% to the gross domestic product of the country. However, many factors impact on the sustainability of traditional agriculture in South Africa. Unpredictable climatic conditions, land degradation and a lack of information and awareness of innovative farming solutions are among the factors plaguing the South African agricultural landscape. Various farming techniques have been looked at in order to mitigate these challenges. Among these interventions are the introduction of organic agriculture, greenhouse agriculture and hydroponic agriculture, which is the focus area of this study. Hydroponic agriculture is a method of precision agriculture where plants are grown in a mineral nutrient solution instead of having the roots of the plants grounded in soil. Hydroponic agriculture is also a labour- intensive activity that requires an incessant monitoring of the farm environment in order to ensure a successful harvest. Hydroponic agriculture, however, presents a number of challenges that can be mitigated by leveraging the recent mobile Information and Communication Technologies (ICTs) breakthroughs. This dissertation reports on the development of a wireless ICT monitoring application for hydroponic agriculture: HydroWatcher mobile app. HydroWatcher is a complex system that is composed of several interlacing parts and this study will be focusing on the development of the mobile app, the front-end of the system. This focus is motivated by the fact that in such systems the front-end, being the part that the users interact with, is critical for the acceptance of the system. However, in order to design and develop any part of HydroWatcher, it is crucial to understand the context of hydroponic agriculture in South Africa. Therefore, complementary objectives of this study are to identify the critical factors that impact hydroponic agriculture as well as the challenges faced by hydroponic farmers in South Africa. Thus, it leads to the elicitation of the requirements for the design and development of HydroWatcher. This study followed a mixed methods approach, including interviews, observations, exploration of hydroponic farming, to collect the data, which will best enable the researcher to understand the activities relating to hydroponic agriculture. A qualitative content analysis was followed to analyse the data and to constitute the requirements for the system and later to assert their applicability to the mobile app. HydroWatcher proposes to couple recent advances in mobile technology development, like the Android platform, with the contemporary advances in electronics necessary for the creation of wireless sensor nodes, as well as Human Computer interaction guidelines tailored for developing countries, in order to boost the user experience.

Acknowledgements

To **The Lord** through whom everything is made possible.

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Preface (Note on Writing Style)

Writing of Numbers as numerals versus words

Numbers up to and including ten are written in words

Where a number is used in a sentence, it will assume the numeral form; i.e. There are 50 examples that could justify this case.

The use of the words "app" and "application"

The use of the word app is strongly connoted with smartphones. This dissertation describes the development of a mobile application, thus the word app and application will be used interchangeably to refer to the software proposed in this study.

The Oxford Comma

The Oxford comma has been widely used in this study, especially to list items.
Listing without the Oxford comma: The critical factors in hydroponic farming are temperature, pH and humidity.
Listing with the Oxford comma: The critical factors in hydroponic farming are temperature, pH**,** and humidity.

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Abbreviations

DSR	**D**esign **S**cience **R**esearch
DSRP	**D**esign **S**cience **R**esearch **P**rocess
EC	**E**lectrical **C**onductivity
FAO	**F**ood and **A**griculture **O**rganization of The United Nations
GPRS	**G**eneral **P**acket **R**adio **S**ervice
GSM	**G**lobal **S**ystems for **M**obile Communications
HCI	**H**uman-**C**omputer **I**nteraction
ICT	**I**nformation and **C**ommunication **T**echnology
IS	**I**nformation **S**ystem
IT	**I**nformation **T**echnology
OFA	**O**pen **F**ield **A**griculture
pH	**P**otential **H**ydrogen
UCD	**U**ser **C**entred **D**esign

Dedicated to my father, who lit the agricultural spark.

Chapter 1

Introduction

This dissertation presents a tool for monitoring hydroponic agriculture: a wireless ICT monitoring application for hydroponic agriculture that is dubbed in this study as HydroWatcher mobile app. HydroWatcher mobile app is a tool suitable for a developing country, while in this case focusing on the context of South Africa. Beyond the tool itself, the dissertation also describes the requirement elicitation that led to the design and development of the HydroWatcher mobile app. A difference should be made : HydroWatcher refers to the system in it is entirety while HydroWatcher mobile app is the user interface with which the user can interact. This research positions itself in the realm of e-agriculture.

According to Ndame and van Greunen (2014) e-agriculture entails the application of information and communication technologies (ICTs) in innovative ways with the emphasis in the rural development domain.

The Food and Agriculture Organization of the United Nations (FAO) puts forth the following definition for e-agriculture: "e-agriculture is an emerging field in the intersection of agricultural informatics, agricultural development and entrepreneurship, referring to agricultural services, technology dissemination, and information delivered or enhanced through the Internet and related technologies. More specifically, it involves the conceptualization, design, development, evaluation and application of new innovative ways to use existing or emerging information and communication technologies" Both definition intersect and this study adopts a definition that is the synthesis of both: e-agriculture entails the conceptualization, design, development, evaluation and application of innovative ways of using new or emerging ICTs to promote agricultural development (e-agriculture, 2014).

Several researches have been conducted in this subject area in recent years and Wang et al. (2006) argues that the application of technology in agriculture will change conventional thinking as it leads to improved management techniques. This study will not look at agriculture in general but at a particular farming technique: hydroponic agriculture.

Hydroponic agriculture is a farming technique that is essentially characterised by its independence to arable soil or to soil in general. This study will revolve around the coupling of ICT solutions to improve the hydroponic related activities on a farm.

The purpose of this chapter is to provide an overview of the dissertation. Section 1.1 provides a brief background to the dissertation and this is followed by the problem description and statement in Section 1.2 . The research questions and objectives will be discussed in Section 1.3 and 1.4 respectively. Subsequently, a description of the scope and delineation is portrayed in Section 1.5. A summary of the research approach is presented in Section 1.6. This chapter concludes with a description of the dissertation layout.

1.1 Background

1.1.1 Agriculture in South Africa

Agriculture is playing a pivotal role in the socio-economic development in South Africa (Diao et al., 2007). The past years have seen increasingly the inception and evolution of agriculture to become an active engine contributing to the gross domestic product (GDP) of the country along with the industrial sector. The agricultural sector in the year 2013 contributed to over 2% of the South African GDP (Government Communication and Information System, 2013). That contribution has ensured that South Africa achieved food security and that it is not dependent on external food programmes. Additionally, agriculture can contribute significantly to economic growth by means of food production and job creation, and thus it can play an important role in poverty alleviation (Du Toit, 2011). However, many factors impact on the development and sustainability of agriculture in South Africa. South Africa, On the one hand, is impacted by a population growth that has lead the population to inflate to over 51 millions inhabitants, with that, a rising middle class whose food demand will quadruple by 2030 (Statistics South Africa, 2009). On the other hand, the agricultural environment operates in an effervescent economy that is characterized by high interest rates, inadequate infrastructure, lack of financing and access to markets, unpredictable climatic conditions, land degradation and a lack of information or awareness of innovative farming solutions, among others (Mashapa and van Greunen, 2010, Olawale and Garwe, 2010) . Various farming techniques have been looked at in an attempt to curb these challenges. Examples of such interventions include the introduction of organic farming, greenhouse farming and more recently, hydroponic agriculture. Among these methods of farming, hydroponic agriculture promises to deliver the sustainability of urban market gardening farming.

1.1.2 Hydroponic Agriculture

Hydroponic agriculture is a method of precision agriculture where plants are grown in mineral nutrient-laden solution instead of having the roots of the plants grounded in soil (Huang et al., 2002). This technique is based on the premise that soil is not an essential requirement for plant growth, but that it only acts as a reservoir for nutrients. Hence, hydroponic agriculture is an atypical way of introducing mineral nutrients into a water supply system for absorption by the roots of the plants. Following this, hydroponic agriculture therefore allows plants to be grown in a controlled environment even in regions where climatic conditions are not naturally favourable for a particular plant species. When considering Open Field Agriculture (OFA), the ideology entails finding the optimal conditions possible for the growth of crops: the best arable land, favourable weather conditions, sufficient water supply, etc. For hydroponic agriculture, the thinking process resides at the antipode of that of the OFA. Hydroponic agriculture can be characterized as creating the optimal condition for crop growth anywhere, at any time (Ortho Books and McKinley, 2001). Additionally, as it is commonly known, for a plant to grow, a perfect measure of sun, water, and minerals from the soil or the growth medium is required. An overabundance of any of these elements can be as disastrous as the lack thereof. One can immediately picture a desert with its overabundance of sun, that yet has virtually non-existent vegetation. That is where the advantages of hydroponic agriculture lie.

Furthermore, hydroponic agriculture enables a farmer to create the optimal conditions that are closely related to the native environment of the plant species. That process ensures that a year-long production of a certain product, such as tomatoes, is obtainable as opposes to the case with OFA that will only cater for seasonal production. Hydroponic agriculture is a farming technique that bears many advantages. The possibility of controlling the growth environment has proven to generate a superior yield when compare to OFA, sometimes up to 10 times as much, depending on the crops being produced (Jensen, 1997). Hydroponic agriculture also uses fewer resources than OFA. Less water, for instance, is used for irrigation since the plants could reside in their feeding medium: water. Therefore, given just these advantages, a question remains: Why is there no widespread use of hydroponic agriculture in developing countries such as South Africa?

Firstly, hydroponic agriculture is not a new agricultural technique. This technique can be traced to as far back as 600 BC (Tzanakakis et al., 2014). Setting up a hydroponic farm can be a financially stressful venture, and developing countries are characterised by financial constraints. Therefore, hydroponic farms are mostly set up for commercial purposes. Moreover, hydroponic agriculture is labour-intensive. Hydroponic agriculture requires that farmers be available to tend to the farm on a daily basis (Department of Agriculture, Forestry and Fisheries, 2011). Furthermore, to ensure that a high yield from the plants is obtained, farmers must monitor closely the environmental parameters of the farm and must always provide optimum conditions for growth. This task is not easily achieved and will be the subject of the next section.

1.1.3 Monitoring Hydroponic Agriculture

Monitoring is one of the daily activities performed on a hydroponic farm. Monitoring serves the purpose of ensuring that the plants at all times are in conditions that will permit the production of the best genetic outcome. Monitoring entails that farmers must verify, in a timely fashion, that the critical factors dictating the normal growth of the plants are in the right balance and perfect range. Those critical factors include, but are not limited to factors such temperature, humidity, pH of the nutrient solution, electrical conductivity of the nutrient solution and the quantity of water delivered to the plant, just to cite a few. When these factors are not delivered in the right range, they can have disastrous consequences for the plants. For instance, an out of range humidity percentage can lead to the dehydration of the plants or even be conducive to the development of diseases. Other out of balance factors lead to other consequences, all of which are equally unfavourable for the growth of the plants. These premises thus mean that monitoring a hydroponic farm is unavoidable .

In South Africa, most farmers still rely on a manual means of monitoring the farm environment. It requires skilled personnel to go into the hydroponic farm to record the variables at different time intervals. In some instances, there are wired sensors that record arbitrary values in the hydroponic farm. The readings are then stored in a weather station-type mechanism. The farmers will then manually take note of these recordings at intervals, to capture the readings on spreadsheets and to analyse the data for interpretation. Depending on the analysis of the readings, the farmers could conclude that the plants may need more fertiliser, more water, or that they should adjust the temperature in the tunnels. However, a wrong interpretation could lead to an adjustment that will harm the plants; for instance, too much fertilisers is as bad as too little. The manual systems are time-consuming, labour -intensive, and prone to inaccuracies during the recording of variables, the capturing of data onto spread sheets, as well as during the analysis and interpretation of data.

Furthermore, the manual system does not provide any notification in cases where there is a deviation from the required variable range. Also, the manual system does not provide intelligent recommendations to the farmer on how to optimize the available resources in order to get the best yield in the shortest time possible while using the minimal resources available. In spite of that predicament, an ICT-enabled solution could be applied to hydroponic farms to reduce the load that monitoring puts on the farmers.

The impact of wireless technology is mainly perceived through the astonishing growth of the cell phone market. However, the share that interpersonal communication, like cellular phones has currently, will be dwarfed by the share allocated to other wireless communication in a few years (Wang et al., 2006). The potential and versatility of ICT solutions backed by wireless technology have opened up their potential application in diversified domains. They are used for collecting; processing, storing and sharing sensors' data in various applications including habitat monitoring, agriculture, nuclear reactor control, security and tactical surveillance (Bhattacharyya et al., 2010).

A variety of studies that prove the viability and applicability of ICT solution in agriculture have been done. Thus, these solutions have the potential to circumvent the challenges of monitoring and controlling the hydroponic environment for the farmers in South Africa. The farmers will be able to monitor plants in real time for air temperature, water mineral nutrient content and turbidity stress. The real time information from the fields will be the basis for providing intelligent recommendations for farmers to adjust strategies at any time in order to optimize crop production. However, this aspect will not be covered in this study, but will be explored in further studies.

Having presented the background to this study, the specific problem being addressed by this research will be outlined in the next section by means of the research problem.

1.2 Research Problem

Besides having many advantages, hydroponic agriculture is an extremely delicate activity. It requires extensive monitoring of the farm to ensure optimum growth of crops (Izzat Din Abdul Aziz et al., 2009). Currently in South Africa, most of the hydroponic agriculture monitoring is done manually, therefore plaguing the monitoring activity with uncertainty related to human error and other challenges. Examples of such challenges include the monitoring process being cumbersome, time consuming and prone to inaccuracies in data capturing (Mendez et al., 2012). Furthermore, it is important to note that the farmer, through no fault of his own, might not always have the necessary analytic skills or expertise to draw the right conclusion from the gathered data; which data could rapidly overwhelm through sheer volume. These challenges could subsequently result in the rapid death of the crop, low production yields and failure to realize a return on investment from the hydroponic farm. In brief, many hydroponic farmers in South Africa use inadequate monitoring techniques and the decision-making relating to the management of the farm is supported by out-dated data. This problem has an impact on hydroponic farmers, on their commercial partners, on the regional population whose food security and safety is ensured by hydroponic farming and, when examining a domino effect, the GDP of the country is impacted too. The research problem of this study could therefore be stated in these terms:

There is currently a lack of wireless ICT enabled applications capable of adequate monitoring and management of the hydroponic agricultural environment within the South African context.

1.3 Research Questions

From the research problem labelled research questions have been inferred . A main research question was derived as well as three other sub research questions (RQ).

Main Research Question: *What are the components of a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?*

Sub Research Questions

RQ1: *How can hydroponic agriculture be described in the South African context?*

RQ2: *What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?*

RQ3: *How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa?*

1.4 Research Objectives

The problem has been found and questions have been asked. In order for the study to measure its degree of achievement, research objectives (ROB) were set. Those objectives are as follows:

ROB1: To define hydroponic agriculture.

ROB2: To determine the advantages and disadvantages of hydroponic agriculture.

ROB3: To determine the critical factors related to hydroponic agriculture.

ROB4: To determine the challenges faced in hydroponic agriculture.

ROB5: To determine the requirements of a wireless ICT monitoring system for hydroponic agriculture.

ROB6: To design and develop the wireless ICT monitoring application for hydroponic agriculture.

ROB7: To evaluate the applicability of the requirements as demonstrated in the wireless ICT monitoring application for hydroponic agriculture.

The objectives for this study were selected so that by achieving one or more objectives one of the research questions aforementioned will be answered. Table 1.1 illustrates a mapping between the research questions and the objectives of this study.

Research Question	**Research Objective**
RQ1: How can hydroponic agriculture be described in the South African context?	ROB1:To define hydroponic agriculture. ROB2: To determine the advantages and disadvantages of hydroponic agriculture. ROB3: To determine the critical factors related to hydroponic agriculture. ROB4: To determine the challenges faced in hydroponic agriculture.
RQ2: What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?	ROB5: To determine the requirements of a wireless ICT monitoring application for hydroponic agriculture.
RQ3: How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa?	ROB6: To design and develop the wireless ICT monitoring application for hydroponic agriculture. ROB7: To evaluate the applicability of the requirements as demonstrated in the wireless ICT monitoring application for hydroponic agriculture.

Table 1.1: Mapping between the Research Questions and the Research Objectives

1.5 Scope and Delineation

This dissertation revolves around the development of a wireless ICT monitoring application for hydroponic agriculture.

The introduction of technology in agriculture falls in the realm of e-agriculture. For the development of such a system, the factors to monitor must be sought out and the requirements outlined. The scope of this research is thus to:

- Unearth the critical factors dictating hydroponic agriculture in South Africa.
- Specify the requirements for the wireless monitoring system.
- Develop a low cost wireless ICT monitoring application for hydroponic agriculture.
- Evaluate the developed application and established the applicability of the requirements.

A wireless monitoring system for hydroponic agriculture is a system that usually comprises a wireless sensor network that gathers environmental data from the field and sends those data to a data storage unit (database) and interface that the user can utilize to read and analyse the gathered information (Mendez et al., 2012). This study described the requirements for the system in its entirety, but the design and development phase focused and was limited to the development of the system user interface, which is the mobile application. The mobile application was developed to present a proof of the concept of the requirements for HydroWatcher.
Additionally, the mobile application features a notification and alerts system to notify the farmers regarding any deviation from the farm parameters. The wireless sensor network design and development will not be covered in this discussion. The storage structure, also an important part of this type of system, will also not be discussed.
During the evaluation of the app, the data that should have been gathered by the wireless sensor network will be simulated. Also, intelligent recommendations will be excluded from the scope of this study, but will be part of further studies.

Moreover, an exploratory study will be conducted during the data mining process. For this process hydroponic farms were elected in the region of Port Elizabeth, South Africa. This choice was made out of convenience owing to their proximity and access provided to the researcher.

1.6 Research Methodology

The study described in this dissertation followed an elaborated methodology:

Research philosophy : An *interpretivist* stance was adopted as philosophical approach.

Research paradigm: *Design science research* is the paradigm driving this study.

Research approach: In this research two parameters were considered for the research approach, *inductive reasoning* for the logic of reasoning and *mixed methods research* for the perspective of the researcher on the nature of the research.

R**esearch strategy**: Design and creation research was the adopted research strategy.

Data collection methods: The data collection methods employed in this study are *a literature review*, *interviews with hydroponic farmers/farm managers/farm workers*, *an exploratory study*, and *naturalistic observations*.

The design science research process (DSRP) model proposed by Peffers et al. (2006) was used to guide the research process. The research process consists of the following six iterative steps as described in Table 1.2.

Step	Description
Problem identification and motivation	There is currently a lack of wireless ICT enabled applications capable of adequate monitoring and management of hydroponic agricultural environments within the South African context.
Objectives of a Solution	To provide an adequate alternative to the monitoring techniques currently in use in South Africa.
Design and Development	To design and develop a wireless ICT monitoring application
Demonstration	Selected participant sample uses the designed tools for the evaluation.

Evaluation	To evaluate the monitoring application by collecting feedback from experts in hydroponics and potential end users.
Communication	Scholarly publications

Table 1.2: Design Science Research Process Model Steps (Peffers et al., 2006)

The DSRP model steps defined and adopted by this research led to the subdivision of this research into phases that fit into the process model. The phases are illustrated in Figure 1.1 and are briefly described below.

Phase 1 Review and Conceptualisation : This phase involves doing the preliminary survey of the research area followed by the problem identification and formulation of objectives.

Phase 2 Investigation: This entails further investigation into the research problem.

Phase 3 Requirement specifications: This phase involves the development of the requirements needed for the development of the solution.

Phase 4 Building the application: This phase entails the design and development of the wireless monitoring application.

Phase 5 Evaluation : In this phase, the attempted solution is demonstrated and evaluated by experts in the field of hydroponic agriculture, and in the real context of use.

Phase 6 Communication: This phase consists of the development of the documentation pertaining to this study

The outcome of each phases provides the input for the subsequent phases. The correlation between these phases and the DSRP model is outlined in depth in Chapter 2

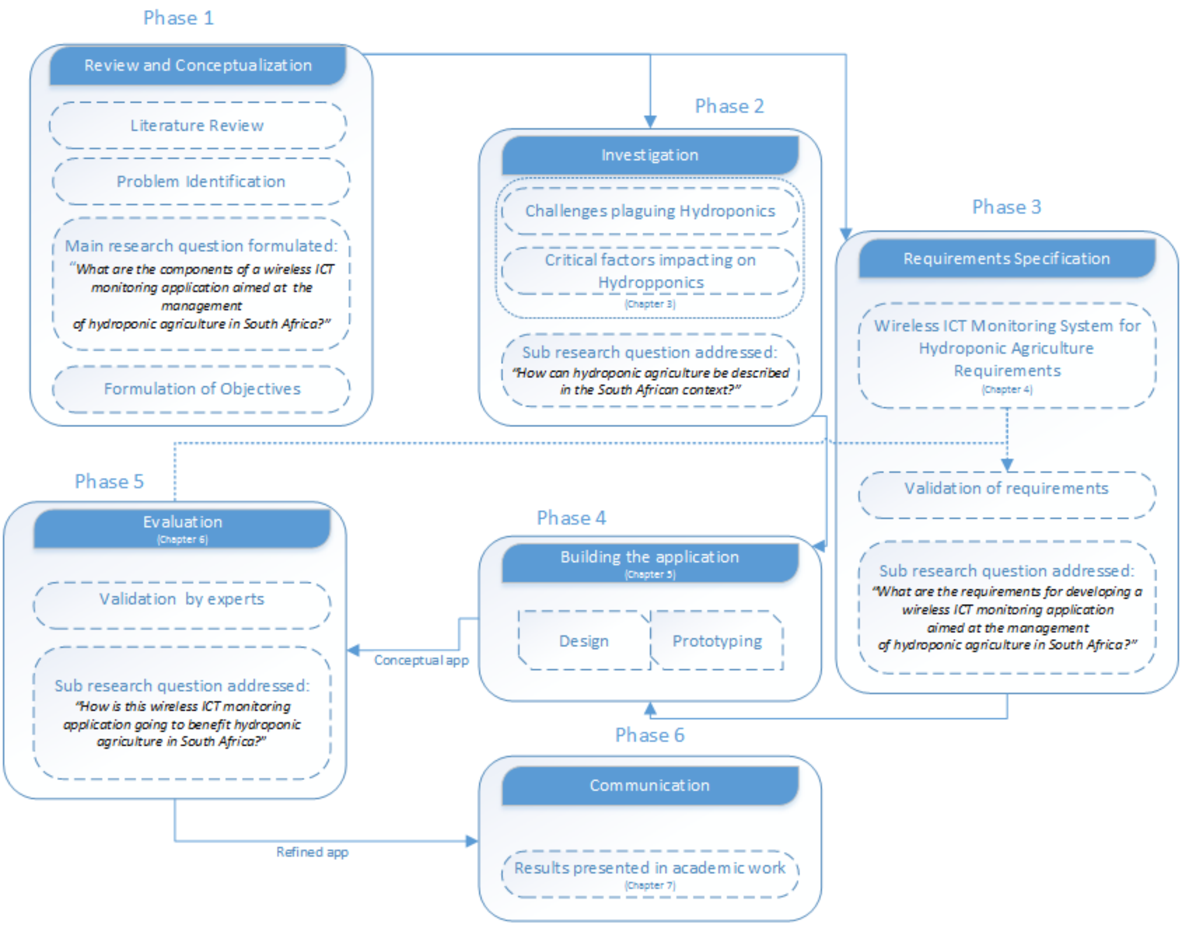


FIGURE 1.1: Research Phases of this Study

1.7 Layout of the dissertation

This dissertation encompasses eight chapters, as illustrated in Figure 1.2

Chapter 1 plays the role of introductory chapter. It is an overview of the dissertation. It provides a brief background to the study and defines the problem statement. Additionally, it lists the research questions and the research objectives. Subsequently, it provides a summary of the research approach and a diagrammatic representation of the layout of the dissertation.

Chapter 2 presents the research methodology applied to the study.

Chapter 3 presents the results from the investigation phase. It presents a deeper discussion of hydroponic agriculture and the challenges surrounding the activity in South Africa. In addition, it exposes some of the solutions proposed to mitigate some of the challenges.

Chapter 4 is part of the requirement identification phase. This chapter is an exhaustive discussion of the multiple aspects to consider when designing and developing a solution for hydroponic agriculture. The requirement-gathering process is also outlined in this process.

Chapter 5 maps the building phase. It presents the development of the app that is part of the wireless monitoring system. The different phases of development are highlighted.

Chapter 6 maps the evaluation phase. This chapter discusses the purpose of the evaluation, the process and analysis method, as well as the metrics used.

Chapter 7 is also a part of the evaluation phase. Chapter 7 describes the result from the evaluation test described in Chapter 6 . This chapter covers the biographical data of the participants, the results and the recommendations that were derived from the test.

Chapter 8 is the concluding chapter. It provides a summary of the study, and reviews the research questions and objectives. Furthermore, the chapter exposes the limitations of the research and discusses the contribution of the research .Finally, it explores future research avenues.

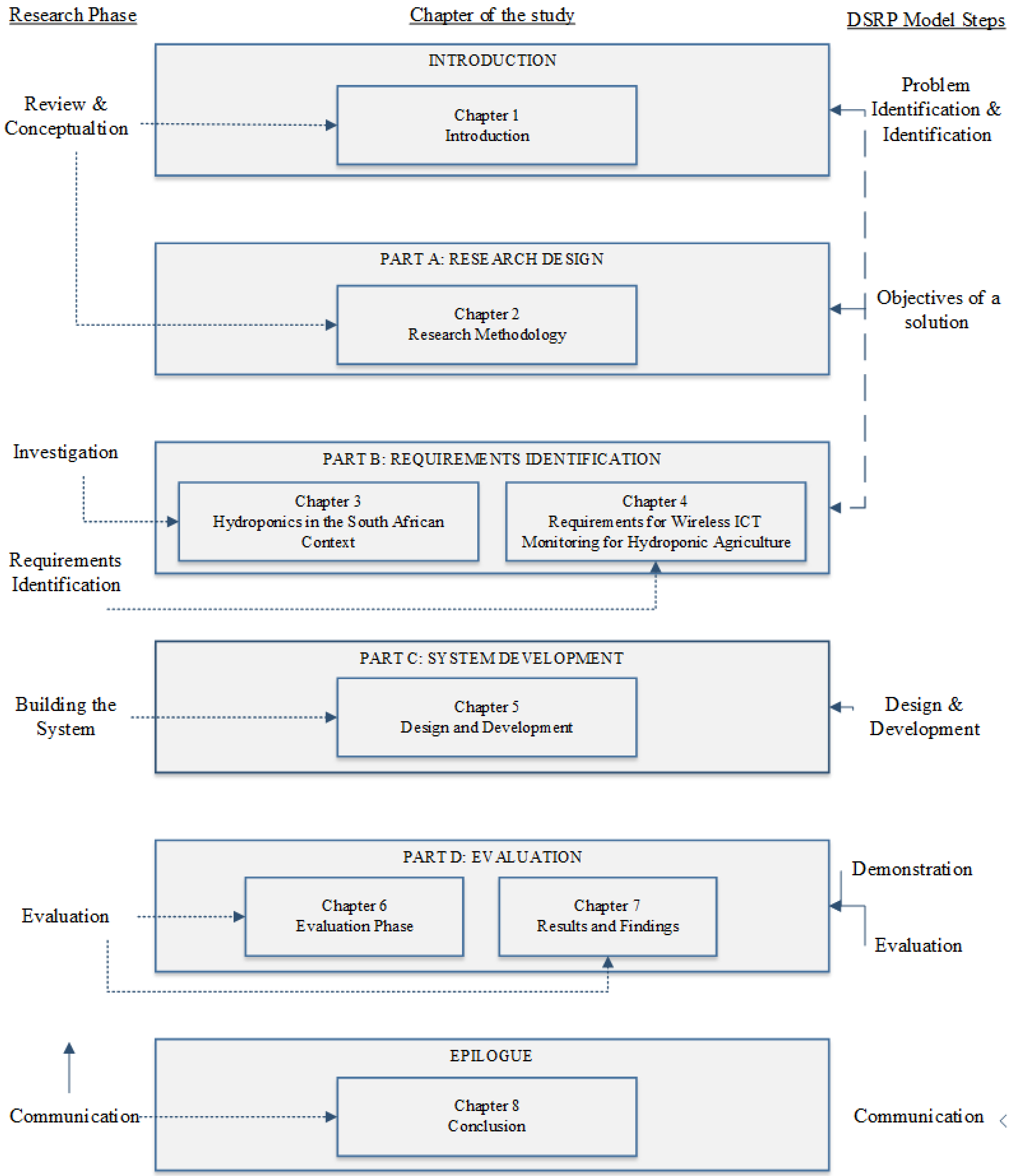
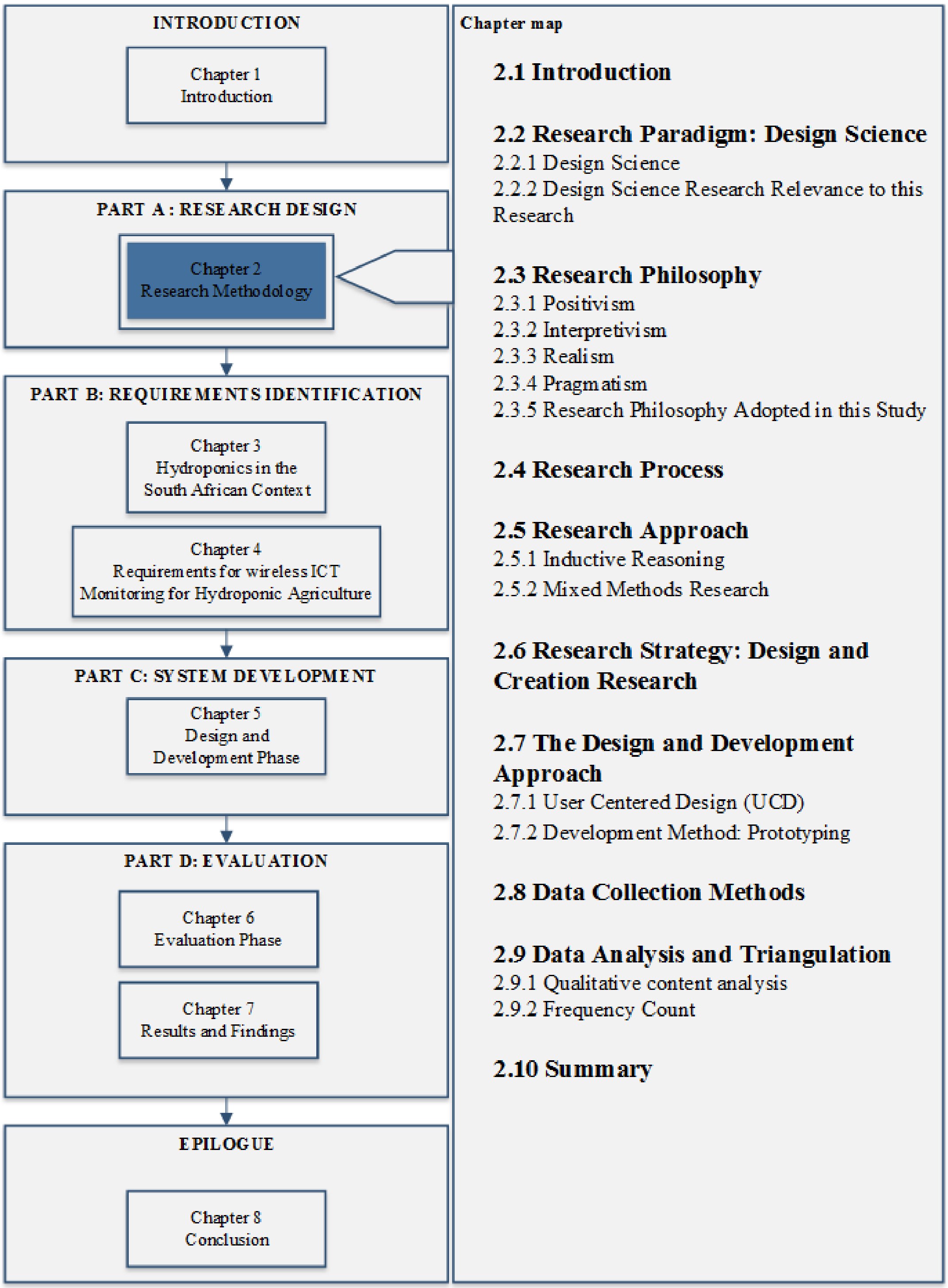


FIGURE 1.2: Outline of the dissertation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Chapter 2

Research Methodology

2.1 Introduction

The aim of this chapter is to describe the techniques and methods used in conducting this study and to give an outline of the methodological approach that was used to provide appropriate answers to the raised research questions. By utilising an organized procedural approach to the research, an expectation is raised that results will be generated that are credible and relevant, in order to solve the problem being studied. The discussion in this chapter starts with the research paradigm in Section 2.2. Following that, the research philosophy is discussed in Section 2.3. Section 2.4 and 2.5 highlight the process and the approach of this study, respectively. The research strategy and the data collection are discussed toward the end of the chapter in Section 2.6 and 2.8 as well as the design and development approach in Section 2.7. Finally, a summary of the chapter is provided in Section 2.10.

2.2 Research Paradigm: Design Science

Upon examination of the research question and the objectives, it becomes abundantly clear that the key message is “design”. This study will go through the process of understanding the field of study, will contrive some requirements, will design and then evaluate the artefactual solution. Therefore, this research must adopt a paradigm that will enable the research to be a success. Information system (IS) is an “applied” research discipline, and it is acknowledged in some sense that IS applies theory, frequently from other disciplines, such as economics, social sciences or, in this case, agriculture, to solve problems at the intersection of IT and organisations (Peffers et al., 2006) . Furthermore, design, the act of creating an explicit applicable solution to solve a problem, has been accepted as a research paradigm in discipline like engineering (Peffers et al., 2006). Design “close cousin” in IS, that deliver the same result, is Design science and will be the paradigm adopted in this study. The next section motivates the suitability of the use of the design science paradigm in this research, upon consideration of the objectives of this research and the characteristics of design science research.

2.2.1 Design Science

The design science approach revolves around the creation of artefactual solutions and artificial systems the purpose of which is to resolve the identified problem (Hevner et al., 2004, Venable et al., 2012) . Design science drives the focus of a study on how the artefactual solution intends to perform and how it can be modelled and evaluated through the creation of an artefact (Kuechler and Vaishnavi, 2008). March and Smith (1995) argue that design science basically consists of two activities : *build* and *evaluate*. Building is the process of developing an artefact to solve an identified process, whereas evaluating is the process of determining how well the artefact performs. Moreover design science also creates methodological tools used by natural scientists, as well as behavioural and design scientists (Venable and Baskerville, 2012).

2.2.2 Design Science Research Relevance to this Research

The purpose of design science research is to develop and evaluate the artefacts with the intent of bringing a solution to the identified problem. The approach of design science research to solving the problem entails an investigation of a wide range of knowledge or a literature review of the relevant existing theories, inquiry from domain experts (prospective users of the artefact) and a triangulation of the findings. In order to have an appropriate artefactual solution that aims at mitigating the problem identified, design science research also involves a rigorous validation of the initial conceptualization. The artefacts that are produced can be in the forms of constructs, models, methods or instantiations citepHevner2004design.

This study aims at providing a solution to the stated problem by developing an instantiation for monitoring for hydroponic agriculture. Although Hevner et al. (2004) define an instantiation as a possible artefact of design science research, instantiations on their own could barely be differentiated from normal development. Thus, on the road to solving the identified problem and improving the overall monitoring techniques used by hydroponic practitioners, this study will highlight the different obstacles faced by farmers and the different requirements leading to the development of the instantiation.

Instantiation:
An instantiation is one type of artefact that can be obtained from design science. An artefact is an entity or a bundle thereof, purposely designed to meet the specific needs of certain people

with certain purposes and goals in certain contexts. An artefact is developed, introduced, accepted, operated, modified, adjusted, and researched within contexts and with various perspectives (Zhang et al., 2011). Instantiations, being artefacts, are further defined by Hevner et al. (2004) as *implemented and prototype solutions.* Therefore, it can be said that an instantiation is an implemented or prototype solution that has a context, a purpose, and beneficiaries. Being in the realm of IT, an instantiation will be an implemented solution that has at its core five specific elements: hardware, operating and system software, application content, and auxiliary artefact (Zhang et al., 2011). Thus, the instantiation that would be the output of this study would have to reflect those traits to be considered an instantiation: have a context, a purpose, beneficiaries. It could be a prototype and have the core elements mentioned.

Hevner et al. (2004) describes seven guidelines of design science research. Adherence to those seven guidelines positions this study within design science and motivates the appropriateness of employing the design science paradigm.

Table 2.1 outlines how this research fits the design science research paradigm.

Guideline	**Description**	**Research relevance**
Design as an Artefact	Design-science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.	An instantiation is the artefact to be produced, the wireless ICT monitoring for hydroponic agriculture. Its viability lies in the claim that it can be applied to mitigate the problem of adequate monitoring of hydroponic farm
Problem Relevance	The objective of design science research is to develop technology-based solutions to important and relevant business problems.	The problem addressed in this study is: *"There is currently a lack of wireless ICT enabled applications capable of adequate monitoring and management of a hydroponic agricultural environment within the South African context."* Literature reviews and exploratory studies in the field of hydroponic agriculture in South Africa have confirmed the relevance of the stated problem (Chapter 1, 3 and 4). The proposed Wireless ICT Monitoring System for Hydroponic Agriculture aims at providing a means for hydroponic farmers to monitor hydroponic farms adequately, therefore improving their daily routine and the output of the farm.

Guideline	**Description**	**Research relevance**
Design Evaluation	The utility, quality, and efficacy of a design artefact must be demonstrated rigorously via well-executed evaluation methods.	The instantiation is tested for validity using expert review with domain experts (Described in Chapter 6).
Research Contribution	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.	The primary contribution of this research is the wireless ICT monitoring application for hydroponic agriculture (instantiation). The other contributions of the research are summarized in Chapter 8.
Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.	Research rigor has been obtained through a thorough research process, triangulation of findings from the literature review (Chapter 1, 3, 4) as well as an evaluation of the instantiation by domain experts. The rigorous methods used to develop and evaluate the application are presented in Chapter 5 and 6.
Design as a Search Process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.	This study adheres to a well-defined methodological design and triangulation of findings. The research design consists of defining the research paradigm, the research strategy, development method and the data collection methods (Described in Chapter 2).
Communication of Research	Design science research must be presented effectively both to technology-oriented as well as management-oriented audiences	The communication is done through this dissertation.

Table 2.1: Motivation for Design Science Research

Table 2.1 depicts that the nature of this research, the research objectives and the followed research process make design science an appropriate paradigm for this research. The following section discusses the research philosophy shaping the adoption of design science as the paradigm for this study.

2.3 Research Philosophy

A research paradigm whether it be for qualitative or quantitative research, is generally shaped by the philosophical assumptions of the researcher. The research philosophy is thus a lens through which the researcher can perceive and attempt to understand the phenomenon under study; it is therefore the basic guidelines on how knowledge may be acquired in research, thus guiding data collection and analysis (Hathaway, 1995, Oates, 2006). These assumptions, whether explicit or implicit , affect the process that the researcher employs to execute the research. Moreover, a paradigm can be characterized by four philosophical assumptions: the ontological assumptions that refer to the world view; the epistemological assumptions that relate to assumptions about knowledge and how it can be obtained and disseminated to the world; the methodological assumptions relating to the methods used in executing the research; and the axiological assumptions that refer to the values that a researcher brings to the study (Creswell, 2003, Vaishnavi and Kuechler, 2013). Mertens (2014) argues that there are four philosophies, namely positivism, interpretivism, realism and pragmatism. The four philosophies will be discussed in the following paragraphs.

2.3.1 Positivism

Positivism aims at the discovery of causal relationships between dependent and independent variables through hypothesis testing. It is drenched in the assumption that the world consists of a static external reality, and is governed by natural scientific laws (Wardlow, 1989). The objective of the research is to describe, predict, prove or disprove measurable variables and it begins with hypotheses and theories (Krauss, 2005).

2.3.2 Interpretivism

The main goal of interpretivism is to gather a deeper and richer understanding of the context of study, as opposed to making predictions. The researchers will not distance themselves from their participants and will acknowledge that their interactions could potentially affect the result of the study (Vaishnavi and Kuechler, 2013). Interpretivist research deals with qualitative data and makes uses of an inductive reasoning strategy in order to understand the reason behind the behaviour of the studied phenomenon (Glesne and Peshkin, 1992).

2.3.3 Realism

This philosophical position takes the stance that entities, despite the perception of the researcher, or no matter how the theories are formed about them, are in real existence. Realism assumes that knowledge about a phenomenon can be acquired scientifically(Bhaskar, 2011).

2.3.4 Pragmatism

This philosophical stance embraces common sense that deviates from the justification or the falsification of the objectives of positivistic research, but rather aims to facilitate the capacity to solve human problems (Powell, 2001). Pragmatism revolves around the idea that the function of thought is as an instrument or tool for prediction, action, and problem solving, and also asserts that most philosophical topics are best viewed in terms of their practical uses and successes rather than in terms of their representative accuracy.

2.3.5 Research Philosophy Adopted in this Study

Owing to the subjective nature of e-agriculture, there is no single way to approach a solution and it must be contextualized to the environment where the solution is to be deployed. This study requires a deep understanding of the landscape of the research. Moreover, the purpose of the study is to understand the landscape of hydroponic agriculture in South Africa, to gather requirements and to implement a solution that fits the context of developing countries. As such, the researcher recognises that he cannot distance himself from the study and that his interpretation of the data gathered deeply affects the design and development of the solution. Therefore, an interpretivist stance is found to be appropriate for this study. This is additionally motivated by ontological, epistemological and methodological as well as axiological assumptions that fit the characteristics of design science and the objectives described for this research.

Having defined the research paradigm and the research philosophy driving this study, the process followed in this research will be discussed next. That discussion will form the focus of the next section.

2.4 Research Process

Since the work of Archer (1984) that forms the basis of what design dcience should be about, IS researchers have developed an interest in design science over the last 23 years. Facilitating research to address the kind of problem faced by IS practitioners could be the contribution of design research, as argued by March and Smith (1995) . Although several publications can be found outlining recommendations on how to conduct design science research, no consensus has been reached. However, Peffers et al. (2006) define a process model that is the result of the synthesis of the work of Archer (1984),Takeda et al. (1990), Eekels and Roozenburg (1991), Nunamaker and Chen (1990), Walls et al. (1992), Rossi and Sein (2003) and finally, Hevner et al. (2004)

The design science research process model proposed by Peffers et al. (2006) can provide some guidance to the reviewer and the editors about what to expect from design science research outputs. Peffers et al. (2006) defines a process model for design science that consists of six activities. Those activities are as follows:

Problem identification and motivation: This step involves the definition of the specific research problem and sets the basis of the justification of the value of the solution. Since the artefactual solution will be developed while employing the problem definition, it will be useful to atomize the problem conceptually, so that the contrived solution is a true reflection of the problem complexity.

Objectives of the solution: From the problem description a set of objectives will be inferred that the solution must reach.. The objectives can assume two qualities: *quantitative*, i.e.. the desirable artefact would be better than the current ones; or *qualitative*, i.e. the envisioned artefact is expected to provide a solution to a problem not hitherto addressed.

Design and Development: During this activity the artefactual solution is created. Four types of artefact could be the result of this activity: constructs, models, methods and instantiations.

The March and Smith differentiation of constructs, models, methods and instantiations (1995) as artefact types is critically acclaimed and widely used in IS design science research (Winter, 2008). That differentiation of artefact is as follows:

- *Constructs*: They provide the terminology and symbols with which the problem and the solution are described.
- *Models*: Models make use of constructs to depict a real world situation.

- *Methods*: Methods define the process. Methods provide the guidance on how to solve problems; how to search the solution space.
- *Instantiations*: The feasibility of the design process and the designed product are demonstrated by instantiations .

Demonstration: Corroborate the efficacy of the artefact to solve the problem. This process could involve the use of the artefact in experimentation, simulation, a case study or any relevant activity.

Evaluation: In this activity, the researcher must observe and measure to what extent the artefact supports a solution to the problem. A comparison between the objectives of the solution and the observed results from the use of the artefact during the demonstration must be conducted.

Communication: the research must be communicated in a manner that will suit both technical audiences and non-technical audiences.

Figure 2.1 provides a graphical representation of the Design Science Research Process model as described by Peffers et al. (2006)

This study adhered to the Design Science Research Process model proposed by Peffers et al. (2006), showing that the artefactual solution, the product of this study, is the result of IS research and not just a development project. The DSRP was adhered to in the following manner:

Problem identification and motivation: This process has been outlined in Chapter 1. The problem statement has been clearly presented (see Section 1.2); not only has the motivation begun to be established, but wherever necessary, the reason why this study is conducted will be outlined throughout this dissertation.
Objectives of the solution: like the problem statement, the objectives were also described in Chapter 1 (see Section 1.4).
Design and Development: This study encompasses a clear design and development phase that is clearly and fully described in one of the subsequent chapter of this document.
Demonstration: Through the use of case studies and other relevant methods, the feasibility and efficacy of the solution has been demonstrated.
Evaluation: The demonstration will be evaluated and compared to the objectives set for the solution. This will be the topic of one of the subsequent chapters of this document.
Communication: the communication is made through this document.

Figure 2.2 outlines the DSRP as applied to this study.

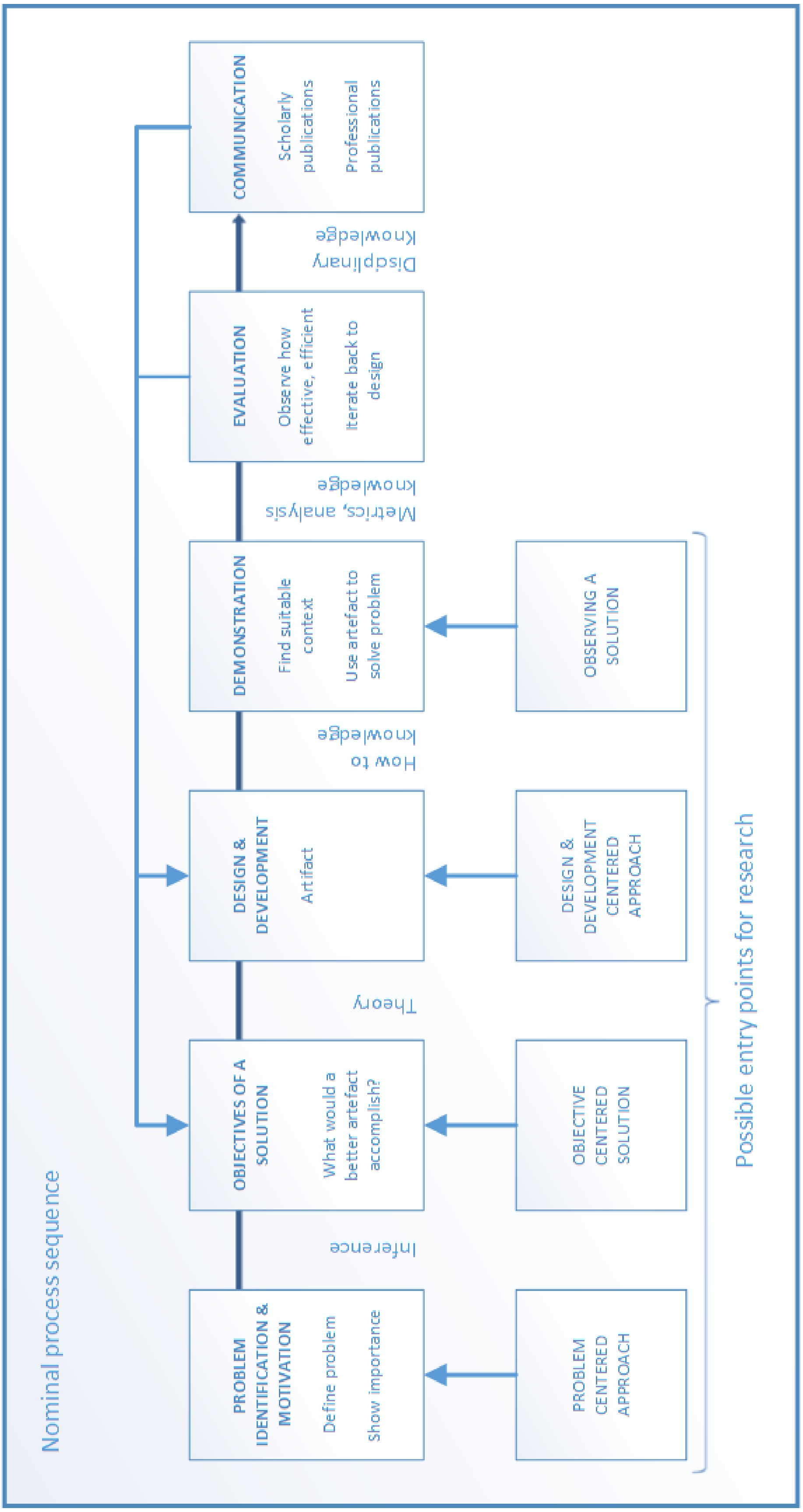


Figure 2.1: Design Science Research Process (DSRP) Model (Peffers et al., 2006)

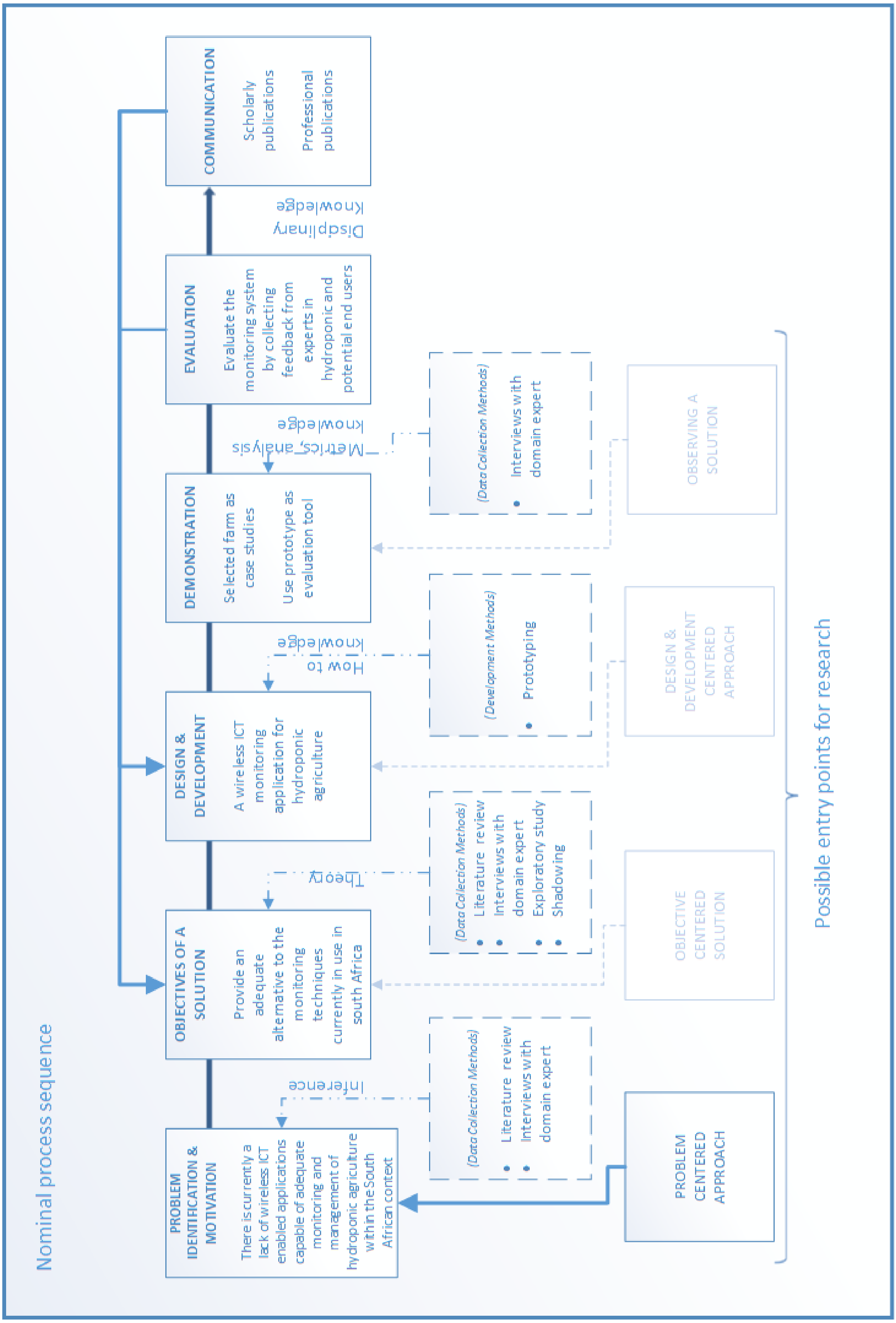


FIGURE 2.2: Design Science Research Process (DSRP) Model Applied to this Study, adapted from (Peffers et al., 2006)

This approach led to subdividing this research into phases derived from the design science research process model. The outcome of each phase addresses an aforementioned research question. Figure 2.3 illustrates a mapping between the phases and the research questions.

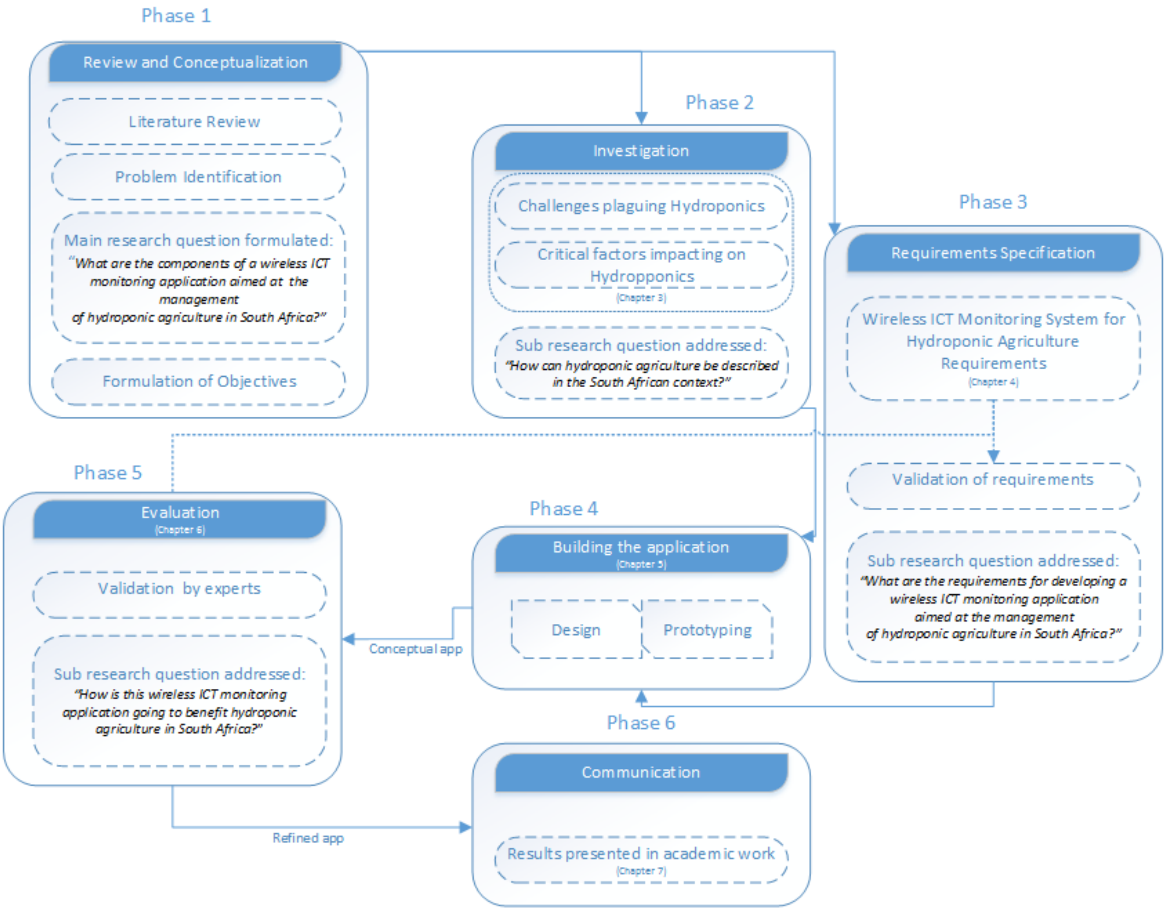


FIGURE 2.3: Research Phases of this Study

The correlation between the difference phases of this study and the steps of the DSRP model are as follow:

Phase 1 Review and conceptualisation: This phase is the starting point of the study. This phase entails undertaking the literature review, identifying the problem and the research questions. Objectives are formulated as well. The review and conceptualisation phase maps to the problem identification and motivation steps and the objectives of a solution step of the DSRP model.

Phase 2 Investigation: in this phase, the problem area is refined, interviews are conducted with domain experts and observations are made. This phase can be mapped to the problem identification and motivation and the objectives of a solution step of the DSRP model.

Phase 3 Requirement specifications: it aims at uncovering the requirements relevant to the development of the wireless system. This phase links to the design and development step of the DSRP model.

Phase 4 Building the system: in this phase the artefactual solution is designed and developed and prototypes are obtained. This phase relates to the design and development step of the DSRP model.

Phase 5 Evaluation: the evaluation phase entails demonstrating the usability and the overall user experience pertaining to the wireless monitoring system. This phase corresponds to the evaluation step of the DSRP model.

Phase 6 Communication: reporting of the result in a form of a scholarly publication. It maps to the communication step in the DSRP model.

2.5 Research Approach

The role of the research approach is to provide guidance with regard to the manner of inferences about findings and meanings, and is drawn from the results. The perspectives of the research investigations shape that guidance. The research approach employed in this study is grounded on two parameters. This study followed an inductive reasoning and it used a mixed methods research. These two parameters represent respectively the logic of reasoning and the perspective of the researcher on the nature of the research.

2.5.1 Inductive Reasoning

Inductive reasoning is deemed a bottom-up approach. It is also a reasoning in which the premises aim to supply strong evidences for the truth of the conclusion; which conclusion is considered probable, based on the evidence provided (Copi et al., 2006).
During inductive research, observations about the phenomenon are made, and patterns are outlined. Thereafter, some hypotheses are derived and finally, a theory is gained. An inductive reasoning follows a progression from specific observations to broader generalizations and theories. Inductive reasoning is not, however, just a simple progression from observations to broader generalisations, but rather the premises of an inductive argument indicates some degree of support of the conclusion. This research aims at developing an application that will monitor hydroponic agriculture (Holland et al., 1989) . This endeavour is achieved by observing the factors that affect hydroponic agriculture, analysing the pattern relating to the daily routine of hydroponic farmers and then developing the application for monitoring

hydroponic agriculture. The objectives and the subjective nature of the study supports the appropriateness of the inductive reasoning for this study.

2.5.2 Mixed Methods Research

Creswell (2003) defines a mixed methods approach as one in which the researcher will strive towards basing knowledge claims on pragmatic assumptions such as a problem-centred approach. To reach a better understanding of the research problem, strategies of inquiry that involve the collecting of data, either simultaneously or sequentially, are used in this approach. The data collection entails gathering both numeric information (e.g. frequency count) and text information, such as interview scripts data, so that the sum of all gathered data represents both quantitative and qualitative information. A Mixed method can be summarised as pragmatic knowledge claims where the collection of both qualitative and quantitative data is the key to understanding the problem. A study employing a mixed method approach will typically start a broad survey in order to generalize the results to a population. In a second phase, the researcher will then focus on detailed qualitative open-ended interviews to gain the perspective of the participants (Creswell, 2003).

This study is neither purely qualitative nor quantitative. For this reason a mixed approach was selected to overcome the limitations of just a single design. Additionally, owing to the limited literature on hydroponic farming in South Africa, a mixed method is employed to explore the context of hydroponics and furthermore to develop and test the HydroWatcher mobile application, which is a new instrument being introduced in this study. Moreover, the use of a mixed method can help to generalize the findings generated by the qualitative data (Creswell, 2003).

The next section describes the strategy used during the research.

2.6 Research Strategy: Design and Creation Research

The design and creation emphasis of research is on the development of new IT products or artefactual solutions (Oates, 2006). The design and creation research strategy is the strategy employed in this study. This research aims at producing an instantiation – which is one of the four types of artefacts prescribed by design science that can be the product of IS research (Construct, Model, Method, Instantiation) as aforementioned - as the main artefactual solution. The design and creation research strategy could be employed in research where the IT artefact is the main contributor to knowledge (Oates, 2006).
Normal design and creation is usually a feature of enterprise development. It, more often that

not, adds no new knowledge in the field : the less that is learnt the better. Normal design and creation often deliberately leaves out risky and uncertain parts of the project, owing to time constraints and the lack of technical skills in the subject area, in order to ensure success (Oates, 2006). The design and creation research strategy, through the adhesion to its process, distinguishes this study from normal design and creation. After the awareness and suggestion phase that could be translated into problem identification and objectives settings (just to map those with the adopted paradigm process) comes a development phase that will be conducted by using a development methodology indicated for IS research. The design and creation research strategy will set the premise for this study to focus on the unknown without neglecting the known and bringing forth a novel solution to solve the identified problem, thus adding new knowledge to the subject area.

Design and creation research strategy is a problem-solving approach and as such Oates (2006) describes an iterative process for IS research that aims at the development of the artefactual solution (Instantiation), which solves a research problem. The process is composed of five distinct steps

Awareness: Recognition that there is a problem after proper study of the literature, which led the author to identity areas for further research.
Suggestion: Devising a tentative idea of how the problem should be addressed.
Development: The tentative idea is implemented. The implementation process is thus linked to the type of artefact that is to be produced.
Evaluation: The developed artefact must be assessed to ascertain its worth and possible deviations from the expectations.
Conclusion: the results are consolidated.

Oates (2006) argues that these steps do not comprise a rigid prescription and should not necessarily be undertaken in the nominal step-wise manner. This study adopted the design and creation research strategy and adhered to the steps cited in the following manner:

Awareness: The study started by investigating the awareness of various problems and existing solutions.
Suggestion: The researcher envisions various potential ideas and some other ideas may be suggested to the researcher on how to approach these problems.
Development: A clear development phase would need to be a reality in this study.
Evaluation: A Clear evaluation phase would need to be a reality. This evaluation could trigger a number of smaller cycles of the design and creation strategy.
Conclusion: Results from the previous phases were consolidated and conclusions were drawn

concerning the study.

This study encompasses a clear design and development phase. As such, a design and development approach needs to be adopted in this study. The next section discusses the design and development approach embraced in this research.

2.7 The Design and Development Approach

Throughout the design and development phase, this study embraced a user centred design (UCD) approach. The potential users of the system were involved from the early stages of conception. Their input was invaluable during the requirement elicitations. Thus, a system that will suit their needs is ultimately the goal. However, the design and development process of this study only described the prototype mobile app that acts as the user interface for HydroWatcher (indicated in the scope and delineation of the study). This section will discuss the approach used during the design and development phase as well as the method used.

2.7.1 User-Centred Design (UCD)

User-centred design (UCD) is a design philosophy and process during which the needs, the wants and the limitations of the users are given extensive focus from the early stages of design and development of a product (Norman and Draper, 1986). In the past years UCD was widely employed during the development of ICT applications such as interface development in software systems, situation awareness, virtual environment and cross-language information (Jiang et al., 2011). UCD is recognized as a core approach in design issues and the methods employed during UCD are effective to obtain the design of pleasurable products (Jiang et al., 2011, Petrelli et al., 2004). UCD can be described as a multi -stage problem solving process during which the researcher must analyse and predict the manner in which a user is likely to in interact with the designed product. Additionally, the researcher must test the validity of the prediction made with regard to user behaviour in real world tests with potential users of the products (that will constitute the core of Chapter 6) (Gulliksen et al., 2003).
Furthermore, the collaboration between the designers and the users in the creation of ICT applications plays an important role in the early stage of the design process. Users are not just information providers, but also information collectors: as much as the researchers learn from the potential users what they might expect from the products, the users learn about the potential limit of the product or the technologies involved (Jiang et al., 2011, Kontogiannis and Embrey, 1997).

UCD methodologies find their basis on the international standard ISO 13407: Human-centred design process. The ISO 13407 standard prescribes a general process for including human centred activities through a development phase, but it is not rigid regarding methods that may be employed (ISO, 1999). That process is described in Figure 2.4.

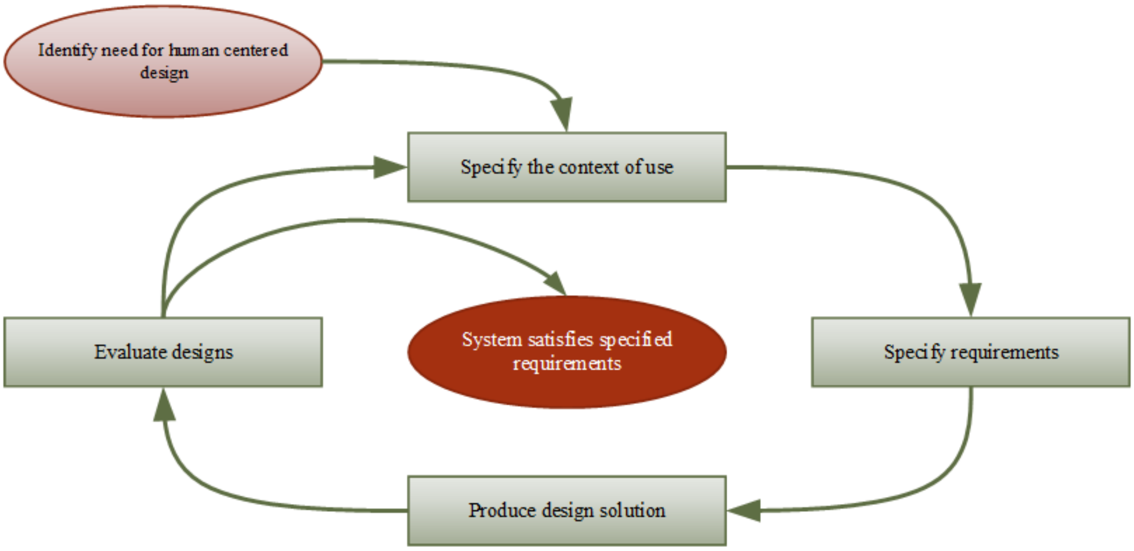


Figure 2.4: UCD process adapted from ISO 134707:Human-centred design process (ISO, 1999)

1. **Specify the context of use**: This entails identifying the people who will use the product, the purpose of use and the conditions under which it will be used.
2. **Specify the requirements**: In this stage the researcher will identify any requirements or user goals that must be met for the product to be successful. The requirements are described in Chapter 4
3. **Produce design solution**: This part could be done in phases, going from a rough concept to a complete design. This part is described in Chapter 5.
4. **Evaluate designs**: Arguably, this is the most important part of this process. The ideal situation is to request the help of potential users of the system. Experts on the field of hydroponics were employed during the evaluation phase that is described in Chapter 6 and the results of the evaluation discussed in Chapter 7.

2.7.2 Development Method: Prototyping

A prototyping approach was elected for this study in order to maintain the focus on what needs to be studied in this research (Olivier, 2009). In this case those aspects are the benefit of the artefactual solution, its efficacy at solving the problem and the applicability of the requirements on the artefact. It was argued previously that this study could be distinguished from normal development but the prototyping method used in the development is not different from the normal IS development methodologies in practice. The aspect in which prototyping is acclaimed in research, particularly in design science research, is the knowledge creation process: the prototype instantiation is not the only objectives of the development (Zheng, 2009). Figure 2.5 below illustrates the prototyping and knowledge creation in design science.

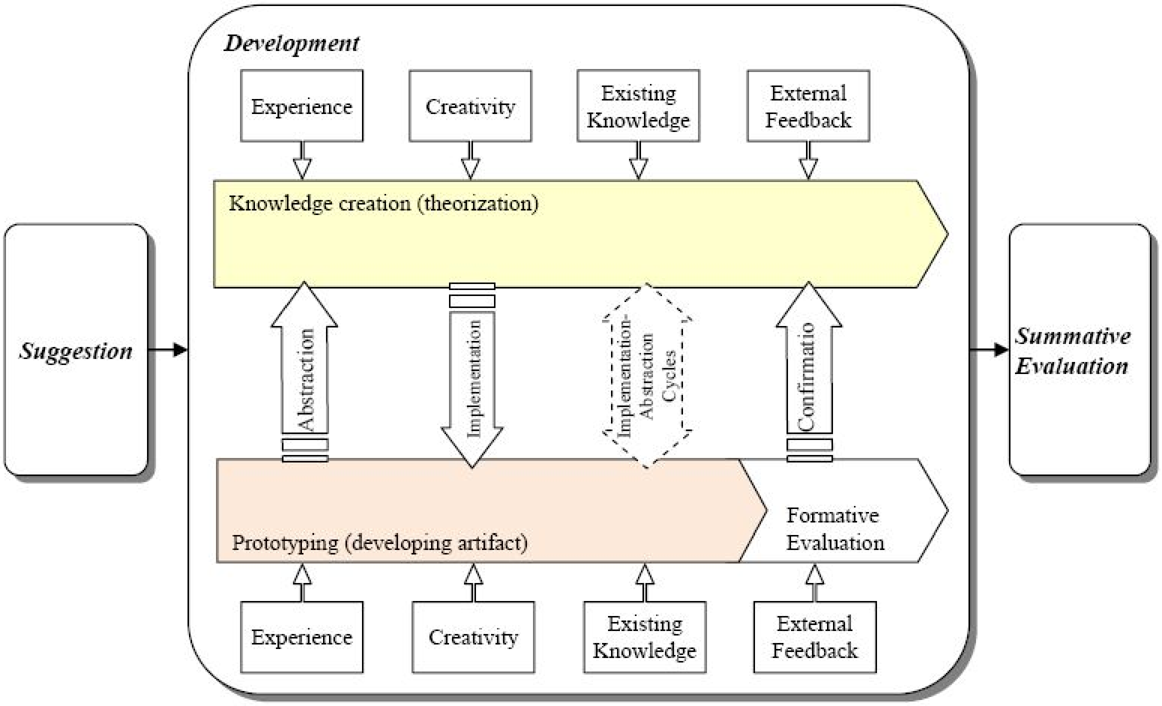


Figure 2.5: Prototyping and Knowledge Creation Process (Zheng, 2009)

In order to develop a solution suitable for the context and the beneficiaries of this study, relevant data had to be collected to achieve the objectives of this study successfully. The data collection methods that enabled the gathering of the data are discussed in the next section.

2.8 Data Collection Methods

Several data collection methods were employed during this study. For IS research, an extensive variety of methods and techniques are available for data collection. Those methods could be qualitative or quantitative. Examples of qualitative methods, on the one hand, include, but are not limited to literature review, interviews, observations. Quantitative methods, on the other hand, could include experiments or questionnaires (Olivier, 2009). This section briefly outlines the data collection methods used during this study.

Literature review: "A literature review is an objective, thorough summary and critical analysis of the relevant available research and non-research literature on the topic studied" (Cronin et al., 2008).

The goal of a literature review is to help the researcher establish the status quo on the subject area and to form the foundation for another goal such as the justification for future research. Additionally, It can be used to point out the weaknesses in previous research (Cronin et al., 2008, Oates, 2006).

An extensive review of the literature from published books, conference proceedings, industry journals, and publications on hydroponic advancement was conducted. The goal was to achieve a thorough understanding of hydroponic agriculture to determine its advantages and disadvantages. Furthermore, the literature review was conducted to gather a sense of what the challenges are that are faced by hydroponic farmers in their daily routine. Additionally, the literature led to a review of some of the attempted solutions at mitigating, in South Africa as well as abroad. Finally, the literature search was conducted to draw out some of the requirements for the development of the wireless monitoring system.

Interview with domain experts: A domain expert is someone, who is very skilful and very knowledgeable about a given discipline. Interviews with experts deliver means of added knowledge and understanding of the current state in a subject domain (Farrington-Darby and Wilson, 2006).

Interviews were held with experts in the field of hydroponic agriculture. The experts were hydroponic farmers and managers. The interviews provided valuable insights into the state of hydroponic agriculture in South Africa. The interviews gave the researcher a genuine sense of some the challenges that hydroponic farmers face and indicated the critical factors that dictate hydroponic agriculture. Moreover, the interviews allowed the researcher to gain an in- depth understanding of the processes required for the monitoring of hydroponic agriculture. Furthermore, the data derived from the interviews led to the establishment of the requirements for the development of the wireless monitoring system. The interviews were conducted during the awareness phase, the suggestion phase and the evaluation phase. The experts were part of the review process.

Exploratory study: As opposed to surveys that allow the researcher to gather a little information about a large population, case studies are designed to gather a lot of meaningful information about one or a few members; sometimes the population definition can be fuzzy, and only the "cases" matter (Olivier, 2009) . There are three basic types of case studies:

exploratory study is used to define the hypotheses and to fill the gap between an insufficient literature and the reality of the field. A descriptive study is conducted to have a rich and detailed analysis of a particular phenomenon and its context. An explanatory study goes beyond the scope of a descriptive study in its attempt to explain the phenomenon and its particular occurrence.

An exploratory study was conducted as a form of case study to provide valuable insight into the status quo of hydroponic farming in South Africa. The case provided valuable data for this study. Exploratory study was employed, in this study, to get in-depth data about the context where the solution will be implemented and to gather contextualised requirements for the development of the artefactual solution, the understanding of the challenges of hydroponic agriculture and the critical factors related to hydroponic agriculture.

Naturalistic Observation: Naturalistic observation involves following a subject closely over a period of time to investigate what activities the subject actually does in his daily routine instead of what his job description prescribes (Quinlan, 2008). Data gathered from shadowing have events that are witnessed by the researcher as their foundation instead of recollection from memory as occurring in focus groups or the interviewing collection technique. Naturalistic observation is well-known in vocational education. It is employed to expose students to potential career paths in some trades or professions by observing the daily activities of seasoned veterans (Levesque et al., 2000).

During the investigation phase of the study, several key personnel at different hydroponic farms from the selected cases were observed by shadowing them. The aim was to compare their actual challenges (as observed by the researcher) with the self-reported challenges during the discussions with the domain experts. Also, the observations enabled the researcher to understand the process of hydroponic farming. A technical point of view was essential to determine how best to attempt the design of the artefactual solution. Furthermore, additional requirements for the development of the wireless monitoring system, as well as challenges not gathered by methods like interviews with domain experts, were obtained. These shortages are the result of omissions by the interviewees or just of the fact that the interviewees considered certain aspects of their daily routine not as challenges, but just as facts of life.

Before, a mapping between the research questions and the research objectives was done in Table 1.1 on page 7, Table 2.2 illustrates a mapping between the research questions, the research objectives, and the methods used to achieve those objectives.

Research Question	Research Objective	Methods
RQ1 :How can hydroponic agriculture be described in the South African context?	ROB1 : To define hydroponic agriculture	Literature review
	ROB2: To determine the advantages and disadvantages of hydroponic agriculture	Literature review
	ROB3 : To determine the critical factors related to hydroponic agriculture	Literature review / Interviews with domain experts / Exploratory study / Naturalistic observation
	ROB4 : To determine the challenges faced in hydroponic agriculture	Literature review / Interviews with domain experts / Exploratory study / Naturalistic observation
RQ2 : What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?	ROB5 : To determine the requirements of a wireless ICT monitoring application for hydroponic agriculture	Literature review / Interviews with domain experts / Exploratory study / Naturalistic observation
RQ3 : How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa?	ROB6 : To design and develop the wireless ICT monitoring application for hydroponic agriculture	Prototyping
	ROB7 :To evaluate the applicability of the requirements as demonstrated in a wireless ICT monitoring application for hydroponic agriculture	Interviews with domain experts

Table 2.2: Mapping between the Research Questions, the Research Objectives and the Research Methods

2.9 Data Analysis and Triangulation

In this study an analysis of the overall results of the study was conducted and conclusions and recommendations were derived in order to address the main research question and to satisfy the stated objectives. The data analysis is performed by applying convergence triangulation, which involves the use of multiple sources for data collection and multiple measures for data collection (Miles and Huberman, 1994). Guion et al. (2011) define triangulation as the method used to corroborate and establish the validity of qualitative research by analysing the research question from multiple perspectives. Triangulation has the benefit of increasing confidence in research data, creating innovative ways of understanding a phenomenon, revealing unique findings, challenging or integrating theories and providing a clearer understanding of the problem (Thurmond, 2001). Patton (2002) argues that the goal of triangulation is not ultimately to arrive at consistency across data sources and approaches, but rather, that uncovered inconsistencies should not be interpreted as a flaw in the process, but as an opportunity to uncover deeper meaning in the data.

There are basically five types of triangulation (Guion et al., 2011):

Data Triangulation: Different sources of information are used in order to increase the validity of a study. Participants sharing the characteristics that the desired attributes of the research have are purposively selected to provide the required data;

Investigator Triangulation: Several researchers are involved in the study and the analysis process. The different researchers carry out the research using the same methodology;

Theory Triangulation: This involves the use of multiple perspectives to interpret a single set of data. This method typically involves professionals not assimilated to the field of study during the research;

Environmental Triangulation: The research is conducted in different locations, settings and other keys factors related to the environment sheltering the study. The key is identifying the environmental factors having a major influence on the problem being researched;
and

Methodological Triangulation: This type of triangulation entails the use of multiple qualitative and/or quantitative methods to study the phenomenon that is the object of the research.

In this research data triangulation is used to collate the findings that were acquired through the literature review and expert review interviews. Additionally, environmental triangulation will help to combine the results from the exploratory study and shadowing.

Data analysis is the process of reducing large amounts of data in order to produce an understanding, an interpretation; briefly, to make sense of them (Kawulich, 2004). The explanation of the phenomenon on the basis of the interpreted data is the strength of data analysis. The data collection methods used in this study are literature review, interviews with domain experts, exploratory study (a form of case study) and naturalistic observation (a form of observatory technique). The data gathered from those techniques are of a qualitative nature thus a qualitative data analysis technique was adopted as the main analysis technique.

A qualitative content analysis coding was used to analyse the gathered data. Additionally, interviews conducted revealed to contain quantitative data. The quantitative data were addressed in a form of frequency count.

2.9.1 Qualitative content analysis

Qualitative content analysis can be defined as a systematic, replicable technique for compressing the context of text into fewer content categories through a process of coding and identifying themes or patterns (Hsieh and Shannon, 2005).

Qualitative content analysis focuses on the characteristics of language while paying attention to the content or the contextual meaning of the text; text data can assume a verbal form, an electronic form or can be printed (Hsieh and Shannon, 2005). Saldaña (2012) describes code in qualitative research as a word or short phrase that assigns a summative, salient, essence-capturing and/or evocative attribute symbolically for a portion of language-based or visual data.

According to Hsieh and Shannon (2005), there are three types of qualitative content analysis.

Conventional content analysis: The conventional approach to content analysis is used with studies whose aim is to describe a phenomenon. This approach is also appropriate when the existing theory and research literature is limited regarding the phenomenon. It thus allows the researcher to avoid preconceived ideas, but instead allows the categories and names for the categories to flow from the data.

Directed content analysis: A directed content analysis is conducted if existing theory or prior research about a phenomenon exists. That pre-existing research will serve as guidance for the initial code. In this case, the prior research could be incomplete and could benefit from further description.

Summative Content analysis: The summative approach entails identifying and quantifying certain words or contexts in the text with the aim of understand the contextual use of the words or content. The quantification serves to explore usage of the word or content.

In this study, the content analysis adopted a **conventional approach**. An in vivo coding was therefore undertaken to identify and code the factors. In vivo coding entails assigning a label (code) to a section of data, like an interview transcript, while employing a word or short sentence extracted from that section of the data. The purpose of creating an in vivo code is to ensure that concepts stay as close as possible to the own words or terms of the research participants because they capture the essence of what is being described (King, 2008). Following the guidance of Hsieh and Shannon (2005), the steps of the analysis are as follow:

Step 1: Each transcript should be read from beginning to end, as one would read a novel.

Step 2: The transcripts should be read closely while carefully highlighting the text that appears to describe emotional reaction from the participant, and writing down a text or keyword that captures the essence of the emotional reaction using the words of the participants.

Step 3: The developing code was limited as much as possible.

Step 4: After a number of transcripts have been studied, preliminary code should be taken into consideration. Then the remaining transcripts will be coded using that preliminary code and new codes will be created when necessary.

Step 5: This step involved examining all the data within a particular code. The codes that belonged together should be combined while the other codes should be spilt into subcategories.

Step 6: The final codes should be organised and then rearranged into a hierarchical structure.

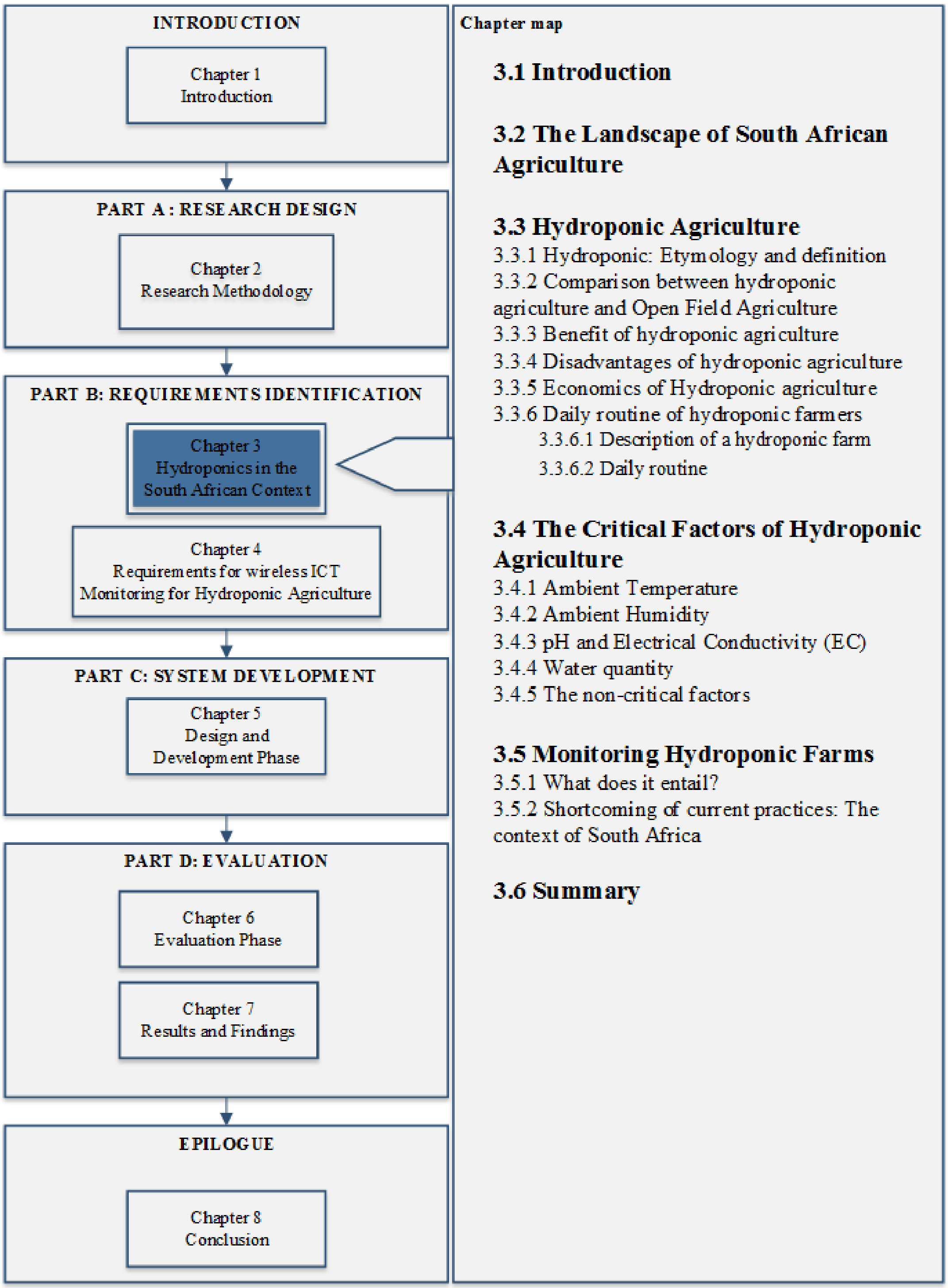
2.9.2 Frequency Count

Frequency count is considered to be the most straightforward approach to working with quantitative data. Frequency count entails the classification of items according to a particular category or context and an arithmetical count is made of the items, within the text, which belong to each classification (Nisbet, 1961). Frequency count was employed in this study to quantify identified metrics, thus enabling a deeper grasp of the benefit of the application.

2.10 Summary

This chapter describes the methodology and techniques used to conduct this study. Design science, the paradigm adopted in the research, was discussed followed by the research philosophical stance in this study. That discussion was followed by the description of the research process. The description of the research process was centred on the design science research process model proposed by Peffers et al. (2006). Subsequently, inductive reasoning and mixed methods research, the two parameters of the research approach, were described. That led to the discussion of the research strategy, design and creation research and the development approach, user-centred design. Finally, the chapter concludes with the description of the data collections methods, as well as the data analysis and triangulation techniques.

The next chapter leads to the discussion of the findings from the investigation phase. Chapter 3 provides a detailed analysis of hydroponic agriculture and the challenges faced by South African hydroponic farmers.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Chapter 3

Hydroponics in the South African Context

3.1 Introduction

Previously, the methodology that was applied to this study was described. Before starting with the core the study, which is the development of a wireless monitoring application for hydroponic agriculture, there is a need to take a step back and to put this study in the proper context. This chapter outlines hydroponic agriculture in the South African landscape, as well as the difficulties that hydroponic farmers face in their daily routine, thus conveying the need for the endeavour described in this dissertation. Therefore, this chapter addresses and provides an answer for the following research question raised in Chapter 1: **"How can hydroponic agriculture be described in the South African context?"**

At first the status quo of the agricultural landscape of South Africa will be portrayed. Following that premise, hydroponic agriculture will be described; a definition will be provided; the advantages and disadvantages, and the economics of hydroponic agriculture will be explored. Thereafter, an account of the daily routine of hydroponic farmers will be described. This chapter will then detail the critical factors linked to hydroponic agriculture and their impact on the crops, as well as some of the solutions already in use to face those factors, leading to the requirements to take into account for the proposed system, which entail the core of the topic of the next chapter.

3.2 The Landscape of South African Agriculture

It is now an irrefutable fact that agriculture is playing a pivotal role in the socio-economic development of South Africa. In the span of the last few years an increased inception and evolution of agriculture has led to its becoming an active engine contributing to the GDP of the country, alongside the industrial sector. In number, agriculture represents 2.5% of the South African GDP, but directly it is the main source of income for over 9 million people and it affects indirectly a major portion of the South African workforce (Government Communication and Information System, 2013). Agriculture is a powerful instrument in poverty alleviation due to its contribution to the economic growth via means of food production and job creation(Du Toit, 2011). However, many factors affect the development and sustainability of agriculture in South Africa. The agricultural environment in South Africa operates in an effervescent economy that is characterized by high interest rates, an absence of adequate infrastructure, a lack of financing and access to markets, unpredictable climatic conditions, land degradation and a lack of information and awareness regarding innovative farming solutions just to cite a few (Mashapa and van Greunen, 2010, Olawale and Garwe, 2010). Many techniques have been investigated in an attempt to restrain theses challenges. Examples of such interventions include organic agriculture, greenhouse agriculture and more lately, hydroponic agriculture. Among these methods of agriculture, hydroponic agriculture promises to deliver the sustainability of the urban market gardening agriculture (Ndame and van Greunen, 2014). The next section will go more in-depth into hydroponic agriculture.

3.3 Hydroponic Agriculture

Hydroponic agriculture is not a "new" technique of agriculture. Hydroponic agriculture can be traced back as far as 600 BCE in the hanging gardens of Babylon (Tzanakakis et al., 2014) . This section will explore hydroponic agriculture; will compare it to Open Field Agriculture, and will outline the advantages and disadvantages of hydroponic agriculture.

3.3.1 Hydroponic: Etymology and Definition

Hydroponic agriculture is an agricultural technique that allows the growing of plants without using soil as a medium (Munoz, 2010) . Dr. W. F. Gericke conceived the word hydroponic in 1936 from the Greek words "hydro" meaning water and "ponos" meaning labour (Pabiania et al., 2011). In other words, hydroponics involves providing to the plants all the nutrients they need via a nutrient-laden solution and a medium like perlite or saw dust that is used to provide mechanical support to the plant (Department of Agriculture, Forestry and Fisheries, 2011).

3.3.2 Comparison between Hydroponic Agriculture and Open Field Agriculture (OFA)

Open Field Agriculture (OFA) is a popular form of agriculture and can be found throughout the globe. To put hydroponic agriculture in context, this section will cover a comparative analysis between OFA and hydroponic agriculture as reflected in Table 3.1.

Hydroponic	Soil based production
No soil is required	Good top soil
Plants are irrigated automatically; No water stress (Constant water supply to the roots of the plants)	Plant need to be irrigated to minimize water stress
Nutrients are available at all times	Nutrients must be added to the soil
Only soluble fertilizers from balanced nutrient formulations are used	Unless laboratory analysis is done, too much or too little nutrients can be added
Soil borne diseases can be eliminated	Soil borne diseases can build up in the soil
Hydroponic production is not organic	

Table 3.1: General Difference between Hydroponic Agriculture and Soil Agriculture ((Department of Agriculture, Forestry and Fisheries, 2011))

3.3.3 Benefit of Hydroponic Agriculture

Hydroponic agriculture presents many advantages and the list below outlines some of those advantages according to (Munoz, 2010).

- Hydroponic farms can yield more crops in less time than required in traditional agriculture
- Crops can be grown more densely
- No soil depletion will occur from repeatedly cultivating the same crop variety
- More crops per surface unit could be obtained when compared to OFA
- Cleaner and fresher products can be reaped
- Plants have a balanced supply of air water and nutrients
- Harvests can be timed more effectively to satisfy market demand
- Soil borne pests (fungi) and diseases can be eliminated

- Crops are more resistant to diseases
- Healthier crops could be obtained
- Natural or biological control can be employed
- Troublesome weeds and stray seedlings, which result in the need for the use of herbicides and increased labour cost, can also be eliminated
- Reduction of health risks associated with pest management and soil care
- Reduced turnaround time between plant cycles as no soil preparation is required
- Stable and significantly increased yields and shorter crop maturation cycle
- Can be utilized by families with small or no yard space
- The water stays in the system and can be reused - thus, lowering water costs
- The possibility exists of controlling the nutrition levels in their entirety - thus, lowering nutrition costs
- Minimal nutrition pollution is released into the environment because of the controlled system

3.3.4 Disadvantages of Hydroponic Agriculture

Unfortunately, no technique is perfect and as such hydroponic agriculture also has some disadvantages. The next list outlines some of the disadvantages as mentioned by Munoz (2010).

- Hydroponic agriculture requires a minimum of technical knowledge as well as a good understanding of the principles of agriculture
- The initial investment of a hydroponic farm could be relatively high
- Great care and attention to detail is required, particularly in the preparation of nutrient formulas and plant health control
- A permanent supply of water is required
- Hydroponic agriculture is labour-extensive: Labour must be available 7 days a week

3.3.5 Economics of Hydroponic Agriculture

The high start up cost is one of the disadvantages of hydroponics when compared to OFA. However, balanced against the high capital and operational costs, hydroponic agriculture has significantly higher productivity when compared to OFA (Jensen, 1997, Munoz, 2010) . Yield data can be found in many publications. Table 3.2, for instance, describes the yields for crops grown hydroponically in the American south-west desert and compares them to the typical “good” yield of open field crops

Crop	**Hydroponic agriculture**			**OFA**
	Yield/Crop (MT/Ha)	No. Crops/yr	Total Yield MT/ha/yr	Total Yield MT/ha/yr
Cucumber	300	2	600	30
Eggplant	165	2	330	20
Green bell peppers	250	1	250	16
Coloured bell peppers	200	1	200	10
Lettuce	31	10	313	52
Tomato	550	1*	550	100

* Tomato crops grown in a greenhouse over 11 months period

Table 3.2: Yield comparison between Hydroponic Agriculture and OFA (adapted from (Jensen, 1997))

As Table 3.2 indicates, the yield per crop per area unit is greater in hydroponic agriculture than in OFA owing to the optimal growing conditions in a controlled environment. The controlled environment ensures a year -round production whereas OFA is seasonal. Given the yield, high gross returns from hydroponic agriculture could be achieved. Nevertheless, to achieve the high yield and thus the high gross return, there is little room for error and no shortcut is permitted pertaining to the environmental control (Jensen, 1997). Under these premises, the system proposed in this study want to help in the environmental control of the tunnel/greenhouse to ensure that a high yield is obtained year after year.

3.3.6 Daily Routine of Hydroponic Farmers

The researcher, in order to grasp first-hand the reality of a hydroponic farm, undertook to observe some of the actors responsible for the monitoring activities in the hydroponic farm, in their daily routine. The objective of the observation visits has been to determine and to contextualize the hydroponic agricultural environment setting within the South African context. The researcher elected to observe the fertigation operator at two distinct hydroponic farms in the region of Port Elizabeth, Eastern Cape, South Africa. The two farms are: Olive Tree farm, is a hydroponic farm that is situated in Port Elizabeth, at the intersection of Seaview Road and Heron Road in Lovemore Park in Port Elizabeth (see Figure 3.1).

FIGURE 3.1: Olive Farm

Oshry Farm is situated in Port Elizabeth in the vicinity of Kragga Kamma Park (see Figure 3.2).

FIGURE 3.2: Oshry Farm

3.3.6.1 Description of a Hydroponic Farm

A hydroponic farm is an atypical farm. The two hydroponic farms visited, typically have 3 major components: tunnels, water retention tanks, and a fertigation station.

Tunnels or greenhouses, fitted with a network of irrigation pipes, give shelter to the crops and provide an internal climate that mimics the ideal growing conditions for the crop species. There are two basic tunnel/greenhouse concepts. The first strives toward maximum climate control to maximize the productivity. This concept requires the use of sophisticated tunnels. Tunnels falling under this type will be referred to as **high-tech tunnels** in this study. The second concept pursues minimum climate control while still enabling the production under modified but non-optimal conditions. Tunnels corresponding to this concept will be referred to as **low-tech tunnels** in this dissertation. It is important to note that those two concepts represent two extremes of a spectrum. Depending on the type of crop to be cultivated, the geographic location, and the prevailing socio-economic conditions, a particular tunnel falling between the ends of the spectrum can be selected (Castilla, 2013).

Figure 3.3: Tunnel Concept

Fertigation station: fertigation is the practice of fertilizing through irrigation. The fertigation station is where all the nutrients necessary to grow the plants are mixed and then sent to the water retention tanks through a underlying network of pipes.

Water retention tanks retain the water that will be supplied to the tunnels for irrigation purposes. A water retention tank can supply one to several tunnels at the same time, but most farmers ensure that a water retention tank supplies identical tunnels. In other words, whatever η tunnels supplied by a particular water retention tank, shelter crops of the same species and of the same age. In some cases, the farm can be subdivided into logical areas referred to as zones. A zone will encompass many tunnels and one or more water retention tanks. A zone is created to ensure uniformity in the tunnels and to reduce the impact of customized irrigation patterns. Figure 3.4 presents a conceptual graphical illustration of a hydroponic farm.

Whether the farm has high-tech or low-tech tunnels, a minimum amount of human labour is necessary for the farm to be functional. They do not all perform the same activities. In this study, the focus is on the monitoring activity on a hydroponic farm. As such, the next section describes the typical daily routine of the personnel responsible for monitoring a hydroponic farm, as observed in South Africa.

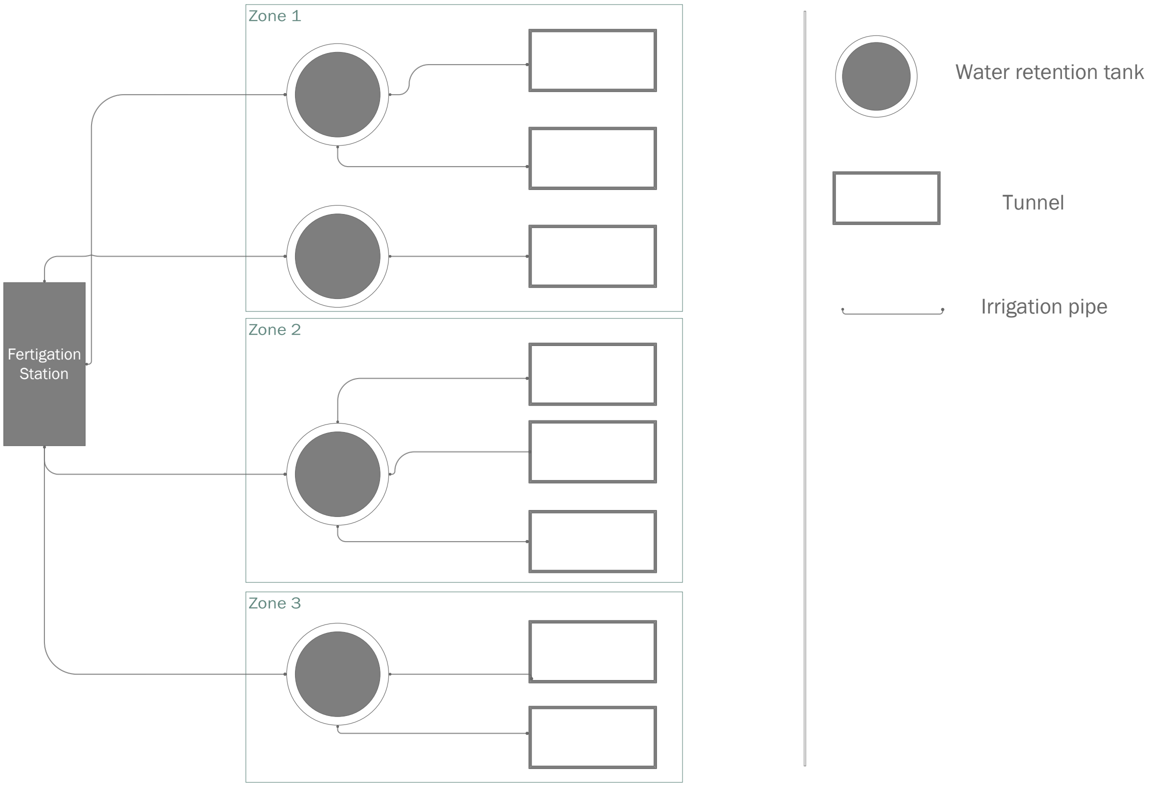


FIGURE 3.4: A Hydroponic Farm

3.3.6.2 Daily Routine

As is the case on any other farm, the labour at a hydroponic farm starts at the crack of dawn. The first order of business will be "to check the vitals" of the farm. The fertigation operator must verify the status of all the environmental factors on the farm: pH, electrical conductivity, ambient temperature and ambient humidity must be between the threshold values.

Before proceeding to the readings, the fertigation operator has to calibrate the equipment On some farms the operator uses a Hanna Instrument Combo pH & EC HI 98130 (see Figure 3.5) to read the pH and electrical conductivity in the water retention tank and the vegetative bags. Calibrating that tool for every round of checks consumes around 20 to 30 minutes. Once the calibration process is done, the next step will be to verify the pH and electrical conductivity in each water retention tank. Verifying the tank consumes up to an hour owing to the fact that the fertigation operator must walk from tank to tank across the farm. Thereafter, the fertigation operator will make the necessary adjustments. The operator will, however, not verify the adjustments made because of the time consumption involved. A few hours later, after one or two irrigation cycles, the operator will repeat the same process, but instead of verifying the water retention tank, the operator will now direct his/her attention to the tunnels. The fertigation operator will take advantage of the logical division of the farm and will elect a tunnel in each zone, where the readings will be gathered. The fertigation operator will take readings regarding the ambient temperature and the ambient humidity of the tunnel. Then he/she will inspect the volume of water delivered to the crops as well as the volume drained from hydroponic grow bags. Thereafter, inspection will concern the pH, the electrical conductivity of the water delivered to the crops and the water drained from the hydroponic grow bags. This process is very time-consuming as yet again the operator needs to walk from tunnel to tunnel across the farm. The fertigation operator will repeat this monitoring process 2 or 3 times per day.

FIGURE 3.5: Hanna-Instruments-HI98130 pH EC Reader

3.4 The Critical Factors of Hydroponic Agriculture

An initial investigation to uncover the major critical factors was undertaken. After the visits were conducted on the farms, a thorough understanding of the impact of the critical factors was obtained. The visits to the farms helped, not only to have a clear understanding of those critical factors, but also confirmed the findings of the literature review. More importantly, the visits provided a context for those factors.

The major critical factors impacting hydroponic agriculture in South Africa are the *ambient temperature* inside the tunnel, the *ambient humidity* inside the tunnel, the *electrical conductivity* and *pH* of the water in the retention tank and of the water out of the vegetative bag. Additionally, the water quantity received during an irrigation cycle that will be coined in this study as *Water in* and the water quantity drained out of the vegetative bag referred to in this study as *Water out*.

The vegetative bag refers to the bag, usually made out of plastic or nylon, that retains the gravel, saw dust or any other means of providing mechanical support to the root system of the plant. Additionally, some criteria are not as critical as the one previously listed, but contain geographical relevance.These are the *ambient temperature of the farm*, the *wind direction and speed* and the *weather forecast*.

These factors, whether by themselves or in combination, affect the outcome of the harvest. The following paragraphs provide more depth on the possible impact of the factors labelled..

3.4.1 Ambient Temperature

Each plant species has an acceptable temperature range that relates to its native environment. Although there are some varieties of crop species that can adapt to the environment over time, there are some that do not compromise. Therefore, controlling the temperature in the tunnel is imperative in order to ensure a successful harvest. Most plants native to temperate regions as well as subtropical foliage thrive in temperatures between 12 °C and 21 °C (55 °F - 70 °F) and can tolerate temperatures as low as 10 °C (50 °F) without noticeable effects. However plants will wither in daytime if the temperature rises above 26 °C (80 °F) (Castilla, 2013, Ortho Books and McKinley, 2001).

3.4.2 Ambient Humidity

Humidity also plays a vital role in hydroponic farming. Plants will wither under a tunnel where the ambient humidity has been kept below 50% for an extended period of time. Under those conditions leaves lose water faster than they can replace it. Additionally 80% of humidity for an extended period of time is a favourable environment for disease proliferation (Ortho Books and McKinley, 2001).

3.4.3 pH and Electrical Conductivity (EC)

The pH and EC measurement are arguably the two most important factors dictating the life of a hydroponic farm. Simply put, regular monitoring of the nutrient solution pH and EC will eradicate almost all problems associated with fertilizations

pH is a measure of the acidity or the alkalinity of a solution . pH is expressed on a logarithmic scale from 0 to 14, where 0-7 is the acidic range; 7-14 the alkaline range and 7 is considered to be neutral, e.g. water. The pH of the nutrient solution affects the availability of the micro-nutrients in the solution. At a high pH, some nutrients that are vital for good crop growth become unavailable and the plants will start developing deficiency symptoms. Almost all plants prefer a slightly acidic pH and thrive if the pH is between 5.4 and 6.0 (Pennisi and Thomas, 2009). The observations of Figure 3.6 give an idea of the micronutrients intake depending on the pH of the nutrient solution.

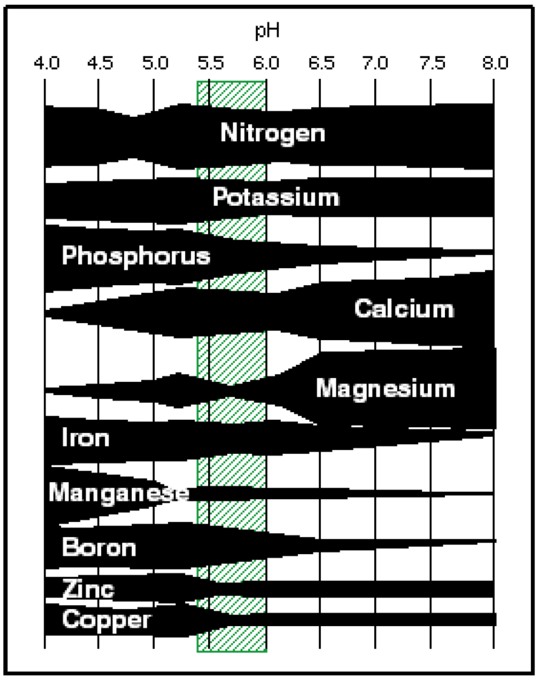


FIGURE 3.6: Influence of pH on the availability of essential nutrients in a soilless substrate containing sphagnum peat moss, composted pine bark, vermiculite, and sand. The pH range recommended for most greenhouse crops is indicated by slashed lines (Bailey and Bilderback, 1997)

Electrical conductivity (EC) is a complex parameter. EC is a measure of the total amount of salt, including fertilizer salt, in the growing medium because the majority of salts in fertilizers are macro-nutrients. Therefore in essence EC can be an indicator of the amount of nutrient still present in the growing solution. EC can also indicate the rate at which the nutrient will be absorbed by the plants. The total amount of ions of dissolved salts in the nutrient solution exerts a force called osmotic pressure, which is a property relating to the concentration of atoms, ions and molecules rather than to their nature and it is clearly dependent on the amount of dissolved salt (Trejo-Téllez and Gómez-Merino, 2012).

The ions associated with EC are Calcium (Ca^{2+}), Magnesium (Mg^{2+}),Potassium (K^{+}),Sodium (Na^{+}), Hydrogen (H^{+}), Nitrate (NO^{3-}), Sulphate (SO_4^{2-}), Chlorine (Cl^{-}), Bicarbonate (HCO^{3-}), Hydroxide (OH^{-}). The supply of micronutrients, namely Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn), Boron (B), Molybdenum (Mo) and Nickel (Ni), are very small in ratio to the others elements (macronutrients), so it has no significant effect on EC (Sonneveld and Voogt, 2009).

The ideal EC is specific for each crop and is influenced by environmental conditions. Nonetheless, the EC values suitable for hydroponic agriculture range from 1.5 to 2.5 ds m-1. Higher EC impedes nutrient uptake by increasing osmotic pressure. In contrast, a lower EC may severely affect plant health and yield (Samarakoon et al., 2006). Dalton et al. (1997) argue that the decrease in water uptake has a strong and linear correlation to EC.

3.4.4 Water quantity

Water in
The interviews with hydroponic farmers revealed that monitoring the volume of water received is critical to the well being of the plant. Plants at different stage of maturity require different volumes of water. In the visited farms, a zone (logical or physical subdivision of the farm) will only contain a single plant species of the same age in an effort to control the water delivered during irrigation cycles. However, a point of failure may still exist. Pumps can be clogged owing to algae growth inside the pump, or pipes can burst fully or partially.

Water out
While visiting hydroponic farms, it was noted that the medium of choice to provide mechanical support to the root system of the crop was either sawdust or coconut fibres. When an enquiry was made as to the reason for this, the simple answer was: "It is cheap and retains water longer". However, those two mediums present a disadvantage. After a prolonged period of use the mediums retain more and more water for extended periods of time owing to the fact that sawdust and coconut fibres are biodegradable and will eventually start to decompose. The extra water for prolonged periods of time in that decomposing medium will, in turn, lead to the roots of the crops rotting. That premise justifies the need to monitor the quantity of water drained out of the vegetative bag.

3.4.5 The Non-Critical Factors

Ambient Temperature of the Farm
Hydroponic farms, in general, have several tunnels. Monitoring all of them would be the ideal solution, but owing to the current price of the equipment required to monitor temperature and the time it will require for that practice to be done adequately, some farms do not measure the temperature of each and every tunnel. Instead, they rely on the local external temperature to derive an estimate of the temperature in the tunnel. The farmers will then make the necessary adjustment to avoid the impact that the ambient temperature of the tunnel would have on the plants.

Wind Speed and Direction
The wind direction factor can be seen as a factor that is relevant depending on the geographical location of the hydroponic farm. In a region like Port Elizabeth or Cape Town wind gusts of 26 m/s (94 km/h) have been registered and are a frequent occurrence (Kruger et al., 2010). The strength of the wind has a negative impact on the structural rigidity of the tunnel.

Weather Forecast

This factor serves the role of a planning tool. Farmers reported that knowing the weather helps then to adjust the irrigation cycle of the crops when anticipating a sunny day, for example.

All those factors that are important to the development of crops need to be monitored. The crucial aspects of the monitoring activity will be underlined in the next section.

3.5 Monitoring Hydroponic Farms

3.5.1 What Does it Entail?

In the previous sections, the delicate aspect of hydroponic agriculture and the critical factors that give this intrinsic characteristic to hydroponic agriculture were labelled. Also, the advantages of undertaking hydroponic activities were outlined and during that discussion some emphasis was accorded to the enormous yield obtained from hydroponic agriculture when compared to soil based agriculture. However, to obtain the documented yield farmers must constantly pay attention to the status of the critical factors outlined in the previous section. Depending on the type of crops, the ambient temperature and humidity, the pH, and EC for instance, must always be kept at an optimum range favourable to obtaining the best genetically possible outcome from the plant (e.g. tomatoes the size of a human fist). The timely monitoring of crops can not only increase productivity, but can also aid in the development of new breeds by observing climate adjustment interaction (Kumar et al., 2009). Moreover, environmental monitoring and control of the greenhouse or tunnel is crucial in order to increase productivity and prevent diseases (Nikhade and Nalbalwar, 2013).

Although continuous monitoring is necessary, monitoring of any particular environment can be challenging, as it is a cumbersome and time-consuming activity (Mendez et al., 2012). Nonetheless, employing technology to support the monitoring activity can result in a significant shift in hydroponic agriculture. The utilization of technology, notably recent advances in ICT, can allow for the remote monitoring of environmental factors like temperature, humidity or pH, thus leading to proactive or quicker reactive responses to adverse situations on the farm (Ndame and van Greunen, 2014). The application of ICT in the field of agriculture has been coined e-agriculture and precision agriculture.

E-Agriculture and Precision Agriculture

E-agriculture entails the use of ICTs to promote the development of agriculture with a focus on the rural region. The FAO defines e-agriculture as follows: "E-agriculture is an emerging field in the intersection of agricultural informatics, agricultural development and entrepreneurship, referring to agricultural services, technology dissemination, and information delivered or enhanced through the Internet and related technologies. More specifically, it involves the conceptualization, design, development, evaluation and application of new (innovative) ways to use existing or emerging information and communication technologies (ICTs)" (Chandra and Malaya, 2011).The role of e-agriculture is to ensure the systematic diffusion of information while employing ICT on agriculture, animal husbandry, fisheries, forestry and food, to provide access to comprehensive, up to date and detailed information, particularly in rural areas. Additionally, e-agriculture should empower public and private partners to seek to maximise the use of ICT as a tool to increase and improve production (Davis et al., 1998).

Precision agriculture is a management philosophy or approach to the farm rather than a prescriptive system. Precision agriculture prescribes identifying the critical factors where the yield is limited by controllable factors and determines intrinsic geographic variability (Lei and Lejiang, 2010). Precision agriculture is therefore just a more precise form of farm management through the use of advancement in technology.
The underlying principle of precision agriculture and e-agriculture is gathering a considerable amount of data that will be analysed and a conclusion that will be drawn in order to manage the farm. However, concerns have arisen that big data collection has been targeted at well-educated farmers and that smallholder farmers find themselves overwhelmed by the amount of data (Palmer, 2011). The system resulting from this study aims at aligning itself with e-agriculture and precision agriculture by providing a system that will produce information for the management of the farm. The system will focus on small to medium farms and will disseminate easily usable, relevant results to farmers in a timely manner.

3.5.2 Shortcomings of Current Practices: The Context of South Africa

In South Africa, hydroponic farmers in an effort to stay competitive and to ensure a considerable yield from harvests, have already embraced e-agriculture and precision agriculture. From the field observations, it was gathered that the following are some of the tools that are used in hydroponic farms:

The GVI System Micro 400 Fertigation is used to mix the fertilizers and the water and to bring the nutrient solutions to desired parameters before sending it to the retention water tanks (Danvan A/S, 2015);

The Rainbird Irrigation Controller, as the name indicate, help the farmers programme the irrigation cycles and to set the volume of water to be delivered during the irrigation cycles (Rain Bird Corporation, 2015);

The Hanna instrument pH and EC reader is a handled device that allows the farmer to collect readings on pH and EC of a solution (Hanna Instruments, 2014).

Additionally, some farms have more complex systems like the HortiMaX Clima 300 system, which is a comprehensive system that monitors several parameters specific to the tunnel it is installed in. The system is fitted with actuators that enable the system to make the necessary adjustments in a tunnel to maintain the monitored parameters within ideal ranges. For instance, the system Hortimax Clima can open the vents on the tunnel if the temperature inside the tunnel is above the set range. Through their use, those systems have proven to have a significant effect in hydroponic farming (Hortimax, 2015).

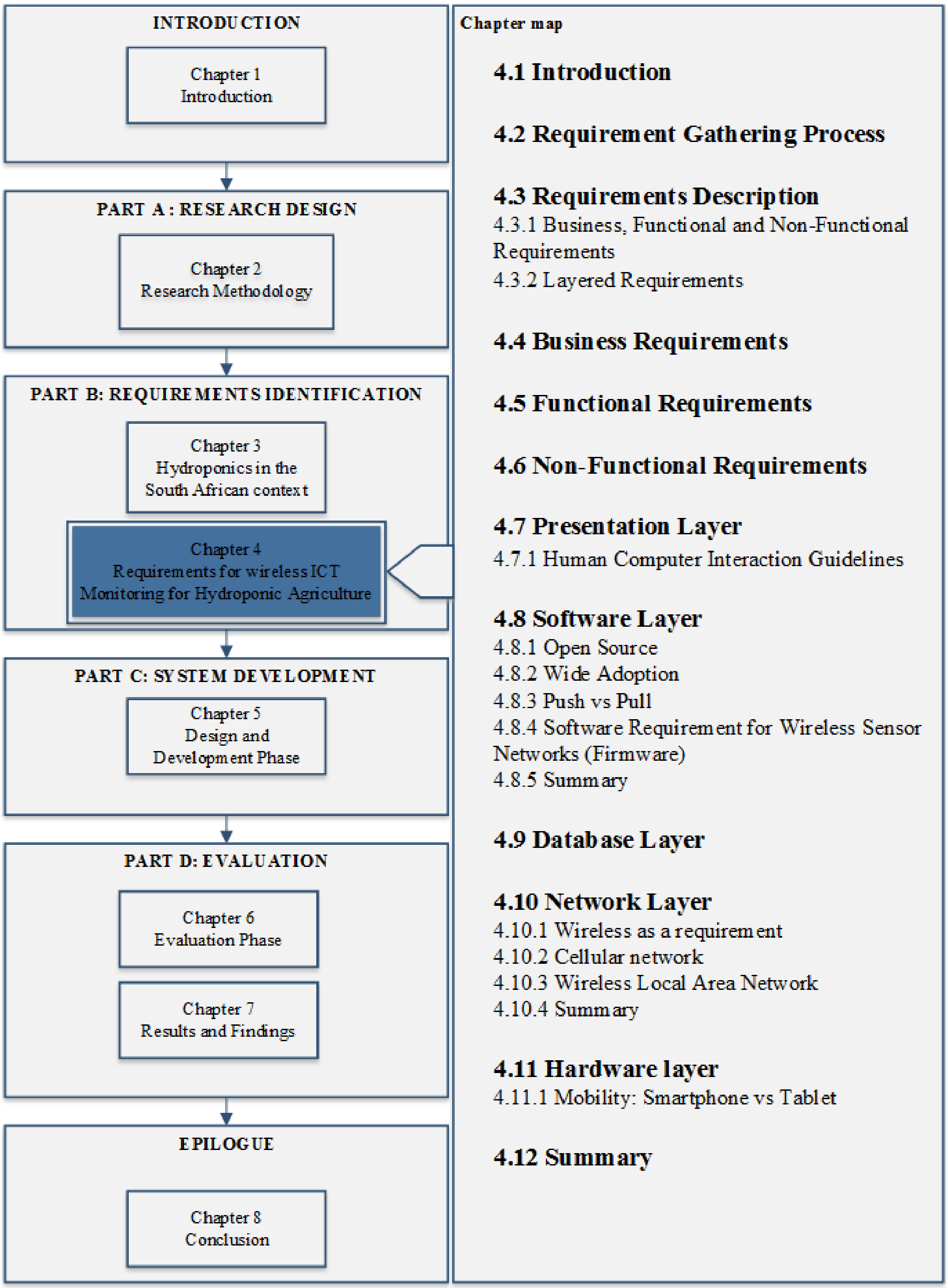
However, the methods and tools used have several shortfalls. From the field observations it was gathered that the systems used lacked mobile aspects. The monitoring systems are grounded at a specific place: they have no *mobile interface* . Although the monitoring is performed by the system, the onus still resides on the farmer to walk to the system interface and to assess the reading in a timely manner (*pull approach*). The systems used present complex user interfaces and functionalities (see Figure 3.7). Moreover, a single farm may

FIGURE 3.7: Hortimax Reading and Programming Interface (Hortimax, 2015)

use several systems to accomplish overlapping tasks. Those systems are not integrated. The use of several systems requires the farmer to learn to use each system efficiently. That also means *high acquisition costs and high maintenance costs.* At Olive Farm (one of the visited farms) for instance, the systems used are the GVI System Micro 400 Fertigation unit, the Rainbird Irrigation controller, the Hanna instrument pH and EC reader and the HortiMaX Clima 300 system. Additionally, the solutions are *not easily scalable* and usually developed for high-tech tunnels and/or integrated in high-tech tunnels. Low-tech tunnels will usually be monitored manually. Real time monitoring is not possible with the current equipment.

3.6 Summary

This chapter aims at providing a context for hydroponic agriculture in South Africa. The work described in this chapter is the result of the investigation phase. The status quo of agriculture in South Africa was described. It was argued that despite the urge impact of agriculture in over one fifth of the South African population, the methods used give little promise in terms of sustainability. Hydroponic agriculture appears thus as one innovative method that can lead to significant changes. To corroborate that point, a comparative analysis between OFA and hydroponic agriculture was conducted and the advantages and disadvantages of hydroponic agriculture were thus exposed. Following that premise, the critical factors driving hydroponic farming were outlined: temperature, humidity, pH, electrical conductivity and water quantity in and out of vegetative bags. The potential impacts that those critical factors could have on the crops were debated. Finally, the last section of the chapter outlined the importance of monitoring those factors and described some of the methods used to that effect in South Africa, as well as outlining their shortcomings and thus providing relevance to this study. The data gathered throughout this chapter are the basis of the requirements that will serve as guidelines for a system that could monitor hydroponic agriculture adequately in the realm of South Africa. The next chapter describes a comprehensive list of requirements needed for the development of a system that can mitigate the challenges exposed in this chapter.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Chapter 4

Requirements for Wireless ICT Monitoring for Hydroponic Agriculture

4.1 Introduction

The previous chapter outlined the landscape in which hydroponic agriculture operates in South Africa. Chapter 3, as part of the investigation phase, provides the input for the requirement elicitations. The data gathered in Chapter 3 are the foundation for the requirements described in this chapter. This chapter describes the requirements for the wireless ICT monitoring system for hydroponic agriculture. The purpose of this chapter is to answer the research question which states: **"What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?"**

The requirements described in this chapter encompass the business, functional, and non-functional, as well a set of characterized requirements that do not fall into the previous categories. That set of requirements is subdivided into different layers that will be discussed in depth throughout this chapter. One of the objectives of this study is to develop a wireless ICT monitoring application that aims at monitoring accurately the essential environmental variables that are critical for the optimal growth of crops. That application is part of a whole complex system. In order to build an application that will be integrated seamlessly into all the moving parts of a complete system, it will be misguided only to focus on the requirements of the application. This chapter therefore describes the requirements for the whole system, thus including the requirements for the application. The introduction is immediately followed by the discussion of the requirement gathering process used to acquire the different requirements discussed in this study. Subsequently, the system value, the business requirements, the functional as well as the non-functional requirements are discussed in the requirement specification section. Following that, a classification of requirements into layers similar to TCP/IP or OSI model will be made and each layer will be discussed.

4.2 Requirement Gathering Process

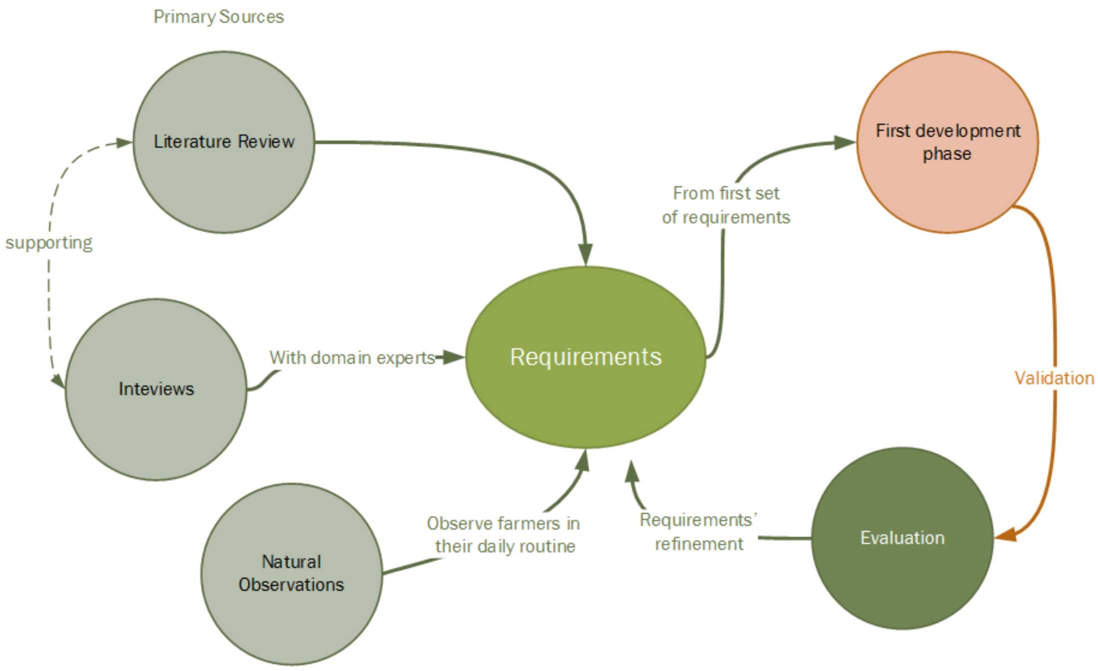


FIGURE 4.1: Requirements Gathering Process in this Study

Before starting with the design of the application, it was imperative to gather the requirements necessary to produce a system that will meet the expectations of the user and will fit the context of use. To obtain the various requirements listed in this chapter a rigorous procedure was followed, as illustrated in Figure 4.1 . At first, a thorough literature review of journals, articles and books on hydroponic agriculture was conducted with an emphasis on the South African context. The literature review was followed by interviews with hydroponic farmers, farm managers, and farm workers on hydroponic farms. The interviews with the hydroponic farmers were performed with the aim to bridge any gap in the literature and to refine the contextual environment. Interviews allowed the researcher to perceive the challenges of hydroponic agriculture through the eyes of those that face that reality on a daily basis.

During the interviews, the farmers were asked to comment on the daily activities on a hydroponic farm, the challenges that they are facing on a hydroponic farm, and on the way the farm operates. Furthermore, the hydroponic personnel were asked to comment on what composed the critical factors, parameters or activities on a hydroponic farm. The results provided by the hydroponic farmers were supported by the findings of the literature reviews. The combined results and findings of the literature and the interviews were outlined in Chapter 3.

Interviews tend to be riddled with omissions of facts that could be important for the designer and developer because they seemed minor to the interviewee. Therefore, to further contextualize the environment, naturalistic observations of the farm personnel were made at the farms during normal day to day operations to ascertain the difference between what was prescribed by the job of farmers on a hydroponic farm and how they actually performed their task. That step was performed to gather requirements for a system that will suit their needs and mitigate their actual challenges.

Following those first steps, the researcher devised a first set of requirements and a first interactive prototype. The prototype was based on the interpretation of the first set of requirements gathered from literature reviews and the interviews with hydroponic farmers, the farm managers. The first interactive prototype is discussed in detail in Section 5.3.2.

The prototype was evaluated by the hydroponic experts during a series of interviews. The results of the interviews not only led to the refinement of the requirements during the requirements validation, but also any assumption derived from the interpretive nature of the data gathered was either confirmed or discarded. The evaluation of the prototype is discussed in detail in Chapter 6 and 7.

The next sections describe the requirements needed for the development of the wireless monitoring system. At first, the abstract requirements will be described and then a layered classification of the requirements will be discussed.

4.3 Requirements Description

The envisaged system in this study will have the capability of providing real time monitoring aimed at maximising crop yield while using minimum resources. This approach enables the farmers to have periodic updates regarding the conditions of the hydroponic farm without physically visiting the farm, thus saving time and reducing labour intensiveness, as well as limiting human errors while collecting accurate data.

The value of such a system lies in that it will provide graphical visualisation of data, historical data and real time monitoring, via a mobile device, of the subsystems of the hydroponic farm including:

- Real time and historical data visualisation of gathered data on environmental factors such as ambient temperature, ambient humidity, the water level of hydroponic bags, pH and electrical conductivity;
- Real time monitoring : That includes alerts for abnormal conditions and tips/advice on what to do to solve those alerts. For instance, a situation may arise during which time a farmer needs to add more water, more nutrients, to raise temperature, etc...;
- Provide intelligent recommendations on how to optimise yield production with minimum utilisation of resources.

This study analyses the requirements of hydroponic agriculture in the South African context in order to define a product that will increase the level of management, control and operation by means of the provision of a wireless solution for the farmers and operators. While considering that this solution is intended for use in developing countries, the proposed system aims to be a low-cost mechanism for the purpose of monitoring the hydroponic agricultural environment and will provide benefit through having:

- Limited dependency on 3rd parties (except evaluation of the system);
- No significant large investment is required (the system will be deployed in existing hydroponic farms).

4.3.1 Business, Functional and Non-Functional Requirements

The following sets of requirements have been gathered in this study:

Business requirements (Br): This set of requirements specifies the value that is to be derived from the use of the system. A system that fulfils the set business requirements helps the organisations to attain its broad objectives.

Functional requirements / System requirements (Fr): The functional requirements indicate the function that the system must perform in order to fulfil the business requirements. Therefore, there is a connection between the functional requirements and the tasks to be performed using the system.

Non Functional requirement/ User requirements / Usability/ UX Requirements (NFR): These represent the requirements on quality attributes that define the characteristics of the features needed in order for the system to be effective and efficient and appealing to the users.

Each of the requirements have been prioritised based on the following criteria:

Priority 1: The requirement is mandatory. The system may not be deployed if it is not satisfied.

Priority 2: The requirement is nice to have. Its inclusion in the system improves ease of use, aesthetics, cosmetics and overall user experience of the system.

Priority 3: The requirement is viewed as an added feature to enhance the capabilities of the system. The system may be deployed without it and the requirement may be considered for release in a subsequent version of the system.

4.3.2 Layered Requirements

The requirements listed in the previous section can be complemented by the following set of requirements. The requirements presented in this section are classified in layers similar to the OSI or TCP/IP layers. The OSI and TCP/IP models are conceptual models that describe the internal functions of a communication system. In this case, the system at hand could be easily described by breaking it down into several layers, which like the OSI and TCP/IP layers interact with each other and also present the functions of the whole system (Alani, 2014, Zimmermann, 1980).
The requirements will span the following layers: The Presentation layer, Software layer, Network layer and Hardware layer. Table 4.1 outlines the different layers, their description and from where the requirements on that layers were derived.

Layer	Description	Source
The Presentation Layer	The presentation layer encompasses the requirements that will enhance the experience of end users (User requirement).	Interview, Observation, Literature review
The Software Layer	The requirements related to the platform, utilities or tools that will support the system;	Interview , Literature review
The Database Layer	This layer is composed of the requirements relating to storage and data availability	Literature review
The Network Layer	Those are the requirements necessary to achieve connectivity between the different components in the most efficient and cost effective mean possible	Literature review, Naturalistic Observation
The Hardware Layer	It consists of the physical requirements necessary for the system to strive and be durable	Interview, Naturalistic Observation

Table 4.1: Requirement Layer

The diagram at Figure 4.2 illustrates at which level every layer intervenes in the realisation of the envisioned system.

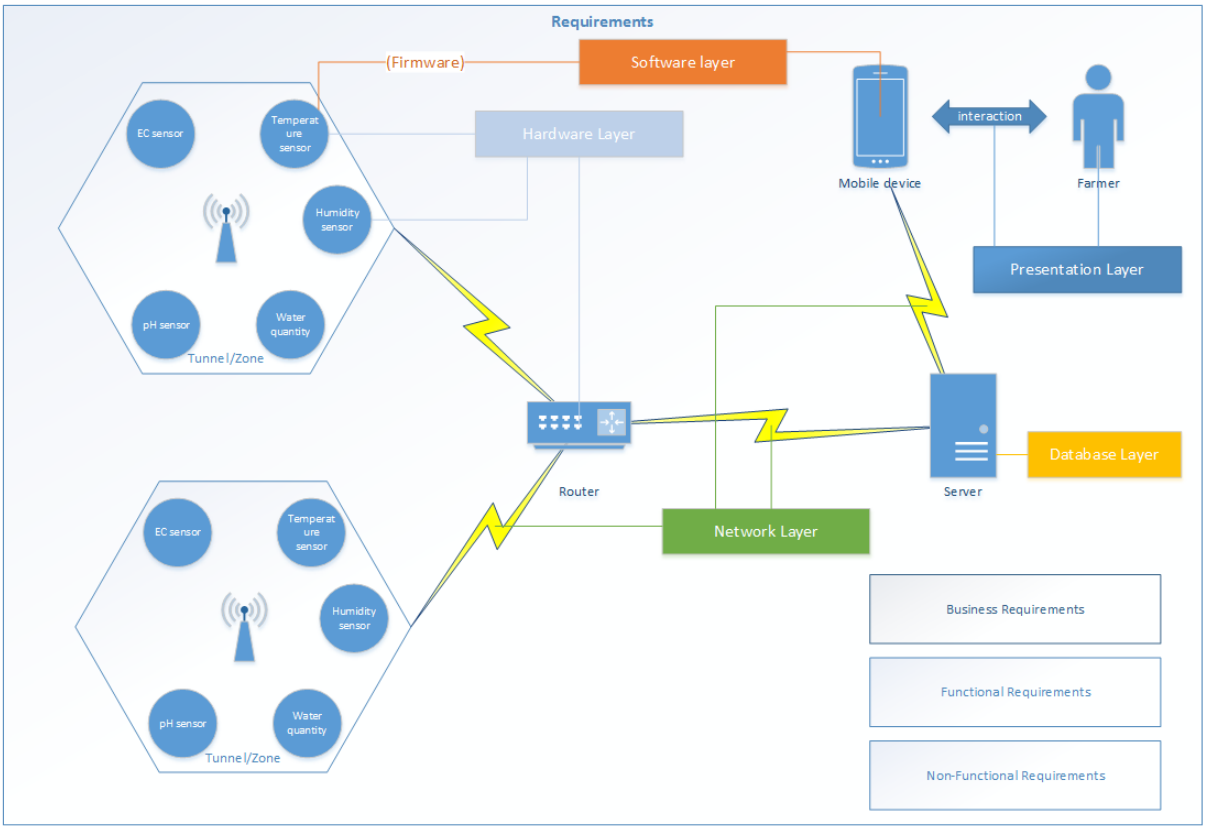


FIGURE 4.2: Holistic Conceptualisation of the Requirements

This study focuses on the development of the mobile application which is the interface of the system (see the scope of the project in Section 1.5). The interface of the system falls under the presentation layer of the requirements. In the following sections each set of requirements will be outlined, starting with the business requirements.

4.4 Business Requirements

Table 4.2 outlines the business requirements pertaining to the development of the system.

ReqID	Requirement	Comment	Priority
Br_01	The system be must cost-effective and time-efficient.	Less time will be needed for the monitoring activity on the farm.	1
Br_02	The system must reduce the cost and labour intensiveness	The farm environment will be monitored while requiring less manpower.	2
Br_03	The system will optimise crop yield using available data and resources	By giving recommendations on how to use available resources adequately, crop yield optimisation can be achieved.	3
Br_04	The system should capture accurate data	The accuracy of the data is crucial to enable the farmers to make adjustments to the farm.	1

Table 4.2: Business Requirements

4.5 Functional Requirements

Table 4.3 outlines the functional requirements that dictate the design of the system.

ReqID	Requirement	Priority
BR_04:FR_01	The system should capture real time environmental parameters. The environmental parameters that will be considered in this study are the ambient temperature , the humidity, the electrical conductivity , the pH of the solution and the quantities in and out of the grow bag.	1
BR_04:FR_02	The system should provide real time data visualisation in graphical and tabular views. Real time visualisation should be provided for the ambient temperature, the humidity, the electrical conductivity, the pH of the solution and the water quantities in and out of the grow bag.	1
BR_03:FR_03	The system should keep a log record of historical data on the parameters.	1

ReqID	Requirement	Priority
BR_03:FR_04	The system should have the capability to aggregate customised dynamic reports on the parameters. Reports can be based on time period, greenhouse, parameters, etc...	1
FR_05	The system should have data translation capabilities, and should be able to export data to other formats.	1
FR_06	The system should notify the user on any faults and discrepancies in the hydroponic farm.	1
FR_07	The system should allow the farmers to configure acceptable greenhouse environmental parameters.	1
FR_08	The system should allow the users to personalise the application.	3
FR_09	The system should have a Help functionality.	1
BR_03:FR_10	The system should provide recommendations by comparing crop generations.	3
BR_03:FR_11	The system should allow farmers to share information with other farmers.	3
BR_03:FR_12	The system should be able to provide alerts regarding expected catastrophic weather conditions. The system should be able to connect to weather forecast systems.	3
FR_13	The system should provide secure access privileges based on user roles: Only administrators should be able to configure greenhouse parameters, clear notifications and alerts.	3
FR_14	The system should provide a calendar of major farming activities.	3

Table 4.3: Functional Requirements

4.6 Non-Functional Requirements

Depicted in Table 4.4, the non-functional requirements of the system

ReqID	Requirement	Priority
BR_04: FR_01: NFR_01	The system must allow the users to visualise real time data in graphical and tabular views.	1
NRF_02	The system must use user interface elements that are familiar to the users.	1
NFR_03	The system must use terminology that is appropriate for the target users.	1
NFR_04	The system must be consistent with conventional standards: in this case the application should conform to adopted development platform design guidelines.	1
NFR_05	The system should have the same and consistent look and feel throughout.	1
NFR_06	Every user action should be accompanied by relevant feedback.	1
NFR_07	All icons must be accompanied by text.	1
NFR_08	High contrast colours must be used.	1
NFR_09	The system must be responsive to suit the screen size.	1
NFR_10	The tactile elements should be placed within comfortable proximal range for touch based interactions.	1
NFR_11	The system should use spinner for numeric number input.	1
BR_01:NFR_12	The time to accomplish a task should not exceed 2-3 minutes after the first encounter with the task	1

ReqID	Requirement	Priority
NFR_13	The system must provide error messages that are meaningful and informative.	1
NRF_14	The devices must be waterproof and dustproof.	2
NFR_15	The system should be able to perform on a Wi-Fi, GSM/GPRS Network.	1
NFR_16	Data pertaining to the system must be available 24/7.	1
NFR_17	The environmental data gathered must be provided to the user in a manner that will be meaningful to the user. The education level of the user should not be a barrier to interpreting what is displayed on the interface	1

Table 4.4: Non-Functional Requirements

4.7 Presentation Layer

The presentation layer outlines a set of Human Computer Interaction guidelines that dictated the design and development of the monitoring system, but can be applicable to any app development within the context of a developing nation.

4.7.1 Human Computer Interaction Guidelines

The wireless monitoring system intended in this study is composed of two major components: a user interface and a wireless sensor network. It is important to note that the user interface target population is users from developing countries. Therefore in addition to the requirements labelled, the design process will also abide by a set of Human-Computer Interaction (HCI) guidelines. When access to the end users is not possible, employing guidelines to advise and scrutinize design decisions reduces the gap between adequate knowledge about needs of the users and context of use, as well as the acceptance of the product. The HCI guidelines used in this study are classified in four majors areas as proposed by (Devezas et al., 2014): Interface Design (Text, Graphics, as well as Voice and Audio), Device Manipulation, Navigation and Information Architecture, and Content.

HCI 1. Interface Design

- **HCI 1.1 Text:** For illiterate users minimal text should appear in the interface; however, not all text should be removed because it provides a visual pattern to the illiterate user.
- **HCI 1.2 Graphics:** The interface should present culturally relevant icons to the user and should be accompanied by captions. The design should also favour realistic cartoons for representing pictorial content. Additionally, when used to identify actions, visual elements should indicate motion (e.g., water running from a tap, steam puffing out of a kettle).
- **HCI 1.3 Voice and Audio:** Voice content should be provided in the local language and accent. Help has to be available. Oral information should be kept short and simple while audio feedback should be provided on-demand. Additionally, high speed recognition accuracy is essential for the success of a speech-based system.

HCI 2. Device Manipulation

- **HCI 2.1 Help users gain confidence with technology:** Favour a mechanism that boosts the confidence of the user in the use of technology.
- **HCI 2.2 Avoid complex interaction styles:** Multi-function buttons, complex buttons, over-cluttered buttons and double-tap interaction should be avoided.

HCI 3. Navigation and Information Architecture

- **HCI 3.1 Use linear navigation:** Linear navigation is more easily understood than branched or hierarchical structures for low technology-literate users.
- **HCI 3.2 Encourage interface exploration:** Technophobia should be overcome by encouraging exploration of the system. One effective way to do so is to provide an "undo" function and always to ask for confirmation before fatal operations.
- **HCI 3.3 Keep the screens simple and limit the number of tasks:** The screens of the application should be kept simple and the number of tasks should be minimal.
- **HCI 3.4 Avoid scrollbars:** Because they are not well understood by low technology literate users, scrollbars should be avoided.
- **HCI 3.5 Use real-life metaphors to explain foreign concepts:** Textual illiteracy is often followed by low technology literacy or a lack thereof. Therefore, explaining foreign concepts to low-literacy users should be achieved by using metaphors that pertain to their real life context.

HCI 4. Content

- **HCI 4.1. Use familiar language:** The language and terminology used in the system must be such that the users are familiar with.

The next section discusses requirements related to the software layer.

4.8 Software Layer

In this layer questions such as “What is the most suitable platform for the deployment of the system?”, “What is a suitable mechanism to get the notifications to the user?” or “What should be the property of the software used?” are answered. The requirements pertaining to the software layer (SOF) are outlined below.

4.8.1 Open Source

SOF 01: Use open source software : When developing a product for rural settings or for a developing country in general, the main concern is to lower the price of the solution as much as possible while still providing a scalable and robust solution to the problem at hand. It is often understood that the hardware section must be very cost-effective, but so does the software component. Open source entails universal access via a free licence to the design of a product and a universal redistribution of that design (Lakhani and von Hippel, 2003). That access or redistribution is extended to subsequent improvement by anyone (Gerber et al., 2010). An open source software is a software than can be used, modified and shared by anyone. Thus, in this case, the use of open source software or such a platform to support or even develop the intended solution dramatically lowers the cost of production.

4.8.2 Wide Adoption

SOF 02: Favour a deployment platform that is widely adopted : A solution such as the one proposed in this study, intends not to add any additional burden onto the potential user. Instead, the solution should embrace facilities already available and should transition into the life of the user seamlessly. Therefore, the deployment platform of the solution should be one that is already likely to be in the possession of the user.

4.8.3 Push vs. Pull

SOF 03: The system should provide alerts and notifications to the users through push technologies: Push technology is a technology based on server/client mechanisms that allows useful information (notifications) to be transmitted to the client side by the server. Push technology is widely used by the internet content service because of the advantages in personal information, the initiative of the service and the timeliness of notifications (Franklin and Zdonik, 1998, Latif et al., 2008).In other words, push technology is the delivery of information from a server side application to a computing device (client node) without a specific request from the client. Push technology can be accomplished in many ways such as Short Message Service (SMS), Wireless Multimedia Message Service (MMS).
Pull technology is usually contrasted with push technology. In essence, pull technology uses the same concept as push technology. The difference emerges in the origin of the information request. For pull technology the client is the one requesting the information or notifications. Until such a request is sent the server will not push any information to the client (Latif et al., 2008). IIn order to make a choice regarding which technology to adopt there is a need to contextualize the advantages and disadvantages of both technologies. Figure 4.3 illustrates the principles of push technology. The illustration is followed by an analysis of the advantages and disadvantages of the push technology in Table 4.5. The same setup is presented for the pull technology. Figure 4.4 illustrates the pull technology and the advantages and disadvantages are presented in Table 4.6.

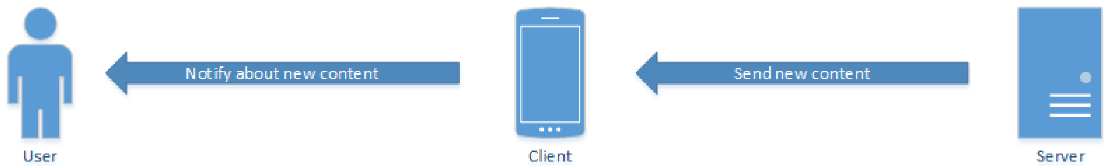


FIGURE 4.3: Push Technology

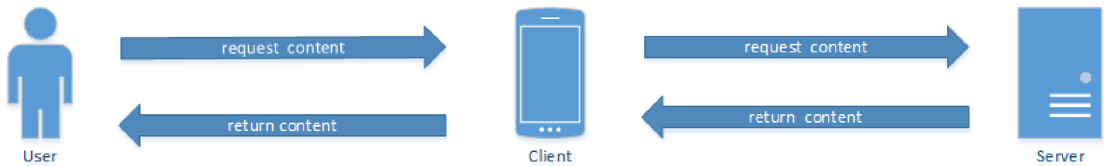


FIGURE 4.4: Pull Technology

The main disadvantage of pull technology in the context of this study is that the behaviour of the technology is comparable to the grounded monitoring station that the farmer has to go and observe in a timely manner to find out if any parameter needs to be altered. Push technology will therefore be adopted for the development of the envisioned system.

Push Technology	
Advantages	Disadvantages
On Time update: The client can know when updates have been made	Annoying: Users get the information as soon as they are available, but that translates to incessant interruptions
Focused Content	Bandwidth problem: Content can consume a large amount of bandwidth especially when feeding several end users
Instant response time is highly suitable for time critical notifications that must receive immediate attention	Congestion: the more push players there are the more it increases internet traffic

TABLE 4.5: Advantages and Disadvantages of Push Technology

Pull Technology	
Advantages	Disadvantages
Provides fast moving content	It increases the time taken to access a content
Favourable for highly dynamic sites	increased stress on the web server
	User can forget to check for updates

TABLE 4.6: Advantages and Disadvantages of Push Technology

4.8.4 Software Requirements for Wireless Sensor Networks (Firmware)

SOF 04: The software of the wireless boards/nodes must have a small footprint to run on small processors (Wang et al., 2006).
SOF 05: The software of the wireless boards/nodes must use energy efficiently and must be capable of fine-grained concurrency (Wang et al., 2006).
SOF 06: The software on the wireless nodes must be capable of high modularity (Wang et al., 2006).

4.8.5 Summary

The election of the software components that will be incorporated in the wireless ICT monitoring system is driven by the fact that they should be open source and cost- effective, thus lowering the cost of the system. Moreover, there should be a wide adoption of the software deployment platform. Furthermore, when considering real time capabilities the use of push technology is considered more effective than pull technology. Finally, the software of the sensor nodes should favour energy efficiency, must have a small footprint to be able to run on tiny processors, and must be capable of high modularity.

In this system storage of data is an unavoidable issue and as such, database requirements are discussed in the next section.

4.9 Database Layer

DB 01: The data gathered must be saved using a traditional database management in a base station or stored in a distributed in-network storage: A sensor network is used as part of the system envisioned in this study. In a sensor network, the large amount of data gathered from the environment by the sensor has a significant effect on the lifetime of the network(Diallo et al., 2013). Each sensor collects certain types of data that are time-stamped and contain additional overheads like the location of the sensor characteristics of the factor being monitored, and the type of sensors. A sensor network database contains the latter data from every sensor in the network. Many approaches have been proposed to store the data generated by the sensor networks.
One approach is to use a **base station that harbours a traditional database management system**. This approach is suitable for continuous query. However, it could shorten the limited power supply and result in a bandwidth bottleneck on the nodes closest to the base station. Also, the sensor could be sending unnecessary packets in the event when incessant monitoring is not needed (Cunha et al., 2007, Mokashi and Alvi, 2013).
Alternatively, **distributed in-network data storage** could be considered. This approach entails using the storage capabilities of the nodes of the network and lets the network handle queries. This approach is suitable for ad hoc queries, which also has the advantages of prolonging battery lifetime (Mokashi and Alvi, 2013). However, the system is extremely volatile: a node could be depleted thus affecting the reliability of the database. This approach must be backed up by a user interface that hides the shortfall of this approach and thus portrait robustness (Govindan et al., 2002).

Khosrowpour (2006) proposes the following requirements for the database layer:

DB 02: The database must be reliable: all information kept will remain unchanged.
DB 03: The database must be robust: there should be no inherent errors to its design.
DB 04: The database must portray accuracy or data correctness: data captured in the database must remain accurate, complete and not be prone to be corrupted.
DB 05: The database must be secure : security levels should be implemented according to the privileges of the database users.

DB 06: The database should be modifiable and extendable: it should be easy to modify or extend the database, with respect to the system changing requirements.

The wireless ICT monitoring system for monitoring hydroponic agriculture underlying database settings has a close relation to the type of network requirements. The network requirements are discussed in the next section.

4.10 Network Layer

This layer encompasses the requirements that represent the network technology that will be suitable for the establishment of the system (NET).

4.10.1 Wireless as a requirement

NET 01: The system should be supported by a wireless network : From the title of the study it could be inferred that the proposed solution in this study will favour a wireless/mobile means rather than a wired one. This section provides a justification for that choice. In South Africa, OFA and hydroponic agriculture are mostly practised in rural areas or on the outskirts of urban or metropolitan areas (Statistics South Africa, 2002). In those areas, the convenience of a wireless medium is preferred over an expensive fixed wired medium. exponentially increase the overall cost of the system and will reveal supplementary installation and maintainability costs; whereas a wireless substitute will be cheaper and more feasible (Li and Agbinya, 2005). Additionally, South African planes benefit from an evenly distributed cellular coverage as demonstrated in Figure 4.5.

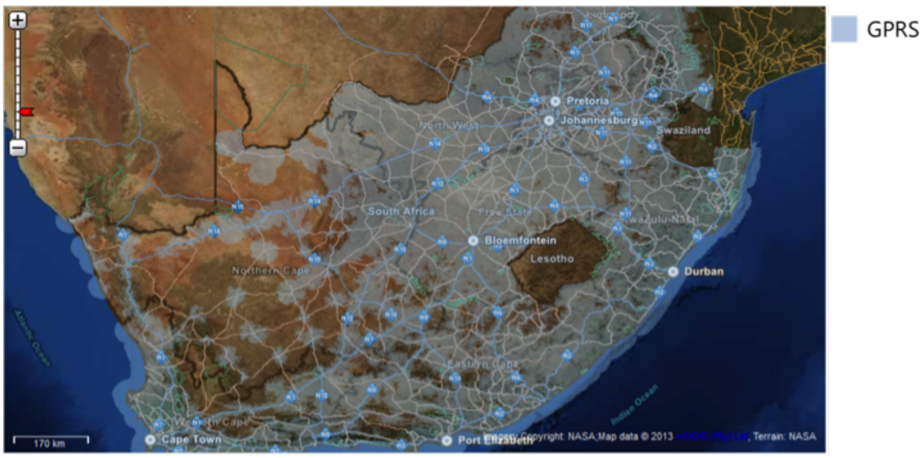


FIGURE 4.5: Cellular coverage in South Africa (Vodacom, 2013)

4.10.2 Cellular network

NET 02: The system should make use of a cellular network to access the internet: The term cellular network refers to a wireless network distributed over land areas named cells that are served by a transceiver, also known as a base station. The use of the term cellular network will also englobe cellular technology such as Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), Enhanced Data Rate for GSM Evolution (EDGE) and Code Division Multiple Access (CDMA). As discussed in the previous section and demonstrated in Figure 4.5 , cellular networks can be accessed virtually anywhere in South Africa. Therefore, it is possible to conceive of a system that will rely on the available cellular network already in place. Each wireless node of the system will transmit the gathered data directly to the server. However, joining a cellular network means a subscription to the carrier that avails itself of the service. Using several individual subscription per wireless monitoring node will lead to a negative financial impact that will by far outweigh the benefits of the technology. Nevertheless, using a cellular network will be suitable for the link between the Wireless LAN of the farm and the remote server. It will also be suitable to allow the farmer to receive notifications and to access information pertaining to the status of the farm even if the farmer is not in the vicinity. What is therefore the ideal fashion to approach a Wireless LAN in such an environment? The matter will be discussed in the next subsection.

4.10.3 Wireless Local Area Network

NET 03: The system local network should be able to receive and transmit data within a range of a 200 meter radius: Hydroponic farms span several hundred meters, thus even the most remote node should be able to connect to a distant hop.

NET 04: The system should make use of Bluetooth Low Energy technology or any similar technology: To comply with the requirement NET 03, the technology used should be able to transmit data over a long range while preserving that data. Various standards have been established for wireless communication. Those standards included the standards for wireless LAN, IEEE 802.11b, commonly know as WiFi, Bluetooth Low Energy (BLE) and IEEE 802.15.4, also called ZigBee. Those standards are used more widely for data collection and automation application (Gomez et al., 2012, Wang et al., 2006).

The standards operate at different radio frequencies. In general, a lower frequency allows a longer transmission and penetrates through walls and glass with greater strength. However, radio waves with lower frequencies can be easily absorbed by other materials, such as water or trees; and radio with radio waves with higher frequencies are easily scattered, so the frequencies alone are not a good indication of effective transmission distance that could be obtained (Wang et al., 2006). Table 4.7 summarizes the characteristics of these standards.

Feature	WiFi (IEEE 802.11b)	Bluetooth Low Energy (BLE)	ZigBee (IEEE 802.15.4)
Radio	DSSS	FHSS	DSSS
Data rate	11 Megabits	1 Megabits	250 Kilobits
Nodes per master	32	implementation dependent	64000
Slave enumeration latency	Up to 3s	6ms	30ms
Data type	Video, audio, graphics, pictures, files	Small data packet	Small data packet
Range (m)	100	>100	70
Extendibility	Roaming possible	Yes	Yes
Battery life	Hours	Up to 12 years	>1 year
Complexity	Complex	Simple	Simple

Table 4.7: Comparison between Wireless Technologies adapted from Gomez et al. (2012), Wang et al. (2006)

NET 05: The system network should adopt a mesh topology: Mesh networks allow autonomous nodes to self-assemble, time synchronization, and low consumption for the slave nodes thus prolonging the battery life of the device in the network (Wang et al., 2006).

4.10.4 Summary

This section emphasizes the use of wireless technologies for the development of the monitoring system. The design of the system should use technologies like GSM or GRPS, cellular technologies to enable access to internet in remote area as opposed to investing in wired means. The design of the local network also leverages wireless technologies like Bluetooth Low Energy or any other technologies that were designed with wireless sensor networks in mind. The next section outlines the hardware requirements.

4.11 Hardware layer

4.11.1 Mobility: Smartphone vs. Tablet

HAD 01: The user interface of the system should be targeting smartphones : Common contemporary tablets have a screen size of 7 inches up to 10.1 inches (e.g. Samsung Galaxy Tab 2), whereas common smartphones have screen size varying from 2.8 inches up to 6 inches. Tablets offering that much surface area were perceived by the researcher as ideal to present a lot of information to the user without much compromise of the information architecture and presentation. That belief was corroborated by existing applications deployed in South Africa by the banking sector, for instance. The First National Bank, in South Africa, banking application for tablets illustrated in Figure 4.6 (right) presents to the end user more information simultaneously, as opposed to its counterpart banking application for smartphones illustrated in Figure 4.6 (left). Both applications present the maximum information possible without overwhelming the user. Such examples led the researcher to opt

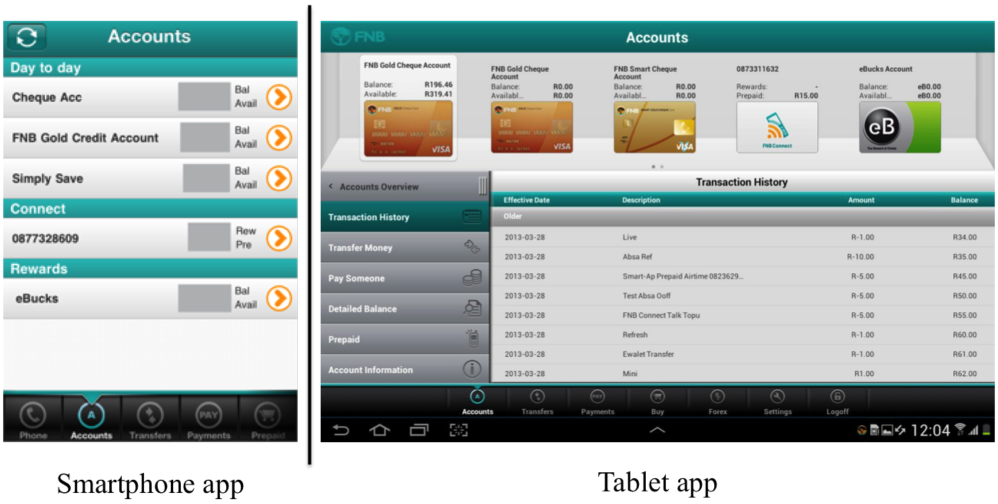


FIGURE 4.6: First National Bank Mobile App (Google Play, 2014)

for a tablet design initially. Field observations and the literature reviews advised otherwise. Owing to their pervasive nature, smartphones have become an “extension of our hands”; our sixth finger almost. Even in a farm environment, hydroponic farmers have their smartphones at hand all the time.

Moreover, the aim of the monitoring system is to provide and to enable real time monitoring with notifications and warnings pushed to the user as they happen. That premise favours a device that is kept on a user almost permanently. Owing to their size tablets are not devices kept in one?s pocket, and owing to their current monetary value, tablet owners tend to keep their beloved device away from any source of harm, namely mud, dust, water (the setting is a farm environment, after all). Nonetheless, it is possible to acquire a relatively cheap tablet. Smartphones provide better mobility and a protective shell can be acquired to protect against the elements (or one's own clumsiness) if they are not already waterproof and dustproof. For all these reasons the monitoring interface was designed and developed to target a smartphone.

4.12 Summary

This chapter outlined the different requirements that dictate the design and development of the Wireless ICT monitoring system for Hydroponic agriculture. The set of requirements encompasses a discussion of the process used to gather the requirements followed by a requirements specification. The latter section consists of a discussion on the business requirements as well as the functional and non-functional requirements. Subsequently, the discussion on additional requirements followed. Those requirements have been subdivided into layers. The layers are:

The Presentation layer, which focuses on requirements that will enhance the experience of the end users;

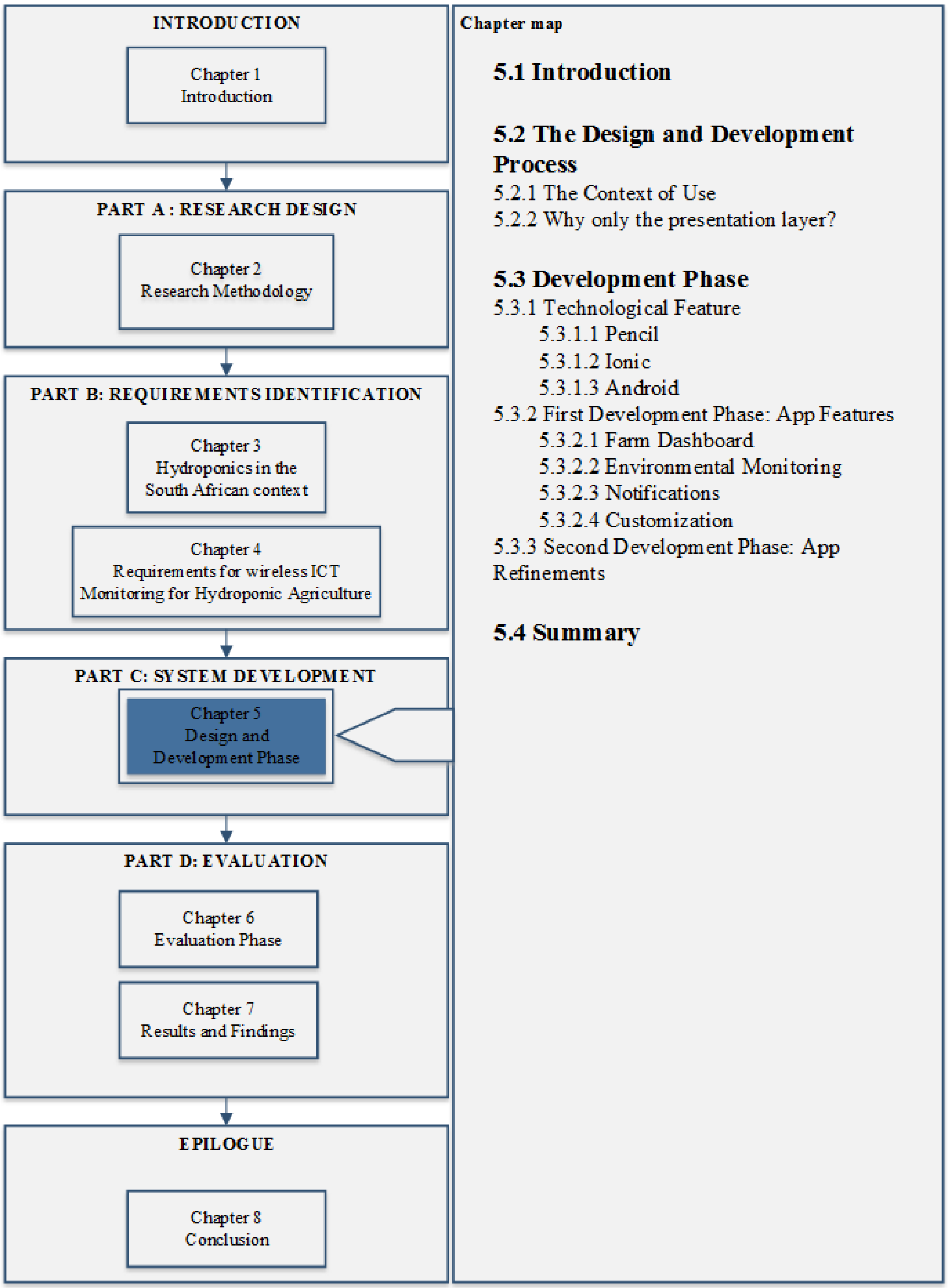
The Software layer that encloses the requirements related to the platform, utilities or tools that will support the system;

The Database layer that consists of the requirements relating to storage and data availability;

The Network layer, which entails the requirements necessary to achieve connectivity between the different components in the most efficient and cost-effective means possible, and;

The Hardware layer that consists of the physical requirements necessary for the system to strive and be durable.

The requirements are the leads that the researcher used to design and develop the artefactual solution for this study. The design and development phase is the subject of the next chapter.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Chapter 5

Design and Development Phase

5.1 Introduction

The design and development of the wireless monitoring app for hydroponic agriculture, the HydroWatcher' user interface, followed a user centred design (UCD) approach. Through the UCD approach the researcher focused on meeting the needs of the potential users. The potential users of the app are, in this case, the hydroponic farmers and managers whose input was actively sought in order to develop an app that meets the requirements previously elicited and presents a local relevance.

However, this app does not represent the whole system. It is a representation of the presentation layer of the requirements. In the previous chapter, the requirements pertaining to the entire system were outlined. During that requirements elicitation, the requirements were classified in several layers; the presentation layer is one of those layers. In this chapter, the motivation behind the development of just one aspect of the system will be provided in Section 5.2.2.

The design and development process in this study is composed of two phases separated by a critical evaluation phase that will be the core of the discussion in the next chapter . The first phase was prompted after the first set of requirements was obtained and properly outlined. That phase entailed the production of mock-up interfaces that reflected the interpretations that were drawn from the requirements. The mock-ups enabled the creation of a prototype mobile interactive application that is described in Section 5.3.2. Following the evaluation of the first phase interactive app and the refinement of the requirements, the second development phase was prompted. That phase saw the production of a refined prototype mobile interactive app that meets the requirements and the recommendations made by experts in hydroponic agriculture that evaluated the first prototype mobile interactive app. The second phase is described in Section 7.4.8. During both development phases of design and development the researcher embraced developing philosophies such as user centered design which was described in Section 2.7.

5.2 The Design and Development Process

In Section 2.6 the research strategy applied to this study, Design and Creation research, was discussed. During the discussion, it was outlined that the adopted strategy was composed of 5 distinct steps: Awareness, Suggestion, Development, Evaluation, and Conclusion. The Awareness step can be tracked through Chapter 1 to Chapter 3, the Evaluation step is portrayed in Chapter 6 and 7 and the Conclusion step in Chapter 8. This chapter tackles the Suggestion and Development steps of the Design and Creation Research strategy.
During the development step of this study, the development approach adopted was user centred design (UCD). UCD was described as a multistage problem solving process during which the needs of the potential users of the system are prioritized. The different UCD stages involve specifying the context of use, specifying the requirements, producing design solution, and evaluating the design (see Section 2.7).

The context of use was briefly outlined in the previous chapters and will be described in depth in the next subsection. The requirements were specified in Chapter 4: the produced design is discussed later in this chapter, and the evaluation of the design is covered in Chapter 6 and 7.

5.2.1 The Context of Use

The intended solution in this study, dubbed the HydroWatcher mobile application, is a solution that aims at monitoring the critical factors of a hydroponic farm. Those factors include ambient temperature, ambient humidity, pH and EC of the water retention tank, pH and EC in and out of the vegetative bag, and the water quantity in and out of the vegetative bag. The solution proposed in this study is tailored for developing countries especially South Africa, and will be used by hydroponic managers and hydroponic farm workers especially fertigation operators and farm personnel in charge of the monitoring activity. HydroWatcher mobile application will be used to provide to the user real time monitoring information on the aforementioned critical factors. Also, the application is designed to be a complete companion to the farmers as they will be able to use the application in the rough environment of the farm as well as when they are away from the farm, thus providing a real time monitoring anywhere, and at any time.

During the requirements elicitation phase, the requirements for the entire system were outlined; however, the design and development process of this study only describes the prototype mobile app that acts as the user interface for HydroWatcher. A question thus arises: if the requirements for the entire system were outlined, what justifies only focusing on a single aspect of the system? That question finds an answer in the next subsection.

5.2.2 Why only the Presentation Layer?

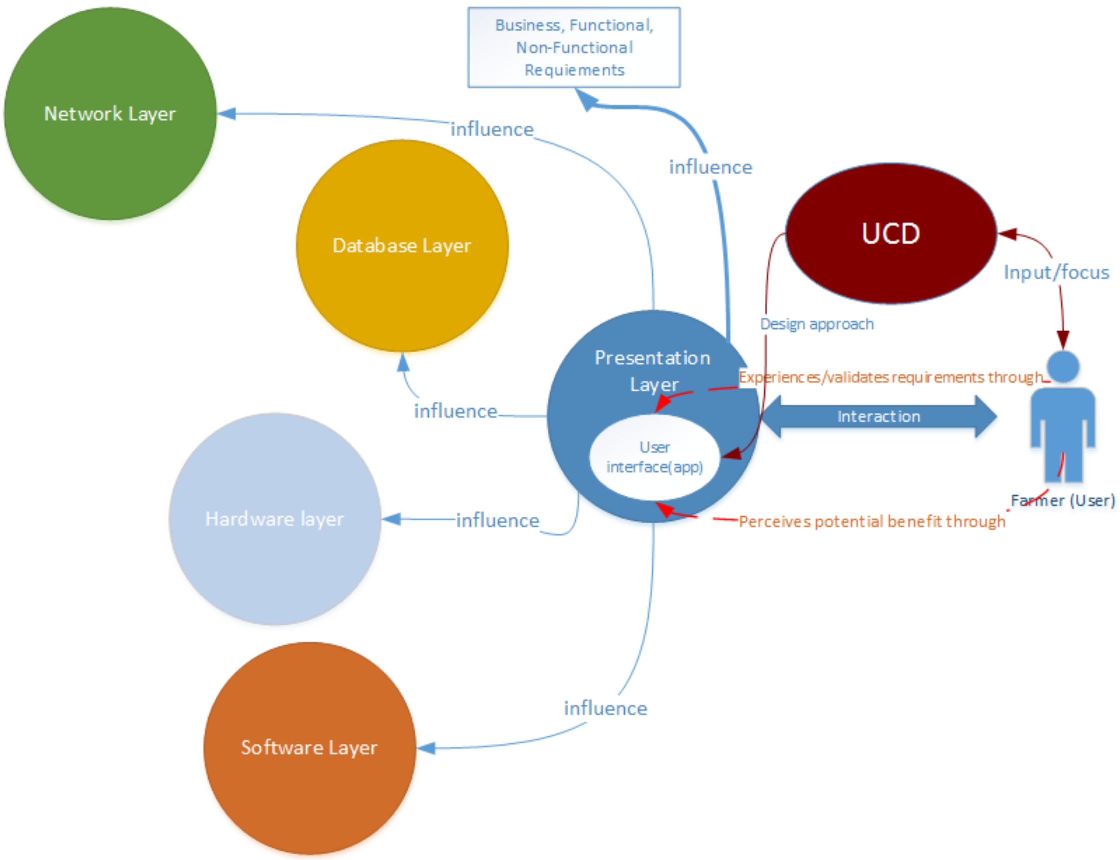


FIGURE 5.1: Presentation Layer: Gateway to System Acceptance

It was argued in the section discussing the use of the UCD approach, that the potential users of the system are at the heart of the development strategies for the system. As such the system should bend to their needs in order to achieve the maximum user experience. During the requirements specification, several layers of requirements were added in addition to the business, functional and non-functional requirements. Those layers are: presentation layer, software layer, database layer, network layer, and hardware layer (see Section 4.3.2). In the diagram representing the holistic view of the requirements, it can be clearly seen that the users, represented by the farmer icon in the diagram, only appear close to the presentation layer and only interact with the system through the presentation layer. The rest of the system could exist in a black box type of settings and that will not affect the user experience of the user in any manner. Therefore, the factor impacting the user acceptance of the system to the utmost is the ability of the user to interact with the system through the user interface regardless of the platform within which it is presented. In other words, the presentation layer is the gateway to acceptance of the system. Figure 5.1 illustrates the dynamic of the system acceptance through the presentation layer. Moreover, owing to the scope and the time constraints by which this study abides, the development and evaluation of the user interface of HydroWatcher was critical to gather the applicability of the requirements presented in Chapter 4. This process also allowed the gathering of information on the potential benefits and usability of the system in the context of a developing country, namely South Africa.

5.3 Development Phase

The development phase in this study is composed of two development phases. The two development phases are separated from each other by an evaluation phase. In this study the UCD process governs the development approach. UCD is an iterative process that has at its core the specified requirements guiding the design of the solution (see Figure 2.4). As such, the UCD process was iterated in this study until the requirements for HydroWatcher were deemed satisfactory for the development of a solution that suits the needs of potential HydroWatcher users.
The first development phase presents a design solution conceived from the interpretation of the data gathered during the investigation phase of this project by the researcher.
Following the first development phase, the conceived design solution was evaluated as prescribed by the UCD approach. The results of the evaluation led to the refinement of the requirements necessary for HydroWatcher to be a solution fit for use by the potential users.
During the second development phase, the recommendations issued from the evaluation were implemented. Additionally the changes in the design necessary in order to align the designed solution with the requirements of the solution were also implemented.

In this chapter, the section discussing the first design phase outlines the major features of the HydroWatcher app as they appeared after the first development phase. The section detailing the second development phase will highlight the changes made to the initial features of the HydroWatcher app as well as additional features added during the second development phase (Chapter 7). Before diving into the development phases the next subsection outlines the tools used for the conception of the HydroWatcher prototype app.

5.3.1 Technological Features

The technological features are the utilities, tools, platforms that are associated with the monitoring app. The technological features relate to the features that were used to design and develop the app, as well as the ones incorporated within the app.

5.3.1.1 Pencil

Pencil is an open source graphical user interface prototyping tool that is used to produce interface mock-ups. Pencil is available on multiple platforms such Linux, Mac OS and Windows (Evolus, 2012). Although there are other popular prototyping tools like Balsamiq, Pencil was elected as a the prototyping tool owing to the familiarity that the researcher has with this particular tool.

Pencil allows the user to draw mock-ups for Windows applications, websites and more importantly, as far as this study is concerned, mock-ups for mobile applications in Android and IOS platforms.

5.3.1.2 Ionic

Ionic can be described as an open source front end for developing mobile apps. Ionic uses web technology like HTML5, CSS and JavaScript to produce an interactive app (Ionic, 2014).

Developing the app with Ionic allows the researcher to focus mainly on the look and feel, and user interface interaction of the app. Focus on the user interaction was one of the key points of the design of the app if a positive user experience from the app was to be achieved.

5.3.1.3 Android

Android is a mobile operating system based on the open Linux kernel. This operating system is developed by Google. It is designed primarily for mobile devices such as smartphones or tablets featuring a touch screen. Android is also available as a specialized user interface for televisions, as wearable technology like wristwatches, and in cars (Burnette, 2009). Google has released several versions of the operating system. At the time this dissertation is written the most recent version of Android is Lollipop also know as Android 5.0. However, it is important to note that it is not necessary to keep track of the latest version. An app that is designed to target a specific version of Android can work with the latest version of Android. The reverse is possible if adapters are used (Developers Android, 2014, Rogers et al., 2009).

The Android platform was selected to respond to the requirements discussed in Section 4.8 referring to the software attributes to be used (SOF 01-02). Android is an open source software platform thus making it cost effective. In the second quarter of 2014 Android represented nearly 85% of the smartphone market, making it widely adopted throughout the world (MOBITHINKING, 2014).

5.3.2 First Development Phase: App Features

The point of this study was to address the key problem of adequate tools and methods to monitor hydroponic agriculture effectively. As such, the mobile app proposed in this study will focus on the monitoring mechanisms and how well it tackles the problem. Keeping that in mind, the discussion will focus on the key features of the app namely those that relate to the monitoring and features that increase the usability and overall experience of the user.

5.3.2.1 Farm Dashboard

The farm dashboard doubles as the default landing page for the application. It provides the logical organization of the farm. From the field observations hydroponic farms are organized in logical units to ensure that in a particular unit , all crops are of an equal nature (same kind, same age). That makes monitoring simple and irrigation patterns organized. The app design mimics that organization and provides to the user a digital map of the farm. The user can enter a particular zone and view the information pertaining to tunnels of that particular zone. The farm dashboard is illustrated in Figure 5.2.

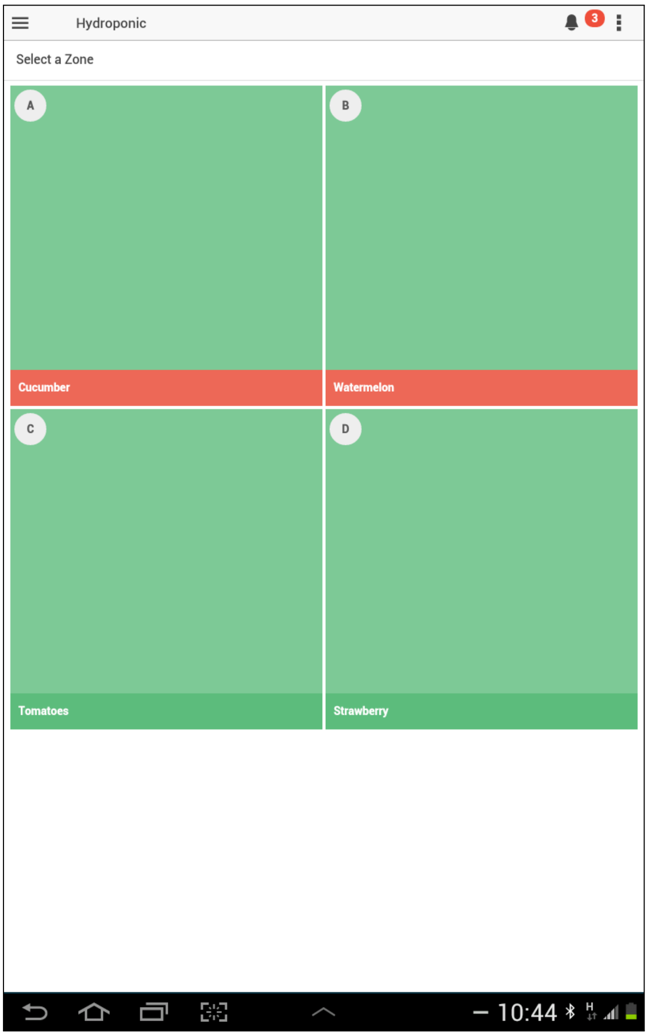


FIGURE 5.2: Farm Dashboard

5.3.2.2 Environmental Monitoring

In Chapter 3, environmental factors that are critical for the wellbeing of the crops in hydroponic agriculture were identified and their possible impacts on the crops were also discussed. Those criteria are temperature, humidity, pH, electrical conductivity and water volumes in and out of the vegetative bag. As such, those criteria will constitute the main parameters to be monitored by the app. Monitoring that each criterion is between the desired or ideal range for the wellbeing of the crops is the objective of the environmental monitoring feature. The environmental monitoring feature comprises real time environmental parameter monitoring, notifications and historic environmental parameter monitoring which is presented in a graphical view.

Real time monitoring of environmental criteria

One aspect of monitoring is to be able to provide the farmer with information pertaining to the status of the farm at a moment's notice. The term real time monitoring in this study is used in rather an abused manner: when the user of the app accesses the screen providing the real time monitoring, the user is presented with data reflecting the latest update of gathered data. Based on the need of the farm or the sensitivity of the criteria being monitored that update could have been performed a few seconds before the user accessed the screen or several hours before. Nonetheless any new update on the status of the criteria will be reflected on the screen as long as the user is logged in to the real time monitoring module. The real time environmental parameter monitoring is a read only module. After the user has gained access to the module the user can only read the data. The data cannot be

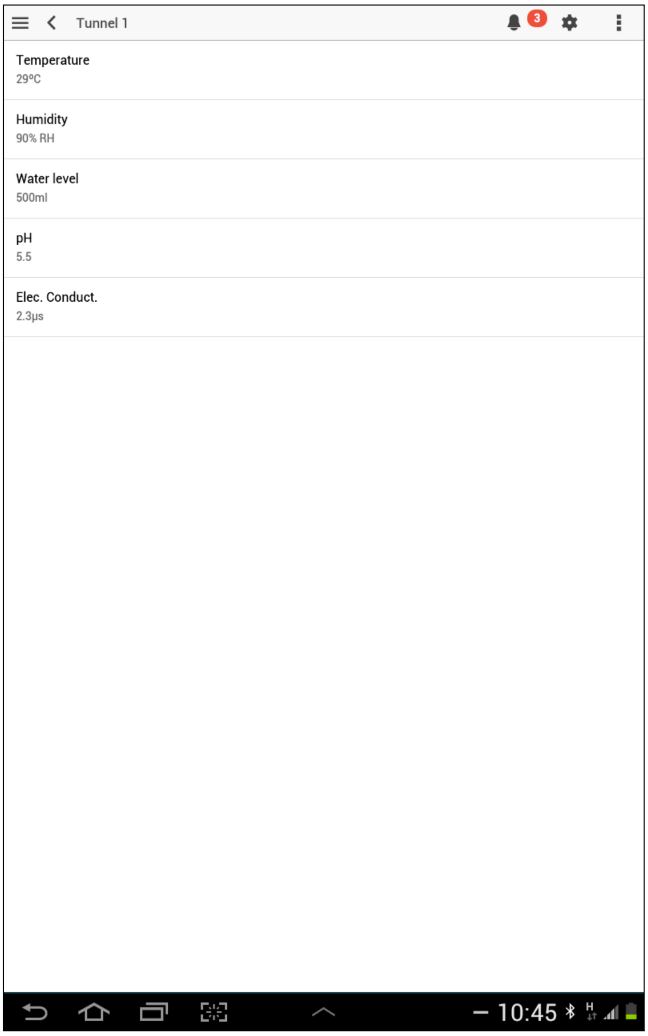


FIGURE 5.3: Real Time Monitoring

edited.

Figure 5.3 illustrates the screen presenting the feature.

Historical monitoring of environmental criteria

In addition to the real time monitoring, a farmer must be able to, or may want, to see the behaviour of a certain criterion prior to the moment when he is monitoring the status of the farm. The app provides a graphical view of the historic data. The user is capable of analysing from a graphical perspective, the previous state of any monitored criteria through the app. The app allows the user to view the entire day or the entire week and goes as far back as 30 days. Figure 5.4 illustrates the screen presenting the graphic view.

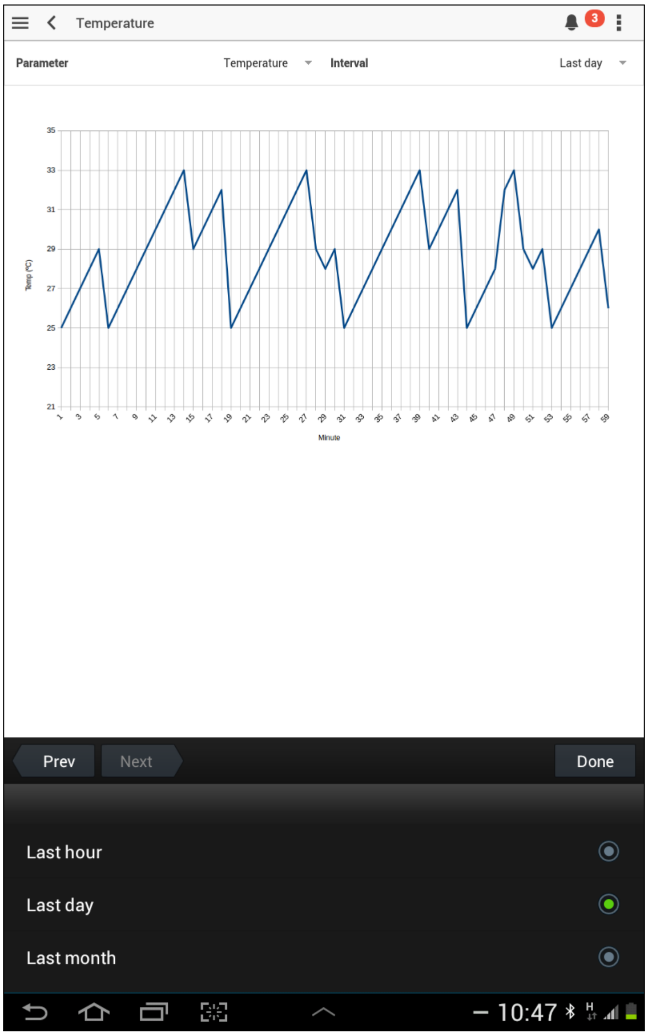


FIGURE 5.4: Historical monitoring

5.3.2.3 Notifications

Relying solely on the user to check in a timely manner that everything is going according to schedule on the entire farm is an unrealistic expectation. After all, everyone is prone to forget or to be occupied with a certain number of alternative tasks, whether they be related to the farm or not. The notification feature is thus a mechanism that is paired and complement the real time monitoring feature.

Notification feature

The notification feature is a feature that is activated to warn the user about matters that need attention on the farm. For instance, if the temperature in tunnel x is below or above the set threshold values, a notification will be sent to the user via the application. The notification feature in the app uses push technology.

Notification disposal

One of the disadvantages of push technology is that, depending on the frequency of the pushed information, that information can be overwhelming and even annoying. The option was therefore to provide to the user a means to be able to discard the notifications related to situations that have already been attended to. The user can discard one notification at a time or discard all them at once.

Figure 5.5 illustrates the notification feature. The notifications can be disposed of by tapping the red button or by tapping the bin icon.

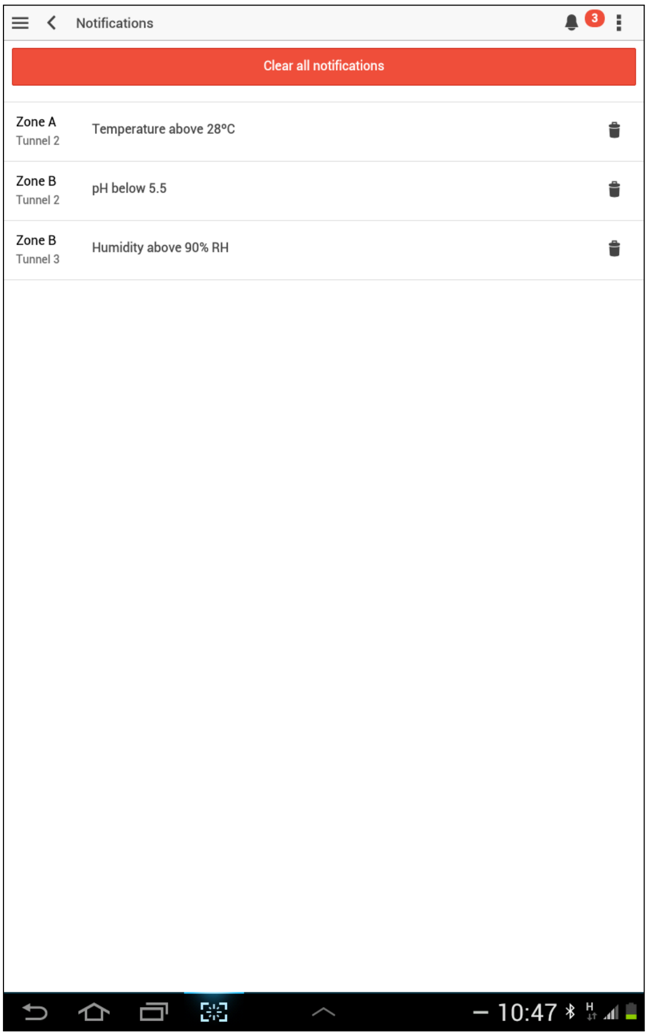


FIGURE 5.5: Notification

5.3.2.4 Customization

The customization feature encompasses the features that alter the settings of the app, and enhance the user experience. Not all farms look alike, thus an application that pretend to be a panacea for every farm is simply unfathomable. Not every farm will monitor all the criteria identified in Section 3.4. There could be periods of the farming year when the farmer would like to focus on a particular zone, for instance. The next subsections discuss some of the implemented customizations in the first development phase.

Adjustable range of environmental criteria

The threshold values for any criteria are indicated by the crop being produced and are more often than not seasonal. The app provides a feature to enable the user to set the ideal range for a particular criterion, as illustrated in Figure 5.6.

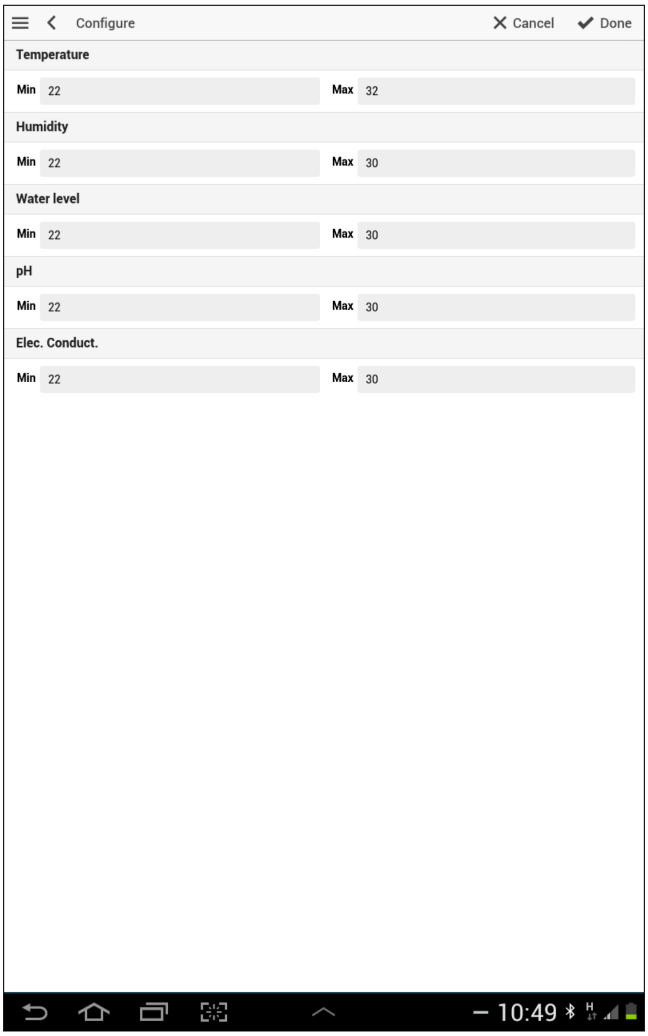


FIGURE 5.6: Adjust Range

Landing Page

The Landing Page feature is another customization feature. To understand how it works, consider the following scenario: By default, the landing page of the app is the Farm dashboard (Figure 5.2). During the year, the farmer might want to pay close attention to a particular zone because it is close to the harvest or it is the only crop left to harvest. As such, instead of having a starting page that presents irrelevant information, the app will start by presenting directly the information relevant to the zone of interest. The landing page can be changed on the screen illustrated in Figure 5.7.

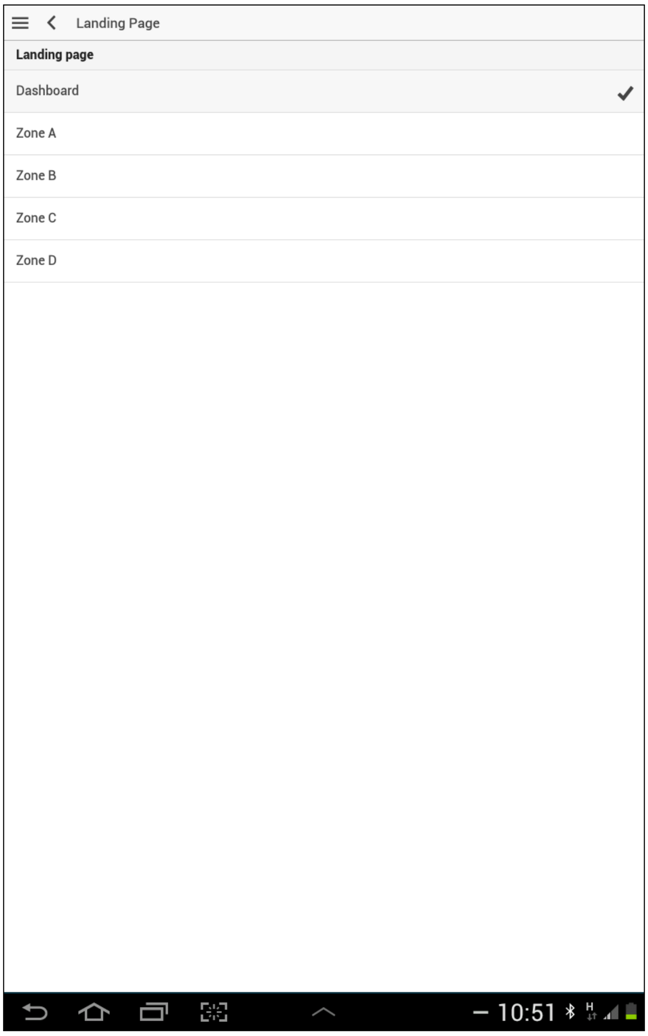


FIGURE 5.7: Landing Page

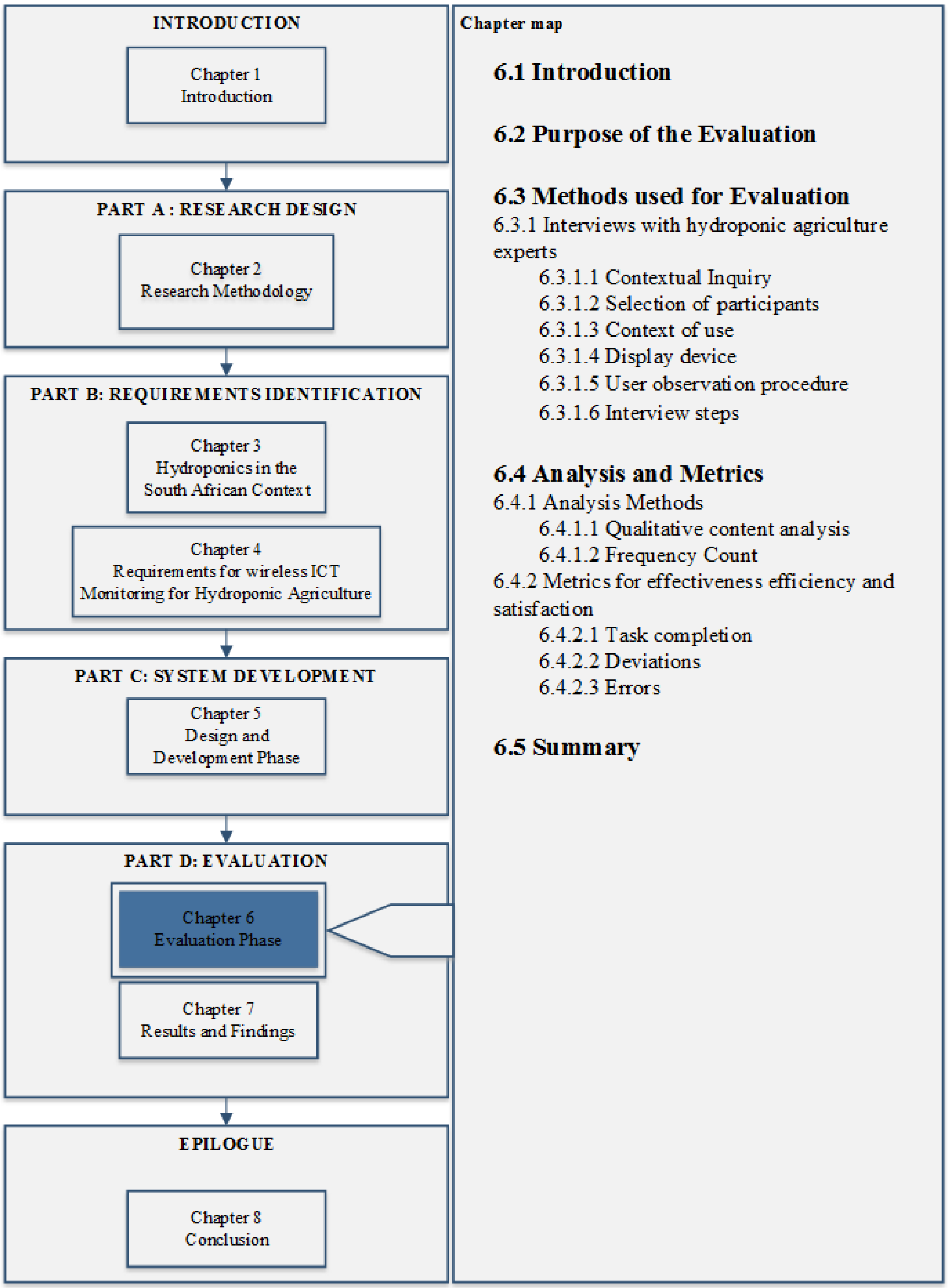
5.3.3 Second Development Phase: App Refinements

The second phase of development pertains to the refinement of the app following the evaluation that was conducted with the hydroponic experts. During this phase, the comments and recommendations that the participants of the evaluation provided were taken into account to improve on the design of the first development phase. Following the iterative nature of UCD approach, the second development embodied the second iteration of the development. This phase will be discussed in detail in Section 7.4.8.

5.4 Summary

Through the use of the UCD approach design model, the app enabling the monitoring of hydroponics was obtained. The design and development process was a collaborative effort between the researcher and the experts in the field of hydroponic agriculture. The design and development in this study was subdivided into two phases. The first phase was an attempt to design an app that will meet the interpretation of the requirements. After that phase, the designed app was evaluated. The results and recommendations, as well as the outcomes of the evaluation provide the entry point for the second phase. The second phase, in essence, was a refinement of the previous design to meet the further requirements uncovered during the evaluation, including the recommendations of the hydroponic experts and improvement with regard to the usability of the app. The second development phase is discussed in detail in Chapter 7.

The app for monitoring hydroponic agriculture presented the following key features: The farm dashboard outlines a logical representation of the farm. Environmental monitoring , both real time and historic, allow i the user to see the real time variable regarding the critical factors being monitored, and the customization enables the user to prioritize the views and to configure the range of the monitored factors. The next chapter discusses the evaluation that was conducted in order to validate the applicability of the requirements in relation to the app.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Chapter 6

Evaluation Phase

6.1 Introduction

Based on the requirements elicited in Chapter 4, the design and development phase in the previous chapter described the creation of a prototype mobile app that was the manifestation of the interpretation of the requirements. The development of the app was followed by an evaluation phase the aim of which was to gather feedback on the applicability of the requirements elicited for the prototype mobile app. The primary objective of this chapter is to describe the evaluation of the proposed UI of HydroWatcher. HydroWatcher prototype mobile application was developed to validate the applicability of the requirements as these pertain to the presentation layer. Moreover, the application was developed using the UCD approach. Therefore, it is imperative to ensure that the presentation layer addresses the user needs and requirements. This premise leads to the need firstly, to validate the presentation layer requirements through the development of the UI. Furthermore, the evaluation also served to test the ease of use of the application, its intuitiveness, its relevance, and its applicability in the context of South African hydroponic agriculture.

This chapter discusses the evaluation conducted on the prototype mobile app. The discussion will cover the purpose of the evaluation in Section 6.2. Subsequently, the methods used during the evaluation will be described in Section 6.3. Following that, the analysis method and the metrics used during the evaluation are outlined in Section 6.4 . The results of the evaluation are not reported on in this chapter as it is the subject of the next chapter.

6.2 Purpose of the Evaluation

The proposed artefact, the wireless monitoring application for hydroponic agriculture should be useful to practitioners (relevant) and it also contributes to the body of knowledge (rigorous). To ensure that the artefact abides by that premise, it must undergo a stringent evaluation. The evaluation process of the application aims at validating the relevance and rigour of the proposed application in order to assess how well it satisfies the need of the target demographics and solves the identified problem.

The evaluation will also answer one of the research questions: **"How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa?"**

6.3 Methods used for Evaluation

Descriptive methods were selected for the evaluation of the proposed application. The application designed and developed in this study followed the design science recommendations as such methods that satisfy the design science paradigm were selected. The following descriptive methods were used to evaluate the instantiation: **expert reviews by means of interviews with hydroponic agriculture experts** and **content analysis of the interviews**.

6.3.1 Interviews with hydroponic agriculture experts

The overall aim of the interviews was to gather feedback about the usability and user experience from the users. The evaluation helped the researcher to assess the user interface elements that were used as well as the navigation and interaction styles. Moreover, the evaluation determined the hindrances to a positive user experience from the farmers using the wireless monitoring app. Throughout the evaluation, errors that occur as the users interact with the application were observed in order to identify opportunities to enhance the user experience. Additionally, recommendations for improving the overall user experience will be provided based on the findings from the user feedback evaluation.

The recommendations aim at ensuring that the app is able to launch, can allow users to browse app easily in order to find the content that they are looking for efficiently, effectively and satisfactorily. Moreover, the recommendations will help in redesigning an app that presents all formats of data content clearly and an app that is designed to promote intuitive navigation among the features of the monitoring app.

6.3.1.1 Contextual Inquiry

The evaluation for Hydroponic mobile app was conducted in the real context of use. A context inquiry based type of test was conducted. The participants were visited in the respective farms and were asked to use the app, as they would do on their typical daily routine. The aim was to make the testing as real as possible and maintain naturalness of the context of use of the app. Also, this way, it is envisaged that the sample of users to be recruited will be a true representation of the actual users of HydroWatcher. The wireless monitoring for hydroponic agriculture mobile app was tested using techniques such as the thinking aloud protocol, user observation, video recording, subjective user comments on the impression of the app and task completion.

6.3.1.2 Selection of Participants

The app was designed in the context of South Africa, but really targets users from developing countries. The screening criteria for participants is based on the fact that the participant should be knowledgeable about hydroponic agriculture and be actively involved in a hydroponic farm in a developing country. Additionally, the participants should have entry-level background knowledge on how to use mobile phones or smartphone-type devices. Moreover, the participant who met these criteria should be willing to undergo a 45 to 60 minute hands-on evaluation on the wireless monitoring for hydroponic agriculture app. During the evaluation the participants will be asked to voice their qualitative subjective feelings on their interactions with the app (thinking aloud).

The evaluation phase mustered 6 participants comprising hydroponic farm managers, supervisors and operators of hydroponic farm equipment (Fertigation station operators). The end user of the wireless monitoring for hydroponic app are expected to have a certain degree of knowledge of monitoring and operating a hydroponic environment. Furthermore, it was expected of the participants to have an appreciation of mobile phone devices or smartphones. However, the competence level of the users may vary owing to the disparity in the technology used on the farms. Some farms are highly technologized, whereas others still operate manually. Also, the level of skill in respect to mobile phone or smartphones device handling vary among the users.

6.3.1.3 Context of Use

The expert reviews test for the subject domain experts were conducted in the farm settings. The users were visited at their respective farms. The location for the test was elected not only as a convenience for the participants, but also to keep the participants in a context of use that is as natural as possible. The wireless monitoring for hydroponic farming app was designed to be used in developing countries, in both rural and urban settings.

6.3.1.4 Display Device

The evaluation of the application was performed on a smartphone with a screen size of 5.3 inches and a resolution of 1280x 800. The smartphone was set to the standard colour mode and automatic brightness. A smartphone was elected to stay true to the observation that was discussed in Section 4.11.1 : Most farmers carry their mobile phones while they are doing other tasks around the farm, thus a smartphone will be convenient compared to a tablet. A Sony Xperia has been selected specifically because the device is both water resistant and dust proof rendering it ideal for use in an agricultural environment.

6.3.1.5 User Observation Procedure

The evaluation was conducted as follows: Prior to starting the test, the app was described to the participant and the purpose of the test was explained. Additionally, it was also explained to the participant that the evaluation session would be recorded, but only the screen interaction and the voiced comments would be recorded, so the anonymity of the participant would be preserved. Furthermore, it was also stressed that the evaluation was not a test of the user skills at either handling the devices or navigating the system, but rather that the participant opinions on how to improve on the system were welcomed. Once parties, the participant and the researcher, had agreed that they have understood each other and that the participant fully understands the app and was happy to proceed with the test, a consent form was given to the participant to complete (see Appendix B). A pre-test questionnaire was then given to the participant. The purpose of the pre-test questionnaire was to screen the users further and to classify them according to the desired user matrix clusters.

After the completion of pre-test questionnaire the system was launched and the participant was ask to free roam the app. The aim of the free roam was to gather an impression of the participant at first glance of the app. The free roam was followed by a set of questions that aims at extracting their perceptions and general comments about the system.

After the free roam the participant was asked to perform specific tasks. The tasks were presented in the form of scenarios that mimic real life issues that they might face on the farm. The scenario route was elected to avoid the leading question bias. Finally, at the end of the task performance steps, the participant was asked to complete a post-test questionnaire.

To summarise, the evaluation encompasses 6 steps: an explanation and consent giving step, a pre-test questionnaire, a free exploration of the app and first impression gathering step, a task performance step and a post-test questionnaire completion step. Throughout the evaluation each participant was encouraged to voice any idea, comment or recommendation that comes to mind as he/she was interacting with the app. The user observation procedure can be found in Appendix B. The next section will discuss in a bit more detail what each step entailed.

6.3.1.6 Interview Steps

Participant briefing and pre-test: Before starting the test there was a briefing session. The briefing consists of explaining to the participant how the evaluation would be conducted. Permission was asked and obtained to film the test under the guarantee that the images would only be used for the purpose of the research and by the researchers only. In an effort to gather more details from the participants and to be able to classify them according to the desired user matrix clusters, questions were asked regarding the current post held and the experience level of the participant from working on a hydroponic farm. Additional information was gathered to evaluate the level of confidence of the user vis-à-vis smartphones or other touch-based devices.

Free exploration: : After the pre-test questions the participants were asked to explore the app to familiarize themselves with it. The participants were encouraged to scan through the app and make comments about it and to voice any thoughts that came to mind. The objective of the free exploration was to observe and catalogue the features that the participants noticed first, while taking note of the overall impressions that the users had with respect to ease of use, navigation and familiarity of the app. Moreover, the free exploration also served to determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they fit the mental models of the users.

After the participants seemed to be satisfied with their free exploration, they were asked questions that helped the researchers to gather the interpretations of the participants about the user interface elements. The researcher focused on user interface elements such as visual appeal, colours used, iconography, terminology used, navigation and menus. It was also asked of the participants to comment regarding the information organization of the application, as well as on their main understanding of what the application is supposed to do.

Scenarios: Four scenarios were used to depict how the app would be used in practice. The purpose of using the scenarios was to mimic the practical use of the app as it would be in a real life situation, and to have the participants comment on how to they perceived the app to be useful and applicable in those particular cases.

The scenarios were modelled from the following cases:
Scenario 1: Viewing real data for a specific tunnel.

Scenario 2: Viewing the historical data, the core of the application. This case served to see if the participant can view the monitored criteria and the gathered data. Additionally, the cases in Scenario 1 and 2 help the researcher to determine the ease of navigation and the familiarity and predictability of findings in the tunnels. Moreover, the cases help to determine the interpretation by the participants of the dashboard and its role as the central point of navigation.

Scenario 3: Changing zone parameters. This case focused on the understanding of the participants regarding the information architecture of the application in respect of the presentation of parameter labels and associated variable values. Additionally, information regarding the interpretation of the different user interface elements was also collected.

Scenario 4: Setting custom preferences. This case provided the value that the users would gain from having the option to customize the viewing preferences. This case also gave insight into the discoverability of functionalities in contextual menus.

Post test questionnaires: Upon completion of the scenarios, the participants were submitted to a post-test questionnaire. The aim of the questionnaire was to find what grabbed the attention of the participants, both positively and negatively . Additionally, the participants were asked to comment on the benefit that they perceived from the use of the application and on other functionalities they would like to see supported, whether by the application or by a mobile phone to assist in hydroponic agriculture activities. Finally, the participants were asked to complete a questionnaire that provided information on the learnability and usability of the mobile app. The questionnaires are available in Appendix B.

6.4 Analysis and Metrics

6.4.1 Analysis Methods

Owing to the qualitative nature of the data gathered qualitative content analysis was used as the analysis technique for the data gathered during the interview with domain experts as part of the evaluation primarily. The analysis of the task performed also revealed quantitative data that were handled using frequency count.

6.4.1.1 Qualitative Content Analysis

A qualitative content analysis can be defined as a systematic, replicable technique for compressing the context of text into fewer content categories through a process of coding and identifying themes or patterns (Hsieh and Shannon, 2005)

According to Hsieh and Shannon (2005), there are three types of qualitative content analysis: conventional content analysis, directed content analysis, and summative content analysis.

In this study the content analysis adopted a **conventional approach**. An in vivo coding was therefore undertaken to identify and code the factors. Following the guidance of Hsieh and Shannon (2005) who define 6 steps for the conventional content analysis, those steps were adhered to in this study as follows:

Step 1: Each transcript should be read from beginning to end, as one would read a novel. In the case of this study, “text” is on the form of videos, thus the video transcripts were watched as one would a documentary.

Step 2: The transcripts should be read carefully. In this case the videos were watched then again closely while carefully highlighting the text that appears to describe emotional reaction from the participant and writing down a text or keyword that captures the essence of the emotional reaction using the words of the participants.

Step 3:The developing code was limited as much as possible.

Step 4: After a number of transcripts were studied, preliminary code were taken into consideration. Then the remaining transcripts were coded using that preliminary code and new codes were created when necessary.

Step 5: This step involved examining all the data within a particular code. The codes that belonged together were combined, while the other codes were spilt into subcategories.

Step 6: The final codes were organised and then rearrange into a hierarchical structure.

6.4.1.2 Frequency Count

Frequency count is considered to be the most straightforward approach to working with quantitative data. Frequency count entails the classification of items according to a particular category or context and an arithmetical count is made of the items, within the text, which belong to each classification (Nisbet, 1961). Frequency count was employed in this study to quantify identified metrics, thus enabling deeper grasp of the benefit of the application. The metrics considered during this evaluation are discussed in the next section.

6.4.2 Metrics for Effectiveness, Efficiency and Satisfaction

To evaluate the usability of the application, it will be measured according to the following metrics:

6.4.2.1 Task Completion

Each task derived from the scenarios will be divided into several steps that form the ideal flow to completion. The accomplishment of these tasks will allow the calculation of the task completion rate. Task completion will be defined and categorised based on the following:

Completed: This metric is attained when the participant has found and indicates that he has found the answer or completed the task goal.

Completed with assistance: In this case, the participant would have asked for help from the researcher moderating the test. This metric requires, however, distinguishing between when the participant asking for elaboration on the question relating to the task and when the participant asks for help on how to complete the task.

Failed to complete: This is when the participant gives up on the task or the participants think that they have successfully completed the task while they have performed it incorrectly.

6.4.2.2 Deviations

Deviations are defined as alternative flows to the completion of the task, meanwhile not being the ideal flow for the completion of the task still enables the participant to achieve task completion.

6.4.2.3 Errors

An error will be counted every time the participant performs an action that does not contribute to the task completion.

Errors are categorized as follows:

Critical errors: Critical errors are deviations at completion from the targets of the scenario. For instance, the participant could report the wrong data value owing to the workflow of the participant. Essentially, the participant will not be able to finish the task, thus task failure. The participant may or may not be aware that the task goal is incorrect or incomplete.

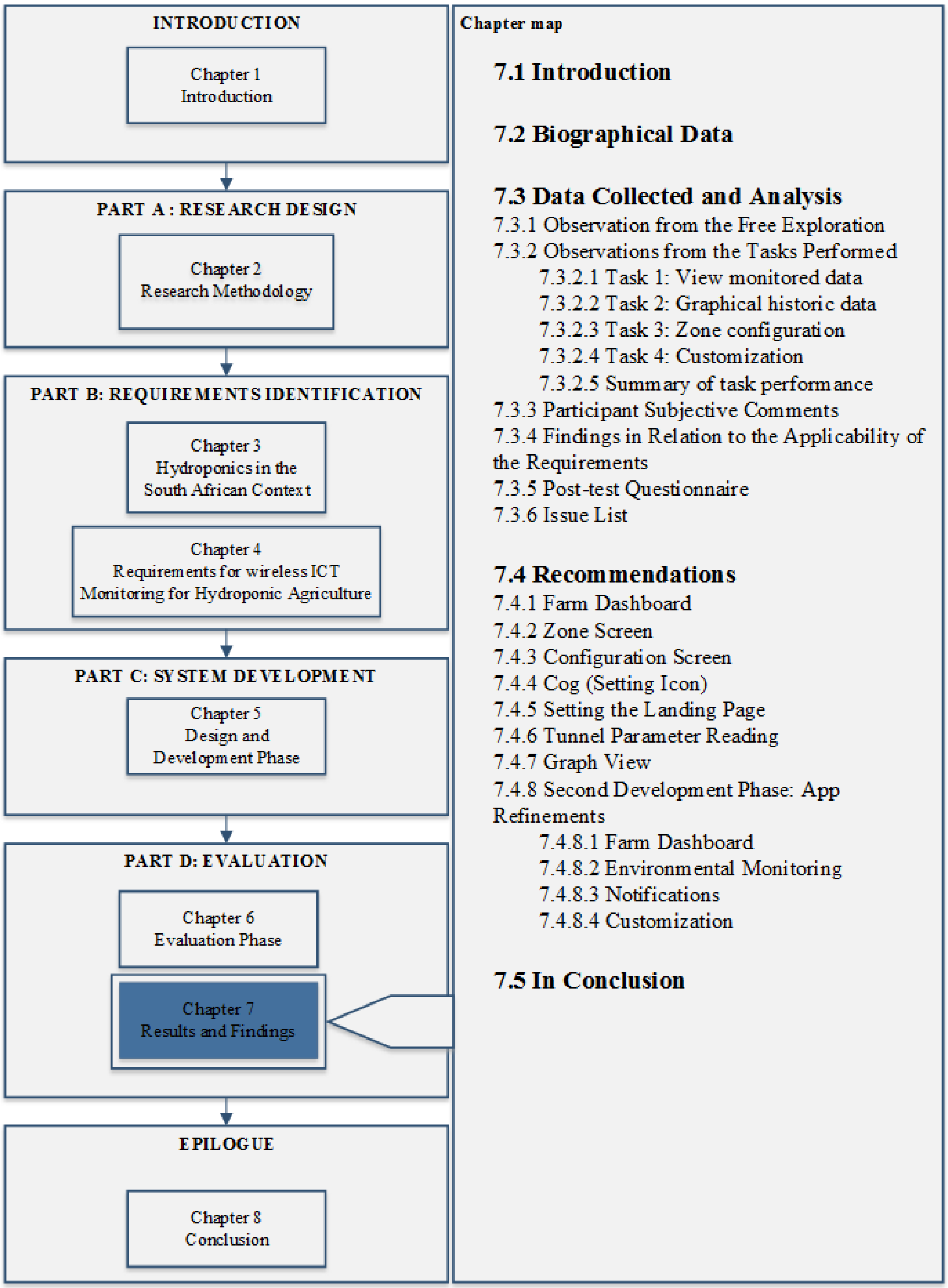
Non Critical errors: These errors are those that slow down the participant from completing the task efficiently. The participants are able to recover from the error and are still able to complete the task

Error-free rate: Error-free rate is the percentage of test participants who complete the task without any errors (critical or non-critical errors).

Additional information will be collected through observation and the think-aloud method. These metrics will be considered as benchmarks for comparison with the next iterations. Nonetheless, the researchers will take into account the overall time spent using the application and the time spent on each task. Clear deviations at appropriate times should be noted.

6.5 Summary

This chapter discussed the evaluation of the prototype developed in the effort to validate the interpretation of the requirements and to ascertain that the wireless monitoring system is both usable and adds value to the life of the farmer. After a description of the purpose of the test, the methods used to conduct the test were described. Expert reviews via the means of interviews with experts in the domain of hydroponic agriculture were used to evaluate the prototype. The interviews were conducted at the different farms to ensure that the testing environment is as close as possible to the real life context of use. The experts were selected following a set of criteria that ensures that not only are they considered experts in their field, but that they could also be potential users of the system. This chapter concludes with a discussion of the metrics used to analyse the results of the evaluation. The results obtained during the evaluation are presented in the next chapter.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Chapter 7

Results and Findings

7.1 Introduction

The previous chapter outlined the purpose and the method used during the evaluation as well as the analysis process and the metrics used. The purpose of this chapter is to present and analyse the findings of the application evaluation process. Qualitative and quantitative data describing the usefulness and the applicability of the application were obtained. Additionally, descriptive data was also obtained from interviews with experts The results of the evaluation of the app provide valuable feedback for the refinement of the application in the second phase of development of the application. This chapter presents the results consisting of the biographical data of the experts, the frequency count of the different metrics, the findings regarding the applicability of the requirements, and the interview comments on the usefulness and applicability of the app, as well as the recommendations provided by the experts during the evaluation.

7.2 Biographical Data

A total of six experts were interviewed. The biographical information of the experts is presented in Table 7.1.

A total of six experts were interviewed, all of them male. Every expert had experience in agriculture although the number of years of experience varied. The occupation of the experts also spanned across a wide spectrum. That variety was beneficial to the evaluation because it provided different points of view and approaches on the perceived benefit of the system.

All the experts had used a smartphone before for at least five months. However, two of the experts had never used a touch-based smartphone. The participants who had never

Participant	Gender	Occupation / role	Years of experience	Smart phone / OS	Duration of using Smartphone	Touch screen experience
P01	Male	Educator / Teacher (Agriculture)	8 years	Blackberry	6 years	No
P02	Male	Farm manager	35 years	Blackberry	4 years	No
P03	Male	Fertigation Technician	2 years	Sony Xperia, Samsung S3	6 months	Yes
P04	Male	Student IT	7 years (Agric Farm)	Blackberry	2 years	Yes
P05	Male	Farm Manager	20 years	Blackberry; IPad, Samsung	8 years	Yes
P06	Male	Trainee Irrigation Technician (University Student)	5 months	Blackberry; Nokia Lumia	8 months	Yes

Table 7.1: Biographical Data of Expert Participants

interacted with touch- based devices before were not hindered and provided data on what will be the expected reaction of a potential user who has not used either a smartphone or a touch-based device.

The next section presents the results of the interviews conducted with the experts.

7.3 Data Collected and Analysis

7.3.1 Observation from the Free Exploration

The free exploration of the app was performed before any task was assigned to the participants. The aim of the free exploration was to help the participants familiarize themselves with the application, but also to observe the elements that the participants found intuitive. The observations of the free exploration are reported in Table 7.2.

Participant	**Free navigation flow**	**Comments**
P01	Dashboard > Zone A >Tunnel 1 > Read variables	The participant mentions that the app has a clear screen and the layout is logical and easy to understand. He expects the app to allow him to increase zones depending on his farm and to be able to change label names to suite respective plants. Expects to be able to monitor parameters ranges from the app and get alerts when parameter vales are out of range.
P02	Dashboard > Zone A > Tunnel 3 > Read Variables Notifications; Configuration Icon; Dashboard > Zone A > Tunnel > Temperature > Graph View	User expects to alter controls from notifications. App should be interface connected to a programme to allow control. User asked what is that "Configurations icon". Graph is good; it shows the fluctuations. He noticed the intervals and parameters on the graph view. Wants the graph to be zoomable. The axis labels do not make sense. Colour is not too important. The participant mentioned that there is a need to record inside temp vs. outside temp, internal humidity vs. external humidity. EC in vs. EC out, Water in Water Out, pH in vs. pH out. Water level is not clear what it means.
P03	Dashboard > Zone A > Tunnel 1 > Temperature > Graph > Back (uses the device's back button) cog drop down	Colour does not matter. The user can easily relates to the terms as they are in daily use, the app is easy to navigate .There is a need to record inside temp vs. outside temp, internal humidity vs. external humidity. EC in vs. EC out, Water in Water Out, pH in vs. pH out. Water level on its own does not make sense at all
P04	Dashboard > Menu > Zone A > Tunnel 1 > Read variables > Back Dashboard > Notifications > Clear All > Delete Dashboard > Configurations Swipes menu left and right	Expected to find bottom menus and drop down menus on swipe. Likes that the menu glides, Easy to navigate, Green colour is appropriate for vegetation. Colour differentiation not clear "is it to show planted greenhouses , or the red shows that there is an alert in the zones". Participant mentioned that he has no idea what the configurations screen is meant to do
P05	Dashboard > Configurations	Notices that ABCD are greenhouse zones. Suggested the following flow Irrigation Controller > Zones > Tunnels. He wants to be able to assign Tunnels to Zones and Zones to Irrigation Controller The participant asked about water level, it is not clear what it meant. The participant tried to zoom the graph and mentions that the labels are not appropriate. Horizontal axis readings do not mean anything. The participant would like to configure the zones and give a relevant name. The colours are fine.
P06	Dashboard > Zone A > Tunnel 1 > Read variables > Graph view > Back (uses device's back button); Dashboard > Configurations > Cog > Landing page Dashboard > Configurations	The participant did not notice the notifications icon. He emphasised the importance of recording pH and EC. Participant did not quickly understand what "Electri Cond" meant. On the configurations screen the participant thought the min vs. max were readings of the minimum and maximum parameter readings.

TABLE 7.2: Free Exploration Summary

Most participants portrayed a lot of confidence while freely exploring the application as outlined by the extended navigation flow of participant P04 or P06. The participants also provided good feedback regarding the user interface and the processes of the app. Although this activity was done to prepare the participants for the rest of the task and to familiarise some of the participants with touch-screen technologies, the activity started proving that the learning curve of the application will not be a long one. This observation will be corroborated in the post-test questions described in Subsection 7.3.5.

7.3.2 Observations from the Tasks Performed

This section presents the analysis of results per task derived from the scenarios (see page 95). The analysis compares how each of the participants interact with the app against the ideal flow. Any deviation from the expected flow was noted. Also, the user errors are presented and categorised based on their severity. A section that outlined the comments for each task is also presented. Data analysis was based on the following metrics:
Task Completion

- Completed
- Completed with assistance
- Failed to complete

Errors

- Critical error
- Non critical error

Deviation

7.3.2.1 Task 1: View Monitored Data

Task 1 was derived from Scenario 1 . The aim of the task was to view real monitored data from a given tunnel. For this task Tunnel 1 in the Zone B was elected.

Ideal path: Farm Dashboard (Home)> Zone B > Tunnel 1
Table 7.6 summarizes the results of Task 1

Participant	Navigation flow	Task Status	Number of errors	Deviations
P01	Home > Zone B > Tunnel 1	Completed	0	0
P02	Home > Zone B > Tunnel 1	Completed	0	0
P03	Home > Zone B > Tunnel 1	Completed	0	0
P04	Home > Zone B > Tunnel 1	Completed	0	0
P05	Home > Zone B > Tunnel 1	Completed	0	0
P06	Home > Zone B > Tunnel 1	Completed	0	0

Table 7.3: Task 1: Performance of Participants

Task 1 was successfully completed overall. All six participants completed the task with satisfaction. There were no errors or deviation in the ideal path of completing the task. Every user reported the task to be very easy.

Participant	Comments of participants
P01	The task was easy, it was just click click click.
P02	It was easy to navigate the app.
P03	Everything was clear to me.
P04	All the information I needed was clear.
P05	Quite easily done. The user suggested adding another hierarchy (irrigation controller) in the flow.
P06	The task was easy.

Table 7.4: Task 1: Comments of Participants

All the participants during this task followed the ideal path intuitively, thus demonstrating that the process for this task satisfied their expectations. The participants reported that the task was clear and easy.

Viewing the monitored data is at the core of the usefulness of the HydroWatcher Mobile application. The fact the participants were able to, successfully and with ease, perform this task greatly impacts the acceptance of the application by the users but also demonstrates the adherence to the requirements.

7.3.2.2 Task 2: Graphical Historic Data

Task 2 was derived from Scenario 2. Here, the aim was to observe the historic monitored data from a given interval.
Ideal path: Farm Dashboard (Home)> Zone B > Tunnel 1 > Temperature> Graph View

Table 7.5 outlines the results of Task 2

Participant	Navigation flow	Task Status	Number of errors	Deviations
P01	Home > Zone B > Tunnel 1 > Temperature > Graph view	Completed	0	0
P02	Home > Zone B > Tunnel 1> Temperature > Graph view	Completed with assistance	1	0
P03	Home > Zone B > Tunnel 1 > Temperature > Graph view	Completed	0	0
P04	Configurations > Back > Notifications > Back > Menu > Gave up	Failed	3	0
P05	Home > Zone B > Tunnel 1 > Temperature > Graph view	Completed	0	0
P06	Home > Zone B > Tunnel 1	Failed	1	0

Table 7.5: Task 2: Performance of Participants

Three participants managed to complete the task successfully, one participant competed with assistance, while the other two failed to complete the task. The maximum number of errors by one participant is three while the least number is zero.

Participant	Comments of participants
P01	The user struggled with interpreting the horizontal axis values and said they are not meaningful. There is a lot of data that makes it difficult to interpret. The user did not notice the intervals.
P02	The user did not realise that the "Temperature" can be clicked.
P03	Everything was clear to the user .
P04	The user gave up. He failed to identify the option for viewing the graph.
P05	The readings on the graph are not clear. 1 - 59 what is that?
P06	The user did not notice that "Temperature" can be clicked and gave up.

Table 7.6: Task 2: Comments of Participants

It has been observed that those who failed to complete the task did not notice that the temperature section is clickable, or totally failed to figure out where the option for graphical view is located. All participants critically acclaimed the graphical visualisation as a feature. However, there has been negative feedback regarding the labelling of the graph and the time intervals used. The resolution made the readings difficult to decipher. Therefore, the recommendations will be to make clickable options more visible. Also, improvements should be made on the presentation of the graph.

7.3.2.3 Task 3: Zone Configuration

Task 3 from the third scenario aimed at configuring the environmental parameters pertaining to a zone.

Ideal path: Farm Dashboard (Home)> Zone A > Tunnel 2 > Configure> Press "Done"

Table 7.7 presents the results of Task 3

Participant	Navigation flow	Task Status	Number of errors	Deviations
P01	Home > Zone A > Tunnel 2 > Temperature > Graph view > Parameter > Intervals > Cog > Settings	Completed with assistance	6	0
P02	Home > Zone A > Tunnel 2 > Notifications > Gave up	Failed	1	0
P03	Home > Zone A > Tunnel 2 > Configure >Press "Done"	Completed	0	0
P04	Home > Zone A > Tunnel 2 > Configure > Press "Done"	Completed	1	0
P05	Home > Zone A > Tunnel 2 > Temperature > Graph view > Parameters; Cog > Settings; Menu > Notifications; Notifications icon	Failed	5	0
P06	Home > Zone A > Tunnel 2 > Configure	Completed	1	0

TABLE 7.7: Task 3: Performance of Participants

Three participants completed the task successfully, two failed to complete while one managed with assistance. There were no deviations observed for this task. However, this is related to the fact that the participant either completed the task or just failed the task. Additionally, there were 14 errors observed from all the participants, with six errors being the maximum numbers of errors from a single participant and the minimum number being one.

Participant	Comments of participants
P01	The participant says it would have been better if he saw a spanner for settings. It has been observed that the participant struggled with the process of inputting numbers.

Participant	Comments of participants
P02	The user gave up. He realised he had seen the screen during free exploration of the app, but could not recall how he got there. After being shown the user noticed the Done button and confirmation that the changes had been saved.
P03	The task was not difficult to perform .
P04	The user initially forgot to use the Done button but realised and rectified. The user noticed the feedback message that the configurations had been saved. "No idea what the gear meant; it was guess work".
P05	There is nowhere that indicates an option for configuring parameters. The participant pointed out inconsistency in the user interface as some screens have setting options while others do not. Having settings on the cog as well as an icon is confusing.
P06	The participant missed the done button.

Table 7.8: Task 3: Comments of participants

Three participants followed the ideal path intuitively. The other half deviated from it indicating that the process was not as clear as intended and needed to be refined.
Some users were confused by user interface elements. The following issues were observed during task performance: the settings icon has proved to be difficult to recognize and match the mental model of the users. There is inconsistency as some screens have the configuration icon while others do not display it. Some users were able to get to the screen concerned in this task , but admitted to not being able to remember how they got there on the previous attempt.

7.3.2.4 Task 4: Customization

Task 4 derived from Scenario 4 has as objective customizing the app by modify the default landing page of the app.

Ideal path: Setting Cog> Settings > Landing Page > Select "Zone B" > Exit app > Open app
Table 7.9 presents the results of Task 4

Participant	Navigation flow	Task Status	Number of errors	Deviations
P01	Cog > Settings > Landing Page > Zone B > Exit App > Open App	Completed	0	0
P02	Home>Zone B>Back> Home; Cog> Settings > Landing Page> Zone B > Exit App > Open App	Completed	1	0
P03	Home > Zone B > Cog > Settings > Back; Configure > Back ;Notifications > Back;Cog > Settings >	Failed	5	0
P04	Menu;Cog> Settings;Home > Zone B > Configurations;Cog > Settings;Gave up	Failed	5	0
P05	Home > Zone B > Configurations; Cog > Settings > Landing Page	Completed	1	0
P06	Home > Zone B > Gave up	Failed	1	0

Table 7.9: Task 4: Performance of Participants

Three participants managed to complete the task successfully, while the other three failed. Yet again on this task no deviation was observed since the participants either completed or completely failed the task. Errors were committed both by participants who completed or who failed the task. The maximum number of errors committed by a single participant was five and the minimum number was one.

Participant	Comments of participants
P01	The user completed the task without knowing that he had finished. There is no option for applying changes or confirmation messages that settings have been saved. The user was left wondering whether the task was done or not.
P02	How do I save and see that the changes have been applied?
P03	The user expected to see the save button. The user did not understand the term "Landing Page".
P04	The user gave up. He failed to interpret what "Landing page" on the settings meant.
P05	It was easy to complete. There is no option to apply the settings or feedback that the configuration has been set.
P06	The user would like to be able to close the Zone at the Home Dashboard. Also, notifications should indicate which Zone they occurred in.

TABLE 7.10: Task 4: Comments of Participants

This task proved to be a difficult one to complete besides yielding split results. The completion time was longer than anticipated, for those participants who managed to complete the task successfully. Personalizing the landing page has been highly appreciated by most users as they said it is important for them to be able to customise their view, add more zones and be able to assign tunnels into different zones. On the minus side, the screen for settings preferences does not have an option for applying the settings and also does not have a confirmation feedback to give the users that their configurations have been applied. The next section will provide a summary of the outcome of all the tasks undertaken by the participants.

7.3.2.5 Summary of Task Performance

The results of all the activities performed by the participants have been recorded in Table 7.11. The table summarizes the performance per task of each participant.

Participant	Task 1	Task 2	Task 3	Task 4
P01	Completed	Completed	Completed with assistance	Completed
P02	Completed	Completed with assistance	Failed	Completed
P03	Completed	Completed	Completed	Failed
P04	Completed	Failed	Completed	Failed
P05	Completed	Completed	Failed	Completed
P06	Completed	Failed	Completed	Failed

Table 7.11: Summary of Task Performance

Summary of Errors

The performance varied among the six participants. All the participants managed to complete Task 1 without any error or deviation from the ideal path. Three participants completed Task 2 successfully; one completed the task with assistance, while two failed to complete the task. The total number of errors registered for Task 2 is five with a single participant committing three of them. The minimum number of errors committed was zero while the maximum number of errors was three. Task 3 was completed by three participants while two participants failed to complete the task and one participant complete with assistance. The minimum number of errors in Task 3 was zero and the maximum was six. In Task 4 , three participants completed the task successfully while the other three failed. This proved to be the most difficult task. The task registered five errors as the maximum number of errors committed by a single participant. The minimum number of errors was zero. Figure 7.1 depicts the errors committed by each participant per task.

The next section outlines all the subjective comments that were generated by the participants, leading to the outline of the issues observed during the evaluation and the recommendations pertaining thereto.

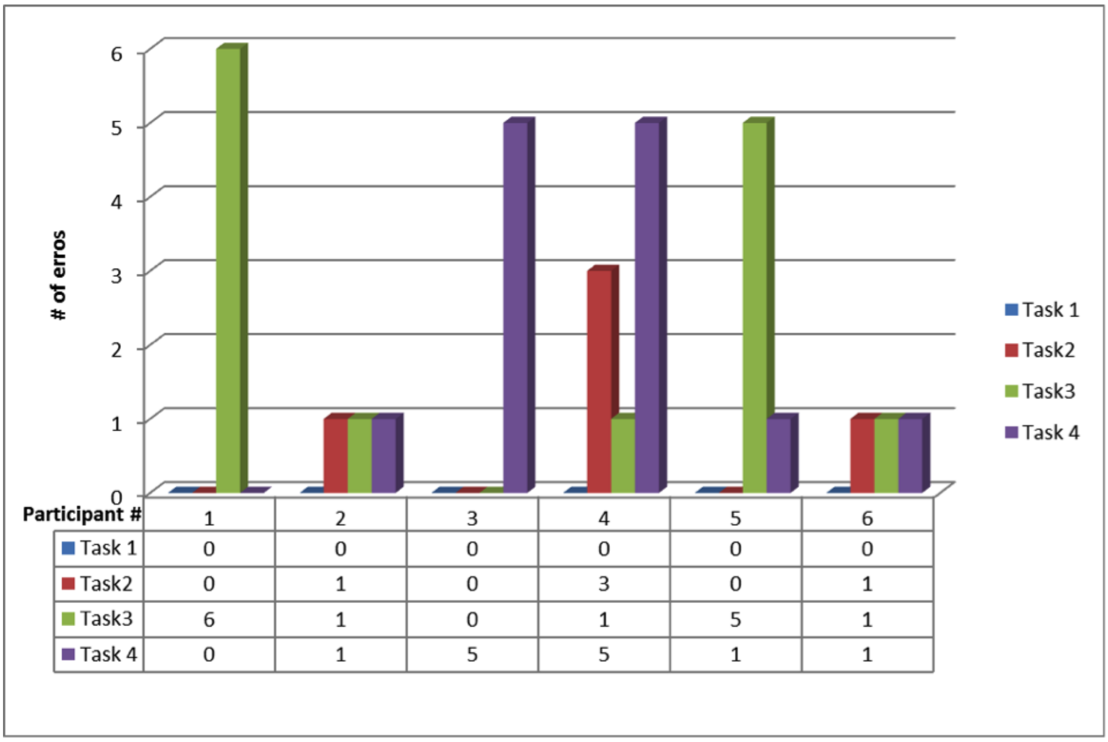


FIGURE 7.1: Summary of Errors

7.3.3 Participant Subjective Comments

Throughout the evaluation, the participants were probed to comment on the app as they were performing the tasks. The main purpose of the tasks was to validate the applicability of the requirements (Presentation layer) on the user interface of the app. Moreover, the tasks also assessed the ease of use of the app. The following paragraphs present the findings from the evaluation based on the qualitative descriptive data that was gathered (Think aloud protocol).

P01:

The participant managed to identify and relate to zones and tunnels and indicated their exploration was intuitive.

The user did not easily understand the three vertical dots for menu. The icon for Settings confused the user; instead he suggested the use of a spanner icon clearly labelled Settings.

The layout of the app was found to be “clean, clear and easy to navigate”.

It was difficult for the participant to identify the option for configuring parameters both in the tunnel and at zone level.

The participant easily noticed the Notification icon and commented that it was easy to identify because of the red colour used. It is similar to other applications that he knows, also the number near it makes it easy to know the number count of notifications.

The term "landing page" was not easily understood but the participant noted that it is important to be able to customise the app to meet personal preferences.

P02:

The participant commented that grouping of Zones makes it easy to navigate to the various tunnels. The notification "Alarm" icon was easily noticed and the participant commented that the colour is good and the number "3" close to the icon shows how many notifications there are.
The Settings icon was not familiar to this participant.
He liked the graphical representation, though the numbers on the horizontal axis are vague and do not mean anything to the participant.
The participant found it easy to navigate within the app.
The participant commented that colours are not important; what matters most is the functionality of the app.
The participant expected to be able to make rectifications to the notifications from the app.
What does "water level and Elec. Conduct" mean?
The participant noted that there is no feedback after changing the settings. It was easy for the participant to navigate from one screen to another.
He did not understand Min and Max in the configurations screen; the participant interpreted that the screen is showing the maximum and minimum recordings. It was difficult too for the participant to input min and max values on the configurations screen.

P03:

Initially, the participant assumed that the purpose of the app is to teach him how to farm.
The participant managed to identify and understand the groupings of tunnels into zones.
This participant said he found navigation within the app was done with ease .
The participant was familiar with the sidebar menu and the three vertical dots for menus.
The participant expected to find an option to save the configurations after making changes to the configurations screen and after setting the landing page.
The term "Elect. Conduct" was not understood by the participant. The participant inquired what "water level" meant.

P04:

The participant expected to slide between the different tasks. He easily noticed the Notification icon and on notification listing. The participant liked the confirmation before deleting the notification.
The Delete icon was well understood by this participant.

He liked the sidebar menu and did not struggle to use this feature.
The participant failed to change the values on the configurations screen. Initially, the participant thought that the feature was to display the minimum and maximum values for the parameters.
The term “Landing page” was not understood.
The participant indicated that he would want an option that allows them to configure the app and customise their preferences.

P05:
The participant suggested that the letters A, B, C, D should indicate irrigation controllers and zones will be assigned to irrigation controllers while tunnels will be assigned to the zones.
Water level does not make sense in terms of what it means.
Graphical presentation showing the fluctuations in parameters makes it easy to read; however, the intervals on the graphs are not labelled and can be hardly understood, there is need of clear labelling of the horizontal axis.
The use of green colour is good and is associated with vegetation; however, the app is inconsistent regarding the use of colour. The colour is only used on the landing page and the rest of the pages look blunt.
The participant indicated that he would like to be able to change the names used on the zone names to suit what he wants.

P06:
The participant understood the zones and grouping of tunnels with their respective parameters. Setting preferences to the desired “Landing page” confused the user; the term “landing page” was not easily understood.
The user did not understand what “Elect. Conduct.” means.
On the Configurations menu, the user misunderstood “Min and Max” to mean the minimum and maximum values recorded by the system.
After changing configurations the participant expected to find an option to save at the bottom and a confirmation message to say that the settings have been successfully saved.
The parameter “water level” was found to be confusing and it was not clear what it meant.
The participant understood the red icon for alerts to mean that there is a warning and the number “3” indicates the number of warnings. Red colour made it easy to notice that something was wrong. The participant easily picked the Settings icon and said it is similar to other applications that he has used.
The placement of the Settings icon close to the three dots menu made the screen cluttered.

Overall, HydroWatcher mobile app was well received by the participants. They indicated that they were content with the information architecture, the simple navigation, and the overall layout of the app. The app received good ratings on its perceived ease of use, usefulness, and was found easy to navigate.

However, some issues were uncovered through the qualitative feedback of the participants. Some elements of the user interface, such as colour codes, were interpreted differently. Some participants did not notice that some textual list items were clickable or they failed to understand the meaning of some icons.

Furthermore, participants pointed out the lack of system feedback after changing some settings. Also, terms such as "landing page" , "Elec. Conduct." Or "water level" were not promptly understood by all the participants. Finally the labelling of the graphical visualization of the parameters and the intervals used coupled to the lack of readability of the values generated negative feedback from the participants.

Those comments were gathered throughout the execution of the tasks. The participants were observed as they performed the tasks and some observations noted were taken during the test. Moreover, video recordings of the interviews were consulted for further analysis of the interaction of the participants with the app (see Appendix E). Thus, the task performance, the think aloud comments of the participants, and the video recordings where triangulated using in vivo coding techniques. The data analysis aims at validating the applicability of the requirements from the presentation layer that the user interface followed. The validation of the requirements is presented in the next subsection.

7.3.4 Findings in Relation to the Applicability of the Requirements

The aim of the evaluation was to establish the applicability of the requirements in the context of South Africa through the app. HydroWatcher mobile app could also be associated with the presentation layer of requirements. The observations made while the participants were executing the tasks, as well as the comments provided by the participants, testify to the applicability of the requirements. The findings relating to the presentation layer requirements are as follows:

HCI 1.1 Text: Minimize reliance on text: The app had very minimal text and the participants commented that they found the app to be easy and clean to interact with it. Also, the app presented text in the form of labels like names of zones, tunnels and parameters, so as not to remove all text, and these were well understood by the participants. Additionally, the text was complimented with icons and colour to improve interpretation. For instance, the Notifications icon was colour-coded red and the participants appreciated that as they said it captured their attention.

HCI 1.2 Graphics: Use relevant icons : Icons like the "delete" and "bell" for alarms were easily understood by the participants. These items are familiar to the users. The use of a "gear" icon to represent Settings did not match the mental models of the participants; instead some of those suggested that they are more familiar with the use of "spanner" icon for Settings. Those observations validated the need to use icons that will be relevant to the potential users.

HCI 1.3 Voice and Audio: This requirement was not implemented in the prototype

HCI 2.1 Help users gain confidence with technology: The participants reported that the application was very easy to use especially with navigation and the click processes that were straightforward.

HCI 2.2 Avoid complex interaction styles: The app interaction style consists of single tap and sliding of the main menu. All the participants found it easy to interact with the app and they mentioned that the app was easy to navigate. However only one participant managed to discover that the menu can be swiped to expand and collapse it. This validated the fact that complex interaction styles should be avoided.

HCI 3.1 Use linear navigation: The participants found the app to be easy to navigate and it was easy for them to return to previous screen or home screen whenever they felt stuck or lost. ("The task was easy, it was just click, click, click")

HCI 3.2 Encourage interface exploration: Some processes in the app did not provide appropriate feedback when the participants completed a task. The notable instance is the customisation task during the evaluation. This left the participants wondering whether they had executed the task properly. Most users welcome a confirmation or warning message when they are about to perform a critical task. That gives them the assurance that the app will prevent them from making mistakes. The confirmation message ,or in this case the lack thereof, discourages the users from exploring the app with confidence. .

HCI 3.3 Keep the screens simple and limit the number of tasks: The app was designed in a way that each screen represented a single task. This contributed to the participants finding the app easy to use and understand. Also, it led to minimal memory load.

HCI 3.4 Avoid scrollbars: The participants struggled with the use of scrollbars when they were scrolling down the configurations screen during the evaluation.

HCI 3.5 Use real-life metaphors to explain foreign concepts: The native "bin" and "bell" icons were used to delete and denote notifications. These were easily associated by the participants as they related to common real-life metaphors that are familiar to them.

HCI 4.1. Use familiar language: Most of the terms used in the HydroWatcher mobile app prototype matched the expectations of the participants. Terms like "pH", "Temp" (temperature abbreviated), "humidity" were well understood by the participants. However, terms like "elec. conduct." (electrical conductivity abbreviated) or "water level" were not easily understood by the participants and caused confusion. This confirms that the terminology used should be common for the context in which the application is to be used.

It was argued in Chapter 5 that the presentation layer was the key to the acceptance of the system. Satisfaction with the use of the system was delivered through the user interface of the system (see page 80). The presentation layer also adds a significant impact to the requirements of the other layers. Therefore, having validated the applicability of the presentation layer in the context of South Africa, the same can be expected from the other layered requirements. However, further studies would have to be conducted to confirm the applicability of the other layers totally. The purpose of evaluation was also to unearth the usability and learnability of the app. Those findings are outlined in the next subsection.

7.3.5 Post-test Questionnaire

The post-test questionnaire comprises questions that were designed to unearth the potential benefit of the app as well as the usability and learnability of the app. For each statement, the participants were asked to provide an answer in the Likert scale illustrated in Table 7.12. This section discusses the data gathered from each statement.

Strongly Disagree				Strongly Agree
☐	☐	☐	☐	☐
Option 1	Option 2	Option 3	Option 4	Option 5

Table 7.12: Post-test questionnaire answer options

Statement 1: I think that I would like to use this system frequently.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 5	Option 4	Option 5	Option 5	Option 5

Five participants selected Option 5 and one selected option 4. All participants agreed that they would be able to use the app on a regular basis. This observation means that this app can be a companion to the farmer and be used frequently on the farm or elsewhere.

Statement 2: I found this system unnecessarily complex.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 1	Option 1	Option 2	Option 3	Option 1	Option 1

The majority of participants (four) stated that the app is not complex. This observation is corroborated by the observation made in the next statement.

Statement 3: I found this system was easy to use.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 5	Option 4	Option 3	Option 4	Option 3

Two participants selected Option 5, two selected Option 4, and two selected Option 3. The participants agreed that the mobile app was easy to use and that the mobile app did not appear to be complex. The gathered responses were very encouraging, when considering the fact that some participants had very low to no exposure to touch-screen smartphones. The ease of use of the app and its lack of complexity can be translated into an acceptance of the processes and navigation of the app by the participant, therefore pointing to the usability of the app.

Statement 4: I think that I would need assistance to be able to use the system.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 3	Option 1	Option 4	Option 2	Option 2

One participant selected Option 5, one selected Option 3, one selected Option 1,one selected Option 4, and two selected Option 2. Half of the participants deemed themselves not needing assistance in using the app. One is undecided and the other two says they will require some assistance in using the app. This observation was expected owing to the profile of the participants. Some participants at the time of the evaluation test had no touch-screen experience. Additionally, the participants that stated they would need assistance also stated that it would only be for the first few days after starting to use the app.

Statement 5: I find the various functions in this system were well integrated.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 4	Option 5	Option 3	Option 3	Option 5

Four participants thought that the app functions were well integrated. Two of the participants were undecided on the issue. One participant did not understand the question and asked for further explanations and then took a neutral stance.

Statement 6: I thought there was too much inconsistency in this system.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 1	Option 1	Option 2	Option 1	Option 2	Option 1

Four participants selected Option 1 and two selected Option 2. The participants stated that they were no inconsistencies in the app.

Statement 7: I would imagine that most people would learn to use this system very quickly.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 5	Option 4	-	Option 5	Option 2

The participants were asked if the application was quick to learn. Every participant agreed that the app was quick to learn with one exception that disagreed. Nonetheless, when considering that some participants had had low exposure to touch-screen devices, the information gathered validated the choices made and the requirements gathered.

Statement 8: I found this system very cumbersome/awkward to use

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 1	Option 1	Option 2	Option 2	Option 1	Option 1

All participants thought that the system is not cumbersome or awkward to use. This relates to the presentation of the system not being foreign to the mental expectation of the user. The language used, the navigation model, as well as the iconography were found suitable to the participants. That premise thus validates the applicability of the presentation layer requirements.

Statement 9: I felt very confident using this system.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 4	Option 3	Option 1	Option 3	Option 4	Option 4

Three patients selected Option 4, two selected Option 3, and one selected Option 1. Generally, the participants felt confident about using the app. That also speaks to the advantages of the UCD approach. Using a UCD gives a sense of ownership of the processes to users when they recognize some of the processes that they recommended during the design and seeing that their needs have been met, boosts their confidence while handling the app

Statement 10: I needed to learn a lot of things before I could get going with this system.

Participant:	P01	P02	P03	P04	P05	P06
Response:	Option 5	Option 1	Option 1	Option 2	Option 2	Option 2

Every participant with the exception of one agreed that the learning curve of the application is a short one. That tell to the researcher that the app appeals to the users and was designed for farmers. With the sum of information gathered from post-test questions, it can be argued that the participants found the app to be usable and easily learnable. Those results translate then to a positive user experience from the participants when handling the application.

The data gathered from the different tasks, the subjective comments, and the post-test questionnaire led to a number of issues arising that need to be addressed in order to satisfy the requirements gathered. The next section outlines those issues.

7.3.6 Issue List

This section outlines the issues that were observed with the prototype mobile app during the evaluation. The issues listed here are presented with the requirements to which they are not fully abiding.

HCI 4.1. Use familiar language:

- The language and terminology used in the system must be such that the users are familiar with. In the evaluated design many participants did not understand the meaning of "Water level" and "Elec. Conductivity" and to some extent the term Landing Page was also problematic.
- The labelling of the graphical visualization, the interval used the lack of readability of the values also raised some negative feedback. This confirms that the terminology used should be common in the domain in where the application is targeted to be used.

HCI 1.2 Graphics:

- Colour should map to the mental expectation of the user: The farm dashboard presented colours that generate a different number of interpretations from participant to participant. That confusion should be avoided.
- The interface should present culturally relevant icons to the user and should be accompanied by captions: : two icons were used to describe two different sets of settings. This turned out to be confusing because the users were more familiar with one icon that they immediately associated with a menu (the three android square), but the cog was not understood well or was said to be a setting icon.

NFR 06 Every user action should be accompanied with relevant feedback: TThe users were left wondering if the changes made to the settings after selecting the landing page had been implemented. The application should present appropriate feedback to the user.

The next section outlines the specific recommendations provided by the participants. These recommendations address specific items that can be mapped to the aforementioned issues.

7.4 Recommendations

The sources of the following recommendations are the results of the test, the notes of the facilitators and their observations during the test sessions of the evaluations, as well as the comments of the participants and the analysis of the video transcripts. The recommendations pertain to the different screens and user interface elements of the app.

7.4.1 Farm Dashboard

Colour coding: It has been observed that different users have different interpretations with respect to colour coding on the name labels of the Zones. Some interpreted the used of the colour red to indicate that there is an alert, while others interpreted that red means that the Zone has plants. The recommendations is therefore that all labels should be of the same colour or should remain consistent with respect to the use of colour throughout the app.
Zone Configurations: Each zone should have an option that allows the user to tap and configure its parameter; also edit to the name of the zone according to user preferences.
Alerts: Alerts should be categorised in respective zones. A Zone that is having an alert should have a notification icon indicating such.

7.4.2 Zone Screen

The users, during the evaluation, encountered some difficulties and the following recommendations thus emerged:

- The zone screen should have an option for configuring Tunnels at parameter level.
- The configurations (Settings) "cog" icon confused the users, some preferred using "the three squared dots" for Settings configurations.
- Configuring Tunnel settings has proved to be difficult for most users. The option should be moved to the top in the Tunnel parameters screen in the form of a button or any other visible user interface element.
- The notification consists of two parts: a bell and an enclosed number indicating the number of notifications. It was observed that the parts of the notification icon look

separated and disjointed. Thus, as a recommendation the two should be brought close together for association.

7.4.3 Configuration Screen

IInputting numbers makes the users prone to mistakes. A number spinner with predefined expected formats of numbers should be used instead. The text entry field should be white with a grey border. This will increase the text field visibility.

7.4.4 Cog (Setting Icon)

The Landing page and Parameter filter should be grouped under the Cog representing the icon for Settings as a setting option. This is more understandable to the users.

7.4.5 Setting the Landing Page

The users were left wondering how to apply the settings after selecting the landing page. Also, there is no feedback to make the user aware that those settings they have applied have been done. When the user navigates from the Settings page after making changes without saving, the app should give a message that the changes will not be effected.

7.4.6 Tunnel Parameter Readings

The users indicated that it would be valuable to have readings for internal temperature and external temperature, water in and water out, internal humidity and external humidity, EC in and EC out, pH in and pH out. This way the readings maps well to the mental models of the users as in their daily application in the hydroponic farm set-up.

7.4.7 Graph View

The users preferred to interact with the graph by zooming it. The horizontal labelling is too squashed and users prefer either viewing the variables per hours or days depending on the interval that has been selected.

Following the philosophy of UCD, the recommendations were taken into account in a next development iteration to produce a design solution that is contextually relevant and providing a positive user experience to the target audience. Those changes were implemented in the second development phase of this study as indicated in Chapter 5. The second development phase is discussed in the next subsection.

7.4.8 Second Development Phase: App Refinements

The second phase of development pertains to the refinement of the app following the evaluation that was conducted with the hydroponic experts. The comments and recommendations that were provided by the hydroponic experts are the basis upon which the app was remodelled. The previous features were not removed, but additional options were added to expand the overall functionalities of the app. The added features improved on the usability and overall user experience that the user could expect from using the app.

The following section describes the improvements to the app as applied in the second development phase.

7.4.8.1 Farm Dashboard

During this iteration, the evaluation revealed that the farm dashboard in its previous form presented some user interface elements that were unclear to the user. The most notable user interface element is the colour coding used on the farm dashboard. The use of the colour red in some portions of the zone panel was widely interpreted. Moreover, during the evaluation, it was recommended that each zone should be configurable and that multiple zones could be added to the dashboard if the need arises. Finally, the alerts should be indicated in the zone to which they pertain.

Figure 7.2 illustrates the design applied to the dashboard in the second phase of development.

The cog in the zone pane reflects the alteration recommended. This leads to the configuration of the zone and the bell leads to the notification.

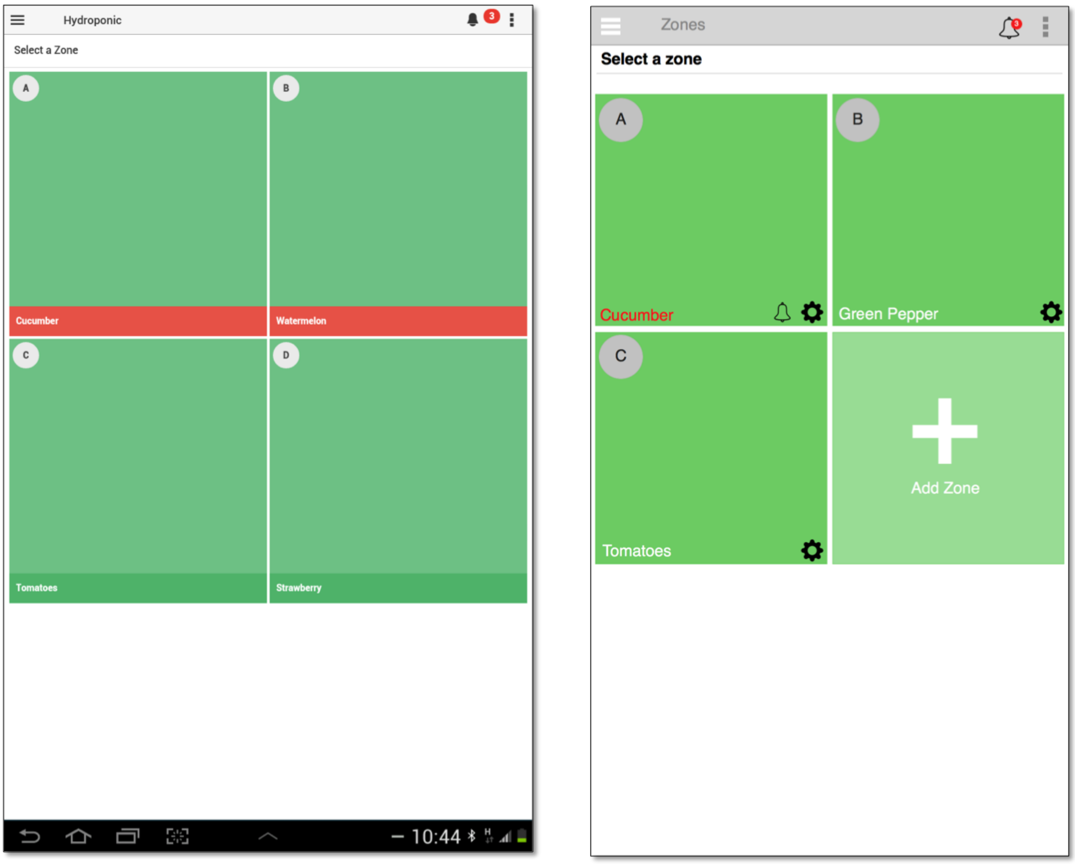


FIGURE 7.2: Farm Dashboard Redesign ($1^{st}/2^{nd}$ phase)

7.4.8.2 Environmental Monitoring

Zone screen: A more visible and accessible way of getting to the configuration screen was added in the form of a button on top of the zone screen and on top of the tunnel screen for the configuration of the zone and the tunnel. Figure 7.3 illustrates the changes made to the app regarding that aspect.

Real time monitoring of environmental criteria

The real time parameter presented a lexical challenge. Some of the terms used were not clearly interpreted. The recommendations were to change the terms and to add some of the missing critical factors. In the previous phase, the environmental factors featuring in the app were the temperature, the humidity, the water level, the pH and the electrical conductivity. Electrical conductivity was abbreviated in the design as "Elec. Conduct." and was not understood by the participants. It was actually perceived that the abbreviation EC is better understood than the one used and even more meaningful than what EC actually means: electrical conductivity. As a correction, the term electrical conductivity is coupled with the abbreviation EC.

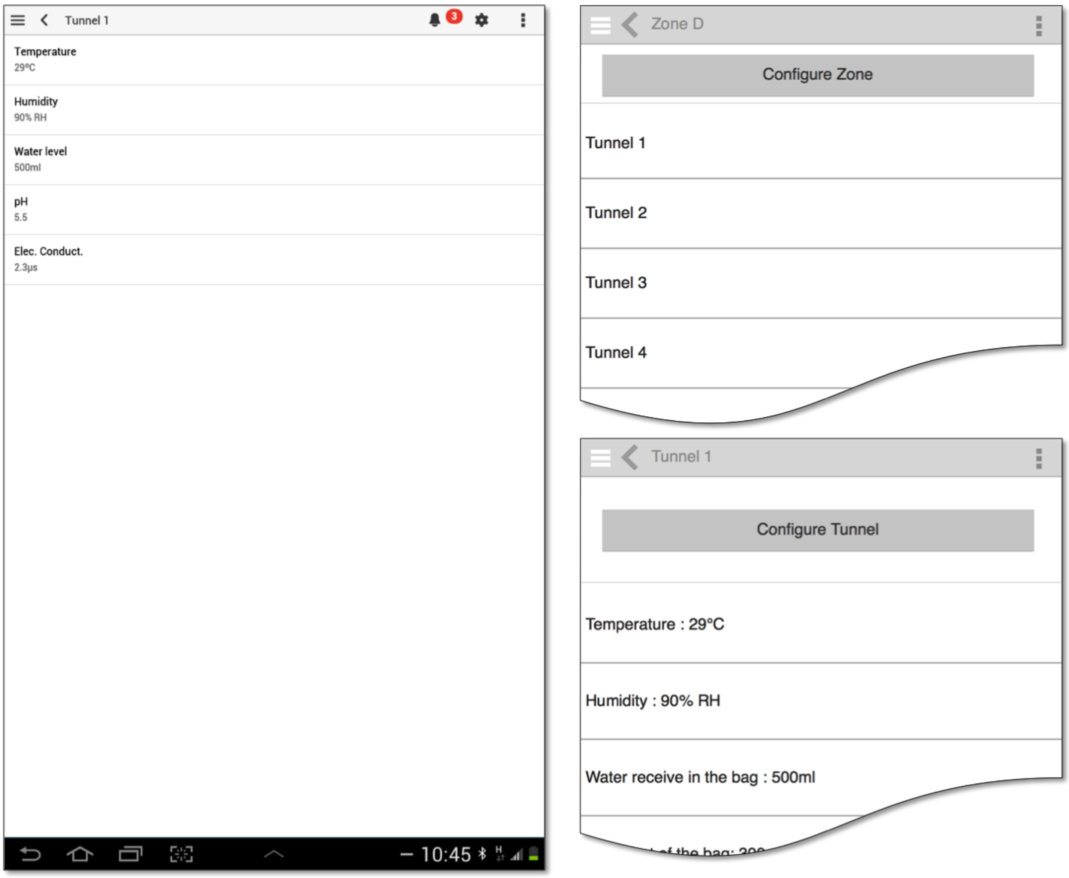


FIGURE 7.3: Zone and Tunnel Configuration Access ($1^{st}/2^{nd}$ phase)

The term "water level" was also misunderstood and the terms "water in" and "water out" were used on some farms while other farms prefer a brief description of the factor being monitored. "Water level" was thus removed and broken down into to factors: "Water received in the bag" to capture the water received by the plant and "Water out of the bag" to indicate the results of the water drained out of the bag. Figure 7.4 illustrates the changes implemented in the real time monitoring features.

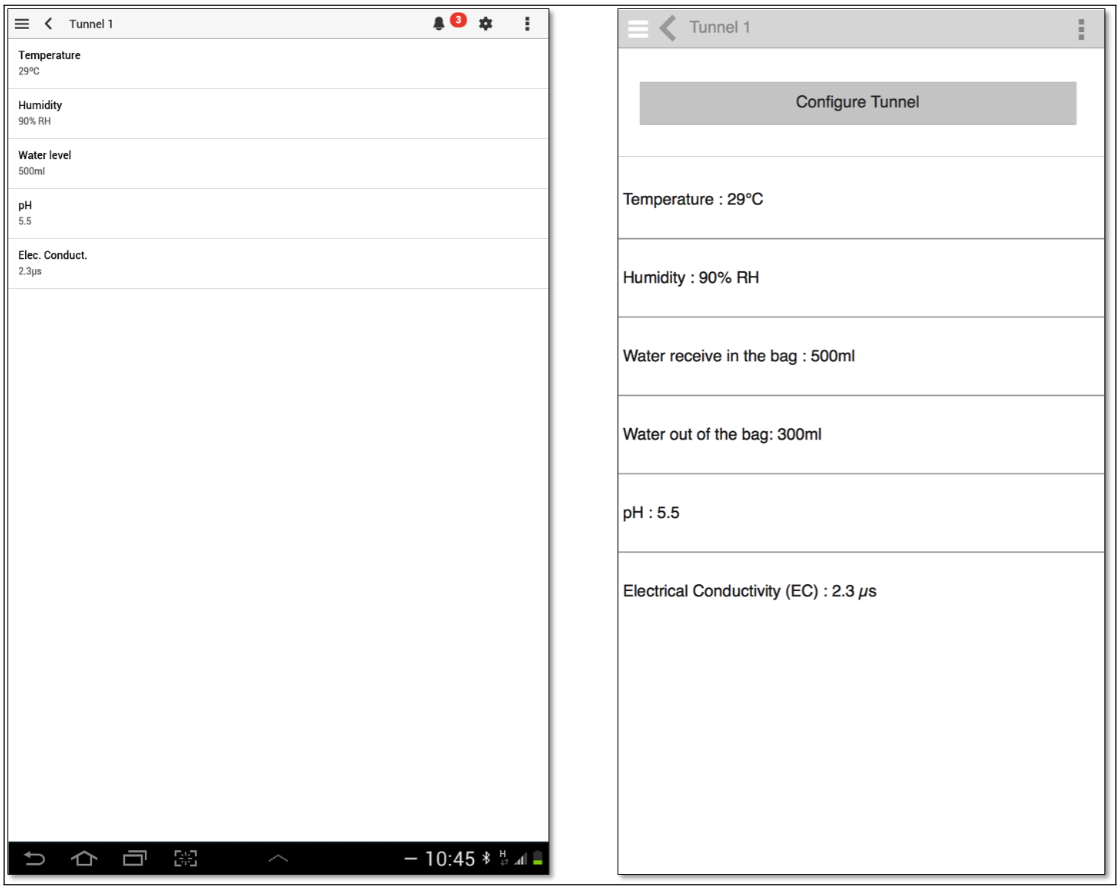


FIGURE 7.4: Real Time Monitoring Redesign ($1^{st}/2^{nd}$ phase)

Graphic view

The graphic view is a feature of the historic environmental monitoring. It provides a graphic view of the past status of any factor being monitored. In the previous design the graph was confusing. As such, the graph was redesigned as follows in Figure 7.5.

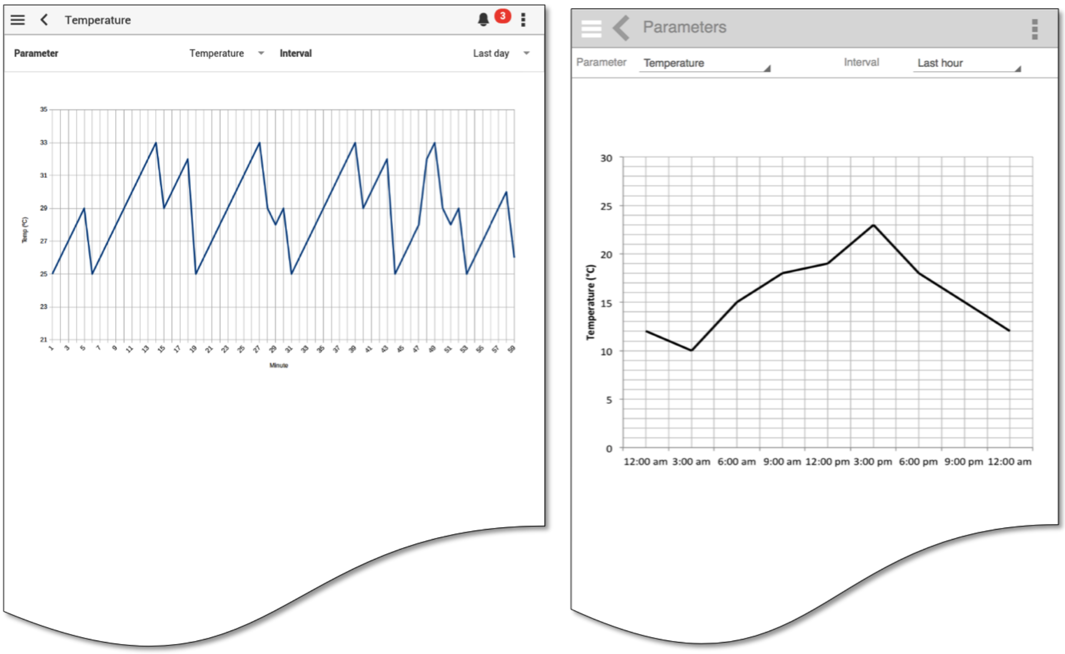


FIGURE 7.5: Graph View Redesign ($1^{st}/2^{nd}$ phase)

7.4.8.3 Notifications

The notification features remains as previously designed (see Figure 5.5) with the exception of the icon that leads to the notification screen. The icon consisted of two different parts: the bell and the number of pending notifications. Owing to the gap between the two parts, the participants interpreted those as two separate icons. The icon was thus redesigned as illustrated in Figure 7.6.

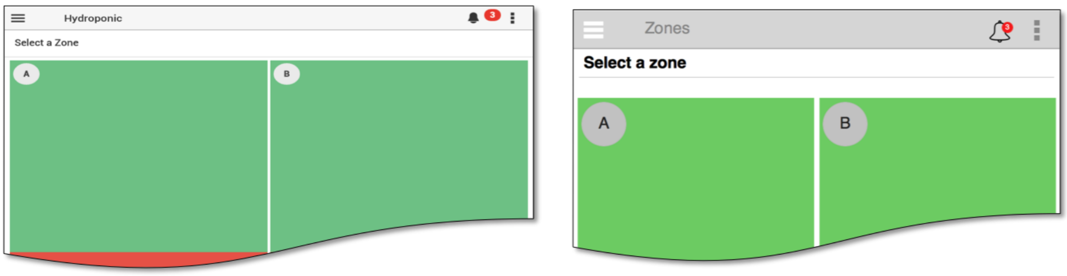


FIGURE 7.6: Notification Icon($1^{st}/2^{nd}$ phase)

7.4.8.4 Customization

Landing page: In the previous design, confirmation was not provided to the users to ensure them that the customization envisioned had taken effect. Upon saving any critical action, the app will now provide a confirmation, such as illustrated in Figure 7.7. When the user presses Done the confirmation message (in green) appears.

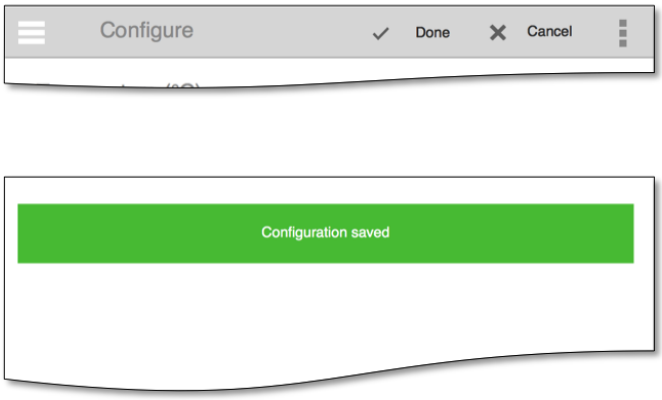


FIGURE 7.7: confirmation

Parameter adjustment and Parameter filtering: The users were able to adjust the minimum and maximum settings of factors being monitored. However, a recommendation was made to add a spinner to simplify the way the values are adjusted. That is illustrated in Figure 7.8. Not all criteria are relevant to a farm, whether seasonally or entirely.

FIGURE 7.8: Spinner

To cater for that premise the app features the possibility to switch on and off the visibility of a parameter. Once a parameter has been filtered no notifications pertaining to the criteria will be pushed to the user. That feature is outlined in Figure 7.9 by the “on and off” switch.

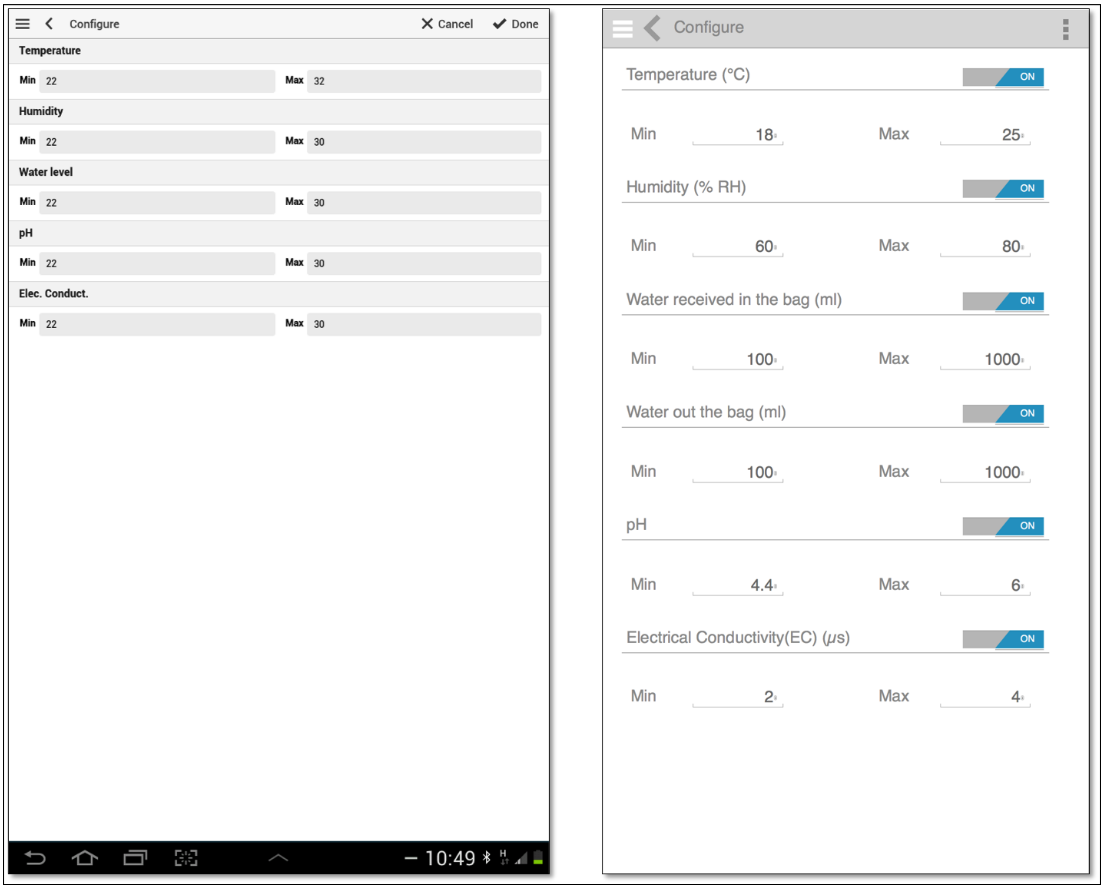


FIGURE 7.9: Parameter Filtering and Adjustment($1^{st}/2^{nd}$ phase)

7.5 In Conclusion

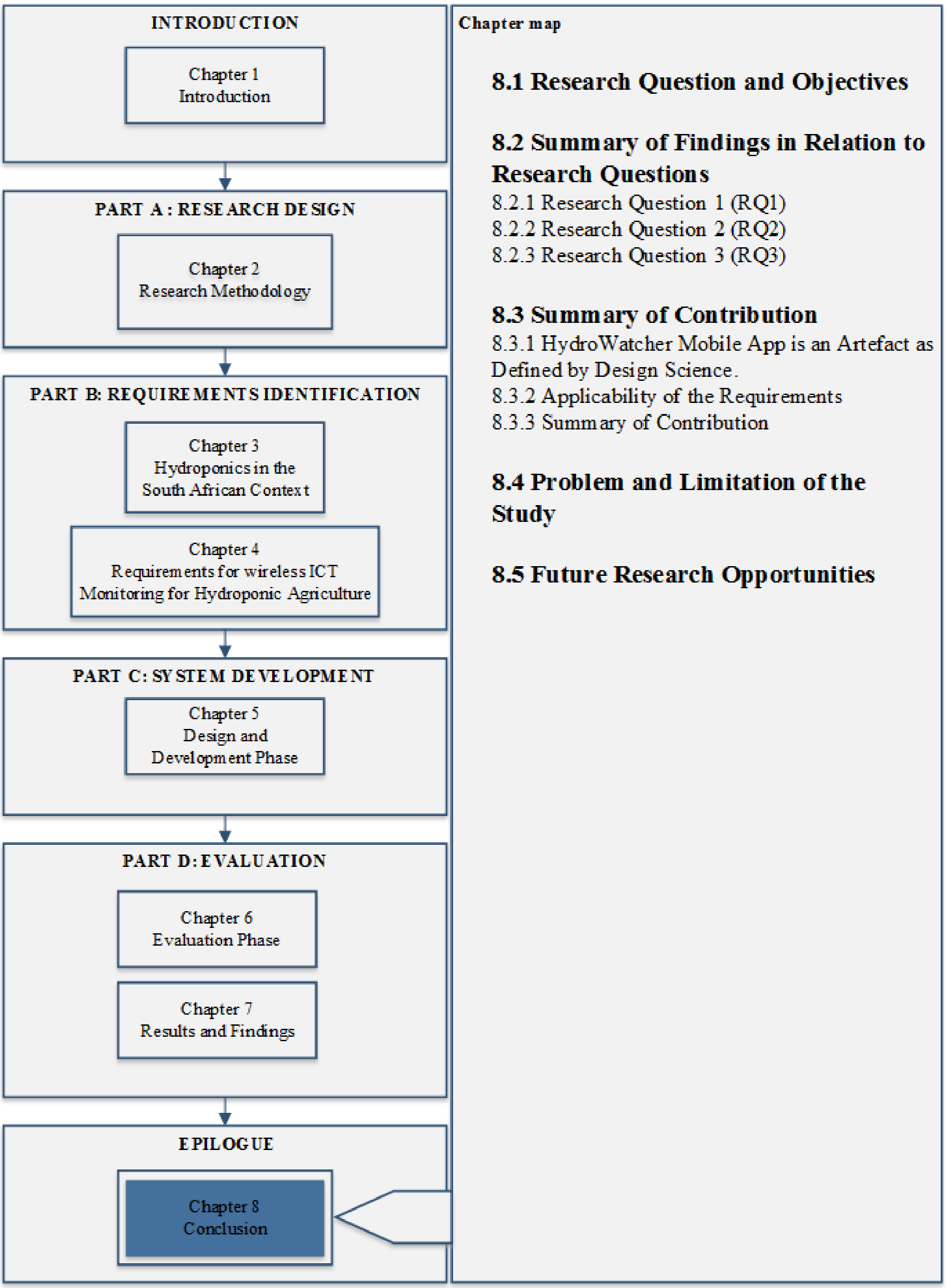
This chapter has discussed the results and the findings of the evaluation phase of this study. The evaluation mustered 6 participants with knowledge of hydroponic farming who are actively working on a hydroponic farm. HydroWatcher mobile app was developed so that it could be deployed on a smartphone featuring a touchscreen. The participants presented various degrees of experience with touch-screen smartphones: from no experience to very experiences. However, the touch-screen was not a hindrance to the performance of the participant, hence validating the applicability of the hardware layer requirements.

During the evaluation period, the participants were asked to performed four distinct tasks. The tasks mimicked real life situations that the participants would encounter on the farm. Most participants executed the tasks successfully; out of 24 possible outcomes only seven failed attempts at task completion were registered. These results, coupled with the post-test questionnaire, testify to the ease of use and quick learnability of the app.

Moreover, throughout the evaluation, the participants were asked to voice their comments as they were coming to mind (Think aloud protocol). The aim was to capture, not only their comments being as fresh as possible, but also to capture the essence of the emotions behind the comments. The participants provided comments like “this task was very easy”, “it was just click, click, click” or “what does water level mean?”. The sum of the comments provided, paired with the performance of the participants during the execution of the task helped to established the applicability of the requirements for the development of a system like HydroWatcher in the context of developing countries.

Furthermore, the design and development of this study adheres to a UCD approach. As such, the needs of the potential users are at the core of the design. The participants were therefore probed for recommendations on improving the evaluated design. The list of recommendations was described in this chapter and the changes were implemented during the second development phase, which was also described towards the end of this chapter.

This dissertation will be concluded in the next chapter.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Chapter 8

Conclusion

The aim of this study was to develop a suitably adequate application to monitor hydroponic agriculture while focusing on the South African context. The application aims at providing an alternative to methods currently in use in hydroponic farming and reduces the workload that monitoring a hydroponic farm puts on farmers. The study outlined that currently in South Africa, the monitoring methods used to monitor hydroponic farms are still inadequate, thus making monitoring a hydroponic farm very cumbersome and time consuming. The study outlined that design science was adopted as the research paradigm and highlighted the philosophical stance and methodological approach that was followed in order to develop and evaluate the application.

In this concluding chapter an overview of the research questions and objectives is provided. Subsequently, the summary of the findings in relation to the research questions is discussed. Thereafter, the summary of the contribution of this study is outlined leading to the problems and limitations faced in this study and finally, an outline of future research opportunities is given.

8.1 Research Question and Objectives

The problem that this study tackled was outlined as followed: **There is currently a lack of wireless ICT enabled applications capable of adequate monitoring and management of a hydroponic agricultural environment within the South African context.** From that statement a main research question and sub-research questions were inferred: **Main Research Question:** *What are the components of a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?*

Sub-Research Questions

> **RQ1:** *How can hydroponic agriculture be described in the South African context?*
>
> **RQ2:** *What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa?*
>
> **RQ3:** *How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa?*

Has this study been successful in answering these questions? In this section a response to that question is provided.

In Table 1.1, a mapping between the research question and the research objectives was established. The argument behind the mapping was that by obtaining the objectives a research question would find an answer. Therefore it is imperative to review the research objectives and their degree of attainability. The review of the research objectives is outlined below:

ROB1: To define hydroponic agriculture: the definition of hydroponic agriculture can be found in Chapter 3.

ROB2: To determine the advantages and disadvantages of hydroponic agriculture: In Chapter 3, a comparative analysis between OFA and hydroponic agriculture was conducted, leading to the description of the advantages and disadvantages of hydroponic agriculture as well as the economics of hydroponic agriculture (Table 3.2).

ROB3: To determine the critical factors related to hydroponic agriculture: Identified during the investigation phase, the critical factors dictating the life of an hydroponic farm were described and their possible impacts on the crops were outlined in Chapter 3.

ROB4: To determine the challenges faced in hydroponic agriculture: Also uncovered during the investigation phase, the challenges faced by hydroponic farmers were described in Chapter 3.

ROB5: To determine the requirements of a wireless ICT monitoring system for hydroponic agriculture: This objective was the milestone of the requirements specification phase. In Chapter 4, an exhaustive analysis of the requirements needed for the realization of HydroWatcher was performed. The requirements covered every aspect of the system.

ROB6: To design and develop the wireless ICT monitoring application for hydroponic agriculture: the design and development phase of this study enabled the production of a prototype mobile application. The design and development was done through an iterative process that had two phases. These phases are described in Chapter 5

ROB7: To evaluate the applicability of the requirements as demonstrated in a wireless ICT monitoring application for hydroponic agriculture: HydroWatcher mobile application went through a rigorous evaluation process that involved experts in the field of hydroponic agriculture. During that evaluation process the applicability of the requirements on the mobile app was established. The evaluation process is described in Chapter 7 and the results of the evaluation are outlined in Chapter 8.

To recapitulate the mapping between the research question and the objective, RQ1 links to ROB1, ROB2, ROB3 and ROB4; RQ2 maps to ROB5; and RQ3 maps to ROB6 and ROB7. Every objective proposed in this study was obtained thus this study provided answers to the sub research questions. The main research question was answered by providing an answer to each of the sub-research questions. The process to answer the main research question could be summarised by the diagram in Figure 8.1.

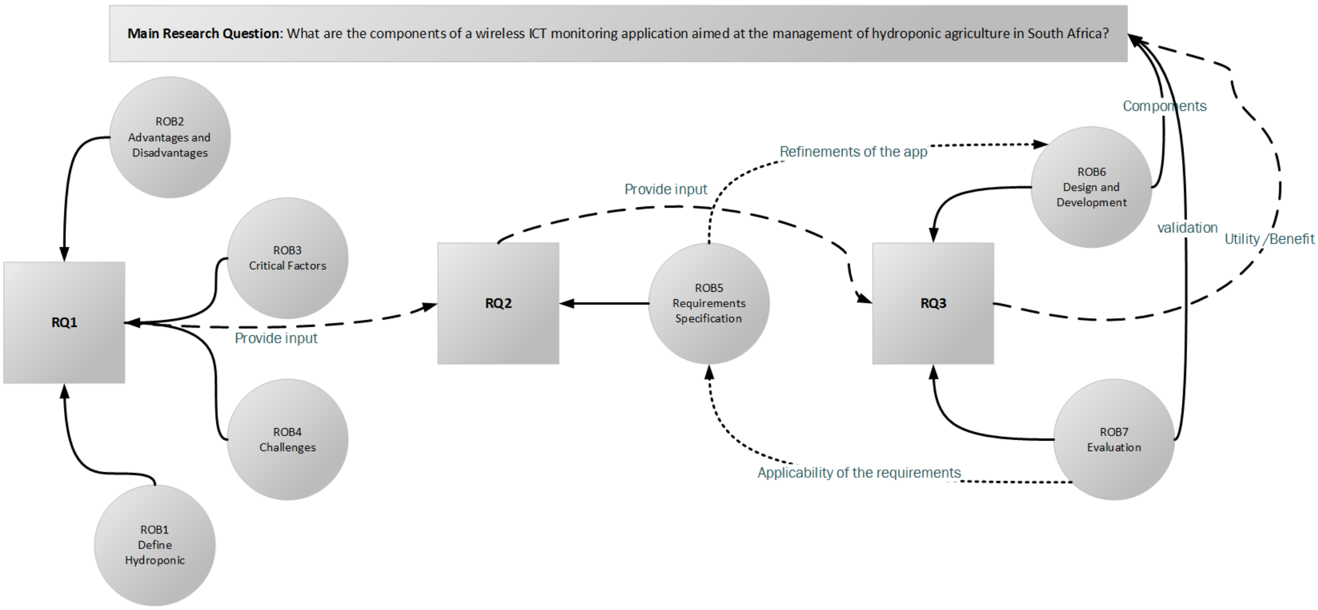

FIGURE 8.1: Research Questions and Objectives

Figure 8.1 outlined the different steps that led to conceptualization of the HydroWatcher mobile app, thus uncovering the components of such an application.

8.2 Summary of Findings in Relation to Research Questions

8.2.1 Research Question 1 (RQ1)

RQ1 asked: How can hydroponic agriculture be described in the South African context? The answer to this question was provided in detail in Chapter 3. It was found that hydroponic agriculture is a progressive agricultural technique that presents more advantages than the OFA. Those advantages include its independence from soil, the large crop yield, bigger, fresher products that can be obtained. However, hydroponic farming also presents some disadvantages. Among those disadvantages is the considerable investment needed to start a hydroponic farm, but more important is the burden that monitoring the crops lays on the labour of a hydroponic farm. Monitoring a hydroponic farm is a process that is time consuming and cumbersome. This process requires that labour be available on a farm on a daily basis. In South Africa, monitoring a hydroponic farm entails monitoring a certain set of critical factors that impact the growth of the plants.

The critical factors being monitored on hydroponic farms in South Africa are the *ambient temperature* inside the tunnel, the *ambient humidity* inside the tunnel, the *electrical conductivity* and *pH* of the water in the retention tank and of the water out of the vegetative bag. Additionally, the water volume received during an irrigation cycle that was conned in this study as *Water in* and the water volume drained out of the vegetative bag referred in this study as *Water out*. Each of these factors, whether on its own or in combination, can have disastrous consequences on the harvest if they are out of balance. Therefore, it is imperative that the farms keep those factors within parameters that are similar to the native environment of the crops, in order to get the maximum yield from the crops.ilar to the native environment of the crops in order to get the maximum yield from the crops.

Furthermore, in South Africa, hydroponic farmers have already embraced precision agriculture and e-agriculture techniques in order to monitor the farm and to ensure high yield. However, the methods used still involves capturing the readings of some factors manually, perhaps with the assistance of sophisticated hand-held tools. Different sets of equipment are used which cannot be integrated with one another. This contributes to making monitoring a hydroponic farm a costly endeavour. Overall, the current monitoring techniques used are still inadequate.

8.2.2 Research Question 2 (RQ2)

RQ2 asked :What are the requirements for developing a wireless ICT monitoring application aimed at the management of hydroponic agriculture in South Africa? Chapter 4 is where a detailed argument on this question is provided. This research question is directed at finding the requirements for the monitoring application; however, the monitoring application is a small part of a larger system. Therefore, in this study the requirements for the entire system are described. The requirements for the system consist of business, as well as functional and non-functional requirements. Additionally, a second set of requirements that was associated with technical aspect of the system was described and classified into layers. Those layers are presentation, software, database, network and hardware. HydroWatcher the mobile application, the output of this study, must satisfy the requirements issued from the business requirements, the functional requirements, the non-functional requirements as well as the requirements from the presentation layer. The requirements and their interaction can be summarised in the figure below. The applicability of these requirements was established through an evaluation phase, which also provided some insight into the answer for the final research question.

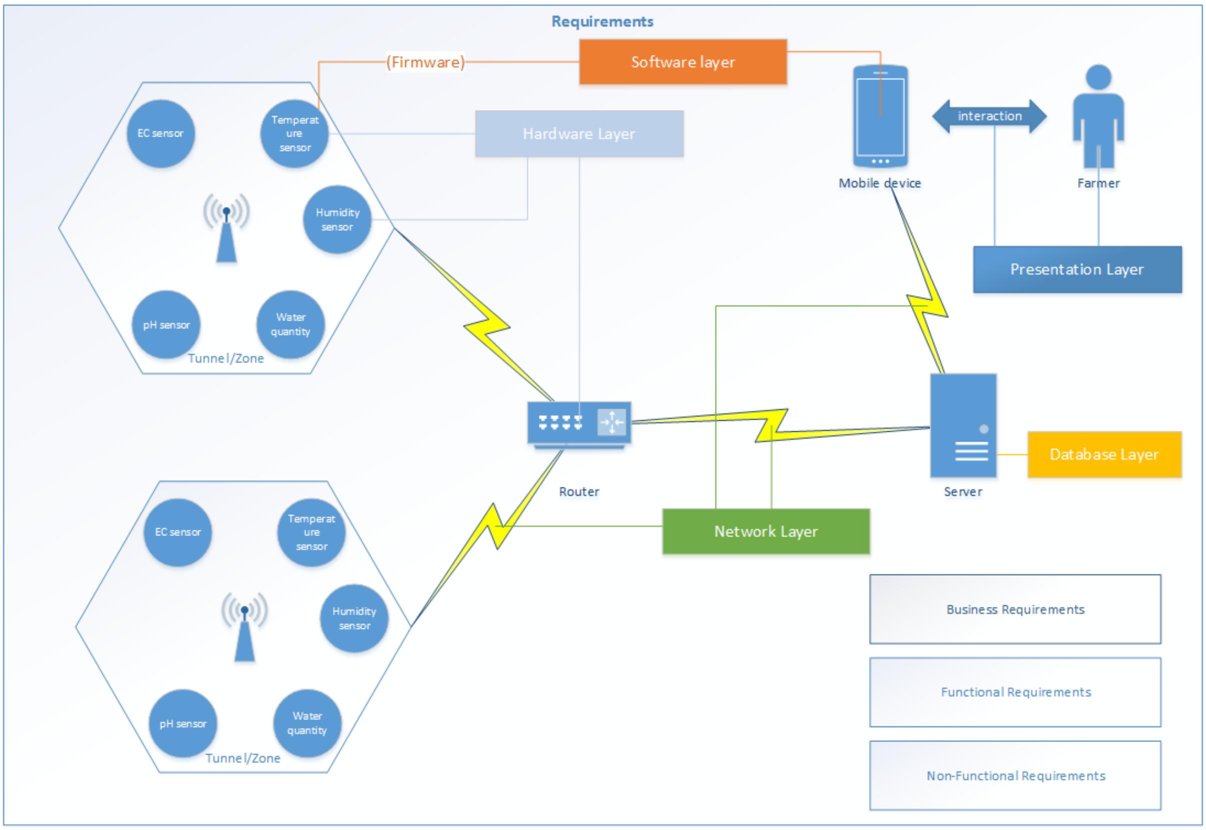

FIGURE 8.2: Holistic Conceptualisation of the Requirements

8.2.3 Research Question 3 (RQ3)

RQ3 asked : How is this wireless ICT monitoring application going to benefit hydroponic agriculture in South Africa? The details can be found in Chapter 7. An evaluation was performed to uncover the applicability of the requirements of the mobile application, the ease of use of the application and the usability of the application. The evaluation consisted of interviews with hydroponic farmers conducted on their farm so as to have the context of use as close as possible to real life. The information gathered revealed that the app is one that they would use frequently and that it is one that is easy to use. The participants were enthusiastic about the app, especially since a UCD approach was used to conceive the app. Through a UCD approach, the needs of the potential users were considered above all.

8.3 Summary of Contribution

8.3.1 HydroWatcher Mobile App is an Artefact as Defined by Design Science.

This research adhered to the guidelines set out by Hevner et al. (2004) pertaining to DSR, towards the development of the HydroWatcher mobile app. On that premise, the HydroWatcher mobile app is an artefact and this study is a not merely a development exercise, but research.

When referring to the guidelines of DSR highlighted in Table 2.1, HydroWatcher mobile app is an instantiation (artefact); it mitigates a problem: It provides an adequate monitoring solution to a hydroponic farmer. The monitoring activity has proven to be a key activity in the life of a hydroponic farm therefore highlighting the problem relevance as defined by the DSR guidelines.

Moreover, the utility, quality, and efficacy of the HydroWatcher mobile app have been rigorously demonstrated via a well-executed evaluation process involving experts in the field of hydroponic agriculture, thus covering the design evaluation guidelines.

This research provides two major outputs: A comprehensive requirements specification of the system HydroWatcher, and the design and development of the HydroWatcher mobile app.

Moreover, this study adhered to a methodological design that is described in Chapter 2 as prescribed by the Design as a Search process guideline of the DSR. Finally, the results of the study are presented throughout this dissertation.

8.3.2 Applicability of the Requirements

The design and development of the HydroWatcher mobile application was directed by the business requirements, the functional requirements, the non-functional requirements, and the requirements from the presentation layer. A UCD approach was used during this study and its principle was firmly adhered to. Also, from the data gathered during the evaluation (observations and comments of participants) it can be concluded that the participants accepted the application. Their acceptance, as well as their positive feedback, testifies that the business requirements, as well as the functional and non-functional requirements are indeed suitable for the development of the HydroWatcher mobile application, therefore applicable in the context of a developing country.

Furthermore, the HydroWatcher mobile application also adhered to the requirements issued from the presentation layer. The following indicates their applicability in the context of South Africa.

HCI 1.1 Text: Minimize reliance on text
The app had very minimal text and the participants commented that they found the app to be easy and clean to interact with it. Also, the app contained text in the form of labels like names of zones, tunnels and parameters and these were well understood by the participants

HCI 1.2 Graphics: use relevant icons
Icons like the "delete" and "bell" for alarms were easily understood by the participants. The items are familiar to the users. The use of a "gear" icon to represent Settings did not match the mental models of the participants; instead some of those suggested that they are more familiar with the use of a "spanner" icon for settings

HCI 2.2 Avoid complex interaction styles
The app interaction style consists of single tap and sliding for the main menu. All the participants found it easy to interact with the app and they mentioned that the app was easy to navigate. However, only one participant managed to discover that the menu can be swiped to expand and collapse it. This validated that complex interaction styles should be avoided.

HCI 3.1 Use linear navigation
The participants found the app to be easy to navigate and it was easy for them to return to the previous screen or the home screen whenever they felt stuck or lost.

HCI 3.2 Encourage interface exploration For some processes the app did not provide feedback to the user, leaving them wondering and therefore unsure of what to do next. That lack of feedback and confirmation messages discouraged the participants from exploring the app with confidence.

HCI 3.3 Keep the screens simple and limit the number of tasks
The app was designed in a way that each screen represents a single task

HCI 3.4 Avoid scrollbars
The participants struggled with the use of scrollbars when they were scrolling down the configurations screen during the evaluation.

HCI 3.5 Use real-life metaphors to explain foreign concepts
The native "bin" and "bell" icons were used for delete and to denote notifications. These were easily associated by the participants as they related to common real-life metaphors that are familiar to the participants.

HCI 4.1. Use familiar language
Term like "elec. conduct." (electrical conductivity abbreviated) or "water level" were not easily understood by the participants and caused confusion. This confirms that the terminology used should be common in the context where the application is to be used.

8.3.3 Summary of Contributions

At the beginning of this dissertation it was argued that e-agriculture entails the conceptualization, design development, evaluation and application of innovative ways of using new or emerging ICTs to promote agricultural development. HydroWatcher mobile app is exactly that. HydroWatcher mobile app is a novel way of integrating the recent advancement in mobile technology in the field of agriculture and, more particularly, in hydroponic agriculture. HydroWatcher mobile app is a management tool at the fingertips of the farmer.

Beyond mobile technology, this study exposes a requirements gathering process and a requirement classification that can be summarized in Figure 8.3 and Figure 8.2.

The requirements gathering process is one that was deemed suitable for developing countries and for subject areas where the literature is sparse and not really contextualised. This process relies on the involvement of the potential users of the system from the very beginning of the study. This involvement not only improves their confidence while facing the final product, but also makes them prone to participate in further research.

The approach of classification of the requirements into layers shows the different areas of focus for such a system. This requirements elicitation classification goes beyond the business, functional and non-functional requirements elicitation. The classification addresses the technological, user interface, and data storage issues that would arise during the development phase. Furthermore, this classification ensures that in the case where different teams are developing different aspect of the system, the different parts will be integrated seamlessly.
Finally, the requirements elicited in this study were tailored for developing countries, in this case, South Africa. This study aimed at producing a set of requirements that will help for the

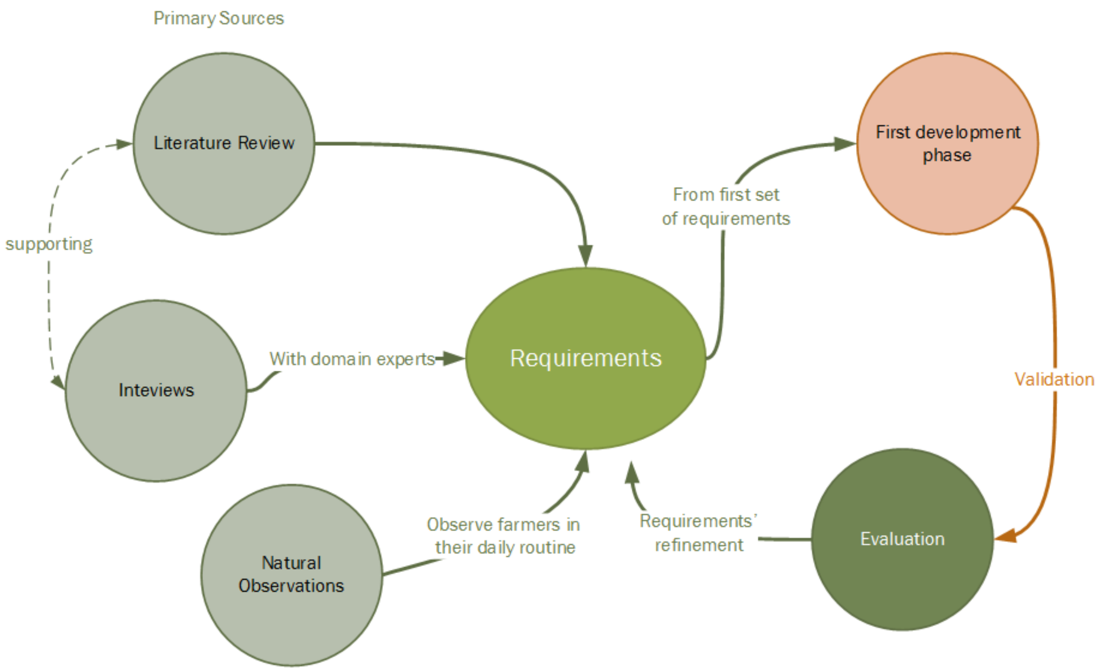

FIGURE 8.3: Requirements Gathering Process in this Study

development of a system such as HydroWatcher in a developing country. The applicability of these requirements was validated in the previous chapter.

8.4 Problems and Limitations of the Study

The research was conducted methodically, to obtain as much credibility and validation as possible. Nonetheless a few challenges were experienced during the study. Those limitations are:

Limited literature in hydroponic farming in the context of South Africa

Limited number of hydroponic farms to explore

Limited availability of experts in the field of hydroponic agriculture

The initial issue was the sparse documentation on hydroponic agriculture in the context of South Africa. As such, the available documentation was supplemented with available literature in hydroponic agriculture and agriculture in general. Special care was exercised in order to retrieve general information as opposed to region specific information. To further grasp the reality of hydroponic agriculture in South Africa, it then became imperative to explore hydroponic farms in South Africa. That premise led to the second problem. The researcher could obtain access only to two hydroponic farms. Although those hydroponic farms represent a good sample of what low technology hydroponic farming is in South Africa, it is, however, not sufficient to draw general conclusion on the results obtained in this study.

Hydroponic farming is still finding its feet in South Africa. As such, the number of experts in the field are still limited. The researcher would have benefited from a wider variety of experts opinions, especially during the investigation phase that aims at describing the reality of hydroponic agriculture in South Africa. Besides these various constraints, the research reached its goals and the future opportunities of this research is discussed in the next section.

8.5 Future Research Opportunities

As argued throughout the dissertation and emphasized in Chapter 4, HydroWatcher is a complex system and this study only tackled a small portion of it.

Further studies could be undertaken towards the realization of the entire system : development and evaluation of each layer of the system as described in the requirements specification in this study. Those studies will unearth the true potential and the breadth and length of the impact that HydroWatcher could have on the local food supply of the community surrounding a farm on which the full system is deployed.

Furthermore, the potential of HydroWatcher could be expanded by the addition of an inference engine (artificial intelligence) that will provide intelligent recommendations to the farmer, potentially leading to better management of the farm.

Future studies could also address other aspects of the management of a farm such as planning, as well as speculation on the procurement of resources such as fertilisers or vegetative bags.

Finally, automation could be a substantial addition to the potential of HydroWatcher; beyond the monitoring activities, farmers could bring to life their farms by enabling some automatic functions to perform certain tasks in the farms.

This study is one that starts to address a very relevant problem for Africa in general, food security. Through the application of ICT this study hopes to open the door that will lead to a series of innovative solutions that will all contribute to food self-sufficiency across the continent.

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Appendix A

Farm Visit Report

Farm Visit Report

HydroWatcher

Loic Andre S. NDAME

5/23/2014

This document reports on the naturalistic observations gathered during the visit to the selected hydroponic farms in the region of Port Elizabeth, South Africa

TABLE OF CONTENTS

1. List of Acronyms

Acronym	Name
NMMU	Nelson Mandela Metropolitan University
EC	Electrical Conductivity
pH	Potential Hydrogen

2. Executive Summary

This report is a summary of findings from visits to the Hydroponic farms in Port Elizabeth, Eastern Cape, South Africa. The objective of the visits has been to determine and contextualize the hydroponic farming environment settings in the South African context. The following farms were visited; Oshry arm (2 days) and Olive Tree Farm (1 week). The site visits to these hydroponic farms were made during the period May 2014 through June 2014. During the visits the farm activities were shadowed in order to understand the workflow at the farm and the activities that the farm workers, including supervisors and farm managers do on regular basis. Secondly, the existing farm technological infrastructure was also observed.
The observations during the farm visits served the purpose of gathering requirements to be included during the development of the Assistive Environment for Hydroponic Farming system.

3. Olive Tree Farm

Olive Tree Farm is a hydroponic farm that is situated in Port Elizabeth, at the intersection of Seaview Road and Heron Road in Lovemore Park in Port Elizabeth. The produce that isgrown on the farm include peppers, spring onions and tomatoes.

Figure 1- Olive Tree Farm satellite view

Physical description of the farm

The farm has an area size of 6 000 m^2 and has a total of 44 greenhouse tunnels and 11 water

reservation tanks. The tunnels are divided into 5 different zones. Each zone has stipulated timelines for irrigation cycles. The farm utilizes the **Rain Bird irrigation system** to set the irrigation cycles in the different zones. In most cases, the zone contains the same plants that are planted at the same time, thus they undergo similar operations like irrigation, spraying, pruning and harvesting. The farm uses the **GVI System Micro 400 fertigation** pump unit with remote radio-controlled valves to open and close the solenoids. Irrigation
water is pumped from the fertigation plant to the different tanks from which the water flows into the various tunnels by means of force of gravity. A particular water retention tank supplies on average 2 tunnels (in some minor cases a tank will supply over 4 tunnels of smaller size).

The farm has one “High tech” **Richel multispan greenhouse** (Tunnel 44) that has a weather station. The weather station monitors the wind speed and direction outside the greenhouse, the temperature in and out of the greenhouse, and the humidity inside the greenhouse. The system used the Hortimax Clima 300
to monitor the temperature, humidity, wind speed, as well as light intensity and rainfall.
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Technologies used

Hortimax Clima 300

The Horimax Clima is a weather station system used in the green houses. It measures the internal and external temperature, humidity, wind speedy, wind direction and rainfall.

Figure 2- Hortimax Clima 300

Richel multispan

The Olive Farm has one high-tech Richel multispan greenhouse. The greenhouse has double inflated film, double roof vents and actuators that can open and close vents based on wind direction and photovoltaic intensity. However, the actuation system is not in use at the farm at the moment.

Figure 3- Richel multispan tunnel

GVI System Micro400 fertigation pump unit

The GVI System Micro400 fertigation pump unit has remote radio-controlled valves that communicate with the solenoids to open and close the valves for sending fertigation EC and pH to the water reservoir tanks. Each tank has a wireless receiver node that communicates with the control unit

Figure 4- Fertigation unit

Fertigation mixture tank

Figure 5- Fertigation mixture tank

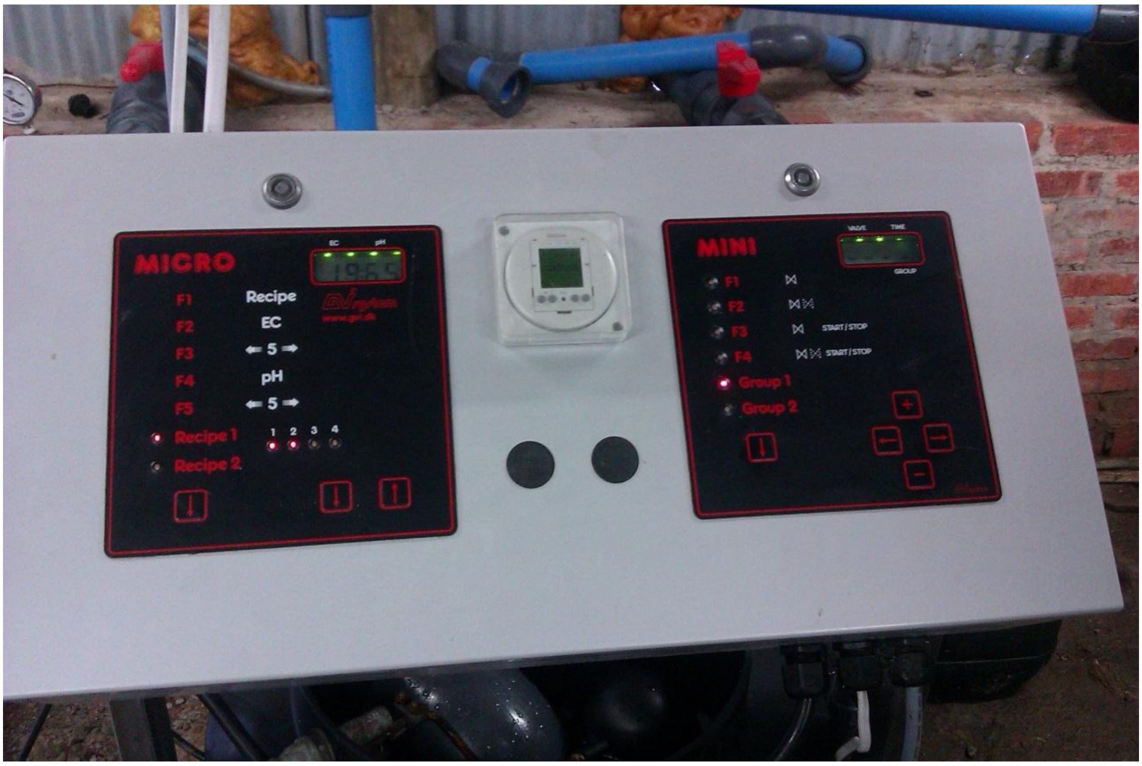

Figure 6- EC and pH measuring at Fertigation Point (pH in and EC in)

The pH and EC values of the solution are measured before the solution is send to the tanks to make sure that the correct values are set.

Rain bird irrigation system

The Rainbird irrigation system is configurable to set irrigation schedules. Ideally, the system has flow management capabilities that monitor low flow and excess flow conditions that may have been caused by broken lines or heads. It has the potential to close the affected nodes while continuing to irrigate

non- faulty nodes. However, no water flow / pressure measurements are currently being recorded on the

farm at the moment.

At Olive Farm the Rainbird system is only used for scheduling the irrigation cycles.

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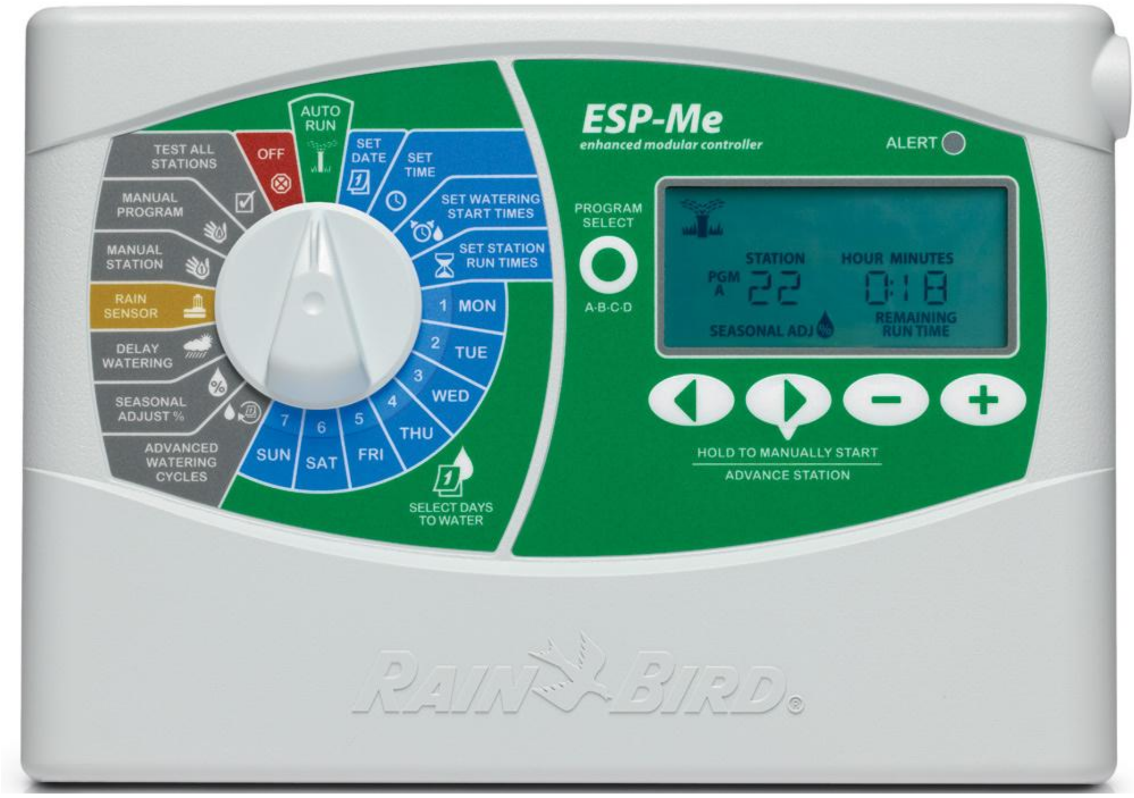

Figure 7- EC and pH measuring at Fertigation Point (pH in and EC in)

(http://www.rainbird.com/landscape/products/controllers/index.htm)

Hanna Scale Instrument

The Hanna instrument is used to measure the level of pH and EC in a solution. The operator has to calibrate the device precisely before using it, in order to take the correct readings. The calibration process takes 25 – 30 minutes per time and this is done every day in the morning. At times the instrument may require a recalibration during the process before the operator finishes taking recordings from all sections of the farm. This instrument is used on the farm to measure the pH out and EC out values of the solutions in the tank reservoir to make sure that the plants are receiving the correct EC and pH values. This is only done once in the morning before the irrigation cycles start

Figure 7- Hanna Instrument

Routine activities

There is a fertigation operator who is responsible for maintain the irrigation cycles, monitoring the pH, EC and recording temperature and humidity on daily basis.

Irrigation

The farm has 5 irrigation cycles for a daily schedule at the following times: 8h00; 10h00; 12h30; 14h00; 15h30. The irrigation cycles are configured and scheduled using the Rainbird irrigation system. The fertigation operator makes rounds to the various tanks every day in the morning and he will modify the irrigation cycle according to the expected weather patterns forecasted. He gets the information on the weather from his smartphone using the application Accuweather or he gets it from the owner of the farm. No data from the Rainbird / irrigation cycles is recorded.

NB: The adjustments are solely based on the experience of the operator's discretion

Reading of pH and EC

As early as 06h00 the fertigation operator conducts a round of the farm during time which he records the pH and EC of the 11 water retention tanks of the farm. Before starting this activity, he has to calibrate the EC and pH Hanna instrument meter for measuring EC and pH. The calibration of the Hanna meter can take over 25 minutes. The readings are recorded as the values for pH and EC out. The recordings are done on a daily basis, once a day and recorded on paper

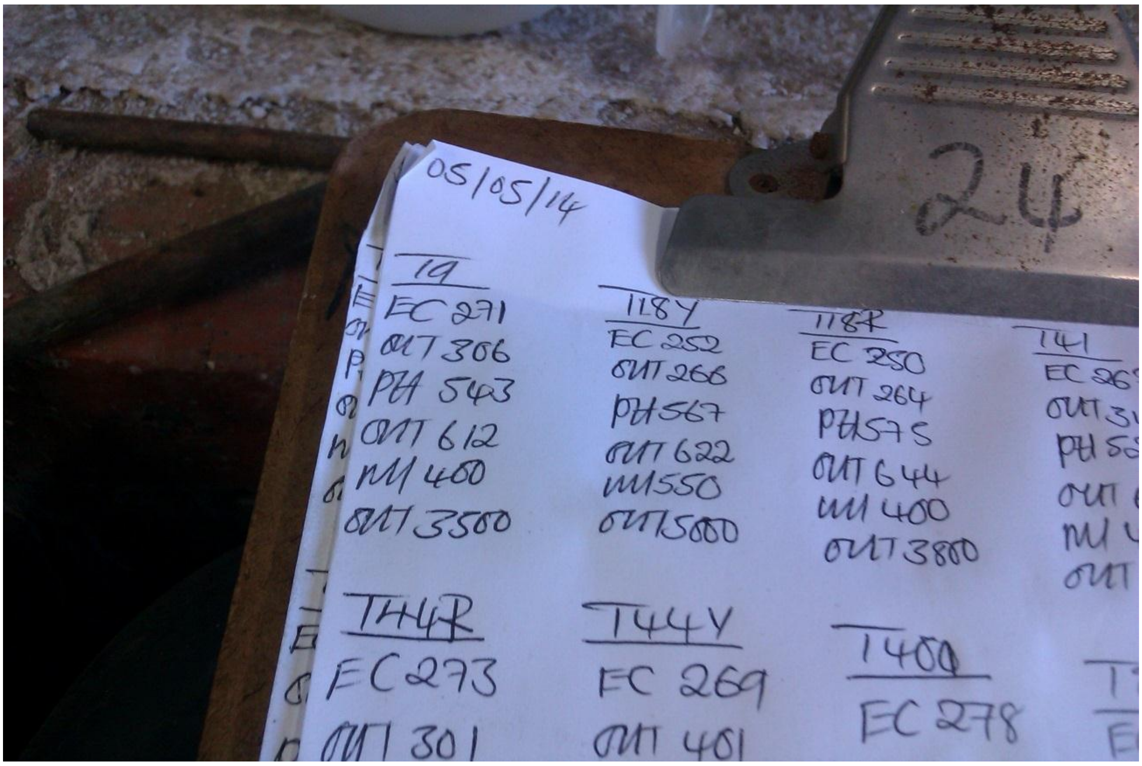

Figure 8- Daily readings per tunnel

The diary shows the recordings in each tunnel. The fertigation operator measures the EC in and EC out, pH in and pH out; also the volume of water that goes into the bag and the drainage water out of selected bags of plants in the tunnel.

Fertigation

The process of applying fertilizer nutrients and pH solution is done through the GVI System Micro400 fertigation pump unit. The GVI Fertigation controller mixes the tank and high Danish standard for a precise EC and pH solution to be supplied to the plants during irrigation. If the operator notices that the pH values are out of the desired norms at times the fertigation operator has to carry a bucket with acidic / alkaline solution and pour it into the tanks manually. The EC is always controlled during the mixing in the fertigation unit.

NB: The amount of acidic / alkaline solution to be poured in the water reservoir tanks is solely based on the experience of the operator's discretion

4. Oshry Farm

Oshry Farm is situated in Port Elizabeth in the vicinity of Kragga Kamma Park in Port Elizabeth. The shadow visit at Oshry Farm spanned 2 days. The reason behind that decision arose from the similarity between Olive Tree Farm and Oshry Farm. The produce that is grown on the farm includes cucumbers, mini cucumbers, Israeli gherkins, celery, turnips, spinach, beetroot, and various herbs.There are students who study agriculture, mostly from Nelson Mandela Metropolitan University , who do

their work related learning at the farms and these students are mostly responsible for observing and recording the farm parameters.

Figure 9- Oshry farm satellite view

Physical description of the farm

Oshry Farm is installed on real estate almost a kilometre long. In the case of Oshry Farm, the physical layout of the farm is not always static as the number of tunnels varies from season to season. The farm is logically divided into several irrigation zones. A zone encompasses several tunnels and that number could vary depending on the season. The farm has the following categories of tunnel sizes: 16m*6m, 14m*4m,32m*6m, and one big tunnel, which is 54*18 m. This big tunnel is fitted with a Richel solution system that monitors the environmental parameters on the farm.

Figure 10- Richel solution system

The Richel solution has the functionalities depicted in the figure below:

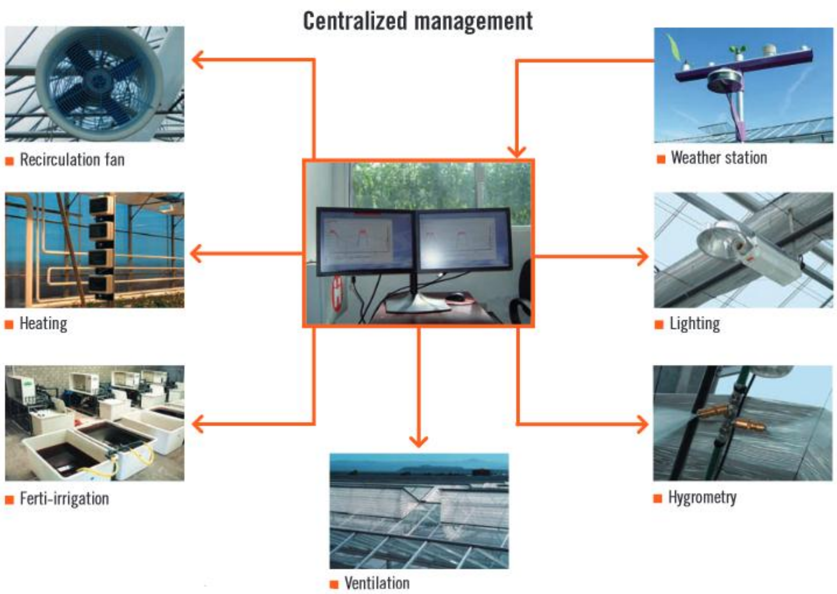

Figure 11- Richel solution functionalities

The Oshry Farm uses the weather station in the big tunnel and a fertigation system. They use the Rainbird irrigation system for setting the irrigation cycles.

The farm has several irrigation cycles in a day, but no more than 6; yet again this number is subject to seasonal variation.

Monitoring of parameters

3 times a day, generally after irrigation cycles, the fertigation operator will explore a designated tunnel per zone and record the water level in the bag of the plant and the temperature in the tunnel. Thereafter, he will record the pH and EC in the water retention tank and in the tunnels..

5. General observations

This paragraph *narrates the observations that apply to both farms.*

The work on a hydroponic farm is a continuous work that requires manpower every day. The rain, the scorching sun, the cold or the strong winds are not factors to halt the monitoring and grooming of the crops (Not even a public holiday).

The tunnels are, designed to create a microclimate that will suit the particular crops that are cultivated in that particular tunnel. More often than not, usually because of expensive maintenance costs, the external climate has a severe impact on the internal environment of the tunnel.

In the “high tech” the floor is made of concrete and the structure allows any equipment to stay in a relatively dry environment. However, the “low tech” tunnels were designed with a layer of black plastic to cover the floor. With time that layer starts to break and, if not replaced, the mud still finds its way over the plastic layer transforming the tunnel into a very damp room.

The criteria of importance for the hydroponic farmer in both locations are the following:

- Ambient temperature inside the tunnel
- Ambient humidity inside the tunnel
- pH and EC of the water retention tank
- pH and EC out of the bag
- Water volume received at the irrigation (Water in)
- Water volume drained out of the bag (Water out)

The following criteria are nice to monitor, but not of a critical nature:

- Ambient temperature of the farm
- Wind direction and speed (Extremely relevant in regions where wind speed can change dramatically)
- Weather forecast

Appendix B

Evaluation Test Protocol

Evaluation Test Protocol

Loic Andre S Ndame

June 20, 2014

This document details the procedure undertaken during the evaluation of the mobile monitoring app by experts in the field of hydroponic agriculture. The questions and scenarios, and tasks performed by the experts are also outlined here.

1 Purpose of Test

The purpose of this usability evaluation is to get feedback on the perceived ease of use and overall user impression of the Hydroponic System application. This formative evaluation serves to provide the basis on finding the user interface design elements that work well for the users, the appropriate navigation and interaction style as well as to determine the hindrances to a positive user experience for the people using the Hydroponic System. Throughout the test we seek to observe any errors that occur as the users interact with the application in order to identify opportunities to enhance the user interface design and user experience. The recommendations for improving the overall user experience will be provided based on the findings from the user feedback evaluation.
The recommendations aim at ensuring that the application:

- Is easy to launch and use;
- Allows users to browse the app easily in order to find the content that they are looking for efficiently, effectively and satisfactorily;
- Presents all formats of data content clearly;
- Is designed to promote intuitive navigation among the sections of the content of the Hydroponic System Application.

2 Methodology

The usability / user experience evaluation for the Hydroponic System application will be conducted in the real context of use. A context inquiry based type of test will be conducted. The users will be visited ion the respective farms and will be asked to use

the app as they would do in their typical daily routine. The aim is to make the testing as real as possible and to maintain the naturalness of the context of use of the app. Also, in this way, it is envisaged that the sample of users to be recruited will be a true representation of the actual users of the Hydroponic System Application.
The Hydroponic System Application will be tested using the following techniques:

- The thinking aloud protocol;
- User observation;
- Video recording ;
- Subjective user comments on the impression of the app;
- Task completion.

2.1 Recruitment of Users

The system is targeted at African users. The screening criteria for the participants is based on the fact that the participant should be knowledgeable about hydroponic farming. Also, they should have entry level background knowledge on how to use mobile phones or similar smartphone devices. Secondly, the participants that satisfy the desired criteria should be willing and able to undergo a 45 - 60 minute hands-on evaluation of the Hydroponic monitoring application, during which time users will be asked about their qualitative subjective feelings on their interaction with the app.
For this evaluation we expect to recruit 8 participants, comprising farm managers, supervisors and operators of hydroponic farm equipment. The end users of Hydroponic System Application are expected to have a certain degree of knowledge on monitoring and operating the hydroponic environment; the users are also expected to have an appreciation of the use of mobile phone devices. However, the competence skills of the users may vary as some farms are highly technologized while others are still operating manually. The level of skill of the users with respect to the use of mobile phones will also vary.

2.2 Context of product use in the test

The evaluation will take place in the farm settings. The users will be visited at their respective farms. The locations were chosen as being the most convenient for the participants and for keeping the context of use as natural as possible. The HydroWatcher mobile app was designed to be used in developing countries, both in urban or rural settings, on the farms.

2.3 Display devices

The evaluation of the Android applications will be performed on Smartphones with the following specs 5.3" WXGA (1280 x 800) screen, in standard color mode and automatic brightness. A Smartphone device has been chosen as it has been observed during the farm visit that most of the farmer will be carrying their phones while they are doing other tasks around the farm. . Thus, a Smartphone will be convenient compared to tablet devices because of its size and portability. Sony Xperia has been chosen specifically because the device is both water resistant and dust proof, which makes it ideal for use in the farm environment.

3 Test Procedure

The scope and functionality of the app is first described to the participant, after which the purpose of the test will be explained. Once the participant has fully understood the app and is happy to proceed with the test he is given a consent form to complete (see Section 4.2). A pre-test questionnaire will be given to the participants. The pre- test questionnaire serves to screen the users further and to classify them according to the desired user-matrix clusters. Upon completion of the pre-test questionnaire the system will be launched and the participant will be asked to give general comments on their perceptions of the system. Following this, the participants will be given tasks to perform. The tasks will be presented in the form of scenarios in order to avoid the leading question bias. Finally, the participants will be given a post-test questionnaire that they have to complete.

3.1 Participant general instructions

Participants briefing:
First of all, I would like to ask for your permission to film the test under the guarantee that these images are for research purposes only and will not be shown to anyone other than the researchers working on the results of this test. I would also like to ask you to read and please to sign this informed consent form. Our goal now is to evaluate the usability of this product and for that we will ask you to perform some tasks using the application and the optical magnification prototype. I will explain a task. You can ask me anything you dont understand about it and then you can try to accomplish the task. Try to do it as if I were not here, but if you feel that you are stuck you can ask me for assistance. You can also voice your opinions regarding any aspect of the prototypes. Remember that we are testing the application and not the user, and that there is no right or wrong way to perform a task. Also, we are looking for both good or bad feedback so dont refrain from expressing a bad opinion or pointing out any errors that you may encounter. They are expected and we appreciate it if you let us know.

The participants should receive the following general information regarding the project: Hydroponic System Application is a project being developed under the scope of the ICT4D Competence Center that targets to provide low-cost mobile-based solutions for developing countries. The primary goal of the Hydroponic monitoring app is to create a low=cost mechanism for mobile monitoring of hydroponic farms. Hydroponic farming is a means of precision agriculture where plants are grown in a mineral nutrient solution instead of in soil. This type of farming is becoming relevant in developing countries, for example in South Africa, since it offers a controlled farming environment thus making urban farming a ore practicable means of agriculture. Market gardening based urban farming is increasingly becoming a major contributing practice to food security in South Africa. The effective management of hydroponic farming requires constant monitoring of inside and outside parameters: monitoring temperature, humidity, turbidity of the nutrient solution, and watering, among others. However, currently, the whole process of monitoring the conditions in the hydroponic environment is done by manual systems, which are time-consuming, labour-intensive and prone to inaccuracies in data capturing. The proposed Hydroponic monitoring app makes it possible for farmers to get to know the conditions in the hydroponic farm without physically visiting the farm, thus saving time and reducing labour intensity while collecting accurate data.

Regarding the prototypes, the participants should be given the following information: The system consists of an interactive prototype specifically designed for android- based smartphones. The system is meant to provide real data readings of the farm environment. It has the settings for customizing the preferences of the user. Users will be able to assign certain tunnels to zones and to configure the zone settings. In addition, the system allows users to be able to configure the parameter values for the desired zones and specific tunnels. Furthermore, the user will be able to view some notifications if there are any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system. This means that each session will include several views. Do you have any question regarding the procedure?

3.2 Pre-test screening

1. What is your current job?
2. How many years of experience have you been working in the Hydroponic farms?
3. Do you own a smartphone? Android/IOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?

3.3 Task list

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen.

Task 1: Warm-up question

Launch the Hydroponic System app and please take a moment and scan through the app homepage and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process)

Objectives

- To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app.

- To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions :

- What is your first impression of the app regarding the following:
  - Visual appeal
  - Colors used
  - Meaning of symbols and icons
  - Terminology
  - Navigation / Menus
- How do you feel about the way the information is organized?
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

Task 2: Viewing real data for a specific tunnel
Scenario 1
It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is? *Expected navigation / flow*
Home > Zones B > Tunnel 1 **Scenario 2** Also, how will you view how the temperature has been changing in the past hour until current time? *Expected navigation / flow*
Home > Zone B > Tunnel > Temperature > Graph view
Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

Task 3: Changing zone parameters
Scenario
It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 oC, pH to 3.7, EC to 2.5, Humidity to 44
Objectives:

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;

- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

Expected navigation / flow
Home > Zone A > Tunnel 2, Configure > "Change Parameter values"

Task 4: Setting custom preferences

Scenario You have recently harvested all your crops in the rest of the tunnels and the only crops that are remaining are in Zone B. How will you find the option for making the app to allow you to view the parameter values of Zone B when you launch the app?
Objectives :

- To determine the value that users would have from allowing them to customize the viewing preferences;
- To determine the discoverability of the functionality of setting preferences.

Expected navigation / flow
Cog > Settings > Default landing page "Zone B"

NB: Each task will have probe questions based on how the user interacts with the app

3.4 Post-test questionnaire

1. What did you find interesting on Hydroponic System app?
2. Would you consider using the Hydroponic System app?
3. What other tasks would you like to do with your phone to support the hydroponic farm activities?
4. What areas if any did you find difficult to use on the Hydroponic System app?
5. How do you perceive this app to benefit you?

Please Complete the following questionnaire:

Instructions: For each of the following statements, mark <u>one</u> box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2.	I found this system unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☐	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found this system very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

Please provide any comments about this system:

4 Performance and Satisfaction Metrics

4.1 Criteria and Measurements

During the evaluation, two to three facilitators will participate. One will moderate the test while the others will be taking observational notes. Since the test includes several tasks and we will encourage participants to use the think aloud method, each evaluation will also be recorded (video and sound) to analyse the data better after the test. To evaluate the usability of the system we will measure effectiveness (via task completion) and satisfaction.

4.2 Metrics for effectiveness, efficiency and satisfaction

To measure the effectiveness of the system we will measure task completion rate, deviations, errors and assistance.
Task completion
Each task will be divided into several steps that form the ideal flow to completion (see Task List). The accomplishment of these tasks will allow the calculation of task completion rate. Task completion will be defined and categorized based on the following:

- Completed: The metric is successfully completed when the participant indicates they have found the answer or completed the task goal.
- Completed with assistance: In this case the user would have asked for help from the moderator. This metric requires distinguishing when the user asks for elaboration on the question relating to the task vs when the participant asks for help on how to complete the task.
- Failed to complete: This is when the user either gives up on the task or the user thinks that they have successfully completed the task while they have performed it incorrectly.

Deviations
Deviations are defined as alternative flows to the completion of the task, that, while not being the ideal flow, still enable the participant to achieve task completion. **Errors**
An error will be counted every time the participant performs an action that does not contribute to task completion. Errors are categorized as follows:

- Critical errors: : Critical errors are deviations at completion from the targets of the scenario. For example, reporting the wrong data value owing to the workflow of the participant. Essentially, the participant will not be able to finish the task, thus task failure. Participants may or may not be aware that the task goal is incorrect or incomplete.
- Non critical errors: Non-critical errors are errors that slow down the participant from efficiently completing the task. The participants are able to recover from the error and will still be able to complete the test. For example, exploratory

behaviours such as opening the wrong navigation menu item or using a control incorrectly are non-critical errors.

- Error free rate: Error-free rate is the percentage of test participants who complete the task without any errors (critical or non-critical).

Additional information will be collected through observation and the think aloud method. These metrics will be considered as benchmarks for comparison with next iterations. Nevertheless, the facilitators will take into account the overall time spent using the application and the time spent on each task, and clear deviations from an appropriate time should be noted.
Satisfaction will be measured through the use of the post -test questionnaire (see Section 3.4). In addition, we will encourage participants to use the think aloud method, which can also give us some data regarding their satisfaction with the application.

Consent Form

I confirm that the purpose of the test and the nature of the questions have been explained to me. I consent to take part in the test to share my experiences, including some ways to provide feedback on the usefulness and applicability of the Hydroponic System Application. I also consent to be recorded during this interview. My participation is voluntary. I understand that I am free to leave the group at any time. None of my experiences or thoughts will be shared with anyone outside the scope of the research purpose and all identifying information will be removed first. The information that I provide during the test will be grouped with answers from other people, so that I cannot be identified.

Name ____________________________________ Date __________________________

Signature __________________________

Appendix C

ICT4D HCI Guidelines: A study for Developing Countries

ICT4D HCI Guidelines: A study for Developing Countries

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Portugal

Abstract

This paper presents a set of research-based Human-Computer Interaction (HCI) guidelines for developing countries. The proposed guidelines were developed under the umbrella of the Fraunhofer AICOS (FhP) ICT4D Competence Center (ICT4DCC). The ICT4DCC follows a collaborative model known as 'Interface Institute' and aims to develop ICT solutions through partnerships between scientific and industry institutions from Europe and developing African countries. By exploiting this collaborative environment, we aim to validate and refine the guidelines by applying them in products targeted at developing countries users. To this end, two of the ICT4DCC partners, the Nelson Mandela MetropolitanUniversity (NMMU) and Eduardo Mondlane University Informatics (CIUEM) are collaborating on the design and development of a mobile application for hydroponic farming following a User-Centered Design (UCD) approach. Insights from a usability evaluation of a functional prototype conducted with the intended users in South Africa were used to validated the guidelines. Further more, highlights on how the model implemented by the ICT4DCC can be a privileged medium to better serve the potential users through the implementation of these guidelines.

Keywords
ICT4D, ICT, HCI, HCI4D, Guidelines, Developing Countries, Interface Institutes

Introduction

Designers and developers from the developed world tasked with creating products for developing countries users face multiple challenges. One of the major hurdles is the difficulty for people living in the developed world to gain an accurate understanding about the user profiles of the people from developing countries, due to a gap between mental model frames of reference and experience with technology (Toyama, 2010) (Smith et al., 2004).

The lack of adequate knowledge about the needs of the users and the context of use can result in detrimental outcomes, such as the lack of acceptance of the product by the intended audience (Toyama, 2010) (Lalji and Good, 2008) (Poole, 2013).

The use of guidelines to inform and inspect design decisions can help close the gap when access to the end users is not possible (Scandurra et al., 2013). In this regard, the guidelines act as design directions serving to inform the designing of the products in order to delivery products that are useful, usable and providing a positive user experience. However, literature is scarce regarding guidelines specific for the development of products meant for use in developing countries in the scope of Human-Computer Interaction for Development (HCI4D).

While the use of guidelines might be adequate when there is an ample research about the target population, the literature is scarce regarding guidelines specific for the development of products meant for use in developing countries. Moreover, even if such guidelines are developed, the lack of access to the users makes it difficult to properly assess their validity.

In this paper, we aim to contribute to solving these problems, firstly, by presenting a set of research-based Human-Computer Interaction (HCI) guidelines for designing products meant for use in developing countries and, secondly, by describing the theoretical Interface Institute collaborative model of the ICT4D Competence Center, through which European and African academic and industry institutions partner to develop technological products that serve local demands.

Regarding the structure of this paper, the first section lists a set of research-based HCI guidelines for developing countries. The following section describes the ‘Interface Institutes’ model and how it is being applied in the ICT4D Competence Center. In section 3, we present the insights from a usability evaluation of a mobile application prototype conducted on-site by South African researchers that illustrates the UCD approach followed by the ICT4DCC interface institute model on the HCI and User Experience (UX) research areas. Finally, section 4 presents the conclusions and plans for future work.

Research-based HCI Guidelines for developing countries

In this section we present a set of research-based HCI guidelines for developing countries with the goal to inform designers and developers in order to achieve suitable, usable and preferred products for audiences in developing countries, and therefore increase their acceptance and a long-term positive UX.

The guidelines were developed after an extensive literature review on the fields of ICT4D, HCI4D and UX. Each guideline was derived from at least one published piece of literature. The literature and studies that support the guidelines were conducted in multiple countries, mainly from Africa and Asia and focus on the main barrier that can be found in those regions, including illiteracy or low literacy (both textual and technological), lack of adequate mental models and understanding of established interaction metaphors, and language and dialect barriers. Therefore, most of the guidelines are aimed at helping illetrate and semi-literate users in the developing countires.

The guidelines are classified under four major areas: Interface Design (Text, Graphics, and Voice and Audio), Device Manipulation, Navigation and Information Architecture, and Content.

Due to space constraints, we’ll only present an abbreviated set. The full set of guidelines can be obtained from the authors.

Interface design

Text

- **Minimize reliance on text**

For illiterate users, minimal text should appear in the interface (Findlater et al., 2009). Full operation of the system should be possible without text (e.g., voice input and output) (Huenerfauth, 2002).

- **Do not remove all text from the interface**

The interface should not be completely text-free. Even when not understood, textual content in the interface can be memorized and recognized as visual patterns by illiterate users (Joshi et al., 2008). Moreover, text in the interface is helpful for the more literate users that often assist the illiterate in tasks that require reading or writing skills (Knoche and Huang, 2012).

- **Complement text with other modalities**

Text has been shown to be beneficial to semi-literate users, for example, by reinforcing their reading skills, motivate learning and improve literacy. Thus, augmenting text with other modalities is recommended (Cuendet et al., 2013). A multimodal interface might cater for users of all literacy levels (Gavaza, 2012).

Graphics

- **Use culturally relevant icons**

Effective icons should relate to the culture and common experience of the user base, referencing concepts in their lives. Icons should be memorable, nameable, and concrete so that users can discuss them with each other (Huenerfauth, 2002).

- **Prefer realistic cartoons for representing pictorial content**

Semi-abstract, realistic, cartoon representations are preferred and understood more accurately by illiterate and semi-literate users than abstract simple graphics (Medhi et al., 2007a). Hand-drawn cartoons also better than photorealistic representations (Medhi et al., 2007b).

- **Use motion to visually identify actions**

When used to identify actions, visual elements should indicate motion (e.g., water running from a faucet, steam puffing out of a kettle). Otherwise, illiterate and semi-literate users associate the drawings with objects or locations (e.g., kitchen), instead of the action (e.g., cooking) (Medhi et al., 2007a).

- **Icon should be accompanied by captions**

Icons should not be used on their own, so a form of visual/audio text captioning should always be available (Huenerfauth, 2002). Graphical icons with voice annotation generally help users in speed of comprehension (Medhi et al., 2006).

Voice and audio

- **Voice content should be provided in the local language and accent**

Providing the content in the local language and accent is a critical success factor in the developing world (Botha et al., 2012). If the user group encompasses multiple languages and dialects, a multi-lingual system might be needed (Sherwani et al., 2009a).

- **Help should be always available**

In addition to providing training on using the voice interface, which can make a significant difference in regard to its usability (Sherwani et al., 2009a), help (e.g., an audio assistant) should be continuously available (Lalji and Good, 2008).

- **Oral information should be short and simple**

Information presented orally needs to be short. Low literate and literate users find it hard to hear long passages of text with the purpose of extracting small nuggets of information. The speech content can be made more conducive for hearing by simplifying sentence structures and replacing difficult words with easier phrases (Sherwani et al., 2009a).

- **Audio feedback should be provided on-demand**

The user should be able to request (e.g., through a button) that the entire contents of the screen, as well as any specific screen element, piece of text, or item, be read aloud (Huenerfauth, 2002).

- **High speech recognition is crucial**

High recognition accuracy is a necessary condition for the success of a speech system (Sherwani et al., 2009a). The voice user interface design and the capability and readiness of the speech technology are the differentiating factors for UX in any mobile speech application (Botha et al., 2012).

Device manipulation

- **Avoid complex interaction styles**

Multi-function buttons, soft keys, over-cluttered buttons and double-tap interaction have been shown to cause problems to low-literacy users.

Navigation and Information Architecture

- **Use linear navigation**

Linear navigation structures are quicker to understand than branched, hierarchical structures for low-literacy users (Medhi et al., 2010).

- **Encourage interface exploration**

Interface exploration should be encouraged to allow users to familiarize themselves with the system's capabilities and overcome technophobia. Some strategies to achieve this include providing reassuring and encouraging feedback, provide a 'undo' function and always asking for confirmation before fatal operations (Huenerfauth, 2002).

- **Keep the screens simple and limit the number of tasks**

The screens of the application should be kept simple and the number of tasks possible at one time (and the ways to accomplish them) should be minimal (Medhi et al., 2006) (Prasad et al., 2008).

- **Avoid scrollbars**

Scrollbars should be avoided, as it has been shown that they are not well understood by low-literate users (Prasad et al., 2008) (Medhi et al., 2011).

- **Use real-life metaphors to explain foreign concepts**

The lack of textual literacy is often accompanied by low or inexistent technology literacy. Explaining foreign concepts to low-literacy users might be achieved by using real-life metaphors relevant to their context (Medhi et al., 2006).

Content

- **Use familiar language**

The language and terminology used by the system must be one with which users are comfortable with. The choice of words and phrasing must be given as much thought as the development of the visual interface (Lalji and Good, 2008). Even when users cannot fully read the text displayed, using their local language gives them a greater sense of familiarity.

The ICT4DCC Model

Despite the booming of mobile ICT market in most developing countries, there have been few success inthe development and adoption of ICT products especially in those. The reason for such high failures has been mainly because the developers of the products meant for use in the developing countries lack an understanding of the target users. In this regard the ICT4DCC proposes a theoretical Interface Institutes model.

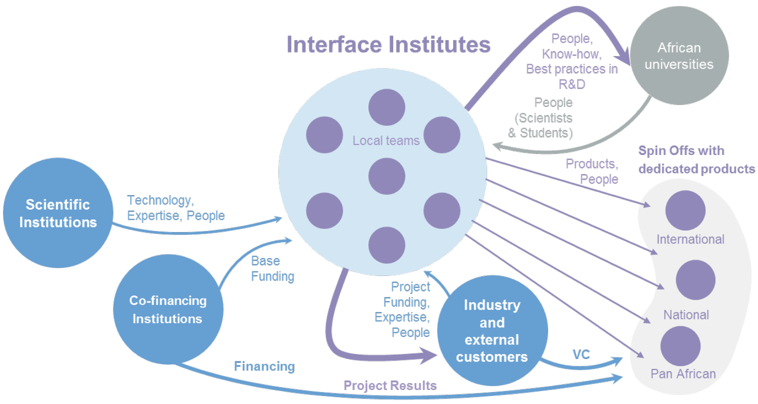

Figure 1 - Interface Institutes Operational Model

The Interface institutes model is a collaboration approach that aim to facilitate the establishment of innovation ecosystems in order to promote the remote creation of ICT products that serve the demands of the local people and fosters the acceptance of products by the target users.

The Interface Institutes is a model that foresees teams from international organizations working together in order to create specific solutions that are address the needs of local users. The operational model of Interface Institutes aims to promote joint knowledge sharing between the remote and local teams working on a project in order to develop products that will have a positive impact contributing to socio-economic growth of the local regions where the outcomes of the project are deployed. This model promises to be a relevant approach towards the development of usable and useful products in scenarios where there is scarsity of literature to provide guidelines on the profiles and requirements of the target users.

Having the Interface Institute model as a reference, the ICT4DCC,gathers a team of international experts working with international partners from scientific institutions and industry to identify and develop pre-commercial ICT solutions with local relevance for developing countries.The ICT4DCC partners include the German Fraunhofer Fokus Institute, the Portuguese FhP AICOS Institute, the Mozambican CIUEM, and the South African NMMU.
Several projects have already been selected to be sponsored and executed under the ICT4DCC and deployed in developing countries. Both in Mozambique and South Africa, local partners have been providing local resources and expertise to different projects tasks.
In Mozambique, partners from the CIUEM recently conducted an usability evaluation for a mHealth application, MalariaScope (Rosado et al., 2014). The results from the evaluation indicated that the application was found to be usable and satisfactory by a sample representative of the intended audience.
After a successful experience with the MalariaScope project in Mozambique, the ICT4DCC is now working in the same collaboration model with NMMU.
Researchers from the NMMU are collaborating with counterparts from ICT4DCC to develop a mobile application for hydroponic farming. The *Assistive Environment for Hydroponic Farming* (AEHF) system was selected as an opportunity to validate the proposed guidelines. The hydroponic system is considered to offer socio-economic growth in the South African context and overly in developing countries. The following section

presents a description of the *Assistive Environment for Hydroponic Farming* and results from a usability evaluation of a prototype of the application.

Assistive Environment for Hydroponic Farming - AEHF

The *Assistive Environment for Hydroponic Farming* is a product developed by ICT4DCC that consists of an Android app. The primary goal of the AEHF app is to create a low cost mechanism for mobile monitoring of hydroponic farms. Hydroponic farming is a mean of precision agriculture where plants are grown in mineral nutrient solution instead of soil. The proposed AEHF app makes it possible for farmers to get to know the conditions in the hydroponic farm without physically visiting the farm, thus saving time and reducing labour intensity while collecting accurate data. The app was design according to the mental models of the users, where a number of greenhouses are grouped into zones and those greenhouses are refered to as tunnels. In the app Greenhouses are refered to as tunnels in order to match the terminology and mental models of the users. Those tunnels were further grouped into zones. The AEHF app is intended to be used by people with precision farming background from developing countries in multiple contexts.

The AEHF app was developed based on the proposed HCI guidelines for developing countries presented earlier. In terms of HCI methods and methodologies, the ICT4DCC follows the recommendations and best practices from the literature and industry. As such, products are developed according a User-Centred Design (UCD) approach. UCD is a broad term that encompasses several design methods sharing the same goal: bringing users into the design process to ensure the product developed meet their needs, demands and desires (Putnam, Kolko, Rose, and Walton, 2009). This involvement of the users in design has been shown to lead to more usable and satisfying products (Abras et al., 2004). While UCD methods are also often used in the developed world, they have added importance when designing for users in developing countries, as their life experiences are likely to be markedly different from those of the designers (Lalji and Good, 2008).

In accordance with the ICT4DCC, a prototype of the AEHF was developed as a collaborative work between FhP AICOS in partnership with a team of researchers based in South Africa, NMMU. The first step in designing AEHF involved an research into the context of hydroponic farming in South Africa. The context of hydroponic farming was examined through a context inquiry study where researchers from NMMU visited two hydroponic farms in Port Elizabeth. The objective of the visit was to gather the requirements for developing the AEHF app. As mentioned earlier, the AEHF is a project under ICT4DCC, thus FhP AICOS and the farm owners contributed with the business requirements of the system. The user requirements were gathered as the researchers interacted with the target users of the AEHF app. The requirements were then consolidated and presented in a user requirements specification document that was shared between the teams. Furthermore, these requirements were prioritised based on the needs of the users and objectives of the ICT4DCC. Thus the objective of the first version of the prototype was to provide the minimal functionality to illustrate the potential usefulness and usability of the app.
The researchers at NMMU went on to design low fidelity prototypes of the app based on the HCI guidelines for developing countries. The low fidelity prototypes were shared with the FhP AICOS team who went on to design high fidelity interactive prototype of the app. The interactive prototype was tested on its potential usefulness and usability by users in the hydroponic farms in South Africa. The evaluation was conducted in South Africa, by local researchers from the NMMU. The use of local researchers can help quickly establish a climate of trust with the users and provide clear feedback to the research team, as well as overcome possible reactions towards foreign researchers, such as hostility, scepticism, indifference, or eagerness to please due to differences in perceived status (Sherwani et al., 2009b) (Toyama, 2010) (Anokwa et al., 2009).

Early involvement of local partners in the usability testing stage allows the results to be incorporated before the product is released (Russo and Boor, 1993) and ensure that the user interface is culturally appropriate, thus enhancing the user experience and increasing its chances of acceptance (Shen et al., 2006).

The usability test of the app is discussed next.

AEHF App usability evaluation

This section describes the usability evaluation of the functional prototype of a mobile application for hydroponic farming. The purpose of this usability evaluation is validate the proposed HCI guidelines for developing ICT products that are meant to be used in developing countries. Through the evaluation we aimed at determining if the app that was developed based on the proposed guidelines will be appealing for the acceptance of the product with a positive user experience. Thus the formative evaluation serves to provide basis on finding the user interface design elements that work well for the users, the appropriate navigation and interaction style also to determine the barriers to a positive user experience of the people through the use of the AEHF app. Throughout the test we seek to observe any errors that occur as the users interact with the application so as identify opportunities to enhance the user interface design and user experience. This way the guidelines will be refined.

The following guidelines were validated of their applicability in this paper: Text; Graphics; Device Manipulation; Navigation and Information Architecture; Content. Guideline Voice and audio and its sub components, have not been considered in the scope of this paper. The reason behind the alienation of validating Voice and audio guidelines is based on the level of the fidelity of the prototype.The AEHF app is a high fidelity prototype to illustrate the visual aspects and expected funtionalty of the proposed system. Secondly, the prototyping tool that was used had limitations of incorporating voice and audio elements.

Methodology

The usability / user experience evaluation for AEHF app was conducted in the real context of use of hydroponic farming. A context inquiry based type of test was conducted. The users were visited in the respective farms and were asked to use the app as they would do on their typical day routine. The aim is to make the testing as real as possible and maintain naturalness of the context of using the app. Also, this way, it was aimed that the sample of users recruited were a true representation of the actual users of the AEHF app. To start the test, the app was launched and the participants were asked to explore the app and make unguided comments on what they think about it. Following this, the participants were asked to complete the four tasks (albeit in a different order), which included common use cases such as general exploration of the app, viewing real data for a specific tunnel, changing the values of parameters in a zone and setting custom preferences. After the test, a System Usability Scale (SUS) survey was administered..

The AEHF app was tested using the following techniques:

- The thinking aloud protocol;
- User observation;
- Video recording;
- Subjective user comments on the impression of the app;
- Task completion.

Recruitment of the participants

The app is targeted at African users. The screening criteria for the participants was based on the fact that the participant should be knowledgeable about hydroponic farming and also a entry level background knowledge on how to use mobile phones or similar smartphone devices or touch screens. Secondly, the participants had to consent that they are willing and able to undergo a 45 - 60 minutes hands-on evaluation of the AEHF app, during which they will be asked of their qualitative subjective feelings on their interaction with the app.

For this evaluation 6 participants were recruited, comprising of farm managers, supervisors and operators of hydroponic farm equipment. The skills of the users may vary as some farms are highly technologized while others are still operating manually.

Selection of devices

The system was evaluated using Sony Xperia smartphones with the 4.3" WXGA (1280 x 800) screen, in standard colour mode and automatic brightness.. The device was selected specifically because it is both water resistant and dust proof which makes it ideal for the context of use. Smartphone device has been chosen as it has been observed during the farm visit that most of the farmer will be carrying their phones while they are doing other tasks around the farm. Thus a Smartphone will be convenient compared to tablet devices because of its size and portability.

Presentation of Results

The performance varied among the six participants. All the participants managed to complete Task 1 without any error. Three participants completed Task 2 successfully; one completed the task with assistance while two failed to complete the task. The average error rate for Task 2 was 0.8 (SD=1.2). The minimum number of errors committed was zero while maximum number of errors was three.

Task 3 was completed by three participants while two participants failed to complete the task and one participant completed with assistance. The average error rate for Task 3 was 2.3 (SD=2.5). The minimum number of error in Task 3 was zero while maximum number of errors was six. In Task 4, three participants completed the tasks successfully while the other three failed. The task had an average error rate of 2.2 (SD=2.2). The minimum number of errors was zero with a maximum of five errors.

The global average satisfaction measured with the SUS scale was 74.2 (SD=16.1). This represents a good, and above the average, score (Bangor et al., 2009).

Participants were probed to comment on the app as they were observed performing the tasks. These tasks were aligned to validate the proposed guidelines. This section presents the findings from user testing based on the qualitative descriptive data that was obtained (Think Aloud Protocol).

Table 1 presents the comments on the AEHF app from the participiants.

Participant	Comments
P1	The participant managed to identify and relate to zones and tunnels also to explore the tunnels to view the parameters. The three vertical dots for menu was not easily understood by the user. The icon for settings confused the user instead the user suggested the use of spanner icon clearly labelled settings. The layout of the app was found to be "clean, clear and easy to navigate". It was difficult for the participant to identify the option for configuring parameters both in the tunnel and at zone level. The participant easily noticed the notification icon and commented that it was easy to identify because of the red colour used, it is familiar with other applications that he knows also the number near it makes it easy to know the count of notifications. The term "landing page" was not easily understood but the participant noted that it is important to

	be able to customise the app to meet their preferences.
P2	The participant commented that grouping of Zones makes it easy to navigate to the various tunnels. The notification “alarm” icon was easily noticed and the participant commented that the colour is good and the number “3” close to the icon shows how many notifications are there. The settings icon was not found to be familiar to this participant. Liked the graphical representation, though the numbers on the horizontal axis are vague and do not mean anything to the participant. The participant found it easy to navigate within the app. The participant commented that colours are not important, what matters most is the functionality of the app. Participant expected to be able to make rectifications to the notifications from the app. What does “water and Electric. Conduct” mean? Participant noted that there is no feedback after changing the settings. It was easy for the participant to navigate from one screen to another. Did not understand “Min and Max” in the configurations screen, the participant interpreted that the screen is showing the maximum and minimum recordings. It was difficult to for the participant to input min and max values on the configurations screen.
P3	Initially the participant assumed that the purpose of the app is to teach him how to farm. The participant managed to identify and understand the groupings of tunnels into zones. Navigation within the app was done with ease by this participant. The participant was familiar with the hamburger menu and there three vertical dots for menus. Participant expected to find an option to save the configurations after making changes to the configurations screen and setting the landing page. Elect. Conduct was not understood by the participant. The participant inquired what “water” meant.
P4	The participant kept on looking for menus at the bottom of the app and he kept on swiping from left to right hoping to flip between the various screens in the app. The participant easily noticed the notification icon and on notification listing, the participant liked the confirmation before deleting the notification. The delete icon was well understood by this participant. Liked the hamburger menu and did not struggle to use this feature. The participant failed to change the values on the configurations screen. Initially the participant thought that the feature was to display the minimum and maximum values for the parameters. The term “Landing page” was not understood. The participant indicated that they would want an option that allows then to configure the app and customise their preferences.
P5	The participant suggested that the letters A, B, C, D should indicate irrigation controllers and zones will be assigned to irrigation controllers while tunnels will be assigned to the zones. Water level does not make sense on what it means. Graphical presentation showing the fluctuations in parameters makes it easy to read, however the intervals on the graphs are not labeled and can be hardly understood, there is need of clear labelling of the horizontal axis The use of green colour is good and is associated with vegetation, however the app is inconsistent regarding the use of colour. The colour is only used on the landing page and the rest

	of the pages look blunt. The participant indicated that he would like to be able to change the names used on the zone names to suit what he wants.
P6	The participant understood the zones and grouping of tunnels with their respective parameters. Setting preferences to desired “Landing page” confused the user, the term landing page was not easily understood. The user did not understand what “Electro. Conduct” means. On the configurations menu, the user misunderstood “Min and Max” to mean the minimum and maximum values recorded by the system After changing configurations the participant expected to find an option to save at the bottom and a confirmation message to say that the setting have been successfully saved. The parameter “water” was found to be confusing and not clear of what it mean. The participant understood the red icon for alerts to mean that there is a warning and the number “3” indicates the number of warnings. Red colour made it easy to notice that something was wrong. The participant easily picked the settings icon and said it similar to other applications that he has used. The placement of the settings icon close to the three dot menu made the screen cluttered.

Table 1. Subjective user comments

Overall, AEHF app was well received by the sampled users. The participants indicated to be happy with the information architecture and the overall layout of the app. The app received good ratings on its perceived ease of use and usefulness and was found to be easy to navigate.

There were, however, some issues that the users’ qualitative feedback allowed to unearth. It was found that some users interpreted colour codes differently, did not noticed that some interface elements (such as textual list items) were clickable or failed to understand the meaning of some icons meant. One recurring case was the “Gear” icon, which was not associated with changing configurations. Some users suggested using a spanner icon instead.

There were also problems with lack of feedback after changing some settings. Terms such as “Landing page” and “Elect. Cond.” (abbreviation for Electrical Conductivity) were not promptly understood by all users. Some participants suggested the addition of new parameters, while indicating that others - “Water level” – did not make sense. The labelling of the graphical visualizations, the interval used and the lack of readability of the values were subject of some negative feedback.

The participants were observed as they performed the tasks and some observation notes were recorded during the test. Also, video recordings were consulted to further analyse how the participants interacted with the app. Thus, the think aloud comments of the users, task performance observations and video recordings where triangulated and analysed using In vivo coding technique (King, 2009). The guidelines have been used as codes for data analysis. A validation of the guidelines based on the results from the user testing is presented next.

Interface design

Text

- **Minimize reliance on text**
  The AEHF app had very minimal text and the participants commnented that they found the app to be easy and clean to interact with it. Colour differentiation between zones,use of

icons made it easy for the users to interact with the app with minimal text.

- **Do not remove all text from the interface**
  The app contained text in form of lables like names of zone, tunnels and parameters and these were well understood by the participants.

- **Complement text with other modalities**
  The use of text was complemented with icons and use of colour. Alerts and notifications were presented with red colour. Colour differentiation between zones that have plants and those without were easily interpreted by the participants. The use of different colours made it possible to get the attention of users even without reading the text. Also, icons that are familiar to the users like, the "bell" for alerts, were easily recognised by the participants without reading text.

Graphics

- **Use culturally relevant icons**
  Icons like the "delete" and "bell" for alarms were easily understood by the participants. The items are familiar to the users. The use of "gear" icon to represent settings did not match to the mental models of the participants, intead some of those suggested that they are more familiar with the use of "spanner" icon for settings.

- **Prefer realistic cartoons for representing pictorial content**
  This guideline was not implemented in the functional prototype.

- **Use motion to visually identify actions**
  This guideline was not implemented in the functional prototype.

- **Icon should be accompanied by captions**
  The icon for alerts had some texts close to it and it was easily noticed and understood while the "gear" for settings and three dots for menu did not have any captions and some participants failed to recognise them.

Voice and audio

- **Voice content should be provided in the local language and accent**
  This guideline was not implemented in the functional prototype.

- **Help should be always available**
  The guideline was not implemented in the functional prototype. However, the participants would ask to the moderator whenever they got stuck while performing the tasks. This validated the need to have availability of Help as a guideline.

- **Oral information should be short and simple**
  This guideline was not implemented in the functional prototype.

- **Audio feedback should be provided on-demand**
  This guideline was not implemented in the functional prototype.

- **High speech recognition is crucial**
  This guideline was not implemented in the functional prototype.

Device manipulation

- **Avoid complex interaction styles**
  The AEHF app interaction style consist of single tap and sliding the main menu. All the participants found it easy to interact with the app and the mentioned that the app was easy to navigate. Only one participant managed to discover that the menu can be swiped to expand and collapse it. This validated that complex interaction styles should be avoided.

Navigation and Information Architecture

- **Use linear navigation**
  The users found the app to be easy to navigate and it was easy for them to return to previous screen or home screen whenever they felt that they were lost.

- **Encourage interface exploration**
  The app lacked feedback when the users completed certain tasks like customising the landing page. This left the users wondering if they had done the correct execution. Most users welcomed the confirmation message when they were about to delete notifications. This gave them assurance that the app would prevent them from making mistakes. Lack of feedback and confirmation messages discourages the users from exploring the app with confidence.

- **Keep the screens simple and limit the number of tasks**
  The AEHF app was designed in a way that each screen represented a single task. Other tasks related to the respective screen were provided as links from the active screen. This contributed to the users finding the app to be easy to understand and use with minimal memory load.

- **Avoid scrollbars**
  The participant struggled with the use of scrollbars when they were scrolling down the configurations screen. It was difficult for the participants not to activate the touch areas while they were trying to scroll down the screen.

- **Use real-life metaphors to explain foreign concepts**
  The native “bin” and “bell” icons were used to delete and denote notifications. These were easily associated with the participants as they related to common real life metaphors that are familiar to the participants.

Content

- **Use familiar language**
  Most of the terminology used by the AEHF prototype matched the expectations of the participants. The terms like pH, Temp, Humidity were well understood by the participants. Terms such as “Landing page” and “Elect. Cond.” (Abbreviation for Electrical Conductivity) were not promptly understood by all users while most users found “water” did not make sense. The labelling of the graphical visualizations, the interval used and the lack of readability of the values were subject of some negative feedback. This confirms that the terminology used should be common in the domain in which the application is targeted to be used.

In addition to the proposed guidelines the following have been found to be important to be included:

- **Allow the users to customize and personalize the system**
- **Use of guided text entry**

While being the first iteration of a prototype, the insights about the users’ goals, expectations and mental models that can be extracted from this evaluation would be very difficult to achieve by conducting desktop research and relying on the intuition of designers and developers without access to a real context of use, hence the need for guidelines based on field test with the target users.

Following the philosophy of UCD, these results will be taken into account in the next iteration of the AEHF app prototype, which will likewise be a joint collaborative effort between European and African researchers on the ICT4DCC context. The resulting prototype will then be tested again with representative South African users in a real setting.

By constantly listening to the feedback from real users the guidelines will be validated and improved on. This expectantly leads to the development of products that are contextually relevant and providing a positive user experience to the target audience.

Conclusions and future work

This paper reveals the challenges faced by designers and developers of ICT products that are meant to be used in geographically remote locations, precisely in the developing countries community. The challenges include a lack of understanding of the profiles of the users, the context in which the ICT products are to be used and the requirements for developing the products that are meant for use in the remote locations. Such challenges can result in the users rejeting the products. The success and acceptance of the products is dependent on how they appeal to the needs and context of the target users.

The paper proposes guidelines that were disseminated from literature. The guidelines serve as design directions to be followed in order to develop products that are meant for use in developing countries.
An interactive prototype of the AEHF app was developed following the proposed guidelines. This prototype was tested with the target users of the app in order to foster the validation of the guidelines.

Future work is focused on further validation of the proposed guidelines in the context of ICT4DCC. The following aspects build avenues for further researching the applicability of the guidelines:

- Application of the guidelines in order to develop ICT products for use in a real-life context;
- A study on impact assessment on the acceptance of products as a result from implementation of the guidelines;
- Conducting multiple case studies in different contexts, using different products and users so as to evaluate the extent to which the guidelines can be generalized;
- Work on the Interface Institutes concept in stages within a longitudinal research projects, so as to evaluate how the model can be implemented;
- Increasing the number of participants for user testing.

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Appendix D

A Prototype Mobile Monitoring System for Hydroponic Agriculture

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A Prototype Mobile Monitoring System for Hydroponic Agriculture

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Abstract: As traditional soil based agriculture is rapidly reaching its limit and other solutions are being considered worldwide to satisfy the increasing demand for food. The use of technology-enhanced agriculture is starting to become unavoidable. Therefore monitoring a farm to determine how the crops are evolving and detecting the point of failure of any given farm, should be the first stop. This paper reports on the development of a prototype mobile monitoring system for hydroponic agriculture. The prototype system proposes the coupling of contemporary advances in electronic capabilities necessary for developing wireless sensor nodes that are at the centre of the farm monitoring with pre-existing wireless networks to transmit recorded data and finally mobile technology to access the data in remote locations as needed.

Keywords: hydroponic**;** monitoring; android; Arduino; wireless sensor node; temperature readings; humidity readings; water level readings.

1. Introduction

No other human activity is as important as agriculture, the latter being the basis of the food supply for the entire humankind [2]. By 2050 the world population will reach a staggering 9 billion people. Subsequently, the current supply of food will have to double if not triple in order to sustain the world demand [3]. Traditional soil based agriculture is already reaching its limit and will not be able to cope with such a demand [3]. Other types of agriculture are already practised that can also increase the current global food production. Hydroponic agriculture is one such agriculture. Hydroponic agriculture produces a better yield per hectare than soil based agriculture [4, 5] but to achieve such a high level of productivity, a hydroponic farm requires persistent monitoring of the field, intelligent management and extensive data gathering[6]. However monitoring any particular environment manually is a cumbersome and time-consuming activity. Such efforts and time can be reduced with the use of wireless sensor nodes (WSN) [7].

Mendez *et.al.* state in 2012 that monitoring an agricultural environment can lead to proactive and quicker reactive responses to adverse conditions and situations within the farm. The utilization of technology would allow for remote measurement of environmental factors such as temperature, humidity or water levels [7]. Controlling these factors can be extremely critical to a successful harvest especially in a hydroponic agricultural environment [8].

Nowadays WSN play an important role in data acquisition that will later undergo the transformation process to produce sensible information. WSN is however not limited to data acquisition. This technology is also used for smart buildings, machine monitoring and maintenance, environmental monitoring, safety management and many other areas [9].In addition the development of the application of (WSN) in precision agriculture coupled with

E-agriculture has attracted considerable research efforts lately as it is suitable for scattered data collection in laborious environments [9].

WSN in the accomplishment of their task require a supporting network to transmit the gathered data. Due to the fact that agriculture, may it be hydroponic or otherwise, in South Africa is mostly practiced in rural areas or in the outskirts of urban or metropolitan areas [10] implementing a wired system will generate significant cost of installation and maintainability [11]. Those regions prefer the convenience of mobile lines to expensive fixed lines thus wireless substitutes which use pre-existing mobile networks will be cheaper and more feasible [11]. That lead then to the problem described in this paper; there is currently a lack of mobile monitoring system for hydroponic agriculture in South Africa. Such a system embraces two emergent approaches to farming: precision agriculture and E-agriculture.

Precision agriculture is a management philosophy or approach to the farm that consists of identifying the critical elements where the yield of the crop is limited by controllable factors [6]. The environmental variations and those occurring in the crop are noted, mapped and management actions are taken consequently due to uninterrupted assessment of the critical factors within that field. E-agriculture follows the same the trends but implies more innovative ways in the application of Information and Communication Technology (ICT) [12].

2. Objectives

This paper describes the requirements for the design of a prototype monitoring system for hydroponic agriculture. In addition to the requirements, the paper demonstrates the methodology followed as well as how the prototype system was implemented. As this is only a prototype monitoring system, a simulated environment was created within which to evaluate the potential uses of the prototype system. This paper will therefore report on the design of the prototype monitoring system.

3. Methodology

Towards the completion of the prototype monitoring system, a case study approach was adopted. The case study enabled a first-hand discovery of the real world implementation of the monitoring of hydroponic agriculture. Additionally a requirement analysis was conducted and the findings were corroborated by a literature review and an investigation of related systems.

The literature review revealed the implication of such a monitoring system. The related systems investigation highlighted the shortcoming of already existing systems in relation to the South African context.

4. Developments and Technology Description

4.1 The prototype monitoring system requirements

A full range of requirements needed to be considered in order to have a prototype monitoring system tailored for the South Africa context. The exhaustive range of requirements covers business, functional, non-functional, user interface and usability requirements in addition to various design constraints that may impede the development of the monitoring system. The requirements were obtained through interviews of potential users and a literature review.

4.2 The design overview of the prototype monitoring system for hydroponic agriculture

The back bone of the E-agriculture and precision agriculture prototype monitoring system based on wireless sensor nodes consists of environmental monitoring nodes, a database server, communication systems and Internet access. Figure 1 outlines the novel model indicated for the system. Environmental monitoring nodes or WSN will be fitted inside a greenhouse and will capture a set of predefined environmental factors. Environmental monitoring nodes via their communication unit will relay all the readings to a database server by leveraging GSM (Global System for Mobile Communications) or GPRS (General Packet Radio Service) networks.

A farmer equipped with a mobile device will then be able to visualize the readings through an application that will download the data from the database server and present the latter in a graphical manner.

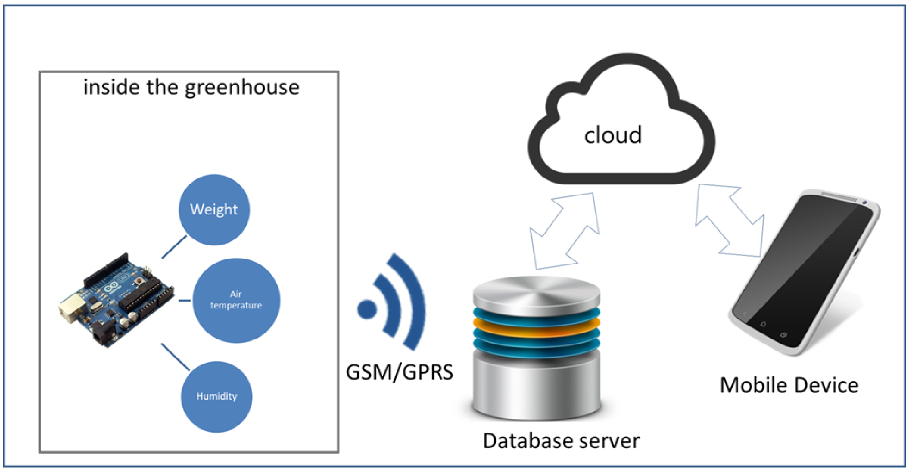

Figure 1: Design Overview Model

4.3 Factor of interest

Although in any given environment there is no shortage of factors to monitor, the prototype system will gather ambient temperature, ambient humidity and hydroponic bags' water levels as the proper management of these factors is indispensable for a successful harvest when farming hydroponically[8].

As a greenhouse get warner plant can start to wilt due to rapid water loss; on the other hand, a greenhouse that is too cold can stop the growth in most plants [8]. Additionally every crop specie has an acceptable range of temperature which is in direct relation with its native environment [8].

Moreover when levels of humidity are too low or too high agricultural products can suffer. At levels below 50% for extended periods, growth can suffer, as loss of water from leaves could be quicker than replacement; humidity levels above 80% can increase the risk of disease [7].

Similarly water levels are a firm indicator of water intake by the plants or a resulting fault of a pump or a faulty hydroponic bag. Water levels need to be watched closely to ensure that the plant received the proper hydration without however drowning the crops under too much fluids [13].

After the WSN in the greenhouse has collected and sent the data to the database, such data must be made available for the farmer in a way that accommodates the environment in which the farmer operates: in a remote area emphasis is given to mobility.

4.4 *Wireless sensor node*

The WSN is responsible for gathering a set of predefined environmental data. The WSN has three sensory units. Temperature measurements are collected via a TMP36 temperature sensor unit. Humidity measurements are collected using a SHT15 humidity sensor unit and a force sensor or a load sensor capture water level measurement. The WSN has at its core an Arduino Uno Rev3 board. The board is the data processing unit and oversees all the sensors attached to it. The WSN is also composed of a communication unit. A GPRS/GSM shield (cellular shield) (Figure 2) attached to the Arduino board relay all the measurements to a database server.

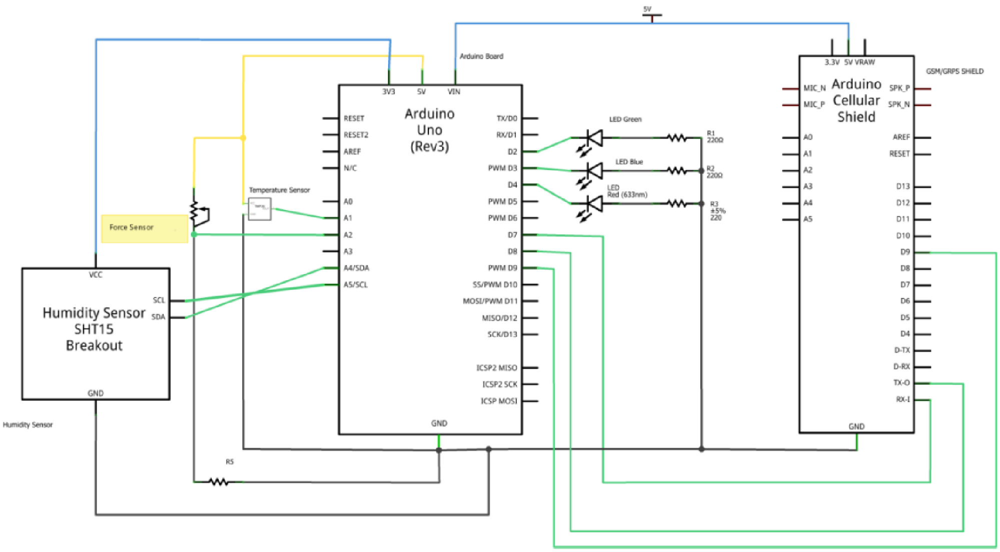

Figure 2: Wireless Node schema

Figure 4 and Figure 3 illustrate the physical view of the wireless sensor mode after being assembled.

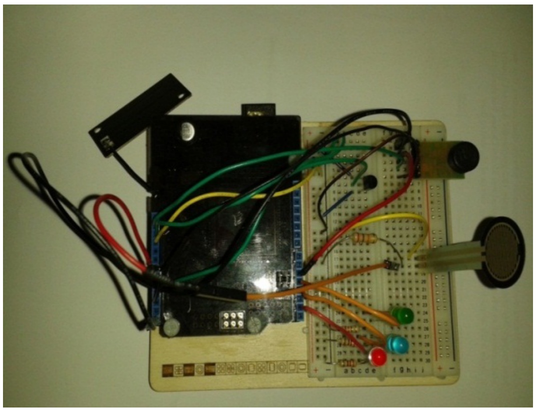

Figure 4: WSN top view

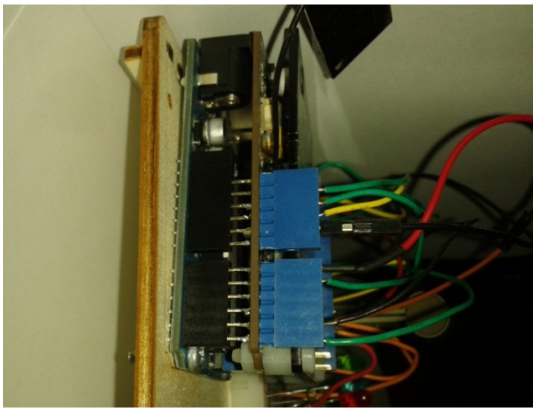

Figure 3: WSN Side view

4.5 *Database server*

Any measurement relayed by the WSN is stored in a remote MySQL database server. MySQL database management system offers the advantage of being robust and relatively cheap to set up [14]. As MySQL operates under an Open source GPL License[15] MySQL Database presents a real economic incentive when developing at a prototype stage.

4.6 Android application for graphically plotting the data

Android is an operating system based on the open Linux Kernel. It is designed primarily for mobile devices such as smartphones and tablets featuring a touchscreen[16].

Additionally when developing any application that will run on Android, a programmer must specify the specific minimum version of the Android platform- an API level- which will set the earliest version of the Android OS supported by the application[17]. In other words if an application targets the minimally Android API level 11, also known as Honeycomb, any Android powered devices running earlier version of the operating system, will not be able to run the application properly if at all.

For the purpose of this project, the minimum version of the Android OS is Honeycomb (API level 11 or Android 3.0) thus the application can run in any Android version equal or higher than Honeycomb. This choice allowed targeting almost 70% of existing devices running on Android (refer to Figure 5) [1]. In Figure 5, Gingerbread (API level 10 or Android 2.3.3) and Froyo (API level 8 or Android 2.2) are the only versions not compatible with the prototype application.

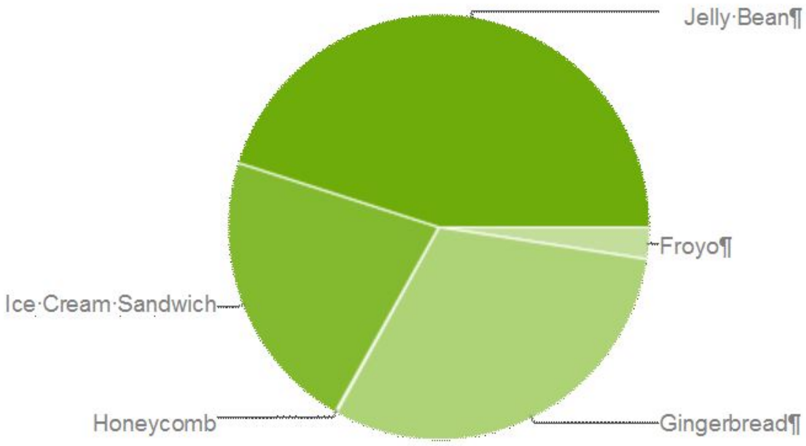

Figure 5: Data collected during a 7-day period ending on September 4, 2013 [1].

5. Results

5.1 Database

The prototype mobile monitoring system was tested in a simulated greenhouse. The database server was hosted by a public company. The expectation was that the database server will cope relatively well when considering the traffic but the database itself will rapidly grow (Figure 6).

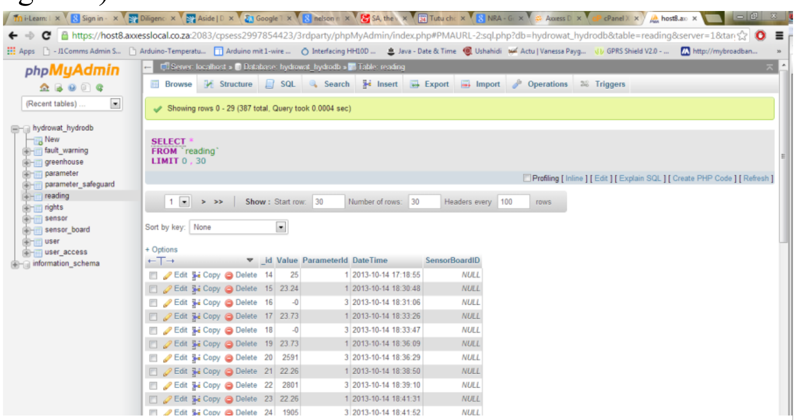

Figure 6: Database - Reading table

After only 48 hours of testing, the database table “reading” that store the sensory reading was already registering over 350 lines. The next step was then to see how the mobile application scaled.

The reading can be visualized for a period of 48 hours. This choice was adopted due the limited size of the device’s screen the test was performed on namely an android tablet of 10” inch and also the fact that related researches have also adopted a similar time frame for testing [7, 18]. 48 hours may seem short in a farming cycle but the point is to demonstrate the working processes of the prototype system.

5.2 Temperature readings

Figure 7 outlines the results acquired by the system and logged for temperature over a period of 48 hours.

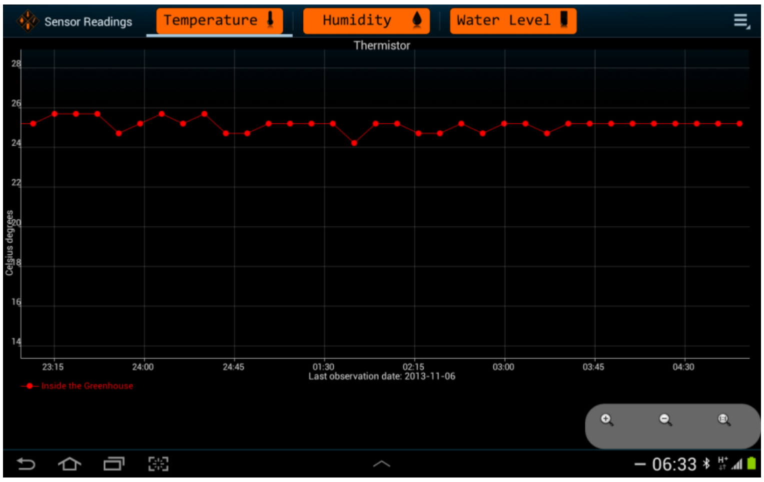

Figure 7: Logged data for Temperature sensor

The measurements are expressed in degree Celsius.

5.3 Water level readings

Figure 8 illustrates the measurements captured by the prototype monitoring over a period of 48 hours as logged for water levels.

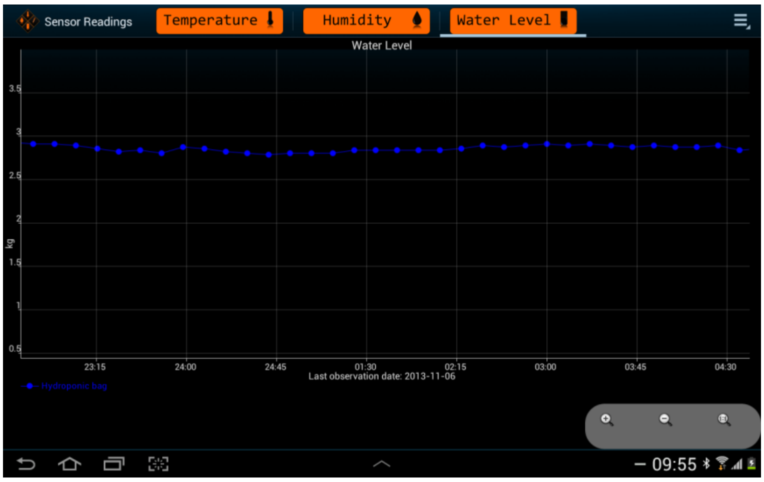

Figure 8: Logged data for Force (Load) sensor

The water levels are actually store in kg and not in cm because the system records the force that the hydroponic bag exerts over the sensor.

5.4 Humidity percentage readings

Figure 9 illustrates the measurements captured by the prototype monitoring over a short period of time and logged for humidity. The measurements are expressed in humidity percentage (% RH).

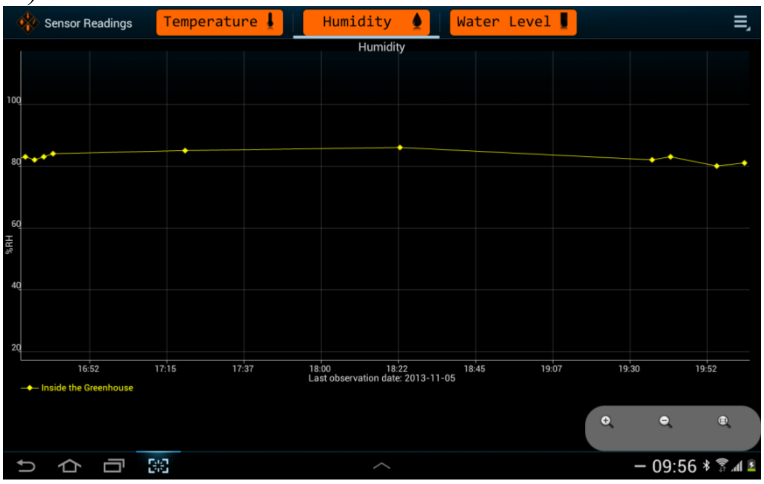

Figure 9: Logged data for humidity sensor

6. Business Benefits

For businesses it is all about the triple bottom line concept: economic prosperity, environmental sustainability and social responsibility [19]. The prototype monitoring system described in this paper fits all aspects of the concept.

The prototype monitoring system allows the farmer proactive management rather than reactive thus avoiding dreadful predicaments to the farm and ensuring therefore better yield from the crops. The prototype wireless system provides the farmer with real-time data which are essential for decision support[20]. The system also reduce the labour intensiveness of the monitoring activity especially when compare to manual monitoring.

Additionally unlike soil based farming and its environmental impact (soil pollution via fertilizer, excessive water consumption) [21], a monitoring system in a hydroponic environment lead to less waste and in turn to a lesser footprint on the environment.

7. Conclusions

The novelty of combining the Android platform, MySQL and electronics especially Arduino in this project, is one of the preeminent achievements of this study.. However it has to be outlined that the prototype monitoring system proposed in this paper was calibrated to fit the need of a particular type of hydroponic farm. Further studies could be conducted to produce a wireless monitoring system that can easily scale to any hydroponic farm. Further investigations can also be conducted to find the most adequate networking approach for large field thus leading to a real life implementation. A usability study can be conducted on the prototype system that will extrapolate hard facts on the prototype not provided by this research. Moreover a study on the impact of such a system can be conducted to deduce the additional value of the system beyond its benchmark data. Finally improvement on the cost effectiveness of the system can constitute a complete study on its own.

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Appendix E

Raw Data and Transcripts of the Interviews

(Video recordings of the interviews in the accompanying CD)

any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system.

This means that each session [SAMPLE] will include several views. Do you have any question regarding the procedure?

3.2. Pre-test screening

1. *What is your current job?* — EDUCATOR – AGRICULTURE
2. *How many years of experience have you been working in the Hydroponic farms?* 8 YEARS
3. *Do you own a smartphone? Android/iOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?* YES. — 2008 | LATEST 2014.

3.3. Task list

ABCD – PRODUCE.

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen.

EASY LAYOUT | 4 PAGES –

Task 1: Warm-up question

– MONITOR TEMP

Launch the Hydroponic System app and please take a moment and scan through the app homepage and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process)

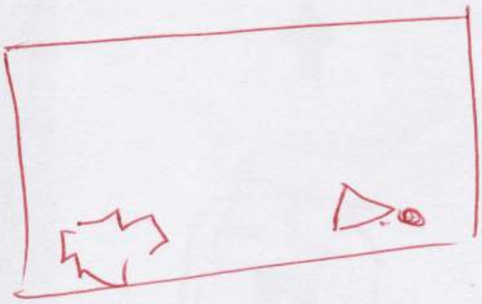
TUNNELS ; CONSISTENCY. Cucumber, Tunnels Parameter

Objectives

- ➢ To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app.
- ➢ To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions

- What is your first impression of the app regarding the following:
  - o Visual appeal
  - o Colors used
  - o Meaning of symbols and icons
  - o Terminology
  - o Navigation / Menus



- How do you feel about the way the information is organized?
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

TASK 3

RUNCAA, TUNNEL 2,

=> GRAPH.

=> SPANNER - SETTINGS

=> SETTINGS

=> TEMP => SETTINGS

INPUT.

+ TEXT FILED OBSCURED
WANT TO SEE WHAT I AM DOING

JUST PUT 44 ?? => DONE ??

ONCE I KNOW WHERE TO DO
OBSTRUCTION WITH KEY BOARD. SET.TEZ

Task 2: Viewing real data for a specific tunnel

Scenario 1

- DAILY BASIS

It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is?

√ TEMP.

Expected navigation / flow

TOUCH ON THE SCREEN: MINUTES

Home > Zones B> Tunnel 1

GRAPH INTERPRETATION - VARIABLES

LABELLING

Scenario 2

Also, how will you view how the temperature has been changing in the past hour until current time?

DAILY INTERVALS,

Expected navigation / flow

Home > Zone B > Tunnel > Temperature> Graph view

MORE DETAILS. PTE THE

- FLUCTIONS CAN BE PICKED UP

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

(#) INTERVALS & HISTORICAL DATA OF VARIABLES: MEASURED WHAT IS IT OUT TO MONITOR.

Task 3: Changing zone parameters

Scenario

It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 °C, pH to 3.7, EC to 2.5, Humidity to 44%. Use the application to show how you will go about this.

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;
- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

Expected navigation / flow

Home> Zone A> Tunnel 2, Configure > "Change Parameter values"

Task 4: Setting custom preferences

Scenario

ZONE B

GRID WITH ZONE B ONLY

→ MULTIPLE SECTION OF ZONE.

⇒ SPLIT PRODUCE IN ONE TUNNEL.

⇒ ALARM ⇒ SET A TIMER.

⇒ NOTIFICATIONS.

⇒ REMINDER

COLORS IS FINE.

*TIMER - IRIGATON CYCLE - FREQUENCY

⇒ IN THE TUNNELS

⇒ LIGHT SPRAYWATERING

⇒

⇒ LIGHT. INTENSITY

⇒

Appendices

1. SUS Questionnaire

Participant ID: 01 System: Hydroponic System Application Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☑	☑
2.	I found this system unnecessarily complex.	☑	☑	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☑	☑
4.	I think that I would need assistance to be able to use this system.	☑	☐	☐	☐	☑
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☑
6.	I thought there was too much inconsistency in this system.	☑	☑	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☑	☑
8.	I found this system very cumbersome/awkward to use.	☑	☑	☐	☐	☐
9.	I felt very confident using this system.	☑	☐	☐	☑	☐
10.	I needed to learn a lot of things before I could get going with this system.	☑	☐	☐	☐	☑

Please provide any comments about this system:

This questionnaire is based on the System Usability Scale (SUS), which was developed by John Brooke while working at Digital Equipment Corporation.

2. Consent Form

I confirm that the purpose of the test and the nature of the questions have been explained to me.

I consent to take part in the test to share my experiences, including some ways to provide feedback on the usefulness and applicability of Hydroponic System Application. I also consent to be recorded during this interview.

My participation is voluntary. I understand that I am free to leave the group at any time.

None of my experiences or thoughts will be shared anyone outside the scope of the research purpose and all identifying information will be removed first. The information that I provide during the test will be grouped with answers from other people so that I cannot be identified.

Name A. September Date 18/6/14

Signature

any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system.

This means that each session [SAMPLE] will include several views. Do you have any question regarding the procedure?

3.2. Pre-test screening

1. *What is your current job?* – STUDENT, 7-8
2. *How many years of experience have you been working in the Hydroponic farms?* B.B
3. *Do you own a smartphone? Android/iOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?* – Yes – Touch. 2 years.

3.3. Task list

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen.

Task 1: Warm-up question

Launch the Hydroponic System app and please take a moment and scan through the app homepage and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process) LOOKED FOR DROP DOWN MENU & BOTTOM MENU, ZONE, TUNNEL I → READS VARIABLES >> BACK CHOSES ANOTHER ZONE, GOES THROUGH ALL ZONES, NOTIFICATIONS DELETE (NO), BACK > CLEAR ALL, MENU. SWIPES TO MENU.

Objectives

- ➢ To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app.
- ➢ To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions

- What is your first impression of the app regarding the following:
  - Visual appeal
  - Colors used
  - Meaning of symbols and icons
  - Terminology
  - Navigation / Menus
- How do you feel about the way the information is organized?
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

GEAR – SETTINGS, NO IDEA WHAT CONFIG IS FOR, NOTIFICATIONS. DONE, SAVED

NAVIGATION WAS NOT AS EXPECTED, SWIPE BUT FOUND THE COMPONENTS, SLIDE DOWN MENU, I LIKE GLIDE AND STAYS AT SIDE; EASY NAVIGATE IN TUNNEL FOUND BACK AFTER A WHILE

I LIKE GREEN, RED INDICATE – WARNING SIGN – PLANTED OR NOT, DIFFERENT VALUE.

LIKES EXPERT ADVICE

LAYOUT – I LIKE, LOGICAL, STEEP LEARNING CURVE.

Task 2: Viewing real data for a specific tunnel

Scenario 1

It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is?

Expected navigation / flow

Home > Zones B> Tunnel 1 — 29 / 90% → TEMP WITHIN THE TUNNEL. RH NO IDEA WHAT THAT IS?

Scenario 2

Also, how will you view how the temperature has been changing in the past hour until current time?

Expected navigation / flow

- Home > Zone B > Tunnel > Temperature> Graph view

HOME, > CONFIGURE, NOTIFICATIONS. THAT MAKES SENSE, NOTICED INTERVAL — PLAYED WITH PARAMETERS

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

Task 3: Changing zone parameters

Scenario

It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 °C, pH to 3.7, EC to 2.5, Humidity to 44%. Use the application to show how you will go about this. DASH · CONFIGURE » DONE ». — GOT CONFIRMATION MESSAGE WELL

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;
- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

GEAR NOT EASY TO FIND MEANING » NO CONFIRMATION DO U WANT TO SAVE!!

Expected navigation / flow

Home> Zone A> Tunnel 2, Configure > "Change Parameter values"

Task 4: Setting custom preferences

Scenario

GOES TO MENU, SETTINGS, CONFIGURE ! OPTIONS. LANDING PAGE??

GEAR - SETTING ! - OPTIONS

GRAPH

Time frame & Values.

* Viewing of historical data.

* LAYOUT OF TUNNELS / Presentation.

* GIVES ME ALL PLANTS I HAVE

* EXPERT ADVICE

* WEATHER INFO ⇒ NEEDS AN ICON.

* Setting trading page /
  - Market pricing
  - Seed prices / feeds

Appendices

1. SUS Questionnaire

Participant ID: _____ System: Hydroponic System Application Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark <u>one</u> box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☒	☒
2.	I found this system unnecessarily complex.	☐	☐	☒	☐	☐
3.	I thought this system was easy to use.	☐	☐	☒	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☐	☐	☒	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☒	☐	☐
6.	I thought there was too much inconsistency in this system.	☒	☐	☐	☒	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found this system very cumbersome/awkward to use.	☐	☒	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☒	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☒	☐	☐	☐

Please provide any comments about this system:

any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system.

This means that each session [SAMPLE] will include several views. Do you have any question regarding the procedure?

3.2. Pre-test screening IRRIGATION ATTENDANT

1. *What is your current job?* FARM MANAGER. 2 YEARS
2. *How many years of experience have you been working in the Hydroponic farms?* -35 YEARS.
3. *Do you own a smartphone? Android/iOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?* - B - B NO - TOUCH & ↳ 4 years.

⇒ USES GLASSES - AID SAMSUNG TAB - 3 MONTHS. 6MONTHS.

3.3. Task list

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen.

- SELECT ZONE - TUNING 3⇒ CONNECT TO PROBE

ADJUST. **Task 1: Warm-up question** ALARM; NOTIFICATIONS. - INFORMING NO

Launch the Hydroponic System app and please take a moment and scan through the app homepage RECTIFYING and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process) WHAT IS THAT THERE.

UNDERSTANDS PARAMETER # FLUCTUATIONS - LAST MONTH DONE! GRAPH - WORKED WITH INTERVALS

Objectives

- To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app. TEMP - INTERNAL.
- To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions

- What is your first impression of the app regarding the following:
    - Visual appeal
    - Colors used - NOT TOO IMPORTANT.
    - Meaning of symbols and icons
    - Terminology - GOOD TERMINOLOGY.
    - Navigation / Menus - NO PROBLEM.
- How do you feel about the way the information is organized?
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

WATER ↳ OUT OF SYSTEM.

pH out | E.C out.

RUN OFF | WATER

AUTO

THE SIMPLER THE BETTER.

WIND SPEED. | WATER LEVEL | NOT MEANINGFUL.

WIND DIRECTION. pH - WHERE |

TASK 1

— THINKS APP IS TO TEACH HOW TO LEARN FARMING.

ZONE; TUNNEL > PARAMETER

⇒ GRAPH.

USE DEVICE BACK BUTTON.

WENT TO G.O.A.

GOOD TO READ PARAMETERS.

(*) COLOUR DOESN'T MATTER.

* TERMINOLOGY IS GOOD

EASY TO NAVIGATE

LIKES THE LABELLING.

T.1

>> 29°C, 90%

BACK TO DATA

GOT FILTER ?? 2B-T.1

BACK TO INTERNAL REAL DATA

BHCCK - E.C.

— HOW WILL I SEE EC IN & OUT.

2,8 - FERTIGATION EASY

2,6 - TUNNEL.

GRAPHICAL PRESENTATION

PARAMETERS

GOT IT FROM (MENU)

DONE: STARTED AT DASHBOARD.

DID NOT NOTICE.

ZONE A T.2

⇒ IF IT GOES RED.

⇒ SWITCH OFF PUMP.

AND KNOWS IT

BETTER TO SWITCH IT OFF.

NOTIFICATION

LEARNING PROCESS.

ZONE - Settings BACK

configure > BACK > NOTIFICATIONS > BACK > COG. > SETTINGS.

EXPECTED TO SEE SAVE | OK.

ZONE 13.

TUNNEL - RATINGS YOU DON'T HAVE TO WALK

— COST.

— WIND DIRECTION

⊖ X-4 Imp

ABILITY TO SET FROM PHONE.

NETWORK

Task 2: Viewing real data for a specific tunnel

Scenario 1

It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is? 29° | 90° EASY. ITS JUST SITTING THERE

Expected navigation / flow

Home > Zones B> Tunnel 1

Scenario 2

Also, how will you view how the temperature has been changing in the past hour until current time?

Expected navigation / flow

Home > Zone B > Tunnel > Temperature> Graph view

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

Task 3: Changing zone parameters

ZONE >> TUNNEL 2 > TEMP > NOTIFICATION

I DID IT BEFORE I CAN'T REMEMBER

Scenario NOTIFICATIONS, VIEW.

It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 °C, pH to 3.7, EC to 2.5, Humidity to 44%. Use the application to show how you will go about this. DONE.) GEAR DONE!

ASSIST.

STRUGGLED ENTERING THE NUMBERS

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;
- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

Expected navigation / flow

Home> Zone A> Tunnel 2, Configure > "Change Parameter values"

Task 4: Setting custom preferences

Scenario

Select zone.

You have recently harvested all your crops in the rest of the tunnels and the only crops that are remaining are in Zone B. How will you find the option for making the app to allow you to view the parameter values of Zone B when you launch the app?

Objectives

- To determine the value that users would have from allowing them to customize the viewing preferences.
- To determine the discoverability of the functionality of setting preferences.

Expected navigation / flow Cog | settings. | set it n. | SAVE ??

Cog > Settings > Default landing page "Zone B" SINGLE SELECTION.

(X). NO CONFIRMATION DO YOU WANT TO SAVE.

NB: Each task will have probe questions based on how the user interacts with the app

3.4. Post-test questionnaire

- What did you find interesting on Hydroponic System app?
- Would you consider using the Hydroponic System app? —
- What other tasks would you like to do with your phone to support the hydroponic farm activities? ALARM.
- What areas if any did you find difficult to use on the Hydroponic System app? — EC, Ph.
- How do you perceive this app to benefit you?

3.5. SUS Questionnaire (c.f. Appendix: SUS Questionnaire)

4. Performance and satisfaction metrics

4.1. Criteria and measurements

During the evaluation, two to three facilitators will participate – one will moderate the test while the others will be taking observational notes. Since the test includes several tasks and we will encourage participants to use the think aloud method, each evaluation will also be recorded (video and sound) to better analyze the data after the test.

To evaluate the usability of the system we will measure effectiveness (via task completion) and satisfaction.

4.2. Metrics for effectiveness, efficiency and satisfaction

To measure the effectiveness of the system we will measure task completion rate, deviations, errors and assistances.

Task completion

Each task will be divided into several steps that form the ideal flow to completion (see Task List). The accomplishment of these tasks will allow the calculation of task completion rate. Task completion will be defined and categorized based on the following:

Appendices

1. SUS Questionnaire

Participant ID: 02 System: Hydroponic System Application Date: __/__/__

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☒
2.	I found this system unnecessarily complex.	☒	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☐	☒
4.	I think that I would need assistance to be able to use this system.	☐	☐	☒	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☒	☐
6.	I thought there was too much inconsistency in this system.	☒	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☒
8.	I found this system very cumbersome/awkward to use.	☒	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☒	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☒	☐	☐	☐	☐

Please provide any comments about this system:

2. Consent Form

I confirm that the purpose of the test and the nature of the questions have been explained to me.

I consent to take part in the test to share my experiences, including some ways to provide feedback on the usefulness and applicability of Hydroponic System Application. I also consent to be recorded during this interview.

My participation is voluntary. I understand that I am free to leave the group at any time.

None of my experiences or thoughts will be shared anyone outside the scope of the research purpose and all identifying information will be removed first. The information that I provide during the test will be grouped with answers from other people so that I cannot be identified.

Name JOHN LOUR Date 19/6/14

Signature

Irrigation Controller – Zone – Tunnel
editable text fields –

any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system.

This means that each session [SAMPLE] will include several views. Do you have any question regarding the procedure?

3.2. Pre-test screening

piping ⇒ Water – each plant is getting per day.

1. *What is your current job?* – Farm Manager
2. *How many years of experience have you been working in the Hydroponic farms?* 20 years.
3. *Do you own a smartphone? Android/iOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?* Yes, IPad – B/B.

early / innovator: Temp – allows to open and cool. heating system.

3.3. Task list

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen. Cost of sensor

Task 1: Warm-up question

Is this one green house with 4 ZONE

Launch the Hydroponic System app and please take a moment and scan through the app homepage and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process) A B C D – Greenhouse

Colors are fine

Zone make sense.?

Objectives Green-Veggies. Irrigation controllers. – Greenhouse

ZONE ↓ TUNNELS INTERVALS ↓ GRAPH ↓ WANTED TO ZOOM

- To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app. (x) Water level.? of the bags
- To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions temp of the month

Drag the tunnels to zones

- What is your first impression of the app regarding the following: * What is the Graph interval
  - Visual appeal
  - Colors used
  - Meaning of symbols and icons
  - Terminology
  - Navigation / Menus

Graph has to be more easier to view, what are the numbers representing.

- How do you feel about the way the information is organized? * Renaming the text fields – personalised.
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

Each greenhouse has a sensor in it
Very useful.

Task 2: Viewing real data for a specific tunnel

Scenario 1

It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is?

Expected navigation / flow

Home > Zones B> Tunnel 1 — 29 — 90%.

Scenario 2

Also, how will you view how the temperature has been changing in the past hour until current time?

Expected navigation / flow

Home > Zone B > Tunnel > Temperature> Graph view — readings ; What does the numbers mean label graph better.

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

Task 3: Changing zone parameters

Scenario — No idea — Parameters

It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 °C, pH to 3.7, EC to 2.5, Humidity to 44%. Use the application to show how you will go about this.

Graph — parameter nothing to make settings.

Objectives — Menu => Notifications

Settings not on other page

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;
- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

cog — Menu — Notification — looking for settings. — Not consistent.

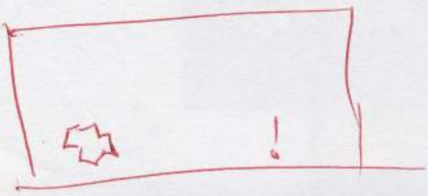
Expected navigation / flow

Home> Zone A> Tunnel 2, Configure > "Change Parameter values"

Where => Zone level. Smart — Controller based.

Task 4: Setting custom preferences

Scenario



Zone B – Setti. Configurations
Cog – Landing Page ✓ Or it suppose to be landing page

You have recently harvested all your crops in the rest of the tunnels and the only crops that are remaining are in Zone B. How will you find the option for making the app to allow you to view the parameter values of Zone B when you launch the app? Zone B -> Settings >>

Objectives

- To determine the value that users would have from allowing them to customize the viewing preferences. Cog landing page.
- To determine the discoverability of the functionality of setting preferences.

Expected navigation / flow

Cog > Settings > Default landing page "Zone B"

NB: Each task will have probe questions based on how the user interacts with the app

3.4. Post-test questionnaire

- What did you find interesting on Hydroponic System app? — Zone level | Cost
- Would you consider using the Hydroponic System app? Fairly easy to navigate
- What other tasks would you like to do with your phone to support the hydroponic farm activities? IT degree.
- What areas if any did you find difficult to use on the Hydroponic System app?
- How do you perceive this app to benefit you?

3.5. SUS Questionnaire (c.f. Appendix: SUS Questionnaire)

4. Performance and satisfaction metrics

4.1. Criteria and measurements

During the evaluation, two to three facilitators will participate – one will moderate the test while the others will be taking observational notes. Since the test includes several tasks and we will encourage participants to use the think aloud method, each evaluation will also be recorded (video and sound) to better analyze the data after the test.

To evaluate the usability of the system we will measure effectiveness (via task completion) and satisfaction.

4.2. Metrics for effectiveness, efficiency and satisfaction

To measure the effectiveness of the system we will measure task completion rate, deviations, errors and assistances.

Task completion

Each task will be divided into several steps that form the ideal flow to completion (see Task List). The accomplishment of these tasks will allow the calculation of task completion rate. Task completion will be defined and categorized based on the following:

Appendices

1. SUS Questionnaire

Participant ID: 05. System: Hydroponic System Application Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☑
2.	I found this system unnecessarily complex.	☑	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☑	☐
4.	I think that I would need assistance to be able to use this system.	☐	☑	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☑	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☑	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☑
8.	I found this system very cumbersome/awkward to use.	☑	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☑	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☑	☐	☐	☐

Please provide any comments about this system: Very Good

2. Consent Form

I confirm that the purpose of the test and the nature of the questions have been explained to me.

I consent to take part in the test to share my experiences, including some ways to provide feedback on the usefulness and applicability of Hydroponic System Application. I also consent to be recorded during this interview.

My participation is voluntary. I understand that I am free to leave the group at any time.

None of my experiences or thoughts will be shared anyone outside the scope of the research purpose and all identifying information will be removed first. The information that I provide during the test will be grouped with answers from other people so that I cannot be identified.

Name M. Oshry Date 23/June 2014

Signature

any anomalies in the farm environment. A Help function will be available to assist the users if they get stuck while using the system.

This means that each session [SAMPLE] will include several views. Do you have any question regarding the procedure?

AGRIC MGMT 3rd

3.2. Pre-test screening

IRRIGATION TECHNICIAN | STUDENT

1. *What is your current job?*
2. *How many years of experience have you been working in the Hydroponic farms?* 5 months.
3. *Do you own a smartphone? Android/iOS/Windows Phone? If not, have you ever used a smartphone or other touch-based devices?* B|B — 1 MONTH. LUMIA — 8 MONTHS.

3.3. Task list

NB: Participants should be encouraged to think aloud during this season. It is important to probe the users to discuss all the UI elements that the notice immediately on the screen.

Task 1: Warm-up question

Stressed pH & EC to be important 3 they are time consuming manually

Launch the Hydroponic System app and please take a moment and scan through the app homepage and make brief comments about it. (Participant is encouraged to explore the app, by navigating the respective screens, and think aloud during the process)

HOME >> ZONE > TUNNEL >
Configure, BACK DEVICE, Cog

Objectives

- ➢ To observe the features that the participant notices first, taking note of the overall impressions that the users get with respect to the ease of use, navigation, familiarity of the app. GRAPH VIEW
- ➢ To determine the intuitiveness, familiarity and predictability of the elements of the user interface of the application and how they comprehend the mental models of the users.

Follow up questions WHAT DO U USE C. E.C ??

- What is your first impression of the app regarding the following:
  - Visual appeal
  - Colors used
  - Meaning of symbols and icons
  - Terminology
  - Navigation / Menus

Configure
Water level min?? | mmm
Read max vs min

- How do you feel about the way the information is organized?
- What is the key message that the app is communicating to you?
- If there is anything that you would change on the app what would that be?

Did not notice notification, expect them to be on device notification bar

T3

UI

Home » Zone A » Tunnel 2 »
Temperature » Graph view
Parameters filter.
If I can just find setting
Expect to change in graph
view.
Intervals - Back
Cog - settings

The screen is not
* Wanted a little spanner to
show settings.
Struggled with number
Input values.

Zone A, T2, settings
Values.
Menu / Cog / settings
Home > Zone B > Settings
Cog / settings

Home > Zone > Tunnel
Notifications
I saw it before by free
exploration but I cant
remember now.

Zone A > T2 > Settings
It is not difficult.

(5)
Zone A, T2;
Graph view
Parameters

Water level
should be in
minutes.

There is nothing that show me
where I can make settings.
Cog
Settings
Menu > Notification
Notifications
Notifications.
The settings was not on other pages.

Task 2: Viewing real data for a specific tunnel

Scenario 1

It has been a sunny day and you are wondering how hot and humid it is in Zone B, Tunnel 1. How would you go about to find out how hot and humid it is?

98%, 29%, Min & Max record at different times.

Expected navigation / flow

Home > Zones B> Tunnel 1

Scenario 2

Also, how will you view how the temperature has been changing in the past hour until current time?

Expected navigation / flow

200 m

Home > Zone B > Tunnel > Temperature> Graph view

time, hrs

Intervals => Got it after told.

Labels do not make sense (Variables)

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the tunnels;
  expects to swipe them. (make it hourly)
- To determine how the participants interpret the dashboard to be the central point to all their navigation;
- To determine how users understand the presentation of tunnels in zones.

Configuration.

Task 3: Changing zone parameters

Scenario

HOME > ZONE > Tunnel > Graph > BACK > Cog

It is the end of the crop cycle and you wish to change the crop in Zone A, Tunnel 2. This also requires you to set the values of Temperature to 28 °C, pH to 3.7, EC to 2.5, Humidity to 44%. Use the application to show how you will go about this.

temp => Graph view, cog => Go settings.

Objectives

- To determine the ease of navigation and the familiarity / predictability of finding the section for configuring the parameters;
- To determine how the participants interpret the use of the spinner for inputting parameter values;
- To determine how users understand the information architecture with respect to presentation of parameter labels and associated variable values.
- To determine if the users can understand the difference between configuring Zone parameters vs Tunnel parameters.

Expected navigation / flow

Home> Zone A> Tunnel 2, Configure > "Change Parameter values"

Task 4: Setting custom preferences

Scenario

0 1 0 3 0 1

Zone B >> Settings Configure

Cog Setting Landing page

6-0-5-1

UI

Home >
Cog > Setting > landing page, Zone B

0 1 5 5 1 1

Zon Home > Zone B > Back > Home (1)
Cog > Settings > Landing Page > Zone B ; how do I (save)

Zone B > Configurations

0 1

1	2	3	4	5	6
0	1	0	3	0	1

Expects close button.

You have recently harvested all your crops in the rest of the tunnels and the only crops that are remaining are in Zone B. How will you find the option for making the app to allow you to view the parameter values of Zone B when you launch the app? Close the other, taps, switch them off.

Objectives

- To determine the value that users would have from allowing them to customize the viewing preferences.
- To determine the discoverability of the functionality of setting preferences.

Expected navigation / flow

Cog > Settings > Default landing page "Zone B"

Get the notification. Notification in the Zone.

NB: Each task will have probe questions based on how the user interacts with the app

3.4. Post-test questionnaire

- What did you find interesting on Hydroponic System app? tell parameter. EC – in the pipes?? in the bag.
- Would you consider using the Hydroponic System app?
- What other tasks would you like to do with your phone to support the hydroponic farm activities? — Zones >> Notification.. Red color. problem??
- What areas if any did you find difficult to use on the Hydroponic System app?
- How do you perceive this app to benefit you? No need to go out. Saves time.

Create new zones — add them to it. How do add more zones?

3.5. SUS Questionnaire (c.f. Appendix: SUS Questionnaire)

4. Performance and satisfaction metrics

4.1. Criteria and measurements

During the evaluation, two to three facilitators will participate – one will moderate the test while the others will be taking observational notes. Since the test includes several tasks and we will encourage participants to use the think aloud method, each evaluation will also be recorded (video and sound) to better analyze the data after the test.

To evaluate the usability of the system we will measure effectiveness (via task completion) and satisfaction.

4.2. Metrics for effectiveness, efficiency and satisfaction

To measure the effectiveness of the system we will measure task completion rate, deviations, errors and assistances.

Task completion

Each task will be divided into several steps that form the ideal flow to completion (see Task List). The accomplishment of these tasks will allow the calculation of task completion rate. Task completion will be defined and categorized based on the following:

Appendices

1. SUS Questionnaire

Participant ID: 06 System: Hydroponic System Application Date: 23 / 06 / 14

System Usability Scale

Instructions: For each of the following statements, mark <u>one</u> box that best describes your reactions to the system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☑
2.	I found this system unnecessarily complex.	☑	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☑	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☑	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☑
6.	I thought there was too much inconsistency in this system.	☑	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☑	☐	☐	☐
8.	I found this system very cumbersome/awkward to use.	☑	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☑	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☑	☐	☐	☐

Please provide any comments about this system:

2. Consent Form

I confirm that the purpose of the test and the nature of the questions have been explained to me.

I consent to take part in the test to share my experiences, including some ways to provide feedback on the usefulness and applicability of Hydroponic System Application. I also consent to be recorded during this interview.

My participation is voluntary. I understand that I am free to leave the group at any time.

None of my experiences or thoughts will be shared anyone outside the scope of the research purpose and all identifying information will be removed first. The information that I provide during the test will be grouped with answers from other people so that I cannot be identified.

Name MAHINTSHO MVUZO Date 23-06-2014

Signature [signature]

Appendix F

Proofreading and Language Editing

RICKY WOODS
Proofreading and Editing

25 January 2015

Prof. Darelle van Greunen

Nelson Mandela Metropolitan University

Dear Madam

Proofreading of Master's Dissertation

I, Marietjie Alfreda Woods, hereby certify that I have completed the proofreading and correction of the dissertation**, Wireless ICT Monitoring for Hydroponic Agriculture,** by **Loic Andre Stephane Ndame**, submitted in fulfilment of the requirements for the degree **Magister Technologiae** in the School of ICT at the Nelson Mandela Metropolitan University

My own credentials are as follows: I completed reading for a BA degree in 1977 at the University of the Witwatersrand, majoring in English and Afrikaans en Nederlands. Thereafter, I completed a Higher Education Diploma. I have been teaching English Home Language since 1979

I am currently Head of Department Languages at Alexander Road High School, where I have been Subject Head of English for the past fourteen years. I have also been working formally in the area of editing and proofreading online since the beginning of 2011. I have accreditation in Copy-Editing and Proofreading from the South African Writers' College.

I believe that the thesis meets with the grammatical and linguistic requirements for a document of this nature.

Yours faithfully

(Mrs) M.A.Woods, BA, HDE (PG) (Wits),BA (Hons)(Psych), Dip Sp Ed (Unisa)

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