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Ubiquitous technologies for agricultural applications

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Abstract

Nowadays, in order to fulfill the demands of the current market conditions, the synergy between products and services is becoming very important. Every day, people are using more technologies being less aware of it. Ubiquitous Technologies (UT) allows the synergy between this new products and its users in a more effective way: being unobtrusive and having information widely available, reliable and relevant. These technologies are a useful approach for the design and development of technical systems for mission-critical applications.

Located in a near future where phenomena as global warming and climate change raise the question of how food will be produced. This work presents a ubiquitous monitoring system for greenhouses. The system is composed by a modular hardware platform and uses Expert Systems (ES) to support the decision making process during the data processing.

The system was designed, built and tested using two different platforms in order to validate its usability for Ubiquitous Systems (US). A step by step process is proposed for the data acquisition, formalization and inclusion of expert knowledge into a US.

Keywords: Ubiquitous Technologies, Cyber Physical Systems, Decision Support Systems, Knowledge Based Systems, Wireless Sensor Networks, Technical Systems Design, Greenhouses.

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Chapter 1

Introduction

1.1 Background

Ubiquitous Technologies (UT) can be defined as a type of Human-Computer Interaction (HCI) where the data acquisition and processing are highly integrated into the daily actions and elements without affecting their final user. Because of the integration in daily life, UT allow the synergy between products and services in an effective way.

A ubiquitous system should be composed by elements covering the following main areas: sensing, transmission, exploration and sensations generation [Gerritsen and Horváth, 2010]. Each one of these areas in a ubiquitous system is another system itself and has its own components and interactions. Although the different areas would be considered on the development of this work, a special emphasis will be made in the exploration area. On this area, the main goal is to process all the incoming data from the sensing and transmission areas in order to obtain information and knowledge that can improve the system. The information and knowledge relevant for this work, is the one that can improve the decision making process based on the real time state of the monitored system.

Decision Support Systems (DSS) are information systems to support the solution of non-structured problems improving the decision making process [Turban, 1995]. These systems are an ideal complement for ubiquitous technologies. By definition, DSS must allow the decision making during the situation analysis time [Turban, 1995] and can be improved by having real time data coming from a system that sense continuously the environment. For specialized systems, traditionally important decisions are made by highly trained humans called experts. However, Expert Systems (ES), an outgrowth of Artificial Intelligence (AI), helps with the automation of this process, by solving complicated problems through a computer application (algorithm). Problems that otherwise require extensive human expertise, consuming considerable time and resources.

Food production systems are vital for human life. Phenomena as global warming and climate change raise the question on how food will be produced in the near future, when the outdoors production wouldn't be an option because of the weather conditions.

The natural necessity of a sustainable food supply, combined with the previously presented phenomena has influenced the development of solutions as greenhouses. Nowadays greenhouses are used as a way of food production out of season in some regions, usually protecting the crops from cold weather. This use could change in the future, when greenhouses can become the only way to grow food in a reliable way all year long, making greenhouses a critical system from which the food supply would depend.

This work attempts to implement a ubiquitous system for monitoring the state of a greenhouse in terms of its main variables and place important data on-line in a dedicated web page. The data coming from the monitoring system would be used to support decisions regarding the system state including scenarios detection, causes and possible consequences. This process is conducted remotely in distributed processing units running an ES based on knowledge collected from human experts in the field.

1.2 Research justification

The Design Engineering Research Group (GRID for its acronym in Spanish) from EAFIT University has under its research topics the design and development of products with high technological content. In association with the Computer Aided Design Engineering (CADE) laboratory from the Delft Technical University (TU Delft), international workshops and courses about UT have been conducted. The courses include not only undergraduate and postgraduate students from both universities but from other countries as USA, China, India and South Africa.

Different projects, aimed to develop the interaction between product and services, have been developed during the last years. The main UT course is called Ubiquitous Product and Service Innovation (UPSI) and the author of this manuscript had the possibility to participate into this course as a student and lecturer. This background gives him a wide overview of the projects developed since 2010, as well as an understanding of trends and challenges in the subject.

During the UPSI course and workshops a gap between the data processing and its conversion on information and knowledge was detected. For this reason, the project “Ubiquitous Technologies for Agricultural Applications” makes special emphasis on the technological processing of data acquired by a ubiquitous monitoring system, aiming to create a real connection between high tech products and the application of ubiquitous technologies. The integration between ubiquitous technologies and decision support systems implies a deeper understanding between the physical phenomena and the dynamic decision making process. Also, defining a way to unify these topics (UT and DSS) improves the ability to design and create intelligent equipment and machinery that could be applied on different systems.

1.3 Problem definition and research question

UT appears as a novel technology approach that aims to provide non-intrusive enrichment to the systems where are implemented and its stakeholders. Agronomy experts are not always available for in-field decisions in greenhouse systems, specially for medium and small production units.

For the monitoring of those systems UT can be applied, however with formal data gathering its analysis depends on expert personal which according to the circumstances define the actions to be taken in order to guarantee the system stability. As the the expert is not always in-field the research question become:

How to include expert knowledge in a ubiquitous monitoring system for greenhouses, in order to support the daily in-field decisions?

1.4 Objectives

1.4.1 General objective

Include decision capabilities in a ubiquitous monitoring system for greenhouses. This in order to have on-line information and a preliminary analysis that guides in-field actions even when the expert is not present.

1.4.2 Specific objectives

- Explore techniques to support the decision making in greenhouses, by the study of different available techniques and the definition of the context and stakeholders involved.
- Design and create a modular hardware platform for the ubiquitous monitoring of greenhouses, by defining the main variables of the system and its relevance.
- Design a decision support system that integrates information coming from the designed hardware platform and provide extra information to the stakeholders.
- Implements and test the designed decision support system in the hardware platform, gather information about the usability for different type of users.

1.5 Research Scope

The scope of the present research is centered on the greenhouse monitoring as an entire system. For this reason specif information about the plants growth and its produce are not considered in this work. However, the subsystem of a plant is taken into account for the design and implementation.

At the end of the project implementation, the expected deliverables are:

- A comprehensive way (step by step) to gather and process expert's knowledge in order to include it into a ubiquitous system.
- A modular expansible hardware platform for ubiquitous monitoring of the main greenhouse variables.
- An informative web page to monitoring a greenhouse state in real time.
- A knowledge model to support in-field decisions for greenhouses based on expert knowledge.

1.6 Research methodology

The project includes the design and development of a hardware platform to act as carrier. The carrier would be used to prove the model of “knowledge gathering” and “data processing" for ubiquitous technologies. In order to define the most appropriate methodology to develop the work, and taking into account the imperative necessity to design and implement a complete physical system, different research methodologies specific for design engineering were analyzed.

In Horvat [2007], a complete comparison among three methodologies for design research was developed. The analysis was carried out from the following aspects:

- Ontological: What the framing methodologies actually are and why they exist.
- Epistemological: What the sources, structures, and contents of knowledge are.
- Methodological: What processes the framing methodologies imply, and what methods they involve.
- Praxiological: To which problems the framing methodologies have been applied, and how they are working in the practice.

The compared design research methodologies were:

1. Research in design context.
2. Design inclusive research.
3. Practice-based design research.

The present project, not only needs the hardware platform but the knowledge acquisition, representation and processing plays the most important role. And, by the nature of the people involved in the greenhouse processes, these aspects must be done in a multidisciplinary environment.

The methodology to conduct the project should be capable to combine fundamental and applied research approaches. The search for specific and specialized information in the field from primary sources is widely related to fundamental research, while the design and development of the platform is closer to applied research.

According to Horvat [2007] from the three compared methodologies, Design Inclusive Research (DIR) is the only one that supports analytic disciplinary and constructive operative design research. It involves various manifestations of design in research processes as research means, integrates knowledge of multiple source domains and lends itself to multidisciplinary insights, explanations and predictions. Can also generate knowledge, know how and tools for problem solving. The DIR methodology provides a specific stage for the design and development of physical systems, as needed in this case, and is also capable to obtain and generate knowledge.

The objective of DIR is to provide a sound theoretical foundation and a robust methodology approach for designer inquiry to meet scientific rigor [Wood, 2000]. In order to achieve the objective, the research process is divided into three phases or research actions: (i) phase of explorative research actions, (ii) phase of creative research actions, and (iii) phase of confirmative research actions [Horvat, 2007]. The general process of DIR methodology is shown graphically in figure 1.1.

1.7 Manuscript organization

This work is organized by chapters following the three DIR methodology phases presented in section 1.6, and ending with an special space for conclusions and further work.

Chapter 2 corresponds to the explorative phase where a state of the art is presented in terms of UT, greenhouses and makes special emphasis in DSS, its design and applications.

Chapter 3 presents the design and implementation actions developed during the present work. This chapter is divided in the main clusters for UT, defining this way the steps followed on each of them. Also two different platforms for the presentation and processing of data are compared.

The confirmative phase is presented in chapter 4 where the different tests of the system functionality are described, as well as the results of its application. Also a generalization of the work is described in order to be applied in order fields.

Conclusions and further research (chapter 5) shows conclusions and the way to improve the work done.

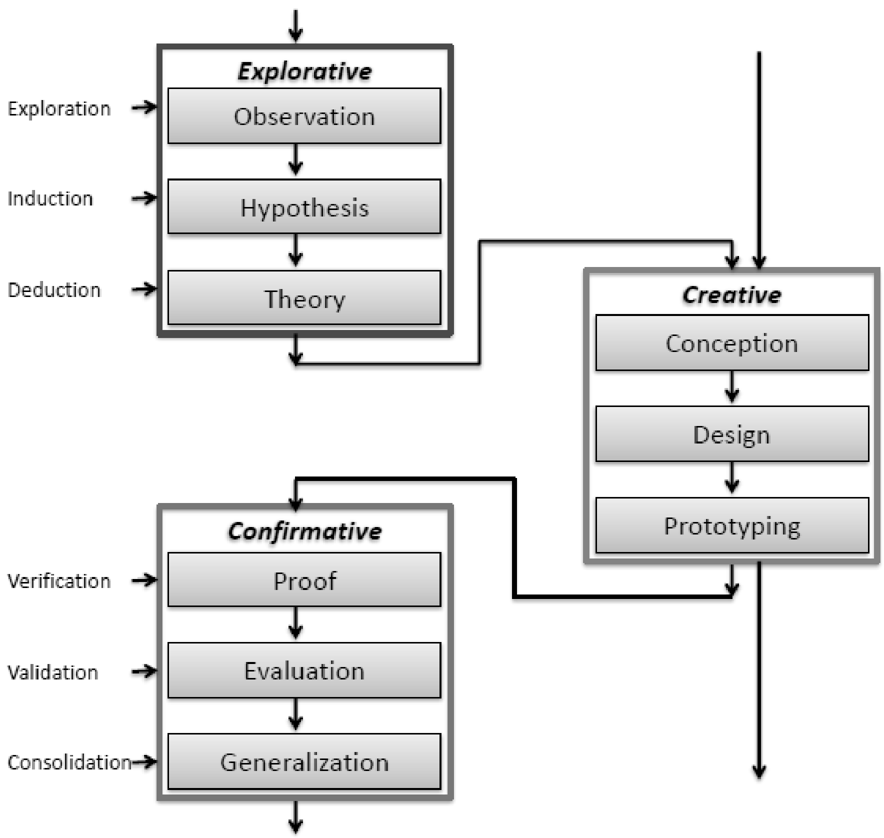


Figure 1.1: Major phases of design inclusive research [Horvat, 2007]

Chapter 2

Explorative: DSS for UT in greenhouses

This chapter presents the explorative research actions carried out during the present project in order to obtain a pre-study (micro-culture) of the problem and the different techniques aimed to solve it. The pre-study includes exploration of techniques and approaches, as well as induction and final deduction of the problem.

The explorative process was carried out including the literature review, primary in field research and web search for the most relevant topics of the work. It includes: (i) Ubiquitous Technologies, (ii) Decision Support Systems and Knowledge Based Systems, (iii) Design methodologies for Decision Support Systems and (iv) Greenhouses.

2.1 Ubiquitous Technologies (UT)

In order to define what UT is, is important to understand the word "ubiquitous", which appears in the oxford dictionary as an *"adjective to declare that something is present, appearing, or found everywhere"*. According to that, on its basic definition UT are technologies widely available and present everywhere.

UT come directly from the concept and development of Ubiquitous Computing (UC), a research field that started in the late 1980s and from which Mark Weiser, is often seen as the founder [Want et al., 1992]. The UC paradigm is centered on the idea of integrating computing power in devices and environments in such a way that they offer optimal support to human daily life activities [Weiser, 1991].

Globally, UT can be defined as a type of human computer interaction where data acquisition and processing are highly integrated into the daily actions and elements without affecting the final user behaviour [Gerritsen and Horváth, 2010]. This integration into the daily elements is the main difference between a ubiquitous technologies application and a typical automation or mechatronic system. In this sense, UT can be seen as an evolution of mechatronics that allows the synergy between products that acts directly in the physical world and services running in a digital or augmented world on a more effective way.

Nowadays, In order to fulfill the demands of the current market conditions, the synergy between products and services is becoming very important. Every day, people are using more technologies being less aware of it. For instance, mobile phones have become a tool now used not only for phone calls. In fact, this pocket device is always keeping track of the GPS position, searching for Wi-Fi networks, among others actions.

Moreover, depending on the collected information, the device is capable to send personalized suggestions to each user according to the recorded preferences. All this happens without the user being aware of it, proving that technology is more embedded in everyday life actions. This phenomenon of the technology becoming ubiquitous for our life is also known as presence-in-absence technologies [Garnæs et al., 2007].

As presented in chapter 1, traditionally UT are composed by elements covering the areas of sensing, transmission, exploration and sensations generation. However, during the explorative phase of this project, a deeper and detailed definition of the composition of a US in terms of three clusters was developed and published [Mejía-Gutiérrez et al., 2014]. Is on these clusters that the present work is framed from now on.

Clusters covering the three main pillars of UT [Mejía-Gutiérrez et al., 2014] are:

1. User/context/system interaction cluster: Cluster directly related to how the system interacts with the physical world, not only for receiving information, but to provide responses. It includes and makes special emphasis in the monitoring of the conditions surrounding the system at any level.

2. Data transfer cluster: Referred to the communication aspects of the system. As it will be shown further in this work that this cluster is usually embedded with the other two and the limits between them are highly fuzzy. It is important to clarify, at this point,

that UT does not have specific limits between the clusters because the main idea is to keep all the system working in synergy.

3. Data processing cluster: Refers to the computational and control aspects of the system. It is on this cluster that the present work is focused on. It deals with the way in which the US process the data coming from the interaction cluster through the communication cluster, in order to generate information and, in advanced applications, produce knowledge. On this cluster the DSS plays an important role and can be introduced into a US.

For the **interaction cluster**, the data gathering is a key aspect. Interaction with the environment has to be taken into account not only for the information that the system provides, but for the information that the system needs to run. It is important to ensure that accurate and relevant data from any type and source can be gathered in a unobtrusive way.

In order to keep the system unobtrusive, knowledge and information from the environment and stakeholders are a key aspect to start the development. For the recognition of a system and its actors, there are different collection techniques available. Most of them to collect data from individuals or groups of people. Some of these techniques are:

- Surveys: This data gathering method is special to collect data from individuals, a survey can be conducted through a printed questionnaire, by mail, on the web, etc. The most important characteristic in a survey is that all the participants are asked with the same questions in the same way, it includes asking people in a structured way.

- Interviews: Interviews can be conducted for individuals or groups in three fundamental types: (i) structured, (ii) semi-structured and (iii) unstructured. The definition of the interest group as well as the type of interview to conduct depends on the information needs. Structured interviews are basically a verbalized questionnaire and can be seen as a survey conducted in person. Semi-structured interviews usually has a series of topics to be covered but not exactly the way or the questions to cover those. While unstructured interviews starts with an open question and the further development depends highly of the main answer to that question.

- Focus groups: This data collection technique is used only with groups of people. Usually are seen as interviews with six to twelve people with similar characteristics or interests useful for the project. Focus groups are conducted by at least one facilitator that guide the session into a predefined set of topics to be covered. In this sense, it shares the semi-structured explanation previously described for interviews.

- Site visits: Site visit consist in going directly to the source of the needed knowledge, not just to meet with the right person (as interviews) but in the right place, this is when the knowledge is applied or developed. This technique is specially useful when information about any physical process is needed.

- Programed or direct observation: Technique closely related to sites visits. This technique provides the opportunity to document activities, behaviour and special physical aspects of the interest system, scenario or environment without depending of the people ability to answer questions. As the site visit technique, the direct observation must be done in the right place. However the main difference is that specific verbal interaction is not needed.

The selection of one ore more of these techniques must be done for each project taking into account the purpose of the data collection process and how the collected data is going to be processed and converted into information and knowledge.

Each of the presented techniques has advantages and disadvantages that have to be evaluated according to each application case. However, none of them are specifically framed, or even take into account the development and inclusion of the obtained data into a ubiquitous system, one of the main outputs of this work.

In automated systems, these techniques can be applied when there is data that is only necessary for the set up of the system. However, for UT based systems, as the system must be as unobtrusive as possible, it is desirable that all the information needed for the system to run comes directly from autonomous systems and are not dependable from the user(s), lowering the subjectivity of the answers.

According to the previous affirmation, sensors are the most common automatic way to collect data form the environment and accomplish the characteristics of a US that have been discussed during this work. Data coming directly from the user or any other stakeholder of the process is also possible to include and most of the time is necessary in order to setup the system, however if information directly provided by the user is needed to guarantee that the system keeps running, the ubiquity level of the system, understood as how the system meets the characteristics of three clusters previously presented will decrease.

A sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal that can be electrical, mechanical, magnetic, etc. [Bishop, 2002]. Usually, when the type of input and output energy are different, the sensor includes a transducer which converts one form of energy into another. However the terms sensor and transducer are normally used as synonyms in literature.

For complex and mission critical systems as greenhouses for the presented framework, where more that one variable is monitored and relevant in the decision making process, Wireless Sensor Network (WSN) has important applications such as remote environmental monitoring and target tracking [Yick et al., 2008]. A WSN also known as spatially distributed autonomous sensors is composed by autonomous, independent and wireless sensors nodes which monitors one or more variables and the network cooperatively passes the data. The processing of all the gathered information from each one of the nodes can be centralized and/or decentralized/distributed.

Sensors of any type depending of the desired information or variables to monitor are the core aspect of any WSN. Also, as presented before, one of the main characteristics of a WSN is its capacity to transfer information wirelessly over the network, capability provided usually by a radio transceiver. For this reason in the implementation of a WSN the communication devices are also important.

No matter communication is a topic of the data transfer cluster and we are exploring the interaction cluster. For US and the application of WSN for the environment monitoring integration between these two clusters is visible and as presented before, barriers between the systems and clusters starts to be fuzzy.

For the **communication cluster** in UT, communication technologies are the main topic. As the ubiquity definition implies the presence of this technologies everywhere communication must be carried out constantly during the system functionality in order to ensure this.

Communication technologies can be divided in two main groups depending of the physical media that employs to transfer the data: (i) wired communication technologies and (ii) wireless communication technologies. Each one has its advantages and disadvantages. For example, wired networks are highly reliable in terms of stability and speed, however the mobility and adaptation capability are compromised.

When the information gathering process is carried out using a WSN, as the name indicates, the network connectivity must be wireless, for this reason a deeper exploration into the different protocols for this type of communication was done during the explorative phase of the project.

Wireless communication starts its development in 1897 with Marconi's successful demonstration of wireless telegraphy [Tse, 2005] and the use of electromagnetic waves for information transmission, which composes the basis of most of this technology, including all the protocols developed in recent times. Wireless technologies have increased its presence and use in the market during the last years for short communication proposes, mainly due to the fact that the required infrastructure is becoming more commonly available, reliable and affordable.

Nowadays, the most used type of wireless communication technologies are:

- Infrared.
- Wireless Fidelity - WiFi.
- Bluetooth.
- ZigBee.
- Near Filed Communication - NFC.
- Radio Frequency IDentification - RFID.

From the previously presented technologies, in WSN, wifi, bluetooth and zigbee communication protocols are the most widely implemented. Protocols as infrared are not useful as view line is needed between the nodes, NFC and RFID protocols are mainly dedicated to the identification of special tags and validations of identities, but not for data transfer. According to that, the main communication protocols were analysed and compared in terms of seven characteristics. The results are summarized in table 2.1.

In UT, bidirectional interaction between the system and the environment is a key aspect. As the system is computer based, it uses and process only digital information, but these information has to come from and back to a physical world that runs continuously. This idea makes clear that the interaction between computational and physical processes is imperative in order to provide physical responses to the user/environment depending on a computational

Table 2.1: Communication technologies comparison

	wifi	**Bluetooth**	**Zigbee**
Module price	USD $35	USD $20	USD $20
Range	30 m	10 m	> 10 m
Networking capability	Multipoint	Point to multipoint	Point to multipoint
Speed	600 Mb/s	720 Kb/s	250 Kb/s
Setup time	1 s	6 s	1 s
Security	Software level	Protocol level	No
Communication mode	Active to active Active to passive	Active to active	Active to active

process. This paradigm brings the more recent approach to UT: the Cyber Physical Systems (CPS), a term coined by Helen Gill at the National Science Foundation in the U.S. to refer to the integration of computation with physical processes [Lee and Seshia, 2010]. CPS as a research field is not dealing with the union of cyber and physical problems, but rather with their intersection. Not looking for a faster computing but for physical actions taken at the right time [Lee, 2010]. During the development of this project UT will be used as the main term to define the technologies employed. However the presented paradigm plays an important role and is taken into account during the entire development.

In the last ten years, UT has been applied in a variety of fields. In figure 2.1 the main areas that uses this type of technologies can be seen. Figure 2.1 was constructed with data collected from scientific databases as Springerlink, Sciencedirect and Scopus organized by discipline and/or subdiscipline of application when "Ubiquitous Technologies" was used as the main search term. It is important to notice that this work uses, includes and applies the four main application areas for UT: (i) Database management and information retrieval, (ii) Human-Computer Interaction, (iii) Artificial Intelligence and (iv) Communication networks.

Summarizing, UT born as a combined evolution of UC, mechatronic systems and the presence-in-absence technologies paradigm. Its applications has been mainly in software and data analysis areas. However, the continuous and fast evolution of technologies; specially in data acquisition and communication has favored the application of this technologies in physical systems, improving the human-computer interaction. This evolution is actively closing the gap between the virtual and the real world, coming to the most novel approach to UT the CPS.

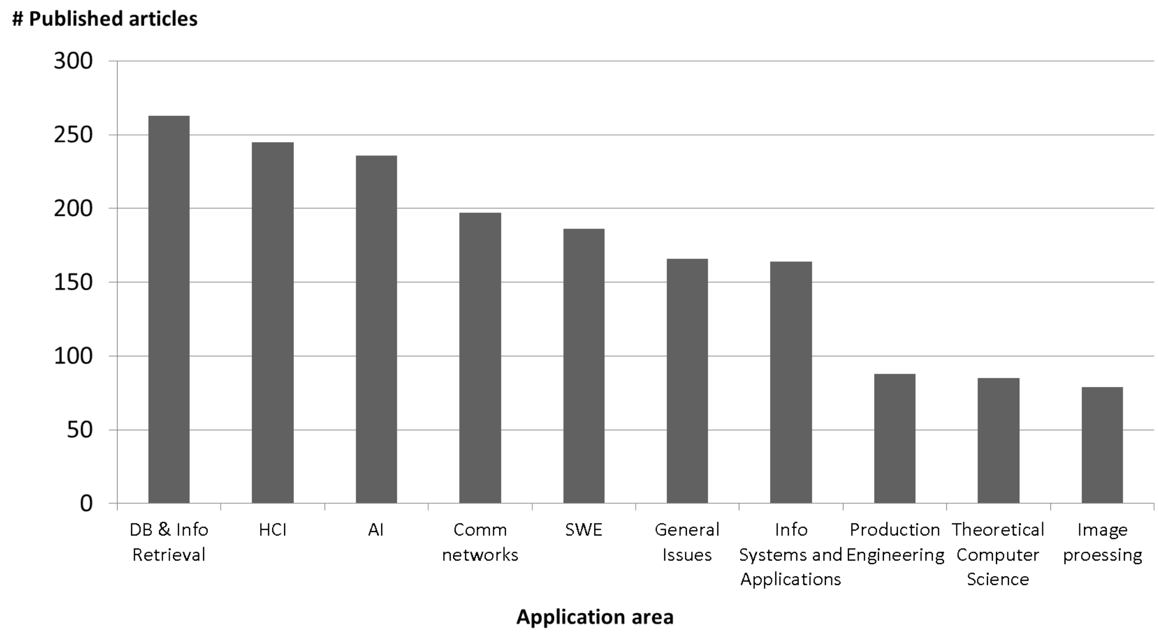


Figure 2.1: Main areas for UT applications

The development of UT in EAFIT University (EAFIT) has been mainly through the Product Design Engineering department in collaboration, among others, with the Delft University of Technology (TU Delft) that has been working in UT research and applications since 2011.

In the projects from the Ubiquitous Product And Service Innovation (UPSI) course (see section 2.1) the students co-operate with students from other universities in international teams, forming academic virtual enterprises together with academic staff and partners from industry. Based on a thorough analysis of society and technologies, product ideas are generated and evaluated. For a selected product idea brokerage is done to find a company. The product idea is elaborated to a concept and a product proposal, and in a final workshop the working prototypes are build, tested and presented. So far, four international workshops have been developed, three of them hosted in EAFIT.

Interesting, novel and innovative products have been developed during the UPSI courses. Some of the results can be seen in Figure 2.2.

Taking into account the three main clusters of UT in which this work is based: (i) user/context/system interaction, (ii) data transfer and (iii) data processing [Mejía-Gutiérrez et al., 2014], it was detected that most of the developed projects has deficiencies in the data

Figure 2.2: Sample projects of the UPSI course

processing cluster, in detriment of the overall global ubiquity concept for the application of these technologies.

From the composition of the data processing cluster presented in table 2.4. It is clear that the capacity to develop application projects with UT, in which the data processing plays a greater role into the general system was a gap to be fill in order to continue the UT research and development process.

By increasing the role of the data processing cluster in the entire system: including expert knowledge, anticipatory capacities and any other advanced type of data analysis, the system autonomy in terms of decision making will increase at the same time with the ubiquity level.

2.2 Decision Support Systems and Knowledge Based Systems

Since the appearance of DSS in mid 70's [Witlox, 2005], different definitions have been given to this type of systems. The most general ones define them as any system capable to make contributions into the decision making process [Sprague and Watson, 1993]. Specific defini-

Table 2.2: User, context and system interaction cluster [Mejía-Gutiérrez et al., 2014]

Features	**Description**
Environment/context-aware, localized, situated, adaptive	In a dynamic environment, the application actively adapts to context changes rather than just present context changes to the user. The system can discover the situation or context such as: location, time and user activity. Physical context-awareness includes more than spatial and temporal awareness, such as environmental information (e.g. Temperature, Humidity, etc.)
User-aware, personalised, tailored	The application is aware of presence of the user, user ID, user characteristics. This may trigger system adaptation and the HCI is tailored to an individual user or type of user, based on personal details or characteristics that a user provides or is gathered about a user.
Hidden, invisible	The application is invisible to the user. It is integrated into the general ecology of the context
Ease of use, tangible, natural, non-intrusive	Interaction is via natural user interfaces and physical/virtual artefact interaction that can involve gestures, touch, voice control, eye gaze control, etc. and can be used intuitively and nonintrusively by users
Reactive, reflex	Environment events are sensed. Events then trigger action selection that may lead to actuators changing their environments

Table 2.3: Data transfer cluster [Mejía-Gutiérrez et al., 2014]

Features	**Description**
Generic	Able to operate across different software platforms, seamless integration of devices and environments
Networked, transparent, virtual	Devices are interlinked using a network which is often wireless
Synchronised, coordinated, response time	Multiple entity interaction can be coordinated synchronously or asynchronously over time and space interactions. It guarantees an adequate response time
Mobile, nomadic	Users, services, data, code and devices may be mobile
Security	Data is only accessible to authorized persons/entities

tions can be founded as the one presented by Gorry and Morton [1971] who defined them as interactive computer based systems that helps the decision making process for non structured problems trough the implementations of data and models.

Literature shows that DSS are commonly used to solve non structured, semi structured or

Table 2.4: Data processing cluster [Mejía-Gutiérrez et al., 2014]

Features	**Description**
Model-based, rule-based logic, reasoning, intelligence, inferences	Systems use a model of how itself operates and the how the world works. There are many types of model representation such as rule-based, different types of logic-based, agent-based, artificial intelligence, etc.
Autonomic, self-managing, self-star	Able to support various properties such as self-configuring, self-healing, self-optimising and self-protecting behaviour
Recursive, interactive	System interacts with shared knowledge (e.g. acces public databases or search for information in the web)
Anticipatory, speculative, proactive	Improving performance and user experience through anticipated actions and user goals in relation to current context, past user context and group context. This overlaps with user context-awareness
Distributed processing	Tasks can be divided and processed independently. It may be distributed to guarantee fault-tolerance

bad structured problems [Keen and Morton, 1978; Turban, 1990]. With the emergence of the DSS the ES appears as well. These systems are also know as Knowledge Based System (KBS) [Witlox, 2005]. ES or KBS born as an extension of Artificial Intelligence (AI) designed to work with structured problems.

An ES is a software that emulates the taking decision ability of a human expert in a specific field [Giarratano et al., 2001]. ES are used to perform a variety of extremely complicated task that in the past could be performed by only a limited number of highly trained human experts [Rolston, 1988]. As ES emulates human experts, its conception and development process is closely related to Knowledge Engineering (KE), specially at the initial phases of knowledge acquisition and representation. It is during these phases when the knowledge engineer starts the interactions with the expert in order to gather its knowledge, this knowledge become more specific as the process advances. After having this knowledge or even while gathering it, is task of the knowledge engineer to represent it in a way that can be processed automatically using any system decided for this purpose in order to create the final ES.

The representation of the knowledge can be made through different techniques as formal logic, semantic networks, frames, scripts, production systems, among others. The selection of the representation method depends on the type of knowledge that is being represented, the programming language that fit the system and usually the shell to be applied. A shell is a tool for the development of ES and are created for a certain type of knowledge representation. The selection of the correct tool allows the obtained knowledge to become useful and actionable over the system and, therefore, is a key decision in the development of an ES as is directly related with the efficiency, speed and maintainability of the system.

As can be deduced from the previous paragraphs, an ES is at the end a computer algorithm that allows the data processing and decision making process to work emulating a human expert. However, the development of this algorithm has some unique characteristics: [Rolston, 1988]:

- The domain expert (customer) is involved throughout the entire process.
- Frequent demonstration of work to date are encouraged.
- Change is not only viewed as healthy but the central concept.

Decision Support Systems based on Expert Systems or Knowledge Systems starts its integrated development since the work done by Mintzberg [1976]. The work looked to support decisions from both perspectives the analytic of classic DSS and the intuition given by the ES and AI [Bonczek et al., 1981].

Different integration ways between DSS and ES or KBS have been appears. The most relevant are [Witlox, 2005]:

- KBS integration into various DSS components.
- DSS integration into a KBS .
- KBS as a separate component of a DSS .

The results of the previously presented integration techniques obtains different names, the most widely spread in literature are: Intelligent DSS (IDSS), Intelligent Support Systems (ISS), eExpert DSS (EDSS), Expert Support Systems (ESS), Knowledge Based DSS (KBDSS) and Agent-based DSS [Witlox, 2005].

As ES and KBS are closely related with AI since its creation, AI techniques can play an important role in these systems. A DSS can include a knowledge model in form of a ES and also can use AI techniques in order to obtain a depper understanding of the problem. For the inclusion of AI into a DSS, as part of the presented work, the main AI techniques were studied and defined in terms of the inputs and the expected output. This in order to clarify the type of information or knowledge representation that must be provided to each of them and what response give back. The analysed AI techniques are:

Neural networks: Artificial neural networks are nonlinear mapping systems whose structure is loosely based on principles observed in the nervous systems of humans and animals [Reed and Marks, 1998], and its main function is based on the emulation of the synaptic actions of the neurons in a biological system.

- Input: Signal vectors.
- Output: Response of the sum of each signal in the inputs vector multiply by defined weights (multiple layers can be used).

Fuzzy logic: Can be defined as a logical system that generalizes classical two-valued logic for reasoning under uncertainty [Yen and Langari, 1999]. This uncertainty is represented by fuzzy sets, following the proposed made by Zadeh [1965].

- Input: Numeric values, fuzzy sets and rules for inference.
- Output: Numeric response calculated according to the inference rules and the defined fuzzy sets. It is useful when is necessary to calculate according to fuzzy concepts or natural language terms such as "cold" or “warm”.

Genetic algorithms: These algorithms are a robust adaptive optimization method based on biological principles where a population of strings represents possible solutions for a problem [Whitley et al., 1990].

- Input: A population of individuals. Usually a fixed length character strings, with a defined alphabet (i.e. binary).
- Output: The best individual from the initial population or offspring of it. The algorithm starts mutating the individuals and evaluates them according to a fitness measurement previously defined. The best individual(s) is(are) selected and copied or mutated for the next generation. The initial population size and the maximum number of generations to be run must be defined as well. Genetic algorithms are useful for search in highly nonlinear search spaces.

Intelligent agents: Can be defined as software programs with an attitude [Bigus and Bigus, 2001], this attitude define the goal of the agent and the way in which it interacts with other agents or software components.

- Input and output: Dependable of the type of agent.

  In AI, an intelligent agent is an autonomous entity which can observe through sensors and acts upon an environment using actuators. An agent directs its activity towards achieving defined goals. Intelligent agents may also learn or use knowledge to achieve their goals. There are different types of agents as: (i) Simple reflex agent: Acts according to the situation, (ii) Model based agent: Internally, has a model of the environment, (iii) Goal based agent: Acts according to a specific objective, (iv) Utility based agent: Define how important a goal is, and (v) Learning agents: Starts with an unknown environment and become more competent.

When the goal is to integrate a DSS that uses Expert Knowledge into a US in order to make the data processing in a more intelligent way, the principal characteristic to take into account is that it can't be intrusive in making the decision process, otherwise the data processing cluster will increase the ubiquity level at the expenses of the interaction cluster making no change or even decreasing the final ubiquity level of the system. The DSS should keep one of the principal characteristics of a ubiquitous system: the context interaction [Kwon et al., 2005].

The decision making process have been working in integration with ES in different areas as health care information systems [Müller et al., 2001] and multi-objective decision making process [Rasmy et al., 2002]. In UT different DSS applications have been developed as virtual tours [Brown et al., 1997], the CoolTown hewlett packard project Kindberg et al. [2002] and the ubiquitous decision support system (UbiDSS) [Kwon et al., 2005].

2.3 Design methodologies for Decision Support Systems

2.3.1 Decision Support Systems Design

Software design and development is a process whose main goal is to automate the solution of complex problems by using computers. A software development method is a systematic organization of the process and products of a software construction project [Lano, 2005], which typically consists of:

- *Notations or languages*, to describe requirements analysis or design models.
- *A process*, defining the sequence of steps to take.
- *Tools* to support the method.

As presented in chapter 2, a DSS can be a software solution that supports the decision making process. Taking this definition, the design of DSS can be seen as a software design. In this sense, the design of a DSS take advantages of the techniques and methods for software design.

Specifically for the design of intelligent DSS, different methods have been applied. Blair et al. [1997] presents an interesting work, analyzing not only the most used DSS design methods, but the support that this methodologies provides for each one of the DSS design stages.

The most widely used methodologies were established using written interviews with different DSS designers in areas as diverse as architecture, farming and traffic signal control; resulting in the following:

- EBS: Expert Based System methodology. [Goul and Tonge, 1987]
- IDS: Intelligent Decision System methodology. [Holtzman, 1988]
- MEDESS: MEDESS Expert Support System methodology. [van Weelderen and Sol, 1993]
- VIM: Visual Interactive Modeling. [Angehrn and Lüthi, 1990]
- TAA: ext Analysis Approach (TAA) [McGovern et al., 1991]
- KBDSS: Knowledge Based Decision Support System methodology [Klein and Methlie, 1990]

In the work done by [Blair et al., 1997], these methodologies were analyzed qualitatively from the perspective of the development phases covering all the design stages of a DSS: (i)

Table 2.5: Qualitative evaluation into a quantitative one

Blair evaluation	**Numeric evaluation**
Yes	4
Existing	3
Few	2
N/A	1
No	0

Requirements Analysis (RA), including Knowledge Acquisition (KA) and Knowledge Engineering (KE), (ii) Conceptual Design (CD), (ii) External Design (ED), (iv) Internal Design (ID), (v) Software Reuse Analysis (SRA) and (vi) Graphical User Interface design (UI).

The comparison framework is composed by different questions for each one of the design stages, covering the topics presented in annex A.

In order to evaluate statistically the different design methodologies, the qualitative evaluation done by [Blair et al., 1997] was translated into a quantitative one, by following the rules presented in table 2.5.

After having the evaluation done by Blair, a deeper study for each methodology was conducted and evaluated following the same framework (annex A).

The evaluation results obtained by following annex A were summarized into the *percentage of compliance* that each methodology has for each of the six design stages. I.E. in table 2.6 methodology VIM supports the knowledge acquisition stage in 39%, and the user interface design stage in a 79%.

Having the percentage in which the evaluated methodologies support the design stages of DSS, it was possible to develop the statistical study as presented in section 2.3.2.

2.3.2 Analysis and qualification of the design methodologies

A Completely Randomized Design (CRD) was used to evaluate the design methodologies in terms of the the support it provides to the six design stages. An analysis of variance (ANOVA) was conducted with the data in order to define if there is statistical differences in how the different methodologies support the design process of a DSS.

Equation 2.1 presents the basic mathematical model used, where:

$$y_{i,j} = \mu + t_i + \epsilon j(i) \tag{2.1}$$

y: Response variable

μ: General location parameter

t_i: Effect of having treatment level i

ϵ: Non controlled factors, experimental error

The CRD is the simplest experimental design. In this type of experiment is only relevant the definition of the experimental factors and its levels in order to determine the different treatments, without taking into account any other nuisance variables. The presented characteristics guarantee that the treatments and the statistical error are the only variation sources for the response variable.

The most important advantage of CRD is the flexibility: any number of treatments and replications can be used. The main requirement to obtain precise data from a CRD is that the experimental units are enough and homogeneous, this is guarantee in the present work as the experimental unit is the methodology itself. Each one of the six design stages are factors for the evaluation of the design methodologies, providing an understanding on how where the methodologies support in a better way the DSS design process.

The results obtained from the evaluation of the design methodologies on each design stage were analyzed in Statgraphics ® in order to globally compare the methodologies and define if statistical difference in fact exist between the support that methodologies provides to the design process. As the data used does not correspond to in field experiments (perception of Blair and the author), the only nuisance factor in the experiment is the subjectivity of that evaluation. The response variable for the experiment is the *percentage of compliance* that the methodologies have for each one of the design stages. As the first qualification is the one presented by [Blair et al., 1997], the CRD has one replication corresponding to the author evaluation.

The data analyzed in statgraphics is presented in table 2.6

A significance level of 95% was used for all the statistical analysis. With the data presented in 2.6 the statistical assumptions for the analysis of variance (ANOVA) were verified in order to validate the obtained data.

Table 2.6: Comparison framework for DSS design methodologies

Methodology	Knowledge	Conceptual design	External design	Internal design	Reuse	User interface
VIM	39%	28%	20%	0%	0%	79%
MEDESS	25%	19%	20%	0%	0%	14%
KBDSS	61%	53%	30%	29%	0%	29%
TAA	27%	25%	25%	25%	0%	0%
VIM	42%	30%	51%	0%	0%	82%
EBS	52%	31%	20%	0%	0%	29%
EBS	45%	20%	37%	0%	0%	37%
KBDSS	70%	40%	25%	39%	0%	14%
MEDESS	40%	26%	17%	0%	0%	25%
IDS	70%	59%	30%	21%	0%	0%
TAA	35%	32%	34%	24%	0%	0%
IDS	55%	57%	26%	36%	0%	0%

For the confirmation of the normally distributed assumption the Shapiro-Wilkś test was used. A Shapiro-Wilkś p-value clearly higher than 0.05 was obtained. This can be verified also graphically in figure 2.3.

The homogeneity of variances and independence assumptions were verified graphically as can be seen in figures 2.3 and 2.4 these assumptions were confirmed.

After the validation the statistical assumptions it was possible to establish if statistically significant differences exists between the different design stages for each one of the evaluated methodologies. As none of the methodologies supports the software reuse design stage, the ANOVA analysis and table was excluded for that stage. As can be seen in figure 2.5 only in the external design stage there is not statistically significant difference between the evaluated design methodologies.

For the design stages that presented differences, multiple range tests were conducted (figures 2.6, 2.7, 2.8, and 2.9).

The statistical analysis can be summarized in the following conclusions:

- None of the evaluated methodologies for the design of DSS supports in any way the software reuse design stage. It depends on the designer to obtain reusable code from

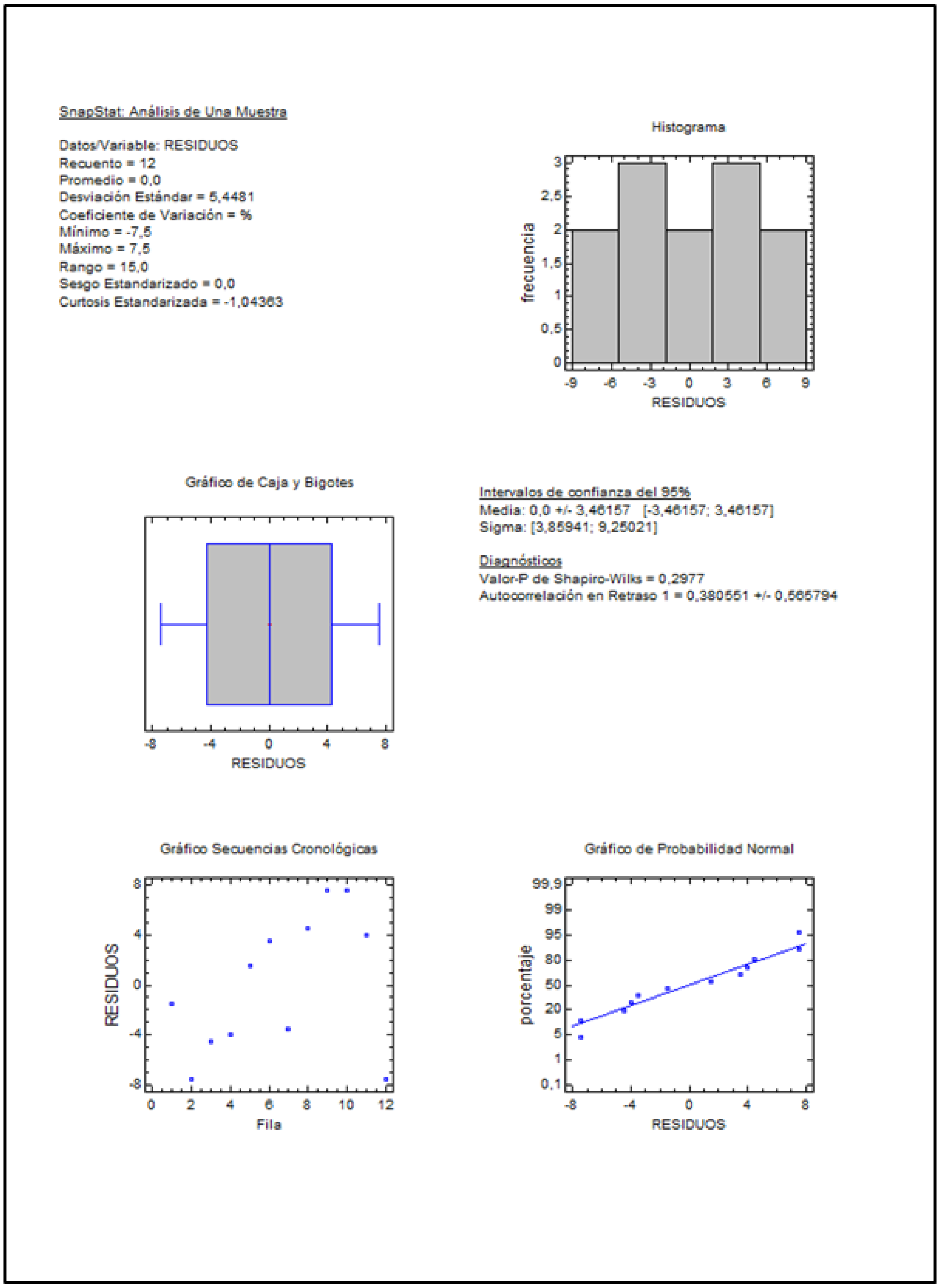


Figure 2.3: One sample analysis for DSS design methodologies

each one of the projects.

- When designing a DSS, there is no difference in the external design stage depending of the selected design methodology.

- From the six evaluated design methodologies for DSS, MEDESS and EBS did not

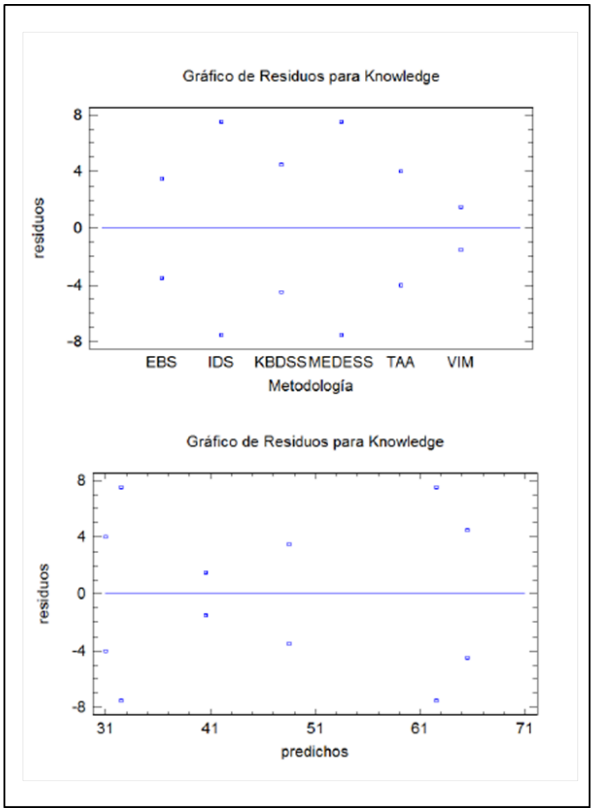


Figure 2.4: Residual analysis for DSS design methodologies

present any outstanding result suggesting its use as the best for any specific design stage.

- IDS and KBDSS present the best results in supporting the requirements analysis, which includes the knowledge acquisition and knowledge engineering processes. Also its performance is the best for the conceptual design stage.
- The internal design stage is best supported by IDS, KBDSS and TAA methodologies.
- In the user interface design process, VIM methodology provides the best support.

The evaluation of the six design methodologies for DSS during the design process, showed that the best methodologies are IDS and KBDSS as they obtained the best performance for three of the six stages. However, as it was the most relevant design methodologies supports only three out of six stages and none of these are specifically created to work with UT, or focused on make the process reusable it was clear that none of them apply directly to the present work.

Tabla ANOVA para Knowledge por Metodología

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
Entre grupos	2185,75	5	437,15	8,03	0,0124
Intra grupos	326,5	6	54,4167		
Total (Corr.)	2512,25	11			

Tabla ANOVA para ConceptualDesign por Metodología

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
Entre grupos	1972,0	5	394,4	11,95	0,0045
Intra grupos	198,0	6	33,0		
Total (Corr.)	2170,0	11			

Tabla ANOVA para ExternalDesign por Metodología

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
Entre grupos	298,417	5	59,6833	0,52	0,7560
Intra grupos	690,5	6	115,083		
Total (Corr.)	988,917	11			

Tabla ANOVA para InternalDesign por Metodología

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
Entre grupos	2614,0	5	522,8	19,24	0,0012
Intra grupos	163,0	6	27,1667		
Total (Corr.)	2777,0	11			

Tabla ANOVA para UserInterface por Metodología

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
Entre grupos	8866,75	5	1773,35	50,79	0,0001
Intra grupos	209,5	6	34,9167		
Total (Corr.)	9076,25	11			

Figure 2.5: ANOVA table per design stage

The design of the system presented in the following chapters, takes parts from the presented methodologies, but it is focused on the usability of the knowledge acquired in the data processing cluster. Its design and development is framed in the three main clusters of UT.

2.4 Greenhouses

According to the Oxford dictionary, a greenhouse is *"a glass building in which plants that need protection from cold weather are grown"*. However right now these buildings can be made by plastic and are used in regions where the plants need protection from hot weather as well. Its development has been influenced by the increasing necessity of a sustainable food

Pruebas de Múltiple Rangos para Knowledge por Metodología

Método: 95,0 porcentaje LSD

Metodología	*Casos*	*Media*	*Grupos Homogéneos*
TAA	2	31,0	X
MEDESS	2	32,5	X
VIM	2	40,5	X
EBS	2	48,5	XX
IDS	2	62,5	X
KBDSS	2	65,5	X

Contraste	*Sig.*	*Diferencia*	*+/- Límites*
EBS - IDS		-14,0	18,0503
EBS - KBDSS		-17,0	18,0503
EBS - MEDESS		16,0	18,0503
EBS - TAA		17,5	18,0503
EBS - VIM		8,0	18,0503
IDS - KBDSS		-3,0	18,0503
IDS - MEDESS	*	30,0	18,0503
IDS - TAA	*	31,5	18,0503
IDS - VIM	*	22,0	18,0503
KBDSS - MEDESS	*	33,0	18,0503
KBDSS - TAA	*	34,5	18,0503
KBDSS - VIM	*	25,0	18,0503
MEDESS - TAA		1,5	18,0503
MEDESS - VIM		-8,0	18,0503
TAA - VIM		-9,5	18,0503

* indica una diferencia significativa.

Figure 2.6: Multiple range test for requirement analysis design stage

supply chain. The global warming, among other phenomena has placed the growing of plants indoors as an imminent issue, making greenhouses a possible solution to have food all the yearlong in virtually any region.

Different solutions of greenhouses have been developed, depending on different variables. Traditionally the most important variables for a greenhouse implementation have been location and weather. Historically greenhouses were created for rural areas where traditional agricultural activities were developed. However the new tendencies in urbanization, including the fact that more than 50% of the world's population lives in urban areas [Agency, 2014] have forced agricultural business and researchers to think in greenhouses not only for rural areas as for home pharming, urban, desert, underground, underwater and floating greenhouses.

Greenhouses have been subject of an intense automation process. This process is evidenced, among others in the works done by [Ottjes et al., 2005; Rodriguez et al., 2006]. In this process the monitoring of variables plays an important role and it's because of this that WSN have been implemented for greenhouses environments [Ahonen et al., 2008] in order

Pruebas de Múltiple Rangos para ConceptualDesign por Metodología

Método: 95,0 porcentaje LSD

Metodologia	*Casos*	*Media*	*Grupos Homogéneos*
MEDESS	2	22,5	X
EBS	2	25,5	X
TAA	2	28,5	X
VIM	2	29,0	X
KBDSS	2	46,5	X
IDS	2	58,0	X

Contraste	*Sig.*	*Diferencia*	*+/- Limites*
EBS - IDS	*	-32,5	14,0565
EBS - KBDSS	*	-21,0	14,0565
EBS - MEDESS		3,0	14,0565
EBS - TAA		-3,0	14,0565
EBS - VIM		-3,5	14,0565
IDS - KBDSS		11,5	14,0565
IDS - MEDESS	*	35,5	14,0565
IDS - TAA	*	29,5	14,0565
IDS - VIM	*	29,0	14,0565
KBDSS - MEDESS	*	24,0	14,0565
KBDSS - TAA	*	18,0	14,0565
KBDSS - VIM	*	17,5	14,0565
MEDESS - TAA		-6,0	14,0565
MEDESS - VIM		-6,5	14,0565
TAA - VIM		-0,5	14,0565

* indica una diferencia significativa.

Figure 2.7: Multiple range test for conceptual design stage

to monitor and track critical variables for the crops in a dynamic way. Other works have presented robots and other machinery specifically designed for crop management and intense agricultural purposes [Belforte et al., 2002; Comba et al., 2010]. The automation evolution followed by the greenhouses also included some works related to intelligent control and AI algorithms, showing that this type of advanced data processing can be applied not only to these type of systems but are even better for the optimization of specific aspects [Kia et al., 2009; Liu et al., 2006]. Finally, DSS has been applied to greenhouse environments as well in order to obtain model based reasoning systems to support the decision making process by improving defined variables inside the system according to the actual interest of the stakeholders [Wang et al., 2009]. This work attempts not only to improve the decision making process in terms of providing information to take actions in real time but to define a way to obtain specific knowledge for UT and apply it directly in the data processing cluster in order to give extended information of the system to the stakeholders.

In the national reality regarding weather change, Colombia, being a tropical country as a result of its geographical location near the Equator doesn't have marked weather changes

Pruebas de Múltiple Rangos para InternalDesign por Metodología

Método: 95,0 porcentaje LSD

Metodología	*Casos*	*Media*	*Grupos Homogéneos*
VIM	2	0,0	X
EBS	2	0,0	X
MEDESS	2	0,0	X
TAA	2	24,5	X
IDS	2	28,5	X
KBDSS	2	34,0	X

Contraste	*Sig.*	*Diferencia*	*+/- Límites*
EBS - IDS	*	-28,5	12,7537
EBS - KBDSS	*	-34,0	12,7537
EBS - MEDESS		0,0	12,7537
EBS - TAA	*	-24,5	12,7537
EBS - VIM		0,0	12,7537
IDS - KBDSS		-5,5	12,7537
IDS - MEDESS	*	28,5	12,7537
IDS - TAA		4,0	12,7537
IDS - VIM	*	28,5	12,7537
KBDSS - MEDESS	*	34,0	12,7537
KBDSS - TAA		9,5	12,7537
KBDSS - VIM	*	34,0	12,7537
MEDESS - TAA	*	-24,5	12,7537
MEDESS - VIM		0,0	12,7537
TAA - VIM	*	24,5	12,7537

* indica una diferencia significativa.

Figure 2.8: Multiple range test for internal design stage

along the year. However, because of the height differences, there are four different climate zones inside the country. 83% of the country lies below 1000 meters with an average temperature of 24 °C. 9% of the land is located between 1000 meters and 2000 meters with an average temperature of 18 °C. 6% of the land area is between 2000 and 3000 meters with an average temperature of 12 °C and snow is found above 4500 meters of altitude [Colombiainfo.org, 2014], having a full range of climates in which greenhouses can and have been developed for different purposes. In part due to the stable weather of the tropic and the different temperatures that can be found in the country, it is possible to have cold and warm weather crops using outdoors planting all the year, keeping agricultural activities as a relevant economic income of the country. Representing above of the the 7% of the gross domestic product [Agency, 2014].

Traditionally, indoors or greenhouse plantations in Colombia have been dedicated mainly to research applications of institutions as the ICA (Instituto Colombiano Agropecuario)[1],

[1] www.ica.gov.co/

Pruebas de Múltiple Rangos para UserInterface por Metodología

Método: 95,0 porcentaje LSD

Metodologia	*Casos*	*Media*	*Grupos Homogéneos*
IDS	2	0,0	X
TAA	2	0,0	X
MEDESS	2	19,5	X
KBDSS	2	21,5	X
EBS	2	33,0	X
VIM	2	80,5	X

Contraste	*Sig.*	*Diferencia*	*+/- Límites*
EBS - IDS	*	33,0	14,4589
EBS - KBDSS		11,5	14,4589
EBS - MEDESS		13,5	14,4589
EBS - TAA	*	33,0	14,4589
EBS - VIM	*	-47,5	14,4589
IDS - KBDSS	*	-21,5	14,4589
IDS - MEDESS	*	-19,5	14,4589
IDS - TAA		0,0	14,4589
IDS - VIM	*	-80,5	14,4589
KBDSS - MEDESS		2,0	14,4589
KBDSS - TAA	*	21,5	14,4589
KBDSS - VIM	*	-59,0	14,4589
MEDESS - TAA	*	19,5	14,4589
MEDESS - VIM	*	-61,0	14,4589
TAA - VIM	*	-80,5	14,4589

* indica una diferencia significativa.

Figure 2.9: Multiple range test for user interface design stage

CORPOICA (Corporación Colombiana de Investigación Agropecuaria) [2], ASOHOFRUCOL (Asociación Hortifrutícola de Colombia)[3] and special projects from the Ministry of Agriculture and Rural Development as the "rural development with equity" program started in 2007 and in which 4.500 million COP were designated to greenhouses construction [MinAgricultura, 2014].

In the last 10 years, despite the usual stable Colombian weather, during the field work carried out in this project, it was possible to find that the greenhouse cultivation trend is also starting to be implemented outside the research and special projects in Colombia.

The greenhouse uses in Colombia are being developed in order to protect the crops from bad weather as hail fall (highly common in lands above 1800 meters) and impulsed in part due to the migration trend from small farms to intensive agriculture or precision agriculture that is rising in the rural part of the country.

[2]www.corpoica.org.co/
[3]www.asohofrucol.com.co/

Precision Agriculture (PA) can be defined as the management of spatial and temporal variability at a sub-field level to improve economic returns and reduce environmental impact [Blackmore et al., 2003] a trend that is becoming stronger in the country.

All of these tendencies and new approaches to the agroindustry in Colombia are being developed in part for the every day more common inclusion of people, mainly dedicated to other business in this industry as an investment. Most of these new actors in the agricultural life of the country have the vision of plantations as companies and its main goal is not only to use the land, but to get financial profit of it and change the environmental conditions when is necessary and possible in order to have better profits. These climate modifications in a controlled environment are easily achieved by the use of greenhouses.

As expressed before, in Colombia is everyday more common that people from the city with technology and marketing knowledge make their investments in plantations on the rural side. However, the farm managers are usually country people with no specific education for that work. The farm manager is supported by an educated and trained agronomist with extensive field knowledge, but usually the agronomist attends more than one plantation and is only able to visit each of them one or two times each month. In figure 2.10 a typical organization chart of a new intensive agriculture farm in Colombia can be seen.

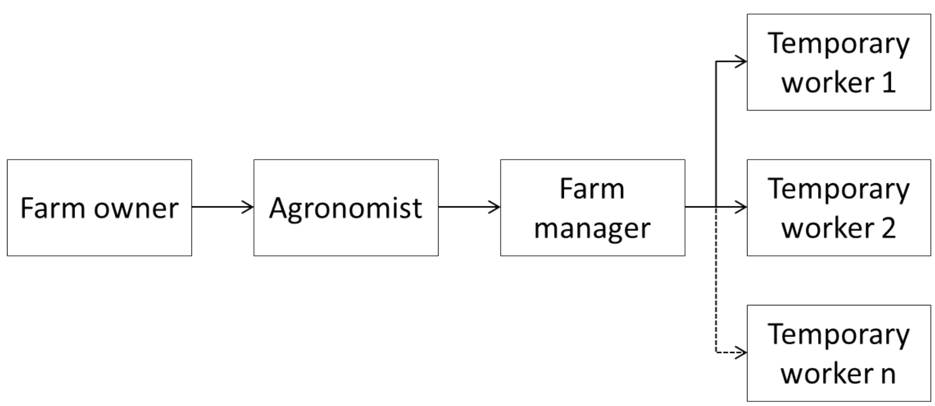


Figure 2.10: Precision Agriculture farm organization chart [constructed with information gathered in field]

The characteristics of the Colombian landscape composed of rugged mountains, flood valleys, geological fault lines, among others, make the topography an obstacle, causing the delay in transportation infrastructure that the country is currently living [Correa and Andrés, 2012]. This bad road infrastructure makes difficult to the farm owners to constantly visit their plantations and usually the only constant information they have about the state of the farm are phone calls with the agronomist in order to maintain them updated about the necessary actions to take and also phone calls to the farm manager in order to follow up the implementation process of the actions suggested by the agronomist. This communication chain is ineffective, not only for the owner who lives in the urban area, but also for the agronomist which, in some cases is not able to see the plantation state and how the actions were taken by the farm manager until the next visit that can occur after a month.

Because of the educational level of the farm managers in Colombia, intensive technology implementation is still difficult in plantations as they are not open to introduce new approaches to their daily labour and are not naturally used to interact with technology.

Ideally, any technological implementation in this field, with the already explained conditions must be as unobtrusive as possible, making UT an appropriate approach for the Colombian conditions in farms.

UT are appropriate for the Colombian conditions in farms, when personal in daily charge of the crops has no formal education and are no used to work with technology. The unobtrusive characteristic of those systems allows the farm manager to use it without even being aware of it. At the same time, by having an ubiquitous monitoring system with information widely available, farm owners and agronomist, which are the ones more interested in having formal data, can have access to it from everywhere with an Internet connection and have a clear idea about the greenhouse state and the actions that need to be done in real time. Also, by modeling expert knowledge in the system, decisions will include an expert in the field even when the presence of high qualified agronomist is not always possible. In the day-by-day the farm owner can be sure that the system will be acting in some sort as the professional will do. In case of an important warning or alarm stakeholders can be notified. Notifications includes not only that there is something wrong with the greenhouse but what and why is exactly wrong and what actions are need to be taken. Also stakeholders can have access to recent variables measures in order to verify this information.

Chapter 3

Creative: Ubiquitous greenhouse monitoring

3.1 Ubiquitous technologies in greenhouses

Due to the generally stable weather, in Colombia UT for greenhouses has not been subject of intense interest. However, during the development of this work it was found that there are companies established and/or founded in the country dedicated to the construction, advisory and automation of greenhouses. Most of them micro and small companies.

- *Kubrir invernaderos Ltda.*[1]: Located in Palmira, Valle del Cauca (south west part of the country), kubrir invernaderos is dedicated mainly to the design, construction and maintenance of greenhouses. They have presence also in Mexico and Costa Rica.

- *Inverca Colombia*[2]*:* Inverca is a greenhouses company from Spain. After an association with a steel company in Colombia starts its development in the country. By the time of this project Inverca Colombia is still a small company represented only by one commercial person and which offers only prefabricated greenhouses.

- *Construinvernaderos Ltda.*[3]*:* Founded in the year 2000 and located in Antioquia department, construinvernaderos is a Colombian company dedicated to the design, construction and maintenance of greenhouses. Its main activity and expertise is been developed

[1] http://www.kubrir.com/
[2] http://invercacolombia.blogspot.com/
[3] http://www.construinvernaderos.com/

for tomatoes. By being a small company is highly dependable of its owner and the contact was difficult for his personal issues.

- *Insuagro*[4]: Insuagro is one of the oldest greenhouses companies in the country, it was founded in 1996 and has experience in flowers cultivation. Is one of the most reliable companies for this crops. Technification of greenhouses is not a relevant issue on its operation.

The presented companies in Colombia, dedicated to greenhouses are mainly focused in the structural design and construction of this spaces. These companies were contacted in order to have a better understanding about the local greenhouse conditions. During this contact it was possible to determine that automation systems for greenhouses are still a second line business for them. For this reason it was not possible to define critical variables for the greenhouse state monitoring directly with them, however temperature and relative humidity appears as the most commonly mentioned and works as a starting point for the further work developed.

Greenhouses for experimentation are available in the EAFIT university main campus. However, most of them does not have any type of instrumentation or monitoring system in order to keep track of the system state. A greenhouse for experimental purposes is ideal to try the implementation of a UT system as its development and testing process implies the constant modification of the greenhouse structure and overall state, which is not desirable in production units.

The previous conditions makes EAFIT greenhouses ideal for the implementations of this work.

The selected greenhouse is located in the - Southern area of the main university campus, near a three floors building on its north part avoiding important shadows during the day. The greenhouse has an area of $50m^2$ and is used for biological tests in plantain plants. The walls are made of plastic, it has two entrances and even closed is not totally isolated from the outside, as it has a space between the walls and the roof.

Plants grown on individual plastic bags. It is not desirable to have a common soil for all the greenhouse, because of the type of treatments that can be performed, which includes: (i) promote plant growth, (ii) induce plant diseases or (iii) leave the plant untreated.

[4] http://www.insuagro.com.co/principal.html

Figure 3.1: Greenhouse: A) Location, B) Roof hole, C) Inside

After analyzing the specific conditions of the greenhouse and, in order to design the US an analysis, design and development in terms of each one of the UT clusters (presented in tables 2.2, 2.3 and 2.4) was done.

3.1.1 Interaction cluster

For the user, context and system interaction cluster, it is important to clearly define where the system is going to be implemented and the different actions that involves the environment in any way, from incoming data to the system to physical responses whereby the system modifies the environment (inputs and outputs). All this analysis must be conducted always within the frame of the most important characteristic of UT which is the capability of operation without changing the normal actions of the user.

From e-mail exchanges and personal semi-structured interviews with the persons who works daily in the selected greenhouse, it was possible to find facts about the system operability that has to be taken into account for the system design. These are:

1. The greenhouse is visited at least two times a day by the expert.
2. The expert does not have specific time for the visits. They visit the greenhouse only following the rule: one visit in the morning and another in the afternoon.
3. Measurements of relative humid and temperature are taken on each visit using the KESTREL 3000 pocket device presented in figure 3.2. The results are written in a conventional notebook in order to keep track of the greenhouse conditions.
4. Irrigation is done manually when needed depending of the measured values of relative humidity and temperature, irrigation is done manually when needed.

From the defined normal daily activities of the experts in the greenhouse, it was possible to define relative humidity and temperature as important variables for the process as were the ones monitored constantly. these variables were used to act into a third one (soil moisture) which can also be monitored in an autonomous unobtrusive way as can be seen further during this work. However no exact measures were taken and the state of the soil moisture was not reported.

All previous findings were discussed with the experts in constant e-mail exchanging and personal meetings, consequently five variables were defined as highly relevant for the process. This in Agreement with the greenhouse team and available literature reporting greenhouses' automation:

- Greenhouse Temperature (°C).

Figure 3.2: Kestrel 3000 Anemometer

- Relative humidity (%).
- Soil moisture (%).
- Light intensity (%).
- UV radiation (1 - 10).

Is important to notice that, as it can be seen in figure 3.1, a distributed punctual measurement of the soil moisture was needed, because of the distribution of the plants' soil (individual plastic bags).

After defining the variables to monitoring, a WSN architecture was proposed for the automatic unobtrusive data acquisition process, in which each unit has the possibility of gather data for all the variables using specific dedicated sensors (Table 3.1). This technology allows the distribution of nodes through the entire greenhouse. Also, is proved that the implementation of WSN to monitor environmental variables as temperature, soil moisture, etc., reduced maintenance and installation costs, related to wiring and harness. This alternative provides installation and operation flexibility, enhancing also the potential to install and expand such systems in remote locations [Kai-yan and Xue-jun, 2008; Wang et al., 2011, 2006]. Additionally, as greenhouses are multi-variable, nonlinear and uncertain systems [Chen et al., 2011], WSN can be used further to find the relationship between environmental conditions and crop diseases or growth problems, which can be used to implement precise greenhouse control systems [Park et al., 2011].

Table 3.1: References of the used sensors

Variable	**Sensor**
Temperature	DHT11
Relative humid	DHT11
Soil moisture	SEN0114
Light intensity	DFR0026
UV Radiation	TOY0044

As the raw data gathered from the sensors has to be processed and converted into useful information (the real value for the physical phenomena), each one of the modules has an Arduino UNO ®board to perform basic signals processing and control (figure 3.3). Also the arduino is in charge to control all the information and communication flow inside the WSN. For the information transmission and using the analysed technological options presented in table 2.1, two arqchitecture options were explored.

- First tests were conducted using Zigbee as communication protocol for the WSN and only the central server uses WiFi or Ethernet to transfer information to the web.

- Second approach was to use WiFi protocol for the entire network.

The modules including sensors for all defined variables, processing, control unit and communication devices were compacted into a specially designed waterproof plastic box (figure 3.4), in order to maximize the useful life of the electronic devices by protecting them, among others from the direct humidity. The case was designed to ensure that the sensors always has direct contact with the measured environmental variables in order to provide an accurate measurement of the physical phenomena.

Because of the total area of the implemented greenhouse, three modules were used for the WSN. In order to improve the "easy of use" characteristic in the US there is not set up process or button for the modules. Automatically when they are plug into the electric network the processes of data monitoring and transmission begins.

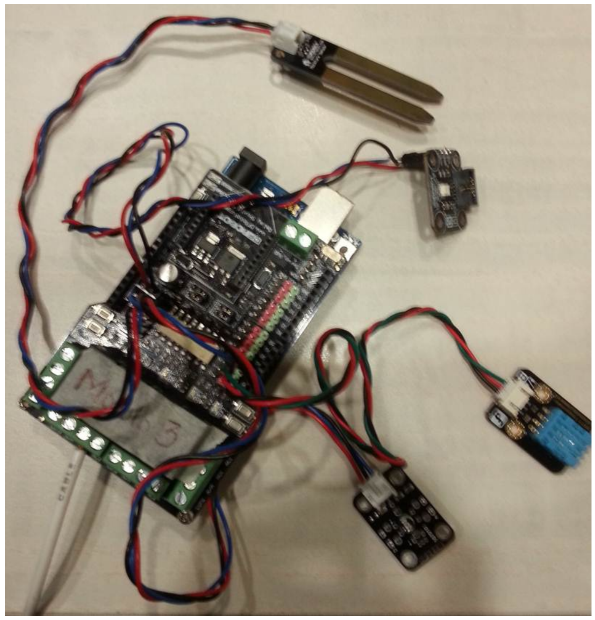


Figure 3.3: Sensors and local processor

Figure 3.4: WSN module

3.1.2 Data transfer cluster

As introduced during the previous section, for the data transfer cluster analysis, a combination of different communication protocols were proved. From the study of the specific conditions of the greenhouse it was clear that it was not necessary to have long distance communication because of its extension, modules are just 4 meters away from each other (figure 3.1). The most relevant aspect was to have a network that works as independent as possible.

ZigBee transmitters were installed for each module allowing them to send data to the main server, which can be located 10 meters away from the greenhouse (when walls are around) and farther in clear space. ZigBee transmitters installed in the WSN modules (named routers) were XBee S2. The main function of these devices is to send the information comming from the sensors to the main server. The devices were configured in "ZNET 2.5 ROUTER/END DEVICE AT" mode using the X-CTU software. The ZigBee connected to the server identified as the coordinator of the network was configured in "ZNET 2.5 COORDINATOR API" mode. API mode [5] is a frame-based method for sending and receiving data to and from a radio's serial UART[6].

As ubiquity refers to the ability to be present everywhere and the focus of this work is the data processing, data and information from the system must be as ubiquitous as possible. For this reason the server not only stores locally the data but, using a program written in java it upload and present information into a web page. The Internet communication in the server can be done using WiFi or Ethernet.

A program written in java guarantee one of the main aspects presented in table 2.3, the possibility of communication and functionality across different platform with non or minor changes. A complete schema of the first communication network proved (Zigbee WSN) can be seen in figure 3.5.

The second communication approach tested was a fully WiFi network in which each one of the WSN modules were equipped with WiFi. This test was made in order to explore possibilities in bigger extensions where WiFi communication was possible. The distance between the nodes is only limited by the general network coverage in the implementation environment. The test of a second communication scheme and system architecture was encouraged in part by the findings made during the explorative phase, when it was possible to confirm that this wireless network availability is increasing even in rural areas.

When the communication gap between the WSN nodes and the main server is filled, sensing modules can not only interact between them and the central server but also directly with any web based structure that can provide information storage, management and analysis.

With the ability to directly connect the WSN modules to the web using WiFi protocol,

[5] Application Programming Interface
[6] www.digi.com/

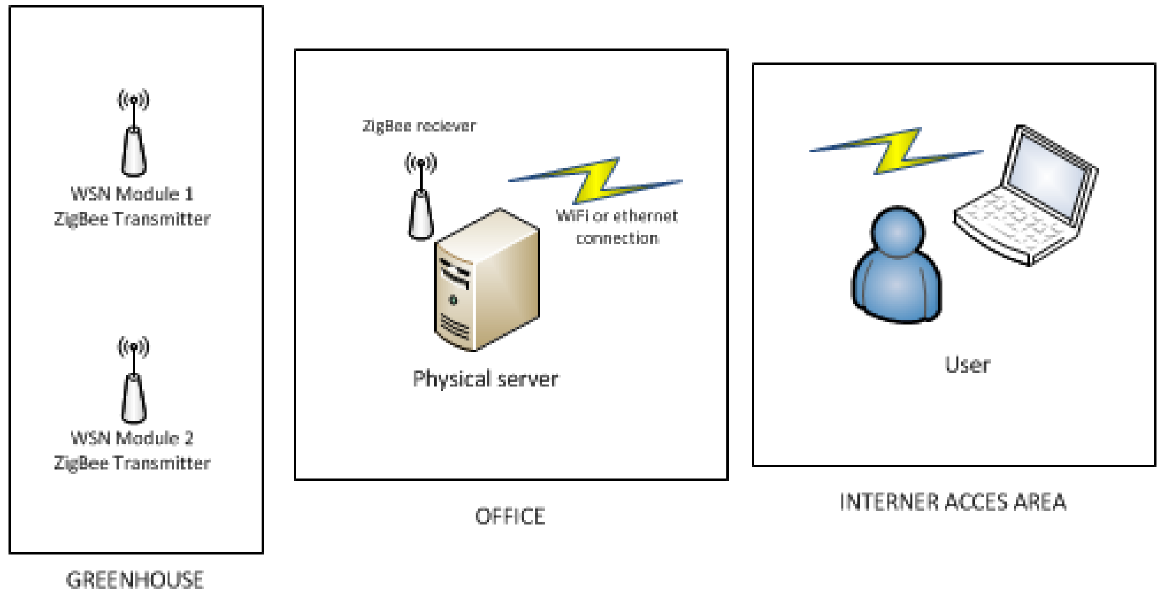


Figure 3.5: Zigbee communication scheme

the data receiving, storage, analysis and deployment into the web, that formerly was in charge of the main server, was also transfer to the web using a novel platform to virtually remove the physical server.

That platform is called Ubidots and is a web based platform that offers a cloud service to satisfy most needs of Internet of Things projects [7]. Its communication focus is on wireless communication. Ubidots provides an standard platform to deploy and present information gathered from any sensor system which fit with all the infrastructure developed during this project (WSN).

In figure 3.6 the schemes for Zigbee and WiFi networks can be seen.

3.1.3 Data processing cluster

In the interaction and communication clusters, the data acquisition and transmission are defined. After having this part of the design, the following step is in the frontier between communication and data processing clusters and is about the data storage for the subsequent analysis and processing. In order to guarantee the high availability of the data, it is necessary not only to present it but to store it on the web.

[7]http://ubidots.com/about-ubidots.html

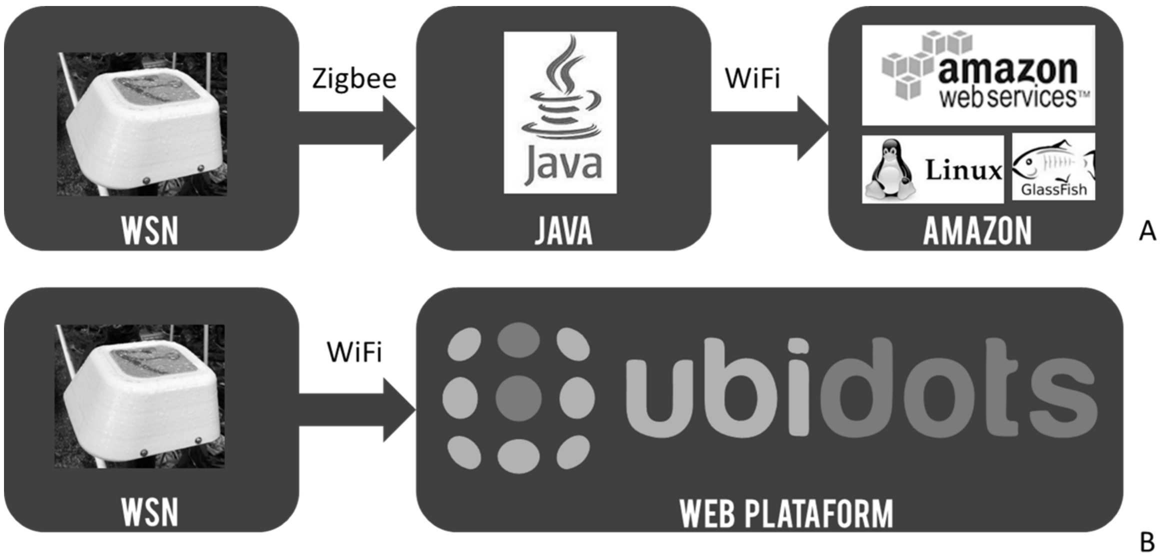


Figure 3.6: Communication platforms: A) Zigbee WSN, B) WiFi network

For the development of the Zigbee network architecture, a MySQL data base hosted in Amazon Web Services (AWS) [8] was developed and used to store the data coming from the WSN.

As presented in section 3.1.1, each one of the WSN modules is equipped with an Arduino board that has an ATMEGA microcontroller. When more than one module is available the data processing can be distributed, consisting on many interacting but relatively independent components [Sunderam, 1990].

The processors in the WSN modules are responsible of the interpretation of the sensors signals and the activation or deactivation of the valves in the irrigation system. They also send data when is requested by the central server (physical or virtual). This last one is in charge of data storage and its display in the web. The central server has the ES which is capable to detect different scenarios about the greenhouse state.

As data processing is the main focus of the present work, the entire section 3.2 is dedicated to give a deeper explanation on how this part is carried in the main server according to the information gathered by the ubiquitous monitoring system presented above. The creation of the DSS in order to provide automatic and proactive expert information to the stakeholders, explained as well how it was defined.

[8] http://aws.amazon.com/

3.2 Data processing and knowledge representation

The data processing starts with the local processing of each one of the WSN modules that has only local processing capabilities. They process the information gathered from the sensors and send it to the main server. However as the main topic of the present work consists in the knowledge acquisition and representation, a knowledge elicitation process was carried continuously with the greenhouse experts (those in daily charge of the crops).

The WSN modules converts data into information and this information is received by the main server. This server continues the information processing, starting from the representation of it in factual knowledge,that is composed by facts and tell us something static about an object [Rolston, 1988].

When the information comes from the WSN in a defined time frame it is considered factual knowledge as it shows static facts. This information only becomes dynamic when viewed as a full data set of information gathered (i.e. during a complete day, week, etc). Declarative facts about the variables' state (variables quantification) are represented as a set of relationships expressed in tables and stored in a cloud data base build on MySQL.

In order to create an ES to support the greenhouse state decision making, based on the dynamic variables data, an elicitation process using participatory methodology with the greenhouse experts was followed. The process includes email exchange and semi-structured personal interactions as: interviews, observation, site visits and surveys.

Looking to start the participatory process with the greenhouse experts, general questions about the greenhouse state were formulated in order to determine how the information about the variables is used. Questions include a general description about an ideal greenhouse to conduct their experiments and how the soil moisture is controlled according to the average temperature and relative humidity they report daily.

Questions were send and answered via email before having personal interactions. This provides written descriptions of the process which facilitates later the knowledge formalization. Also the personal interactions were highly effective as the experts and the knowledge engineer had previous knowledge of the discussion topics.

It was possible to establish that perhaps the experts don't have a direct measure of the soil moisture. The inclusion of such a sensor in the system gave them the possibility to make relationships between the two main variables (temperature and relative humid) and the soil moisture. Soil moisture results, being one of the most relevant conditions for the experiments and its control, was carried out manually and depending on the time (hour), without having a direct measure of the state. Also, by the starting general interactions, two main subsystems related but relatively independent for the decision making inside the greenhouse were identified:

- General greenhouse.
- Specific plant (crop) state.

After having a general description of the ideal greenhouse in terms of the main variables, experts where asked about the different scenarios they look for when checking the greenhouse-/crop state. These scenarios were defined also in terms of variables, the logical deductions the expert does when it occurs, why those scenarios can occur and how the crops or the complete greenhouse could be affected.

Scenarios were defined according to the main variables and subsystems defined:

1. Bush or plant: Regards the specific micro-environment surrounding the plant. As presented in chapter 3.1 each one of the plants has a plastic bag, so the main variable for this specific environment is the soil moisture as it can change drastically from point to point.

2. Greenhouse: This environment provides information about the overall state of the micro-environment. The main variable is the temperature as is from bad weather (extreme cold or hot) that the plants must be protected when are inside the greenhouse.

Starting from the defined subsystems, extreme scenarios were defined in terms of the main variable. These scenarios were defined using linguistic terms:

Bush environment:

```
Plants are too wet.
Plants are too dry.
```

Greenhouse environment:

```
Greenhouse temperature is too high.
Greenhouse temperature is too low.
```

Experts were encouraged to individually analyse the four scenarios by listing or writing a paragraph with the possible causes and effects for each one.

Starting from the four general scenarios presented before, and after listing and prioritizing the possible causes for each scenario presented by the experts, it was possible to define eleven scenarios that the system can detect, know the causes and is able to suggest actions to the stakeholders in order to prevent or correct the detected issue as the expert would do. Following the scenarios are presented:

1. **Controller problem:** A problem in the control algorithm can be detected by either of two options: when the irrigation system is on and the soil moisture level is ideal or higher than that or when the irrigation system is off and the plant is dry. Depending on the type of problem that is happening, the system must be able to define the possible implications and recommended actions to take.

   - *On and high moisture:* A problem with the controller functionality is detected; the valve remains open increasing drastically the soil moisture. The recommendation is to mechanically close the sink to prevent the appearance of fungus and the system must inform the technician to solve the problem definitely.
   - *Off and low moisture:* A problem with the controller functionality is detected; the valve is close and the soil moisture is falling. Manual irrigation is required in order to prevent insects that can attack the crops, also nutrients levels can start to be lower that the ideal ones, affecting the final product. The system must inform the technician to solve the problem definitely.

2. **Highly humid ambient:** This scenario is produced when the soil moisture in the bush is higher than the usual or desired one, there is no problem detected with the controller (see controller problem) and the relative humidity is considerable high. This scenario could imply the increasing of fungus probability and root rot, it is recommended to do an odor inspection of the plant.

3. **Extra manual irrigation:** This scenario appears when the soil moisture level is high, rain was not detected, the relative humidity level is normal and the controller is running normally. The recommendation is to stop doing manual irrigation to the crops and let the system runs autonomously.

4. **Garden sink problem:** The soil moisture in the crop is low, the control is running normally and the relative humidity is high. The recommendation is to check that the water is running normally and the garden sink is open as the valve was automatically checked and is runing normally.

5. **Possible plastic hole:** The system detects a high level of soil moisture; the controller was tested and is correctly working, as the relative humidity in the ambient is not high and rain was detected is possible to have a hole in the greenhouse roof or walls, visual inspection and correction is needed in order to prevent root rot.

6. **Aggressive winter time:** The overall temperature in the greenhouse is lower than the normal one, irrigation has been carried during the day and the current month has high winter probability.

7. **Cold wave:**The overall temperature in the greenhouse is significant lower than the normal one, irrigation has been carried during the day and the current month has low winter probability.

8. **Extra cold:**The overall temperature in the greenhouse is lower than the normal one, irrigation has been carried during the day and the current month has no winter probability.

9. **Aggressive summer time:** The soil moisture is lower than the ideal, the controller is running normally, the greenhouse ambient is dry and the current month has high summer probability. It is recommended to check the soil state and make changes in order to prevent evaporation and start a manual irrigation program during the rest of the month. This scenario is also achievable when the greenhouse temperature is higher than normal, irrigation during the day has run normally and the current month has low summer probability.

10. **Heat wave:** The soil moisture is substantially lower than the ideal, the controller is running normally the greenhouse ambient is dry and the current month has low summer probability. It is recommended to do manual irrigation in order to stabilize the soil moisture; however after one manual irrigation the system must be able to run

normally. This scenario also achievable when the greenhouse temperature is high; the daily irrigation has run normally and the current month has low summer probability.

11. **Extra heat:**The soil moisture is lower than the ideal, the controller is running normally, the greenhouse ambient is dry and the current month has no summer probability.

As mentioned before in this document there is not defined seasons in Colombia. However data about the average maximum an minimum per month and year can be found. Initially summer and winter probability for each month is defined according to the historical data, following the rules (i.e. for summer):

- `If actual month average maximum is higher than average maximum per year then summer probability is high.`
- `If actual month average maximum is lower than average maximum per year then summer probability is low.`

While the system is running, data about the average maximum and average minimum per month is stored and probabilities are calculated for the next year based on the data gathered directly in the greenhouse, making the system more accurate for the closer environment every time it runs.

As can be seen in the description of the scenarios and in table 3.7, different scenarios can occur depending of the order in which the variables state are checked. This was defined according to the variable's prioritization defined in accordance with the experts.

Decisions trees that shows the priority of the scenarios can be seen in figure 3.8 (greenhouse model) and figure 3.9 (bush model).

Having the scenarios and the different options to achieve them clearly defined with a prioritization of the variables. The tree models presented can be converted into nested If-THEN rules easily to codify.

By following the tree models it is guaranteed that no other scenario, different from the one detected, can be achieved. Scenarios are tested in order of importance according to the measurements and checks that the expert would do in field.

According to the problematic scenario(s) that the system identifies, it is capable to send a message via SMS and/or E-mail to inform the user(s) about the defined scenario, the causes, possible consequences and actions to prevent those consequences to happen.

	Scenario / Causes	Soil moisture HIGH	Soil moisture LOW	Relative humid HIGH	Relative humid LOW	Irrigation system state ON	Irrigation system state OFF	Rain TRUE	Rain FALSE	Temperature HIGH	Temperature LOW	Day irrigation YES	Day irrigation NO	Month season SUMMER	Month season WINTER
	Highly humid ambient	x		x											
	Possible plastic hole	x			x		x	x							
	Extra manual irrigation	x			x		x		x						
Aggresive summer time	Bush - Soil		x		x	x								x	
	GH - Temp									x		x		x	
Heat wave	Bush - Soil		x		x	x									
	GH - Temp									x		x			
	Extra heat									x		x			x
	Garden sink problem		x	x		x									
	Aggresive winter time										x		x		x
	Cold wave										x		x		
	Extra cold										x		x	x	

Figure 3.7: Scenarios causes

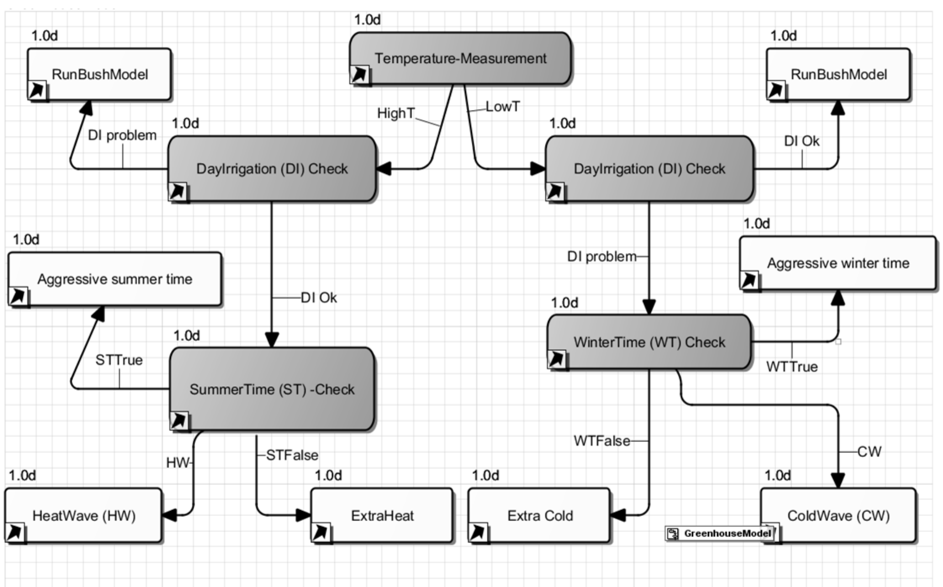


Figure 3.8: Greenhouse tree model

Figure 3.10 presents an example of the message when the "extra manual irrigation" scenario is detected:

Also weekly reports summarizing the system state are achievable via email (figure 3.11).

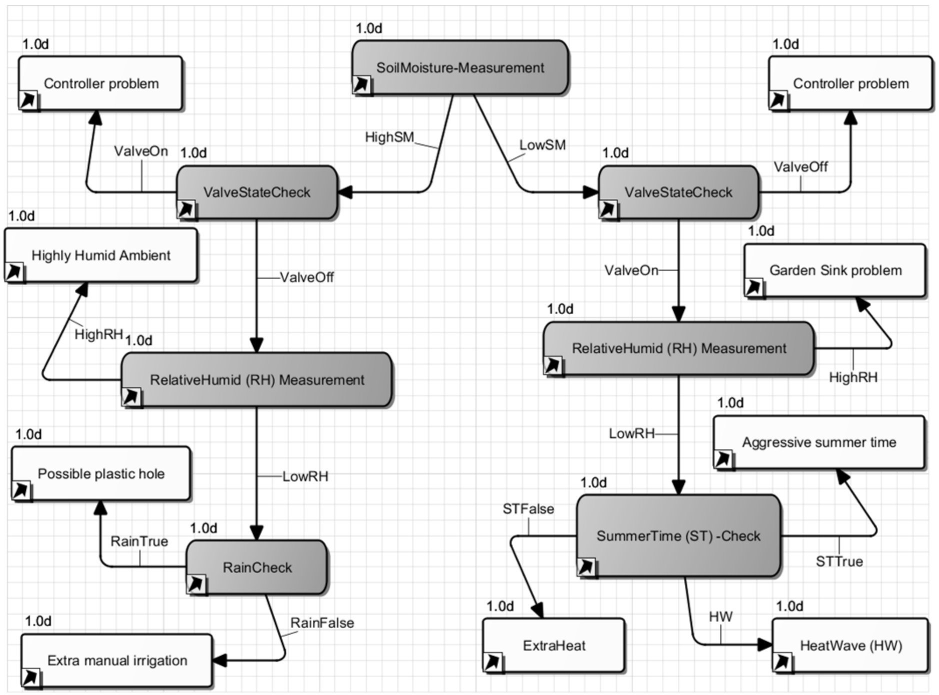


Figure 3.9: Bush tree model

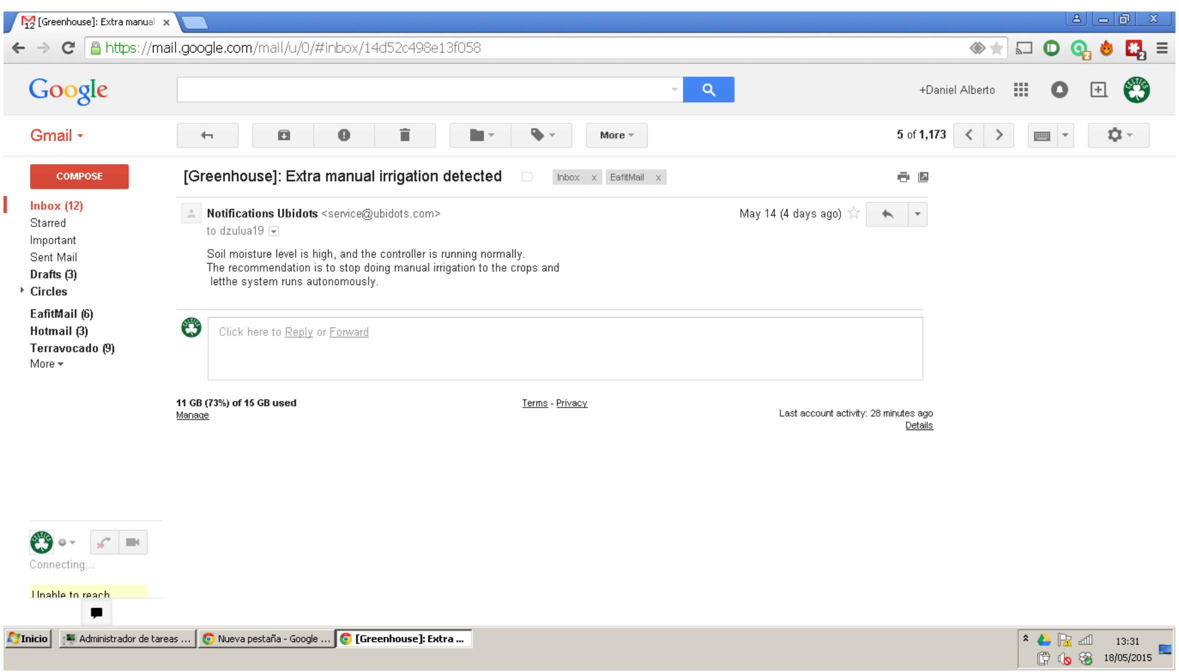
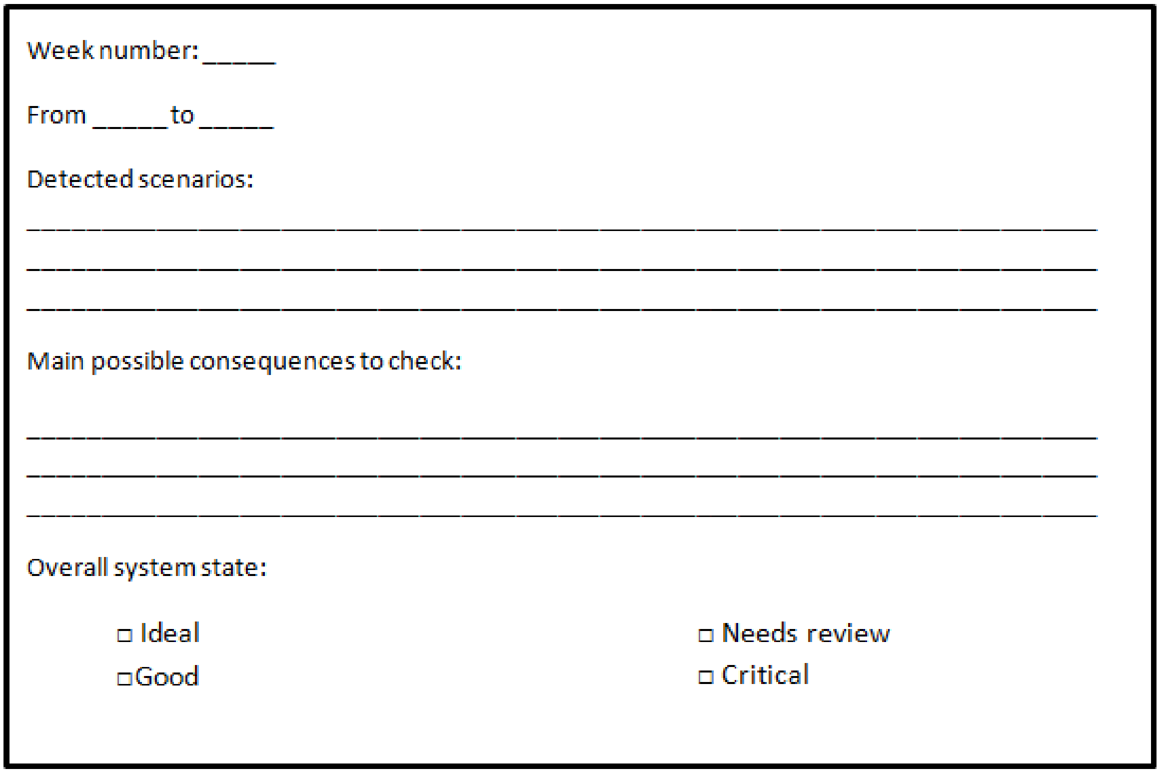


Figure 3.10: Mail notification for extra irrigation scenario



Week number: _____

From _____ to _____

Detected scenarios:

____

____

____

Main possible consequences to check:

____

____

____

Overall system state:

□ Ideal □ Needs review

□Good □ Critical

Figure 3.11: Weekly report template

3.3 System architecture

The complete system is composed by three elements: (i) The WSN , (ii) The physical server and (iii) A virtual server machine.

As it has been seen during this chapter, two architectures were tested (figure 3.6). First one based on Amazon Web Services (AWS) with a physical server running java. A second one fully web based on Ubidots platform for the data storage, processing and analysis.

These two different architectures are explained deeper:

3.3.1 Amazon Web Services®

As presented in section 3.1 the WSN is connected to the physical server using a ZigBee network which puts the data into a COM port. For the physical server a laptop computer (Dell Vostro 1520) was used. The computer runs locally a Java written program that reads the information placed in the COM port and place it into the virtual server in order to store them in the database and display information in the web page.

The program in the physical server acts like a client of the virtual server machine. To run the program in the physical server, the folder structure presented in figure 3.12 has to be created under the C: path.

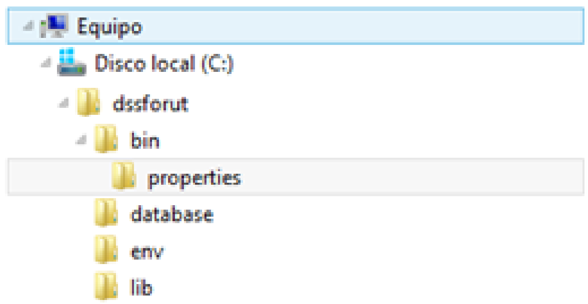
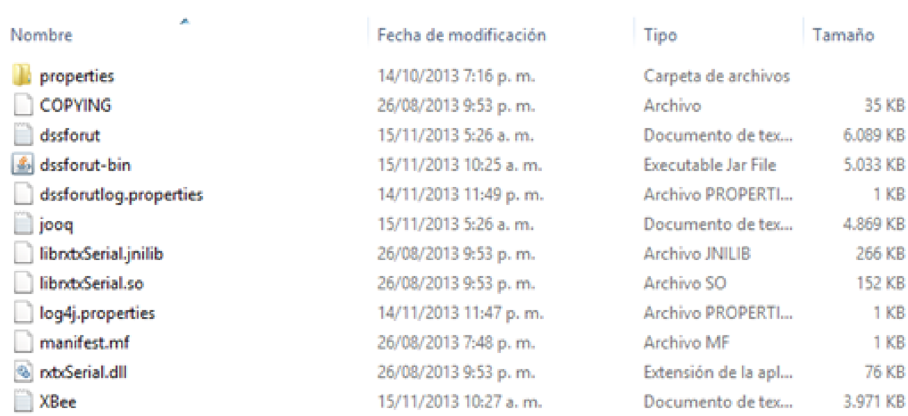


Figure 3.12: Folder structure for Java program

The “dssforut” folder contains four folders: “bin”, “database”, “env” and “lib”. These four folders are explained bellow:

1. **BIN folder:** this folder contains all the executable files the java program needs. It also contains all the .log files that the java program generates as long as the application is running. BIN folder looks like figure 3.13.



Nombre	Fecha de modificación	Tipo	Tamaño
properties	14/10/2013 7:16 p. m.	Carpeta de archivos	
COPYING	26/08/2013 9:53 p. m.	Archivo	35 KB
dssforut	15/11/2013 5:26 a. m.	Documento de tex...	6.089 KB
dssforut-bin	15/11/2013 10:25 a. m.	Executable Jar File	5.033 KB
dssforutlog.properties	14/11/2013 11:49 p. m.	Archivo PROPERTI...	1 KB
jooq	15/11/2013 5:26 a. m.	Documento de tex...	4.869 KB
librxtxSerial.jnilib	26/08/2013 9:53 p. m.	Archivo JNILIB	266 KB
librxtxSerial.so	26/08/2013 9:53 p. m.	Archivo SO	152 KB
log4j.properties	14/11/2013 11:47 p. m.	Archivo PROPERTI...	1 KB
manifest.mf	26/08/2013 7:48 p. m.	Archivo MF	1 KB
rxtxSerial.dll	26/08/2013 9:53 p. m.	Extensión de la apl...	76 KB
XBee	15/11/2013 10:27 a. m.	Documento de tex...	3.971 KB

Figure 3.13: Bin folder structure

- `dssforut.txt`, `jooq.txt` and `Xbee.txt` are log files. Java program uses these files to write down everything that happens with the execution of each aspect.

It is, the dssforut program itself, jooq store the database actions and XBee the communication behavior.

- `COPYING`, `librxtxSerial.jnilib`, `librxtxSerial.so` and `rxtxSerial.dll` are files required by the XBee library. These files must be available from a command line. We make sure about this, putting the bin folder into the environment variables of the windows system.
- The `dssforutlog.properties` and `log4j.properties` are files required for logging aspects. This means, java program needs these files in order to create the presented log files.
- The properties folder has a file named `routes_file.properties` this file contains the routes to reach, `env` folder and `database` folder.
- The `dssforut-bin.jar` file is the executable java file. This is the java program itself. To run this program all the points explained above must be correct. The `bin` folder has to be as presented in figure 3.13; except for log files, because they are created by the java program.

2. **Database folder:** It has a file named $db_config.properties$, this file contains the remote database data. This is required for the java program in order to store data in the cloud database.

3. **ENV folder:** It has a file named `environment.properties`. Java program uses this file to configure the Xbee environment, which can be set as Connected or Disconnected. Connected environment means that actually there is an Xbee sending data from the WSN end and another Xbee receiving data in the physical server. Disconnected environment means no Xbee hardware is connected, so the data must be simulated.

   To configure `environment.properties` file in a Connected way, you have to connect the receiver Xbee to the physical server and open the X-CTU program to see which COM is assigned to the Xbee and set it into the `environment.properties` file. This let java program catch that information and initialize a Connected environment.

4. **LIB folder:** Contains the libraries required by the java program. `Lib` files such as: `jooq lib`, `mysql connector lib`, `log4j lib`, `xbee-api lib` and `RXTXcomm lib`.

Running the Java program:

To run the java program java must be installed on the computer. Also all the points explained above must been set and configured. The Xbee receiver has to be connected to the PC, otherwise, the program will fail. After the configuration is complete, command window must be open (CMD), then the directory must be change using the cd command until reach the address:

```
C:\dssforut\bin
```

Once the directory has been set, write down the next command:`java -jar dssforut-bin.jar`. Program will begin to run. It will print on screen a few lines, those lines are for `RXTX lib` and the other lines let the user know that the java program can be stooped by entering “1” and hitting enter. To know how the program execution is, the log files can be open.

Virtual server:

The virtual server machine is hosted in Amazon web services EC2 (AWS). The acces url is `https://console.aws.amazon.com/console/home?#`, inside the instances tab there is an instance named `dssforut`. The connection to the instance must be done selecting the option “A Java SSH Client directly from my browser (Java required)”, the user name is ubuntu and the key path is `dssforut.pem` which has to be located in the physical server. finally is important to check the ”store in web cache” box ans click on “Launch SSH Client” button, after being sure to have access to the SSH port.

Once the connection to the server is established a window like the one showed in figure 3.14 must appears. This window is an Ubuntu command line, where is possible to run Ubuntu commands to install software, manage it, create folders, etc.

The virtual server has two software installed for the project. One of them is GlassFish Server and the other is MySQL Server. GlassFish Server is a Java Web Application Server, and MySQL Server is a SQL Database Server.

GlassFish server:

Glassfish server is in charge of displaying the real time information about the sensors in web page. It has already the program charged so the only thing that has to be done in the virtual server is start and stop the server (Everything based on the command line):

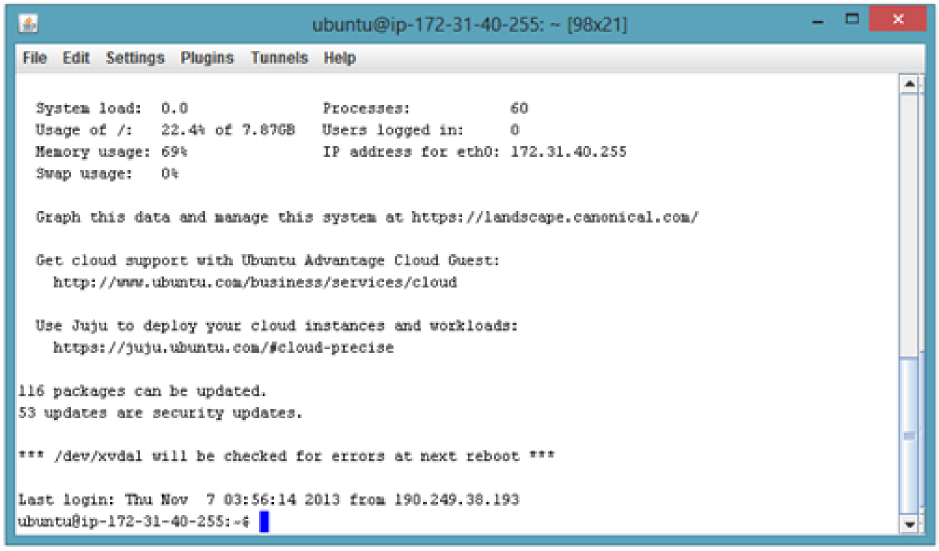


Figure 3.14: Main virtual server window

1. Go to GlassFish folder: `cd glassfish4`

2. Go to bin folder: `cd bin`

3. Run "asadmin" program: `./asadmin`

4. Use `start-domain` to Run the server or `stop-domain` to stop the server

Deploy new apps on the glassfish server is made by the url `https://ec2-54-200-65-16.us-west-2.compute.amazonaws.com:4848/` and follow the next instrucctions:

1. Go to the deployment section and select the option: "Deploy an Application".

2. Select the `.war` file that you want to deploy in the Glassfish server.

3. Delete the Context Root field content.

4. Finally click on OK.

The running app, the real time state of the greenhouse can be seen usign the the url `http://ec2-54-200-65-16.us-west-2.compute.amazonaws.com:8080/`.

MySQL:

The sql server must be configured via SSH client. But, to have access to the data base, HeidiSQL client is usefull.

To run SQL on the virtual server the following code must be typed

```
sudo service mysql start
```

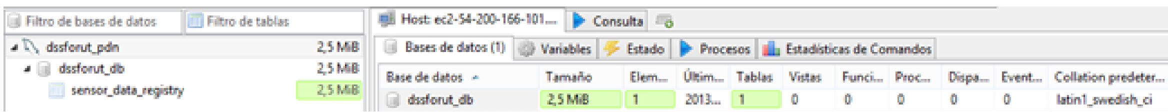


Figure 3.15: Database

To connect to the remote database (hosted in AWS) using HeidiSQL port 3306 must be open and the IP host name is `https://ec2-54-200-65-16.us-west-2.compute.amazonaws.com`. The database thru Heidi looks like in figure 3.16. From here is possible to run SQL commands, modify the schema, amoung other actions in the database.

3.3.2 Ubidots®

As section 3.3.1 shows, the deployment of the "back-office" infrastructure to run the complete system, ubiquitous monitoring platform and the data processing with the ES capable to detect scenarios, was a time and resources consuming task that must be done at least by people with medium technological knowledge.

The Ubidots platform presents a different approach that was combined with the complete WiFi network presented above in this work. With the inclusion of WiFi transmitters into the WSN modules these are capable to directly communicate with the ubidots services. Using ubidots as the virtual platform for the centralization, storage and presentation of the data coming from the monitoring system eliminates the necessity of a physical server, not only making the system simpler but decreasing the setup time and the error possibility due to the number of nodes in the network and the previous dependability of the central server.

After the WSN modules were equipped with WiFi Communication, a data source for each module was created online in Ubidots (www.ubidots.com). Each data source can contain different variables, in this case, each data source (WSN module) contains the five measured variables.

The created variables can be linked in an almost graphical way to different dashboards indicators that helps with the graphical deployment of the information.

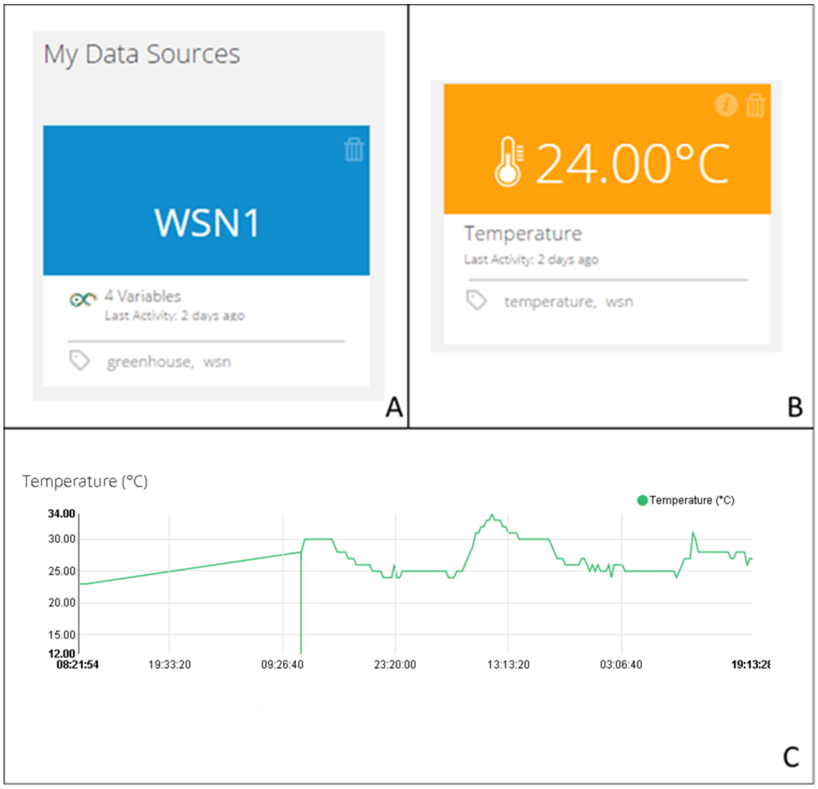


Figure 3.16: Ubidots platform: A) Data source, B)Variable, C) Dashboard

The dashboards created for each variable can be exported and embedded in any website, facilitating the improvement of the user experience with the web page when checking information of the greenhouse state.

For the presentation of the data and make information visible everywhere, the infrastructure created in ubidots was combined with a free web page creation tool. The final web address to access the variables state and relevant information in real time is:

`http://dzuluagah.wix.com/greenhousemonitoring`

The web page has different sections, the most important is an overview of all the variables and its last measurement (Figure 3.17). Also every variable has a dedicated apart where data can be seen graphically and every point shows the exact measurement captured (figure 3.18).

Ubidots has the option to create trigger events depending on IF-THEN rules for the value of the used variables (figure 3.19).

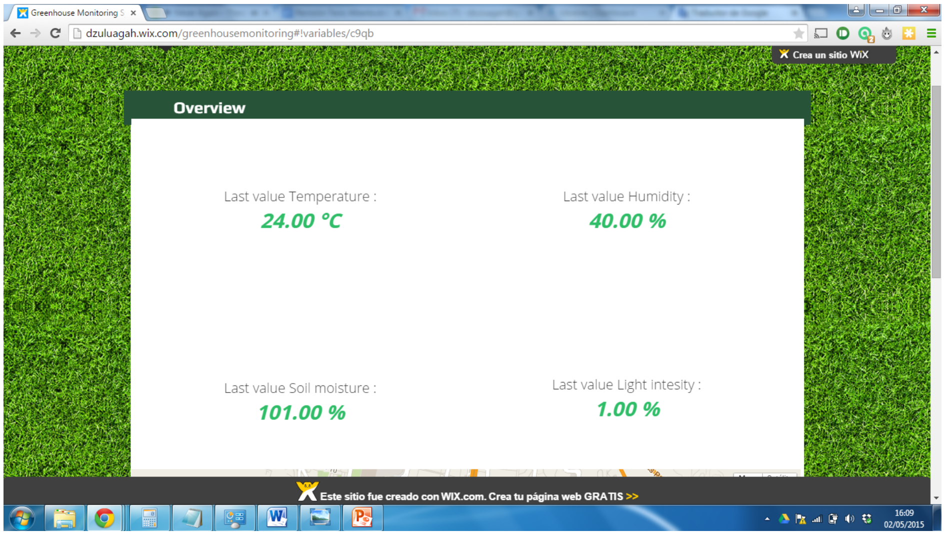


Figure 3.17: Web page showing last captured values for main variables

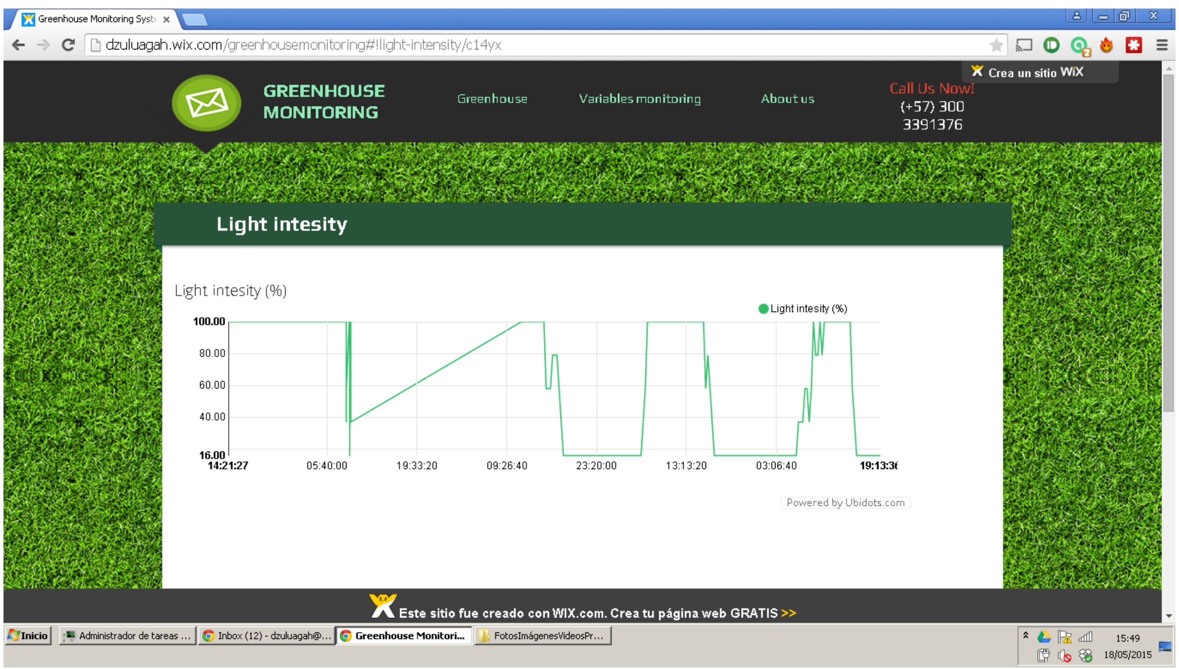


Figure 3.18: Web page showing detailed information about light intensity

As presented in section 3.2, with the scenarios defined and the variables prioritized according to the decision trees. The decision process in terms of scenarios can be modeled and implemented following IF-THEN rules that can be created by non technological expert personal and using Ubidots easily transfer into usable knowledge inside a ubiquitous monitoring system.

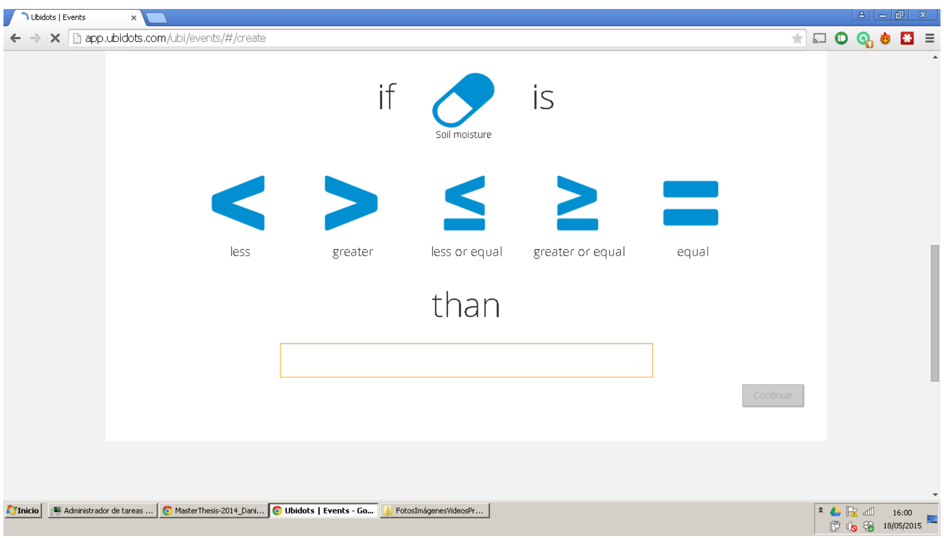


Figure 3.19: Ubidots If-Then rules creation

Chapter 4

Confirmative: Analysis of results

This chapter shows the evaluation of the work “UT for agricultural applications” in the Colombian context. Section 4.1 explains how the evaluation framework was created. In section 4.2 the results obtained with the evaluation of the system are presented. Finally, section 4.3 presents a general overview of the research actions developed during the work in a way that can be applied to similar projects, and how to follow the proposed approach.

4.1 Proof: Definition of the evaluation

During the development of the project “UT for agricultural applications”, a complete system to support the decision making in greenhouses (from the point of view of an expert agronomist) was designed, developed and tested. The entire system presented in chapter 3 can be summarized globally in the following elements:

- A hardware platform for ubiquitous monitoring of agricultural environments.
- A flexible decision making structure depending of the main variables and its prioritization.
- Two different architectures for data transfer, processing and presentation.

As presented during this work, the different stakeholders of the environment, where the US is implemented, play an important role during the whole design and development process. For the evaluation of the developed system, stakeholders that uses the system in different levels or from different points of view were included. They were divided in three groups depending of the interaction and expertise level that they have with the system. In figure 4.1 groups can be seen in a pyramidal representation. As more specialized the interaction with the system, the evaluation group become smaller. However by being an ubiquitous system that must be widely available for all the interested public and not only for the experts the pyramid has a wide base composed by the general users.

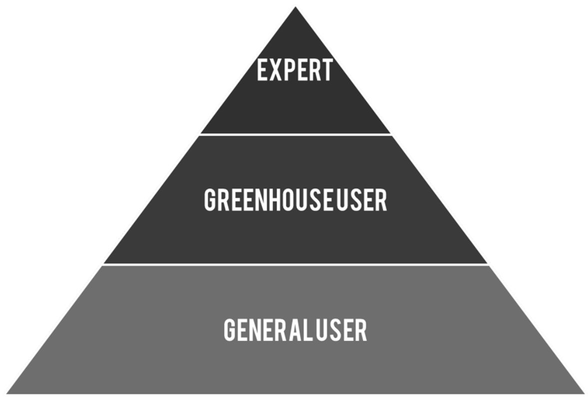


Figure 4.1: Stakeholders for the system evaluation

1. **General user:** Information is the core of any UT application. All of the three clusters of UT are based on information from any point of view: gathering, transfer or processing. Information for this type of system must be clear, precise, accessible, easy to understand, etc. In the bottom of the pyramid (figure 4.1) are represented the basic users. People that can be interested in the information that the system provides such as the variable's state but does not need specialized information, personal updates or deeper knowledge about the process that is running backwards. Its only interaction with the system is the access to the web page were information is presented. For this users the presentation of the information and the possibility to access it via different platforms is the key aspect. According to those aspects of availability and understanding a perception test about the web page and data presentation was conducted using the survey presented in annex B.

2. **Greenhouse user:** These are defined as those who has daily interactions with the greenhouse used for the case study and presented in chapter 3. These users provides information for the creation of the ES. They were asked to evaluate the implemented system in terms of the benefits it presents for they daily work. Questions (annex C)

were designed to cover aspects as the information available for decision making and the necessary time to gather it.

3. **Expert:** For the evaluation phase, this "expert" category includes not only people in charge of the tested greenhouse (the "greenhouse users" explained above), but any person with technical, professional or proven knowledge in the agricultural field. With these users, the accuracy and impact of the ES was evaluated. As can be seen in annex D experts were asked about the importance and prioritization of the monitored variables. Its importance for each subsystem (bush and greenhouses). As well as to define possible causes for defined scenarios.

4.2 Evaluation: Analysis of the results

As presented in section 4.1 for the general users, its experience with the system is based on the availability of the information and the way in which is presented. The validation of those aspects was focused on the evaluation conducted with the general users presented in annex B.

Information regarding the greenhouse state was accessed by computers (60%) and smartphones (40%) showing the ubiquity of those last devices and its relevance in the design of new technical systems. The participation of computers in accessing the web was divided in 20% of desktops and 40% of laptops.

The distribution between desktop and laptops is important as, usually, as well as in this case, the type of communication used (wired or wireless) is directly proportional with this data. A total a 60% of the users access the information using a wireless Internet connection.

For the evaluation of the perception about the web page and the display of the information, a Likert-type scale was used. The used scale, allows the assignation of a quantitative value to a subjective information. This by using typically a five-level Likert item, that in this case are:

1. Strongly agree

2. Agree

3. Neither agree nor disagree

4. Disagree

5. Totally disagree

The web page users and visitors strongly agree in a 60% that the information presented by the system is easy to access (figure 4.2). The evaluation of the accessibility is also encouraged as operative systems as Windows (40%), iOS (30%) and Android (30%) were used to visit and explore the web page. Only one problem about some broken links was reported but it was fixed after the event.

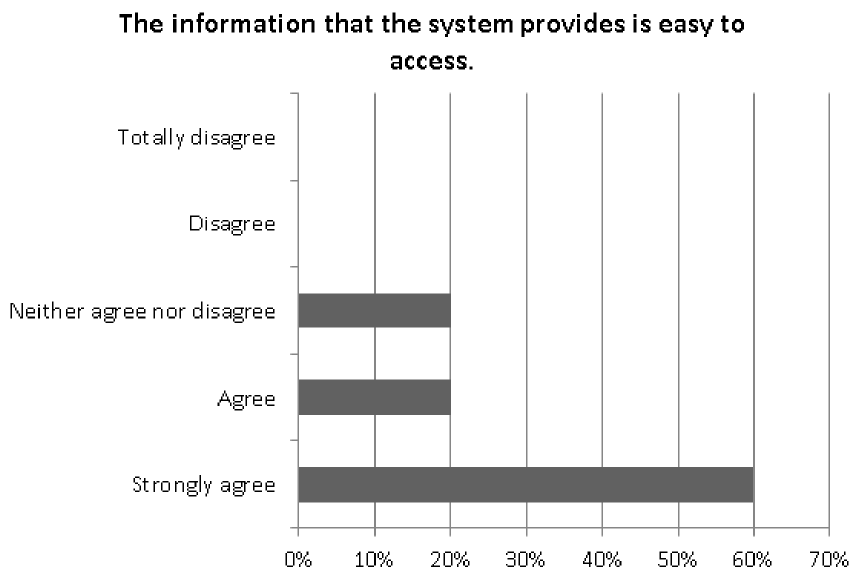


Figure 4.2: Results: Accessibility of the data

According to accessibility 70% of the respondents that strongly agree on the easy access to the variables and the easy understanding of the general composition of the web site (figure 4.3).

Also, the way in which information is presented inside the greenhouse web page was evaluated with the basic users, resulting in 90% of them that agree or strongly agree on a clear presentation (figure 4.4).

As can be seen from the previous results, the accessibility and presentation of the information were approved by the general users. Web page is able to be accessed by mobile devices using wireless devices and the response time using different type of connection, browsers and

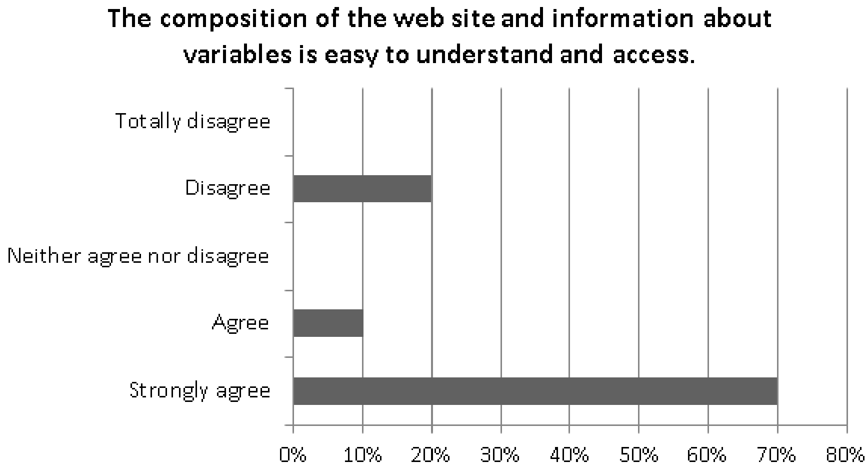


Figure 4.3: Results: Accessibility and understanding of composition and variables' information

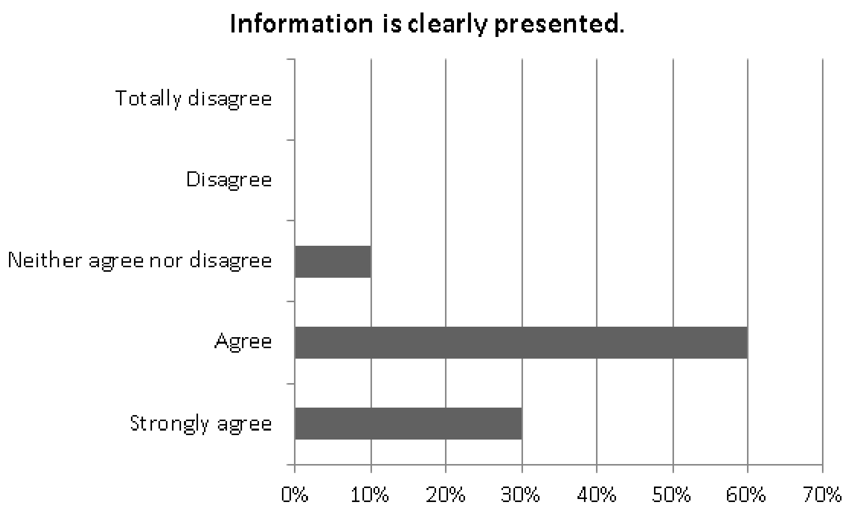


Figure 4.4: Results: Presentation of the information inside the web page

OS was satisfactory in 100% of the results.

For the evaluation of the system by the greenhouse users, a survey was also created in order to be follow (annex C). However as the implemented greenhouse was used for research purposes and the personal involved (experts) were less than four it was not necessary to run the complete survey.

Feedback from the greenhouse users, results in high interest about having the data always available. Also the messages that the system can send when an scenario is detected provide confidence to let less experienced researchers dealing with the greenhouse operation.

The amount of information available about the state of the system considerably increase and the effort continues the same as they still do the daily visits.

By following the annex C it is possible to evaluate the previous points in a quantitative way with larger groups of experts when needed.

For the evaluation of the technical information that the system monitors, its prioritization and the deductions made by the ES, a pull of experts in agronomy was contacted. The survey presented in annex D was sent to a contact data base that includes active agronomist, public and private companies related with agricultural activities in Colombia.

A Likert-type scale was also used for the first part of the survey were the expert has to answer if the monitored variables are enough to have an idea about the greenhouse state.

70% of the experts Strongly agree or agree that the monitored variables are enough to have a clear idea about the greenhouse state (figure 4.5). This prove that the designed ubiquitous hardware platform without any modification provides enough information to monitoring a greenhouse.

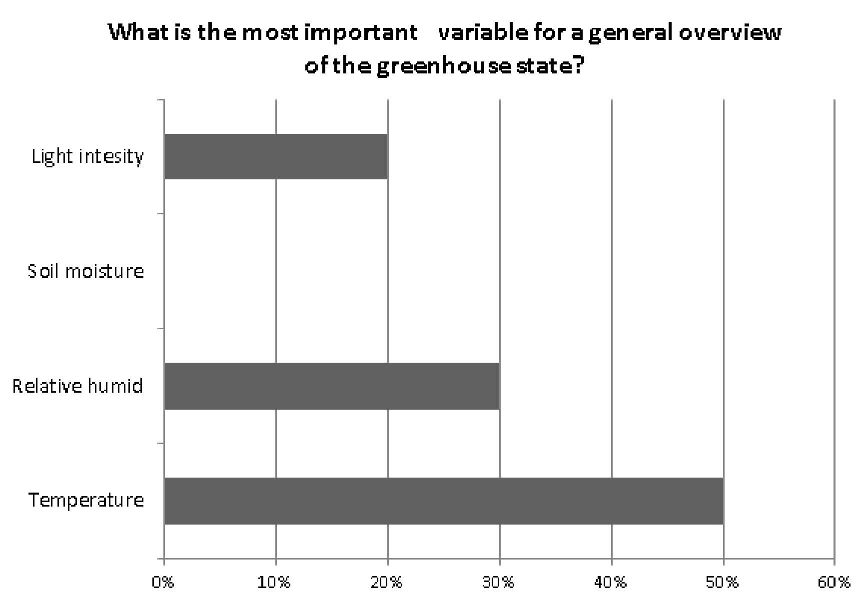


Figure 4.5: Results: Monitored variables

50% of the experts shows interest in add more variables to the monitoring platform. When asked about the variables to be added “date and time” were recurrent named. Also “wind speed” and “height above sea level” are interesting measurements for the experts.

Some of this variables are already in the system as “date and time”. Other named in this point are not variables but set up parameters as “height above the sea level”. This parameter will no change in a dynamic way. However, some of the recommended variables are taken into account for the future work presented in chapter 5.

Prioritization of variables and the definition of subsystems are core aspects of the proposed approach. Experts were asked about the most important variables in order to have general information about the greenhouse state and specific information about a plant inside the greenhouse.

For a general overview of the greenhouse, temperature, which is the most important variable of the presented ES, was found as the main variable by 50% of the experts. The selection was made between the monitored variables. Soil moisture did not appears as an important variable for a general overview of the greenhouse (figure 4.6). However, when the same question was made to define the relevance of variables to have specific information about a plant the soil moisture presents an increase of 20% as can be seen on figure 4.7. It is important to notice that this answers were provided by experts that did not know about the specific conditions of the tested greenhouse, where soil moisture was individual for each plant. This can explain why the variable was not more representative. Its relevance increase considerably, proving that the division of the main system in subsystems has in fact an effect over the relevance of the data.

From the defined scenarios that the system can detects, experts were asked in five of them to organise the possible causes from the most possible to the less possible. Scenarios for the evaluation with experts were:

- Aggressive/severe summer time
- Cold wave
- Sink problem
- Extra manual irrigation
- Controller problem

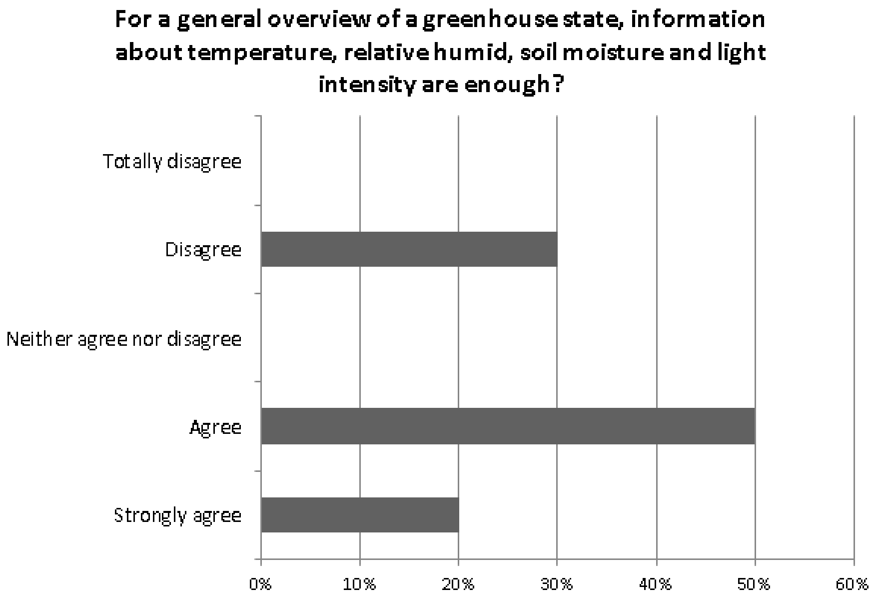


Figure 4.6: Results: Main variable for an overall greenhouse state

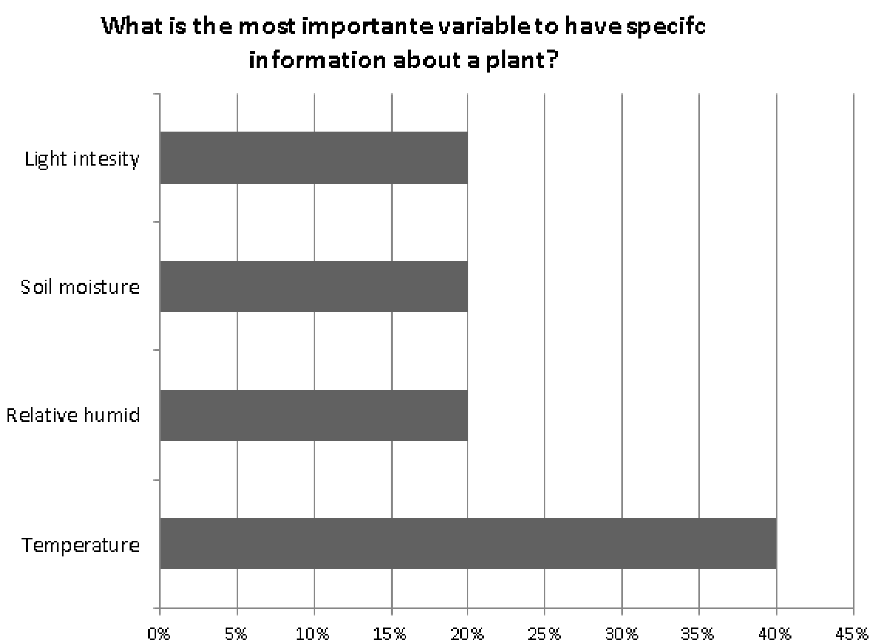


Figure 4.7: Results: Main variable for a plant

Summary of how the cause that the system identifies under certain conditions was selected for the experts as number 1, 2 or 3 cause for the presented scenarios (annex D) can be seen in figure 4.8.

Expert were presented with different scenarios in terms of the variables state. Following three options were presented about why this scenario happened and were asked to organize the options from the most to the less probable. Annex D present this in detail.

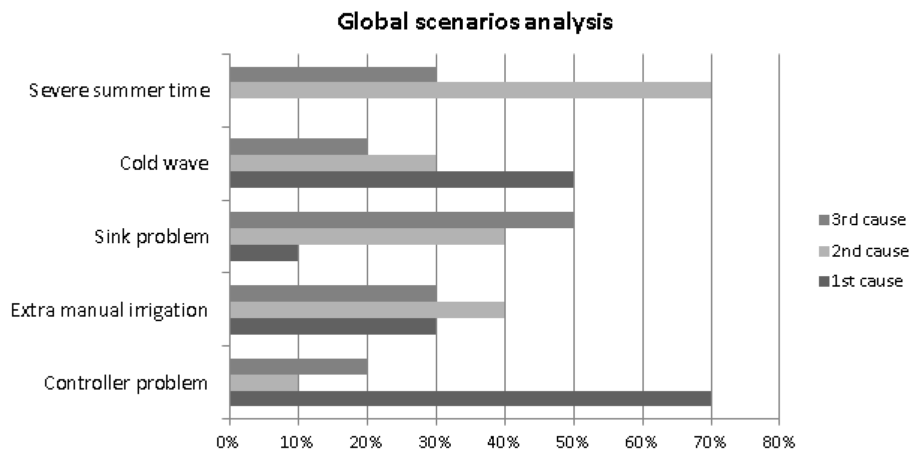


Figure 4.8: Results: Global scenarios analysis

Only in one of the five scenarios evaluated by external experts the cause identified by the system was named as the third option. This scenario was the detection of a problem with the greenhouse sink, but this can be explained by some particular conditions of the experimental greenhouse. There, the sink could be used for different pruposes as it was not only for the irrigation system, past information generate prevention of the experts involved in the process, resulting in a very specific condition of checking the sink as a first option.

For “Extra manual irrigation” and “Severe summer time” the cause that the system identified was tagged by the expert as the second main cause. In extra manual irrigation the first cause identified by the experts was a possible controller problem. As can be seen in annex D it was clear from the question that the irrigation system was checked and it functionality is ok. This response shows that technology implementation in the colombian context (Colombian experts) can be hard as in most of the cases where the control system was involve, experts turns its total attention to a possible problem with it. In the scenario of a “Severe Summer time” the identified cause by the external experts was that the irrigation system was not enough. As the irrigation system for the test was designed looking to have the lower impact as possible during experiments (drip irrigation) this cause is important to have in mind for future improvements of the system.

In scenarios for “Controller problem” and “Cold wave” experts and the system agreed 100% in the main cause for them. The controller problem was found as the main cause by almost 45% of the experts and for cold wave more than 30% of the experts agree on the main cause.

4.3 Generalization

Through the work, a ubiquitous monitoring system for greenhouses, where the data processing is done by following an ES, was presented. UT basics and clusters for its design and development were explained and used for the creation of the functional prototype. Main focus of the work was done on the data processing cluster where information, not only need to be processed and presented, but in order to create the ES information from the field experts must be gathered and represented in a operable way. All these without affecting the characteristics of a US.

The hardware monitoring platform created has five sensors for the defined variables. However, its structure and composition can be used to monitor other environments and variables with minimal changes making it applicable to other interests, mainly in agronomy but any other system that needs constant monitoring of many variables. Its design guarantee to be as less intrusive as possible with the user and requires no attention or setup once is connected, keeping almost by default important characteristics of the UT.

As explained in chapter 2 there is not data gathering process focused on the implementation of the obtained knowledge in a US. The approach followed during the current work for this purpose shows to be effective in transferring the knowledge from the expert to the system in a way which is easily achieved by any non technical person. The general process for data gathering and its implementation into a US was summarized in the steps presented in this chapter in order to make it replicable. Figure 4.9 presents the flow diagram to obtain the three diagram(s).

1. **Definition of the system:** The system from which the knowledge is going to be collected and modeled has to be clearly defined. This is in terms of the context, the

main goal of the implementation and the boundaries of the application. A description paragraph as the following can set the final definition.

"A greenhouse environment of approximate $50m^2$, used mainly for research purpose in which Process Engineering studies are conducted. Located in Medellín, Colombia, inside EAFIT University campus, the typical plant for experimentation is plantain. Principal experiments consist in growth promoting and inductions of diseases, for these reasons each crop has an independent soil to prevent contamination."

It is important to notice that the description of the system for agricultural applications must have:

- A general overview of the system and its uses.
- Location to determine weather conditions.
- Important special characteristics.

2. **Identification of stakeholders:** During the system definition, probably the most important characteristic to take into account is the identification of stakeholders. This step consist in define the different type of interaction that different people has with the environment where the system is going to be implemented. Different stakeholders must be defined in one of the following categories:

   - Informative stakeholders: All interested people/entities whose only interaction with the greenhouse is in order to check its state, the overall functionality, its productivity, among others. The principal characteristic is that they do not affect directly the daily behavior of the system, perhaps its decisions are focused on management and no in the operational aspect of the greenhouse. In the daily basics they only consume information from the system.
   - Operational stakeholders: This is perhaps the most easy and common stakeholder to find during the recognition process of the system. He is usually in daily charge of the system and is always present in the field. Usually for agronomy applications is known as the farm manager or "majordomo". Is easily recognized for its daily task. i.e. In greenhouses, he must include but not limited to: general system check, irrigation of the crops, harvesting, pruning, etc.

- Decision maker (expert): The main characteristic of this type of stakeholder is its technical knowledge about the system. Its main function is to take decisions in order to direct the work of the operational stakeholders (when exists). Usually the decision maker is not always in the field, but its presence is more common for the informative stakeholder. Usually is the main bridge between informative and operational stakeholders previously described.

The needs and interaction of the three types of stakeholders presented above are important for the definition and intervention of a system with ubiquitous technologies, as the informative stakeholder is the main input to define the displaying mode of the general information of the greenhouse and the operational stakeholder can not be affected by the system implementation. However, as the main focus of this work is on the integration of expert knowledge in a ubiquitous system,*all the following steps are designed to be followed with the identified decision maker(s).*

3. **Establishment of communication channels:** After the identification of the decision maker stakeholders according to the description provided in step 2, two communication channels have to be established. The final definition of those depends on the availability that expert(s) has, looking always for the best and faster way to reach him/them. The only requirement is that one of this channels must be written and the other one must be oral.

   Information and communications technologies (ICT's) are willing to be used. In the written channel email and chat are good examples. For the oral channel video conferencing systems can be used.

   It is recommended that all contact from now on with the expert must be done by the written channel before personal interactions.

4. **Written description of state / conditions:** The main goal of this step is to locate expert(s) in a specific scenario inside the defined system. As can be seen in figure 4.9 from this step a loop can start. This in order to increase and refine the knowledge model to be created. When more than one expert is involved in the knowledge acquisition process, this first written description must be done individually by each one to be discussed further during a group face-toface interaction.

The first time on this step, a standard question is made looking for a general overview of the expert's knowledge about the system. The first question to make during the knowledge acquisition process is always:

What is the ideal/perfect state of the system?

As the loop starts its iterative process, this question becomes more specific by asking for the identified scenarios / variables. The main idea is to always situate the expert in a specific scenario between the boundaries of the system. This looking to have a deeper understanding of the system in every interaction.

Expected answers are paragraphs written in the expert's natural terms. These paragraphs are usually short and must be expanded during the personal interaction. However is important to always do a written approach in order to have a clear focus to detail. An example of a possible answer for the greenhouse case is:

Greenhouse should be a place with specific temperature and humidity, where its structure and materials helps to keep these conditions. It should also be free of weeds. All the working material should be organized in one place, in order to avoid cross contamination with the outside environment.

5. **Personal discussion:** The personal discussion can be done individually or in group when more than one expert is involved in the process. The personal discussion follows always a semi-structured approach as the main goal is to discuss with the inputs (scenarios) that were provided by the expert in the previous point. However it could be a personal survey, a guided discussion, among other semi-structured techniques.

   The knowledge engineer must guide the discussion to find important variables. How they create or are influenced by the discussed scenario and the importance level perceived by the expert. In order to achieve this, is important to define how the expert will act if the scenario is indeed happening.

6. **Prioritization of variables:** Based on the discussions with the experts, that can be as many as needed. The next step is the formalization of the variables' importance. There is always at least one variable that experts check in critical systems no matter what and according to its value other actions are done. This relationships between

variables can also be logical. I.e. when the value of one variable affects other one or when the measurement of one variable can only be done indirectly.

Expected output of this point is a prioritized list of the variables where also the relationships can be displayed.

7. **Definition of subsystems:** The prioritization of the variables can give more than one variable at the top level (main variable). This is easily identified as those are variables that are always checked by the expert at first and/or are not directly affected by any other variable.

   When this is the case and is impossible to define which of those variables is the principal, then subsystems inside the global system have to be defined. Subsystems are created according to the smallest part of the global system that is directly affected by each main variable. I.e. Temperature affects the entire greenhouse, but soil moisture affects each crop independently for the special conditions of the greenhouse defined in step one.

8. **Definition of extreme conditions:** When variables are modified, the entire system or subsystem is modified. In order to create different scenarios for the analysis and discussed with the experts, extreme values for the main variables are proposed. I.e. If the main variable is temperature, the extreme scenarios to be discussed with the expert from step four are "What happens when temperature is too high" and "What happens when temperature is too low". When these scenarios have not been discussed with the expert(s) the process continue from step four. When the extreme conditions found were discussed already, step nine can be followed.

9. **Tree model construction:** After the different possible extreme scenarios are discussed, using write and verbal interactions, the knowledge engineer must have a clear idea about: (i) possible subsystems composing the global system and (ii) variables prioritized for each subsystem when applies.

   Using this information, a common tree model must be created for each subsystem. Tree models, as the ones presented in figures 3.8 and 3.9, must present a clear idea about the decision process. Specially he must reflect the order in which variables should be tested according to its priority.

If the complete system is composed by more than one subsystem, the communication between those systems has to be clear in the model. I.e. in figure 3.8, it is clear that when temperature is low and the daily irrigation is ok, then the complete bush model (figure 3.9) runs. This creates the link between the two subsystems and finally develops the complete model.

10. **Definition of scenario(s):** Having as input the created tree models, scenarios must be defined. Scenarios are created having in mind that each of them must answer the questions: (i) what is happening, (ii) why is happening and (iii) recommendations. All these information must be elicited and formalized following the previous points.

    Scenarios must have a paragraph describing the previous points as presented in section 3.2 and a table as figure 3.7 presenting the causes in terms of variables.

11. **Intermediate variables and IF - THEN rules:** As can be seen in figure 3.7, one scenario is usually caused by more than two variables. However, in order to make the formalized knowledge usable inside the US all scenarios must be simplified using nested If -THEN rules. To achieve this, intermediate variables have to be created.

    Intermediate variables are logically Boolean generated variables. This variables, using IF - THEN rules summarizes the state of two or more measured variables. I.e for the Aggressive summer time scenario:

    - *IF* ***SoilMoisture*** *IS "LOW" AND* ***RelativeHumid*** *IS "LOW" THEN* ***LowHumidity*** *IS "TRUE"*
    - *IF* ***LowHumidity*** *IS "TRUE" AND* ***IrrigationSystem*** *IS "ON" THEN ProbSumm IS "TRUE"*

    In the previous example, a first logically generated intermediate variable is *LowHumidity*. As Boolean variable the only two possible values that can take are "TRUE" or "FALSE". The state "TRUE" represents the combination of a lower value than the desired *Soil moisture* and also a lower value than the desired *Relative Humid*.

    Another intermediate variable is *ProbSumm* and its "TRUE" state represents the combination of a "TRUE" value for *LowHumidity* (previously created intermediate variable) and "ON" state for the *IrrigationSystem*.

Once the scenario is summarized in two variables it becomes an intermediate variable itself:

- *IF ProbSumm IS "TRUE" AND MonthSummer IS "TRUE" THEN Aggressive Summer Time IS "TRUE"*

This last statement in which the scenario was summarized can be created directly in Ubidots platform (figure 3.19). Also the paragraphs created during step 10 can be associated to each scenario detection, providing feedback to the user about what is happening, why happened and what are the recommendations (figure 4.10).

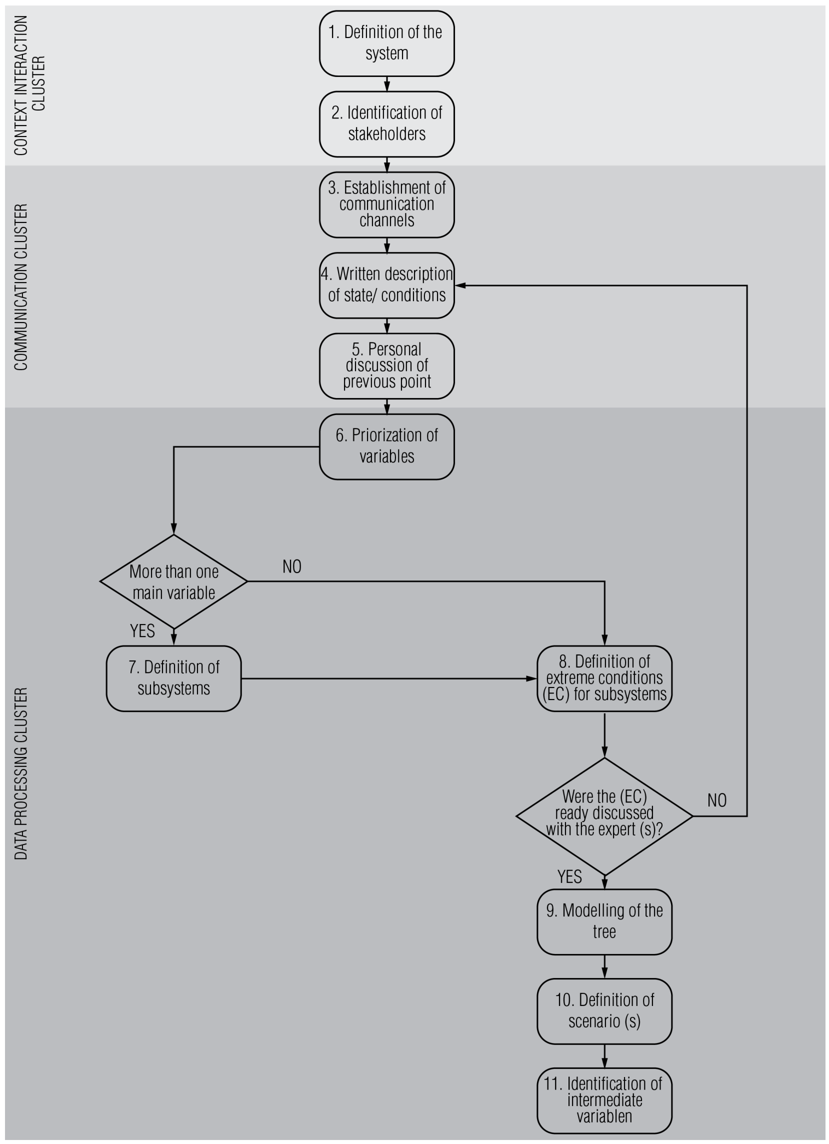


Figure 4.9: Generalization framework

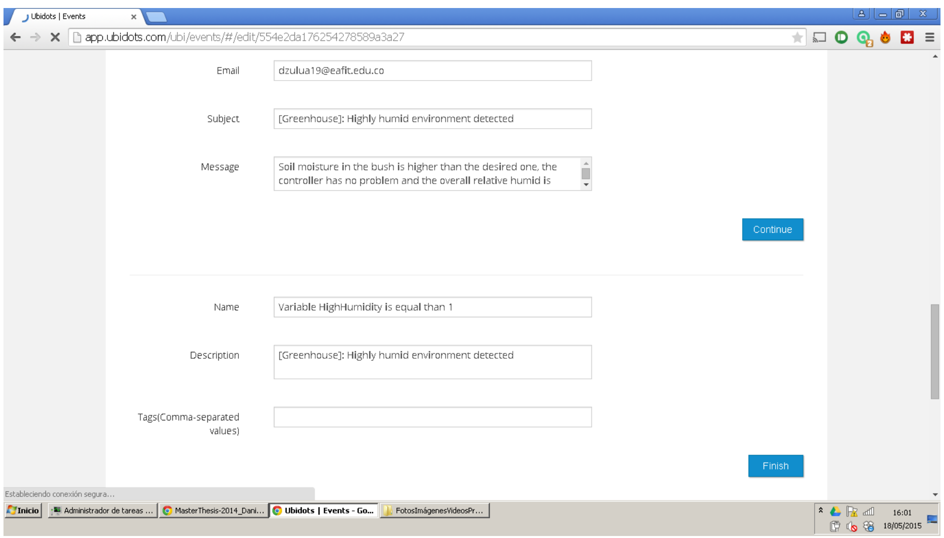


Figure 4.10: Creation of scenarios in Ubidots

Chapter 5

Conclusions and further research

Greenhouses are a reliable way to achieve food safety in the near future. Its implementation is becoming common in areas and countries previously not needed because of its weather conditions. Greenhouses were created to protect crops from cold weather, however nowadays are being used to protect crops from extremely warm weather too.

In tropical countries as Colombia, with a hard topography and greenhouses located in the rural side of the country, UT and CPS represent a useful approach for greenhouses' monitoring. With the implementation of this type of technologies information becomes widely available and physical inspections can be minimized, not only not affecting the amount of information available, but having more data stored and available for decision making.

With the implemented system, five variables can be constantly monitored in different points of the greenhouse. The followed WSN approach allows the system to have as many nodes as needed to cover the entire area with a resolution decided by the expert and design team. Also the hardware platform used for the ubiquitous monitoring of the system can be enriched with other sensors for different applications or expand its capacities for greenhouses.

Stakeholders are the base for any UT application. With the implemented system, informative stakeholders can access the real time information from any device with Internet connection as laptops, smart phones and tablets, in a reliable way.

Having daily and ubiquitous information about the state of the greenhouse, in terms of the most relevant variables, allows information processing to become an automated process in which experts can be involved without the need to having them physically present. Experts must be involved since the beginning in the process of ideation and implementation. Following that idea, it was possible to define the most important variables for the greenhouse, in terms of the general environment and specifically for the plant.

Data gathering from experts and knowledge representation are well know areas. However during this work a step by step process specially created to include the acquired knowledge in a US was proposed and tested. The system showed that can be helpful in the improvement of the decision making process.

Different techniques for having constant contact with the experts can be applied, in this work a scenarios oriented method was followed. The main characteristic was the written contact via email with the expert before having a personal interview. Having previous written contact with the experts was useful in order to have a more formal approach to the knowledge from the beginning. Thanks to that, the interviews have a defined agenda, according to the already answered questions. This approach could be useful for the implementation with trained agronomists, however it is important to notice that this kind of approach could not be followed when dealing with people not familiarised with IT technologies as most of the farm managers in Colombia.

The presented system composed by the hardware monitoring platform and the decision making structure can be improved in order to have specific information about the plants state. As it was shown during this work, the aim was to monitor the greenhouse in a ubiquitous way. However specific information in order to make the decision process even more autonomous can be added in future work.

Consequently as further research and for the improvement of the decision making, new sensors must be added. The hardware platform is flexible enough to allow extra inputs. The recommendations of the different scenarios that the system can identify gives an important idea about the next variables to include. Some of the scenarios detected by the system can bring bugs to the plants and the recommendations provided include a visual inspection in order to look for holes in the leaves. This process can be automated by including images processing in the system that can automatically detect this holes improving the level of information.

Plant growth was not monitored during this work, however this information can be useful for productive units. Sensors can be added to the implemented platform and knowledge about the processing of this information can be obtained with experts in the field, following the approach presented in figure 4.9.

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Appendix A

Annex 1: Framework for the evaluation of DSS design methodologies

The framework used for the evaluation of the DSS design methodologies was the same used by Blair et al. [1997]. Each one of the six defined stages for the design of DSS was analyzed in terms of the items presented in tables A,A, A, A, A and A.

Each table belongs to a design stage of DSS. On each table, characteristics for the design stage are presented. This characteristics are used for the evaluation of the methodology and how it supports the design on each of its characteristics.

Requirements Analysis	
RA1	Investigate class of decisions
RA2	knowledge elicitation
RA3	Multiple knowledge sources
RA4	Decision maker and expert
RA5	Circumstances and preferences
RA6	Uniform analysis approach
RA7	Decomposition and abstraction
RA8	Four decision making phases
RA9	Graphical models
RA10	languages for describing
RA11	Validation and verification

Table A.1: Comparison framework for requirements analysis

Conceptual Design	
CD1	Easy transition
CD2	Decomposition and abstraction
CD3	Normalisation
CD4	Uniform approach for modelling
CD5	Graphical model
CD6	Rich language for knowledge
CD7	Knowledge independent from use
CD8	Suppor for risk and uncertainties

Table A.2: Comparison framework for conceptual design

External Design	
ED1	Easy transition
ED2	Selection of algorithms
ED3	Decision analytical techniques
ED4	External model
ED5	Functional operations

Table A.3: Comparison framework for external design

Internal Design	
ID1	Internal model
ID2	Easy of transition
ID3	Defining operational constraints
ID4	Deciding what should be deduces
ID5	Support risk and uncertainty
ID6	Decision analytical techniques
ID7	Deciding language to implement

Table A.4: Comparison framework for internal design

Software Reuse Analysis	
SRA1	Searching for components
SRA2	Understanding components
SRA3	Interconnection of components
SRA4	Modifying components
SRA5	Evaluation component feasibility
SRA6	Support all development phases

Table A.5: Comparison framework for software reuse

Graphical User Interface	
UI1	Usability before functionality
UI2	Representation schema
UI3	Defining collaboration
UI4	Decomposition and abstraction
UI5	Manipulation of interface
UI6	Rules for visual language
UI7	Easy of transition

Table A.6: Comparison framework for user interface

Appendix B

Annex 2: General users survey

1. Which type of device did you use to access the system?
    - Desktop computer [ ]
    - Laptop computer [ ]
    - Tablet [ ]
    - Smartphone [ ]
    - Other:
2. Which operating system did you use to access the system?
    - Windows [ ]
    - iOS [ ]
    - Android [ ]
    - Other:
3. Which browser did you use to access the system?
    - Internet explorer [ ]
    - Mozila firefox [ ]
    - Google chrome [ ]
    - Safari [ ]
    - Opera [ ]

- Other:

4. Did you experience any problem trying to access the greenhouse information?

    - Yes [ ]
    - No [ ]

5. If “Yes” please describe the problem and the number of times that you had it:

6. Connection type used to access the system:

    - Wired [ ]
    - Wireless [ ]

7. The information that the system provides is easy to access.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

8. The composition of the web site is easy to understand.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

9. Information about the variables is easy to access.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]

- Totally disagree [ ]

10. Information is clearly presented.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

11. The response of the system (time) is satisfactory.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

Appendix C

Annex 3: Greenhouse users survey

1. Number of weekly visits to the greenhouse before having the ubiquitous monitoring system:

2. Number of weekly visits while have the ubiquitous monitoring system:

3. Average visit duration (minutes) before having the ubiquitous monitoring system:

4. Average visit duration (minutes) while have the ubiquitous monitoring system:

5. The available data for decision-making regarding the greenhouse increase considerably with the implementation of the ubiquitous monitoring system.

   - Strongly agree [ ]
   - Agree [ ]
   - Neither agree nor disagree [ ]
   - Disagree [ ]
   - Totally disagree [ ]

6. Important data about the greenhouse state used to be lost before implementing the ubiquitous monitoring system.

   - Strongly agree [ ]
   - Agree [ ]
   - Neither agree nor disagree [ ]

- Disagree [ ]
- Totally disagree [ ]

7. If the information available with the ubiquitous monitoring system was available before, I would make different decisions regarding the greenhouse.

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

Appendix D

Annex 4: Expert users survey

1. For a general overview of a greenhouse state, information about temperature, relative humid, soil moisture and light intensity are enough?

    - Strongly agree [ ]
    - Agree [ ]
    - Neither agree nor disagree [ ]
    - Disagree [ ]
    - Totally disagree [ ]

2. In addition to the previously presented variables (information about temperature, relative humid, soil moisture and light intensity) would you add extra variables for a greenhouse monitoring system?

    - Yes [ ]
    - No [ ]

3. If“Yes” what variable(s) would you add and why:

4. Order the following variables from most important (1) to less important (4) in order to have a general overview of a greenhouse state.

    - Temperature [ ]
    - Relative humid [ ]

- Soil moisture [ ]
- Light intensity [ ]

5. Order the following variables from most important (1) to less important (4) in order to have specific information about the state of a plant inside the greenhouse.

   - Temperature [ ]
   - Relative humid [ ]
   - Soil moisture [ ]
   - Light intensity [ ]

   Scenarios detection: Following scenarios about possible greenhouse states will be described in terms of the monitored variables. Three different options about the possible causes will be given, you should organize these options from 1 to 3, being 1 the most probable cause and 3 three the less probable one.

6. The soil moisture of the crop was detected to be higher than the desired one. However, the irrigation system remains on.

   - There is a severe summer time [ ]
   - The control of the irrigation system has a problem [ ]
   - The desired soil moisture is not the ideal one [ ]

7. Relative humid inside the greenhouse is not higher than normal, rain was not detected and the irrigation system is running ok. However the soil moisture in the crop is higher than the desired one.

   - There is a hole in the greenhouse roof [ ]
   - There is a problem with the control system [ ]
   - Manual irrigation has been applied to the crops [ ]

8. Soil moisture in the crop is getting lower and the relative humid inside the greenhouse is normal to high; however the irrigation system is running ok.

   - Temperature inside the greenhouse is high, so the water evaporation is happening really fast [ ]

- The garden sink is off, so the water is not running in the irrigation system [ ]
- Controller is not running normally [ ]

9. Temperature in the greenhouse is lower than the normal one, the irrigation system is running normally and the winter probability is low.
   - A cold wave is happening [ ]
   - More irrigation than the necessary was done, decreasing the temperature [ ]
   - Winter time is happening [ ]

10. The summer probability is high, the greenhouse ambient is dry (low relative humid) and the irrigation system is running normally. The soil moisture of the crops is lower than the ideal one.
    - A heat wave is happening [ ]
    - Severe summer is affecting the greenhouse [ ]
    - Irrigation system is not enough [ ]