Czech University of Life Sciences Prague

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Bachelor Thesis

Architecture and task analysis of Ambient Intelligence systems within the Smart Environment field of study

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BACHELOR THESIS ASSIGNMENT

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Systems Engineering and Informatics
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Thesis title

Architecture and task analysis of Ambient Intelligence systems within the Smart Environment field of study.

Objectives of thesis

The main objective of this thesis is to examine Ambient Intelligence and subsequent methodologies within the Smart Environment field, through the understanding of the software and physical tools used in the construction of such a system, as well as the governing rules, sensory input and multi-layered communication within the system.

The partial goals of the thesis are:

-to expand on multi-layer software communication specific to Smart Environments
-to examine and analyze sensor input and process methodologies
-to design knowledge rules

Methodology

To achieve the objectives, there is the need to review literature of similar efforts to define a theoretical framework by which, an Ambient Intelligence system will be able to perform a task in our everyday environments as well as to make those environments sensitive to us.

The next step would be the examination and analysis of the software controller of the system, using methods such as pervasive computing and multi-layered software developing.

Through this process, we can identify dimensions relevant to the required task by which the effectiveness and the design of the Ambient Intelligence system can be measured and evaluated.

The empirical research for this thesis will be conducted using already established Smart Environments such as systems that have been developed within the Research and Development department of the Agricultural University of Athens. The resulting findings however, should be applicable to any other Smart Environment, regardless of the target task, with consideration to variables being changed accordingly.

The proposed extent of the thesis

30 – 40 pages

Keywords

Smart environment, ambient intelligence, sensor input-output, software communication

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Recommended information sources

ECKERSON, Wayne W. Performance dashboards: measuring, monitoring, and managing your business. John Wiley & Sons, 2010.

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Prague on 15. 03. 2020

Declaration

I declare that I have worked on my bachelor thesis titled "Architecture and tasks analysis of Ambient Intelligence systems within the Smart Environment field of study" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights of any their person.

In Prague on 15/03/2020 ____________________________

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I would like to thank Ing. Jan Tyrychtr, Ph.D. for his valuable advice and supervision of this bachelor thesis.

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Architecture and task analysis of Ambient Intelligence systems within the Smart Environment field of study

Abstract

This thesis examines the advantages that Ambient Intelligence systems provide within the Smart Environment field of study, their structure and architecture as well as the reasons behind why certain components are used. The theoretical part consists of analysis of various software used in the development of Ambient Intelligence systems, methods used in a Smart Environment by which the system gathers ambient information such as individual sensors or sensor networks as well as means of communication between the sensors, basic modelling and decision making on system-side and parameters by which the decisions are made.

The practical part of the thesis contains the design of an Ambient Intelligence system that automatically grows vegetation without the immediate involvement of the human factor by utilizing a sensor network, custom-made software and custom-made decision algorithms. The parameters by which a certain strain of vegetation thrives and grows are a given. The proposed system accepts those parameters and monitors the Smart Environment through its sensor network at all times. When a single parameter is off the predetermined setting, the system will make the decision to make corrective movements, such as add more water or change the luminosity cycle of the plant. The three most important components of such a system are, the sensor network, the software suite which the decision algorithms will be implemented and finally the knowledge rules according to which the system will be based upon. In order to obtain the most reliable results for this thesis, the theoretical background given in the theoretical part of the thesis is closely followed in the implementation of the practical part.

Keywords: ambient intelligence, smart environment, sensor, sensor network, knowledgebase

Architektura a analýza úloh systémů Ambientní inteligence v rámci oblasti Chytrých prostředí.

Abstrakt

Tato práce zkoumá výhody, které nabízí systémy Ambient Intelligence v rámci studijního oboru Smart Environment, jejich strukturu a architekturu a důvody, proč jsou určité prvky použity. Teoretická část této práce se skládá z analýzy různých softwarů použitých při vytváření systémů Ambient Intelligence, metod použitých ve Smart Environment, pomocí kterých systém shromažďuje ambientní informace, jako například jednotlivé senzory nebo síť senzorů a způsob komunikace mezi nimi, základní modelování a rozhodování na straně systému a parametry, na základě kterých jsou rozhodnutí vytvářena.

Praktická část této práce zahrnuje návrh systému Ambient Intelligence, který automaticky pěstuje vegetaci za využití sítě senzorů, na míru vytvořeného softwaru a rozhodovacího algoritmu, a to bez bezprostředního zásahu lidského faktoru. Parametry, na základě kterých určitý druh vegetace prospívá a roste, jsou předem známy. Navržený systém akceptuje tyto parametry a nepřetržitě monitoruje Smart Environment skrze vlastní síť senzorů. Pokud je kterýkoliv z parametrů mimo předem zadané nastavení, systém provede rozhodnutí o opravném pohybu, jako je například přidání vody nebo změna světelného cyklu rostliny. Tři nejdůležitější komponenty takovéhoto systému jsou pak síť senzorů, softwarová sada, do které bude rozhodovací algoritmus implementovaný, a především znalost pravidel, na základě kterých bude systém založen. Za účelem získání nejspolehlivějších výsledků této práce, teoretický základ popsaný v teoretické části této práce je dodržený i v implementaci praktické části.

Všechny výsledky a zjištění této práce jsou shrnuty v Závěru.

Klíčová slova: Ambientní inteligence, Chytrá prostředí, senzor, senzorové sítě, znalostní báze

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1 Introduction

The last fifty years have been marked by a unique characteristic, never before seen in recorded human history with such linearity and magnitude, advancements in technology. In the last fifty years alone, human was able to make leaps in technology with a disproportionate rate compared to previous centuries. There have been two very important limiting factors as to why we, as a race have not been able to make the technological breakthroughs observed in the last fifty years earlier and those were, the fact that in part we were limited by material science, the ability to manipulate and create materials on which the theoretical science could be tested against and in part, the theorical science itself. Each of these fields is governed by a plethora of different fields of study such as Chemistry and Metallurgy, Physics, Biology and Medicine, just to name a few, which all work in tangent. When a breakthrough is made in any field of study, the results are shared, and its applications help advance a different field of study that was previously limited. A magnificent example to that, would be Quantum Computing. As of 2020 we have established a theoretical physics background on how Quantum Computing will take place but the material science and more specifically the manipulation of magnetism is currently limiting us from making a larger than eight atom model in order to test Quantum systems in a larger scale. It is the nature by which we operate as a species to compartmentalize and segregate into different, smaller more specific and focused fields, before we attempt to seemingly integrate the lessons learnt into everyday life.

This thesis is attempting to examine one of the greatest examples of the aforementioned methodology, the integration of intelligent systems in our everyday life, through Ambient Intelligence within the Smart Environment field of study by ways of examining the how and most importantly the why. Ambient Intelligence possesses one the highest multi-disciplinary rates in today’s research fields, as it is directly dependent on the advances of material and theoretical science. The purpose of Ambient Intelligence (AmI) is to bring intelligence into our everyday environments and make those environments sensitive to us. Applications of such technology can be found from smartphones to elaborate automatically vegetable growing stations. The smartphone, being the immense tool that it is, is able to pinpoint our location and automatically provide information that may be of interest to its user, however after we introduce AmI, it is not only able to provide information but also, tailor the information given to the user based on past experiences, for instance if the user has shown no interest on topical weather, the system will remember and will not prioritize such information, rather it will learn of the user's interests and prioritize those instead. In a vegetable growing environment, the variables as to which each strain of vegetables has the highest growing rate are stable, therefore this field provides one of the best examples where AmI can be applied with great results. With the use of different sensors, we are able to monitor the growing environment and according to certain pre-set criteria by the user, the system is able to make decisions such as watering or lowering humidity. Another case would be a smart home environment in which the temperature is monitored and the control unit is making decisions when to switch on or lower the heating based on the user's preferences, or even inform the user of missing goods and in the case of Amazon's in depth ordering system, even go as far as to place an order for those missing goods.

The way an AmI system achieves such level of integration with the human factor, is divided into two categories. One is the ability to gather information from the environment that such a system is applied to, which happens through the use of sensors or sensory suites. The second is actually making the changes to meet certain parameters by way of the controlling software by which the AmI system will make decisions. The software might be multi-layered or as simple as Boolean conditional. Most are constructed using Python to create communication between the sensors and a rudimentary device such as Arduino, assigning values that correspond to real life parameters such as temperature. The values are then transferred to a control unit commonly written in a more customizable language such as C, where the decision to make the changes is made. There, if the user parameters are not met, the system will make the decision to signal another device to make changes, with the sensors once again verifying the change completing the circle. This circle is in place to monitor and change the environment according to our needs, and that in itself is the main definition of Ambient Intelligence.

2 Objectives and Methodology

2.1 Objectives

Creating an AmI system takes careful planning with consideration to all the parameters required. Further it requires the cooperation of software with hardware as well as different software among each other. Careful study of the needs of the system to cover and pinpointing exactly where each node will be placed. Therefore, based on those needs the objectives of the thesis are presented below.

1. Firstly, to study and expand on multi-layered software communication specific to Smart Environments. Since there is no centralized software component that completely encompasses all the needs of an AmI system, there is the need to use multiple other software techniques and methodologies. We will study how this is done and why and what is the compatibility between the methods used.
2. Secondly, to examine and analyse sensory input and process or reasoning methodologies. How we set the parameters the system will abide by and why, the goals that we try to achieve through such a process and how it is achieved. Furthermore, why we use sensors and what purpose they serve.
3. Thirdly, the design of knowledge set of rules. By setting a theoretical framework on knowledge management and applying it to AmI systems in consideration with the goals the system is trying to achieve.

The practical objective of the thesis however is to design an automatic growing environment using tools analysed in the theoretical part. More specifically this thesis will examine, how the decisions are made inside an AmI system, how as well as how it collects information.

2.2 Methodology

The basis of the development of this thesis is the scientific literature that analyse the different components that compose a Smart Environment and the technology that allows each component to work in tangent with every other part of the system to provide reliable information to the control system, which in turn makes decisions to alternate parameters based on human variables.

To achieve the main objectives, the following three major categories will be examined:

- Software Development
- Sensor suite
- Knowledge rules

2.2.1 Software Development

In an AmI system, the control unit is a software that allows the main processes of the system take place, as well as all the information is collected. This is where the parameters are saved and according to the information collected by the sensors, the decision to make a change is made and implemented. Most software used is custom made like the one shown in the practical example of this thesis but attempts have been made to create a reliable middleware such as HYDRA in order to allow developers to have easier access to the tools needed in order to create an AmI system.

2.2.2 Sensor suite

The eyes and ears of an AmI Smart Environment system. A sensor placed in the point of interest, or in many cases an array of sensors also called a sensor network provides real time information of the situation at the point of interest which then feeds it to the software suite. There are many protocols of communication between the sensors that this thesis will expand on, such as the commonly used TCP or the more AmI oriented ESRT protocols, the later also being the choice of the sensor network implemented in the practical part of this thesis.

2.2.3 Knowledge rules

Essentially the parameters inserted by the human. The system on its own has the capacity to gather information but without knowledge rules it would stop, without having a task or a way to utilize the information it has collected. By applying knowledge rules in the form of an algorithm, the system obtains the decision-making capacity and completes the task originally designed for. The most crucial part of an AmI system is its knowledgebase which is created by using goal specific variables. In the practical part, the goal is to grow vegetables, therefore, the knowledgebase is built with variables specific to the strain of plant and those variables will act as the guidelines of the algorithm.

2.2.4 Practical part

The Practical part of this thesis will try to create an automatic growing station. To better display the attempt, several figures outline how and why the technology will be placed as such. All of the figures of the practical part display the same growing environment, but different layers of it, so the entire technology can be showcased.

- Figure 9 shows the sensor layer. Wind sensors are indicated by purple, luminosity sensors by yellow, humidity by blue and supplements by red, their connections follow the same pattern. Growing Station 1 and 2 are the actual growing beds filled with soil. Control Suite is the main computer, responsible for the operation of the system.
- Figure 10 indicates the control units of the various variables. For instance, the Humidity control, is a system that injects water into the growing beds if the control suite decides that there is such a need. Similarly, for the other variables as well. As shown on the figure, between the actual device and the control suite, stands the HUB which is essentially a controller that switches the device ON/OFF according to the control suite.
- Figure 11 is a flowchart that showcases the decision algorithm's process. Triangle labelled "Sensor Measurements" indicates an *extract or a measurement*. The rectangle labelled "Data parsed into integer values" indicates *data*. The cylinder labelled "Value Comparison" indicates a u *database*. The rhombus indicates a *decision* and the "Variable control" symbol indicates the controls found on Figure 10. Since the algorithm will result in corrective movements, the two work in tangent to achieve a common goal.

3 Literature Review

3.1 Characteristic of AmI systems

Since Ambient Intelligence is a relatively new field of study, many researchers characterize it in different ways. However, there are certain characteristics by which the golden standard of Ambient Intelligence is measured against (Table 1), and those are slowly becoming more and more accepted. In the following table we can see how an AmI is measured against other principles giving it unique characteristics.

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Features of Ambient Intelligence captured by AmI definitions. Features include Sensitive (S), Responsive (R), Adaptive (A), Transparent (T), Ubiquitous (U), and Intelligent (I).

Definition	S	R	A	T	U	I
A developing technology that will increasingly make our everyday environment sensitive and responsive to our presence [4].	√	√				
A potential future in which we will be surrounded by intelligent objects and in which the environment will recognize the presence of persons and will respond to it in an undetectable manner [1].	√	√		√	√	
"Ambient Intelligence" implies intelligence that is all around us [5].					√	√
The presence of a digital environment that is sensitive, adaptive, and responsive to the presence of people [6].	√	√	√			
A vision of future daily life …contains the assumption that intelligent technology should disappear into our environment to bring humans an easy and entertaining life [7].		√		√	√	
A new research area for distributed, non-intrusive, and intelligent software systems [8]				√		√
In an AmI environment people are surrounded with networks of embedded intelligent devices that can sense their state, anticipate, and perhaps adapt to their needs [9].	√		√	√	√	√
A digital environment that supports people in their daily lives in a nonintrusive way (Raffler) [10].				√	√	

Figure 1. Features and characteristics of Ambient Intelligence systems (D.J. Cook, et al. 2009)

Furthermore, AmI incorporates aspects of pervasive and ubiquitous computing, as well as artificial intelligence and as a result of that accepts contributions from machine learning, agent-based software and robotics. (D.J.Cook et al, 2009). Systems are characterized as AmI systems when they exhibit characteristics according to Table 1 and according to D.J. Cook, the definition is summarized in the following:

"a digital environment that proactively, but sensibly, supports people in their daily lives", D.J.Cook, Pervasive and Mobile Computing, 2009

3.2 AmI oriented Software Development, HYDRA

Since Embedded systems can nowadays be encountered on all aspects of life, the need arises for a more cost-efficient method for companies to develop software that encompasses the needs of today's life. In efforts to alleviate the huge costs of software development, companies are leaning against pooling their resources and attempting to network their products with other systems to create more center-based services, in part to cut development costs and in part to provide users with higher value-added solutions. This is a process that although works towards cutting costs, and is in fact less costly than the alternative, it is also immensely time consuming. Working towards the solution of those problems is the HYDRA project by researching and developing middleware for networked embedded systems that allows developers to create cost-effective AmI applications, specifically targeting the European industry sector (Markus Eisenhauer et al, 2010).

Middleware is layered between network operating sustems and application componenets, it facilitates the communication and coordination of componenets that are distributed across several networked hosts and the aim of it is to provide application engineers with high-level primitives that simplify distributed system construction (Wolfgang Emmerich, 2000). It allows software developers to implement communication and input or output methods. The HYDRA project develops middleware to do just that, to allow developers to utilize sensor and device networks (Markus Eisenhauer et al, 2010) easier, without the need to establish communication between the sensory suite and the operating system per case basis, but rather centralizing the processes and providing a platform others can build upon without having to spend time and money on developing the same framework over and over again. This project has greatly been assisted by the breakthrough in other research areas of sensor nodes and radio hardware. HYDRA middleware is placed between the applications and the operating system and contains a large number of managers, or software components, who handle the development of networked embedded systems, furthermore this middleware can be applied in new or already existing networks. That paves the road for developers to implement physical devices into the applications.

More specifically, HYDRA middleware achieves such level of inter-technology communication through the use of the semantic Model-Driven Architecture. This particular choice of architecture enables features such as device and service discovery, peer-to-peer communication and diagnostics (Markus Eisenhauer, Peter Rosengren, and Pablo Antolin, 2010). The following figure demonstrates the HYDRA middleware architecture and its layers.

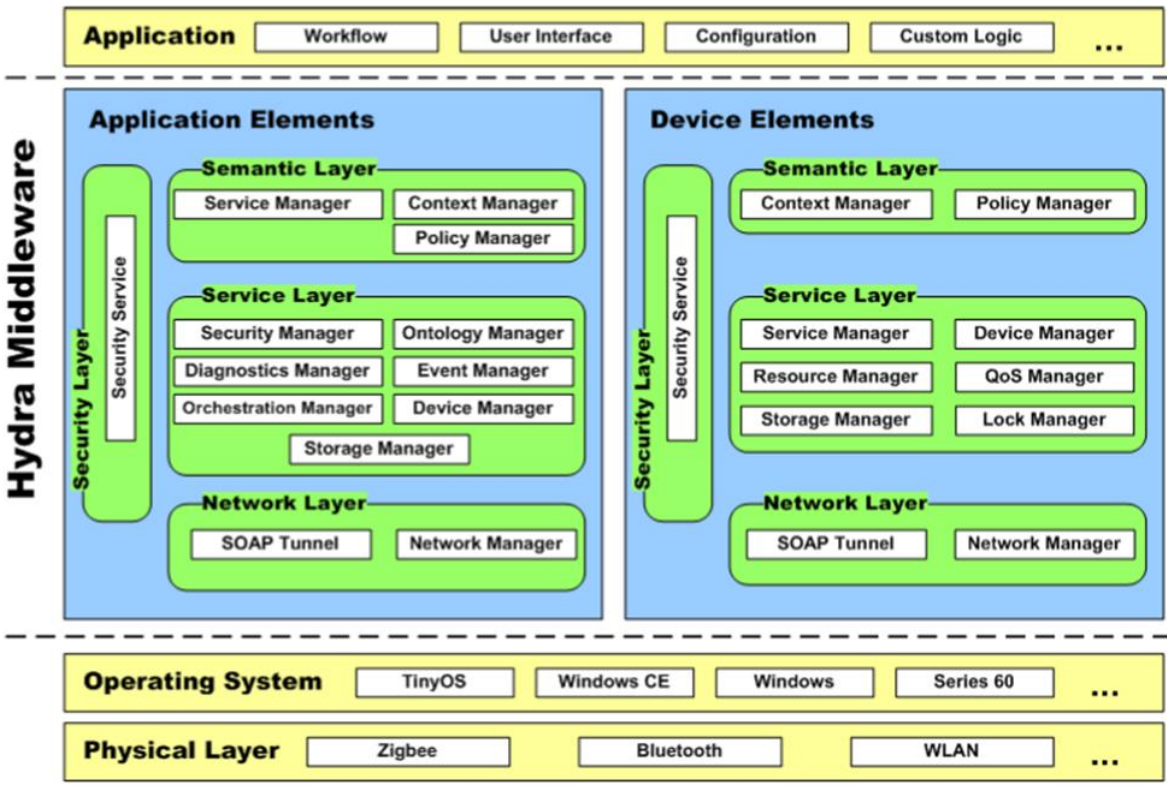

Figure 2. HYDRA middleware architecture (Markus Eisenhaur et al. , 2010)

HYDRA, much like other software development institutes, have release a software development kit (SDK), similar to other SDKs such as Java SDK, further enabling developers to create AmI systems more easily and cost effective.

3.2.1 HYDRA Applications

HYDRA middleware mainly focuses on three big categories which are home automation, healthcare and agriculture.

With the rise of embedded technology, it was natural that people turned to smart environments and one of the first applications we saw to that was in smart homes. Applications of that are not only limited to the domestic sector, but to commercial and industrial complexes, including energy management systems and building controls (Markus Eisenhauer et al, 2010). Smart domestic environments will be able through the use of HYDRA middleware, to detect errors and damages within the environment they are applied, such as heating damages through mainly the detection of drastic temperature change in multiple rooms. The system reaction will be based on two factors, whether the owner is present or not. In case that he is physically present inside the environment a simple notification will take place, through speakers and monitors. If the owner is not physically present then he will receive a notification on his phone, informing him of the situation (Rene Reiners et al, 2009). The potential of expansion in this particular field is immense since the effect of Smart Environments in our everyday lives is heavily affecting us.

In healthcare, HYDRA is able to provide technology that monitors health and develops personal wearable devices for healthcare professional that allows them to be more mobile and stay longer in the workforce (Markus Eisenhauer et al, 2010). The custom developed application eHealth was presented at the GSMA Mobile World Congress in Barcelona and CeBit Hannover (March 3-8, 2009).

Lastly, agriculture is another field that HYDRA middleware hopes to implement its technology through interconnectivity of multiple networks of sensor suites and/or intelligent decision making. Furthermore, it hopes to enable the development of intelligent and secure applications where devices and subsystems cooperate to perform common tasks (Markus Eisenhauer et al, 2010).

3.3 Sensors

Because AmI systems are designed to be implemented in the real world, the environment around us, it is of vital importance to gather information reliably and frequently, otherwise the intelligent agent would not be able to sense and act upon the environment. Sensors are the key that link available computational power with physical applications (D.J.Cook et al, 2009).

Algorithms designed specifically for AmI systems, use data collected from the environment using sensors, and the software in turn perceives the information and acts accordingly to change the state of the environment. To achieve this, a plethora of different types of sensors might be used, such as sensors that measure distance, humidity, luminescence or even radiation just to name a few. As seen in

Table 2 there are a number of different sensing modes available and are categorized based on their common use.

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Different sensing modes and their applications.

Sensing type	Common uses
Strain and pressure	Floors, doors, beds, sofas, scales
Position, direction, distance and motion	Security, locator, tracking, falls detection
Light, radiation and temperature	Security, location, tracking, health safety, energy efficiency
Solids, liquids and gases	Security and health, monitoring, pool maintenance, sprinkler efficiency
iButton	Used to identify people and objects
Sound	Security, volume control, speech recognition
Image	Security, identification, context understanding

Figure 3. Sensor types and their applications (D.J.Cook et al, 2009)

Furthermore, the sensors are also categorized based on the way they function. With today's always advancing communication technology, it becomes easier to install sensors in remote areas since the need for a wired connection is diminishing. Of course, wired-type sensors tend to be useful still due to their reliability and therefore have not become obsolete yet. Another case to note is the use of sensors with their own power source, allowing for minimal maintenance. Table 3 provides some further categorization based on sensor characteristics.

Contrasting characteristics of wired and wireless sensors.

Wired sensors	Wireless sensors
Cheaper sensors	More expensive
Pay for wiring	No wiring
Robust	Not as robust
Need power source	Batteries

Figure 4. Contrasting characteristics of wired and wireless sensors (D.J.Cook et al, 2009)

A characteristic specific to AmI systems is the amount of data collected from sensors. In a normal system, information received by the sensors is analysed manually and intervention happens case by case by the human factor. Due to the sheer amount of variables that are monitored inside a Smart Environment however, human factor intervention would be near impossible or if possible it would take such an amount of time for a human to compare each variable separately against the control and then make changes to each one manually, that it would make the process obsolete and would defeat the purpose of AmI. Furthermore sensor data may often be required to be handed on the spot or as streaming data and the data may have a spatial or temporal component to it (D.J.Cook et al, 2009). To more efficiently deal with this problem, AmI systems use either of the following models, the centralized or the distributed. Sensors in the centralized model transmit data to a central server, which fuses and analyses the data it receives. In the distributed model, each sensor

has onboard processing capabilities and performs local computation before communicating partial results to other nodes in

the sensor network (D.J.Cook et al, 2009).

3.3.1 Sensor Communication

Often the case is such that within an AmI system, information that needs to be gathered is a task not possible to be completed by a single sensor, therefore we use what is called a sensor network. Sensor networks are essentially an array of sensors all working together to measure different events and as mentioned above using one of the two models to provide accurate information to the user. However, in order to optimize the system and not have sensors overlap with each other, the need arises for an efficient way for sensors to be able to communicate with each other, especially in the centralized model. To achieve this, certain protocols are used and are chosen based on the desired outcome of the implementation of the AmI system. Traditional communication protocols such as the widely used Transport Control Protocol (TCP) may be impossible to be implemented in a sensor network or any AmI system, due to its conventional end-to-end retransmission-based error control and the window-based additive-increase multiplicative-decrease congestion control mechanisms (Weilian Su et al).

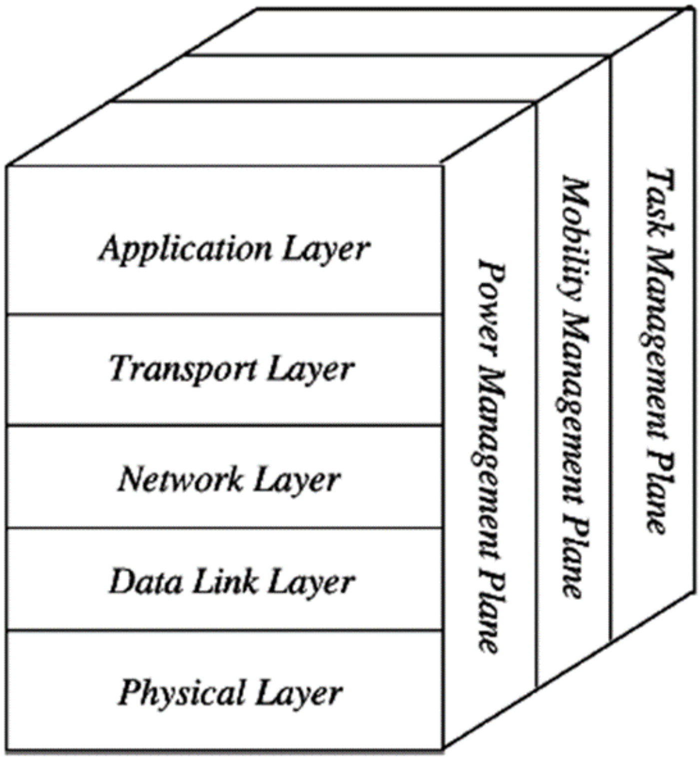

Figure 5. Communication layer representation (M.A. Martin et al, 2012)

The communication protocol works like a stack of different applications, with the information being passed from one layer to the next, as seen in Figure 2.

The transport layer bridges the application and network layers by application multiplexing and demultiplexing , to provide delivery service between the source and the sink with an error control mechanism tailored according to the specific reliability requirement of the application layer and to regulate the amount of traffic injected into the network via flow and congestion control mechanisms (Weilian Su, et al).

All this would mean nothing if the information gathered from a sensor node, could not be passed on to the sink as reliable as possible. This necessitates a reliable transport layer mechanism that can assure the event-to-sink reliability. Typically, due to the vast amount of information gathered within a network the need of reliability goes down as certain significant deviations can be attributed as outliers, the case is not the same when dealing with sensor networks. All events in the sensor field need to be tracked with accuracy at the sink, therefore the use of a mechanism like event-to-sink reliability in the transport layer, is mandatory. The transport layer should address any congestion in the forward path according to the findings of Weilian Su, Ozgur B. Akan and Erdal Cayirci as seen on figure 3.

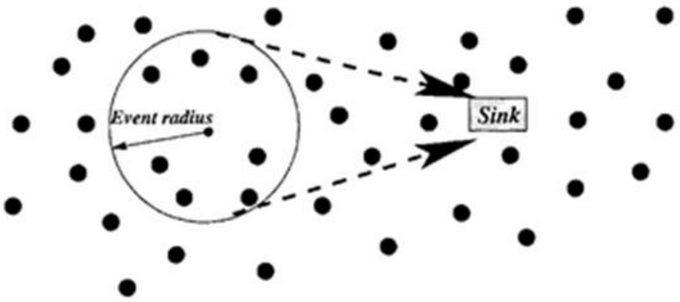

Figure 2.2. Typical sensor network topology with event and sink. The sink is only interested in collective information of sensor nodes within the event radius and not in their individual data.

Figure 6. Typical sensor topology with event and sink (Weilian Su et al 2010)

Moreover, although event-to-sink reliability may be attained even in the presence of packet loss due to network congestion due to the correlated data flows, a suitable congestion control mechanism can also help conserve energy while maintaining desired accuracy levels at the sink mechanisms (Weilian Su, et al). However, these solutions were designed with following more traditional end-to-end transmissions semantics which inherently they based on end-to-end acknowledgement, a method which in a sensor network is not feasible due to the data flow and inherent correlation, not accounting for the vast memory requirements those protocols need. In contrast the Event-to-sink Reliable Transport (ESRT) protocol is based on the aforementioned event-to-sink reliability notion and provides reliable event detection without any intermediate caching requirements mechanisms (Weilian Su, et al). ESRT is a protocol specifically designed to achieve event detection within a wireless sensor network that includes congestion control mechanisms that control both energy consumption and data traffic. Furthermore, the algorithms of the ESRT are run on the sink with minimal functionality required at resource constrained sensor nodes mechanisms (Weilian Su, et al).

The so far suggested architecture however, would not be enough to make a complete and fault proof sensor network, that is due to the need of the sink to also pass information to the sensor nodes as a two-ways communication that may include information on operating system binaries, programming/tasking configuration files, application specific queries and commands mechanisms (Weilian Su, et al.). The reliability requirements for such a task are much tighter and the event-to-sink approach does not cover said requirements. The Pump Slowly, Fetch Quickly (PSFQ) mechanism is proposed according to the findings of Weilian Su, Ozgur B. Akan and Erdal Cayirci, due to its ability to slowly inject packets into the network but aggressively recovering them in the case of packet loss.

3.3.2 Sensor Network implementation in Agriculture

Agriculture is a field where the direct result of the end product is directly influenced by multiple variables that need constant monitoring and fine tuning. It represents one of the best practical examples on the implementation of AmI systems and aspects of them, mainly due to the amount of variables that need to be regulated and partly due to the fact that it provides for a controlled environment where different AmI methods might be tested. Furthermore, the implementation of AmI systems is not limited to just one stage of the production, but to several from sorting the goods to monitoring the growing environment to managerial decisions.

One of the fields that is easier to implement AmI technology to, is the wine production. One of the most important steps to guarantee the quality of wine is grape production, which depends on many different factors (environmental, meteorological) and is not related to objective measurements and parameters but more often is simply related to past experiences (Luca Bencini et al.). It follows that a scientific method could be developed to analyse and predict changes, a process similar to machine learning, in order to drive grape production towards better quality and to steadily achieve and surpass quality year after year through the implementation of an objective growth protocol. That means that the vineyard, or the growing environment in other cases, needs to be closely monitored and continually analysed in a detailed way, which by today’s standards can be done through the use of AmI technology, cutting time and work costs to a minimum. Furthermore, an approach as is proposed by Luca Bencini, Giovanni Collodi, Davide Di Palma, Antonio Manes, and Gianfranco Manes, would also mean a more reliable way to collect information on the different variable.

According to Luca Bencini, Giovanni Collodi, Davide Di Palma, Antonio Manes, and Gianfranco Manes, there are certain features that during the implementation of an AmI system in wine production must be met in order for the system to be reliable and depend-worthy, which are:

A capillary but distributed, continuous monitoring of the parameters of interest must be guaranteed. The acquisition system must be reliable and provide data for a long term. Data should be available to the end user always and everywhere. A Smart Web Interface should provide raw and detailed data to expert users, and furnish an easy and informing aggregation of them to the standard user.

In figure 4, a pretty basic implementation of the system is shown with the addition of a smart interface which enables the user to have access to all the information everywhere and easily accessible.

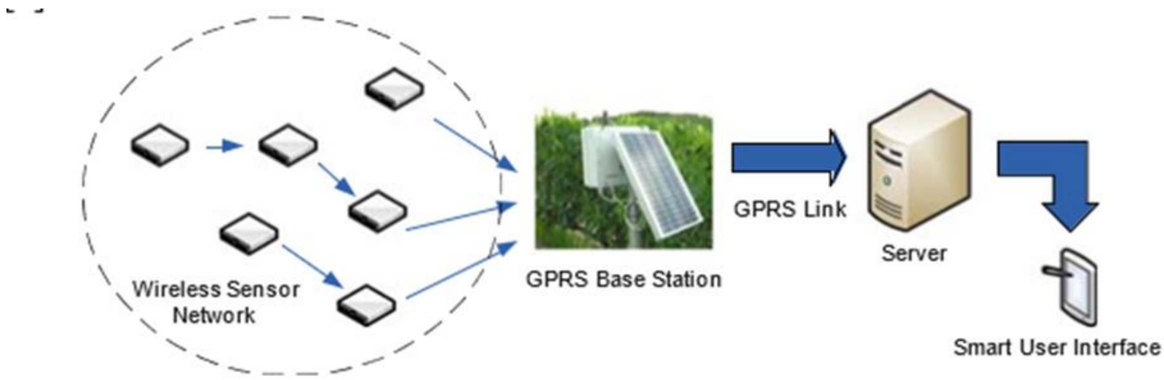

Figure 7. Information path on sensor network developed for agriculture (Luca Bencini et al, 2011)

The system developed by Luca Bencini, Giovanni Collodi, Davide Di Palma, Antonio Manes, and Gianfranco Manes consists of wired sensors but they are looking to implement RFID-Driven sensors giving the system more flexibility and it is comprised of a wireless sensor network technology, a GPRS Base Station, a server and a smart User Interface. The system collects data every 15 minutes which is then placed on wireless nodes and distributed across the entire network following a weighted routing algorithm to a master node located on the FPRS Base Station which is then forwarded to the server using the TCP/IP protocol and stored (Luca Bencini et al). Each node can manage up to 16 different sensors taking measurements from parameters such as soil moisture, soil temperature, trunk diametric growth, differential leaf temperature, air temperature and air humidity. What is interesting in that particular research however is the implementation of a custom MAC layer protocol. Due to the use of such a vast array of sensors, power consumption became an issue as each wireless node is battery powered and in power saving mode has a consumption of 30A and can work approximately 16 months. STAR MAC as it is called, introduces the duty cycle along with advantages provided by the offset scheduling while avoiding penalties in signalling overhead (Luca Bencini et al.). Each node can be set into an idle or energy saving sleeping state. Running on all nodes is the multihop algorithm, which minimizes data losses and will eventually forward the data to the master node on the GPRS Base Station. The research has shown that network sensor systems are extremely reliable and that the most exposed parts of the problems and faults such as nodes and the GPRS Base Station improved with recovery strategies algorithms, in order to restart the operations in case of deadlocks (Luca Bencini et al).

Their research concluded that indeed, Wireless Sensor Networks are a solid and valid solution to monitor parameters within a growing environment using cheap commercially available sensors and forwarding their findings through an infrastructure consisting of wireless sensor network technology, GPRS communication and TCP/IP protocol. Taking the research further, they also implemented end user functionality through the use of smart devices to make changes to the system and query information.

3.4 Knowledge Rules

Having established a way for the AmI system to collect information reliably and for all of its components to be able to communicate with one another, a problem still remains, we are still faced with the problem of having the system make decisions and alter variables. The most efficient way to achieve this kind of autonomy within an AmI system is to apply custom tailored knowledge rules. By feeding information into the control unit of the system, we essentially build a dictionary that is designed to imitate human problem solving via a combination of artificial intelligence and a database of subject specific knowledge, this kind of systems are based on artificial intelligence methods and techniques. (Hao-Chen Huang, 2009). For instance, when studying the agricultural example mentioned above, the variables that insure optimal plant growth are stable, therefore those optimal variables make up the dictionary by which the system will make decisions based on the measurements taken by the sensor network. This reasoning mechanism as well as the knowledgebase which is subject specific are the two core components of the system. Dhaliwal and Benbasat (1996) proposed that the four main components of Knowledge-based systems are the knowledgebase, inference engine, knowledge engineering tool and specific user interface. Chau and Albermani (2002) proposed that Knowledge-based systems comprise three basic components: knowledgebase, context and inference mechanism (Hao-Chen Huang, 2009). For the purposes of designing an automatic growing station the later model seems to fit better. However, it must be noted that in both propositions, the most important component that stands in the heart of the design philosophy is the knowledgebase.

4 Practical Part

Designing an automatic growing environment

One of the best applications of the methods described above, is the automatic plant growing environment. In the following example this thesis will attempt to apply the theoretical background described to practice.

The example consists of a growing environment with very closely monitored conditions, two growing stations, a sensor network and hub, various control units that alter the environment and a central processing station or central control unit that runs an algorithm which makes knowledge-based decisions based on the sensory input. In Figure 5, the general architecture of the system is shown from a top down perspective. The growing environment contains two growing stations with individual monitoring for ground humidity and supplements, one wind sensor and one luminosity sensor. Since wind and luminosity are variables that are not specific to each growing station, there is no need for individual monitoring as is the case with ground humidity and supplements.

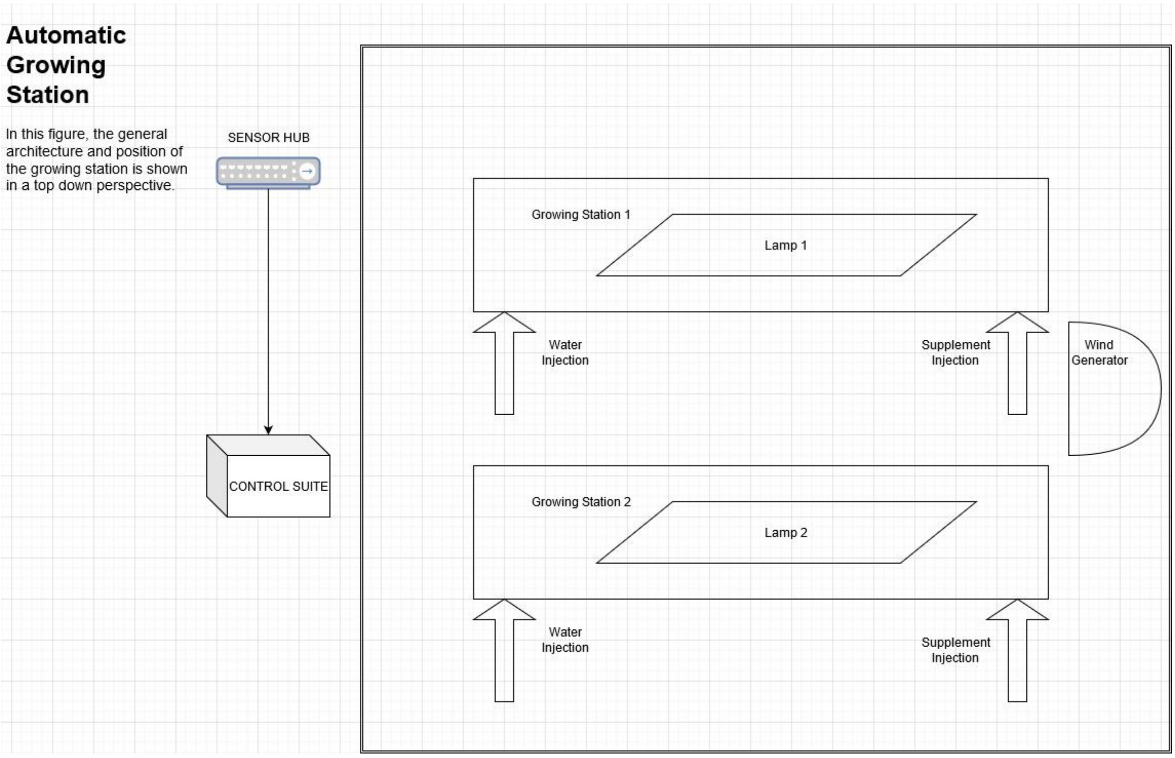

Figure 8. Automatic Growing Station positioning

With this particular design, there is no need to re-arrange the positioning depending on what strain of seed is currently being grown inside the environment. It is universal and applies to the vast majority of common plants grown for human consumption, with the exception of exotic strains or strains that require certain atmospheric pressure or altitude variables, which are not easily replicated in a laboratory environment.

Continuing, this thesis will examine how this system operates with consideration to the sensor network, the devices that make alteration and the decision-making process of the control suite. Furthermore, for the purposes of this thesis, we will assume that only one strain of vegetables will be grown in both growing stations at the same time in order to limit the variables that need to be monitored and/or altered, maintaining one knowledge-base common for both growing stations. The case is not the same however when dealing with the sensors, in particular the sensors that monitor ground humidity and supplement percentages, since each growing station is a different vessel with different variables. In this case, there is a need for sensor communication, using methods described on different parts of this thesis, as well as for the control suite to be able to recognize and separate the two different sensor clusters. Wind and luminosity have not the same need, since they are variables common to both growing stations, therefore a single sensor hub is used for each of those variables as explained in the following chapter. However, since luminosity and wind are variables that in their nature tend to deteriorate according to distance and are also extremely susceptible to obstacles, a sensor network is used to take measurements from different parts of the growing environment which then are fed to a single sensor hub and a single control hub in contrast with the aforementioned example where different sensors give information to different hubs. The reason for this particular choice is the optimization of the ability to collect viable environmental information, which in turn leads to better decision making and better yield at the end of the growing cycle.

4.1 Variables and why they were chosen

There is a plethora of different variables that serve very specific roles in the growth cycle of any plant, and not every strain shares the same variables with each other strain. For instance there are plants that thrive with a constant wind blowing on them, making them stronger and more robust, other plants thrive with plenty of sunlight or artificial light, others need more water while others need no water at all, other plants thrive on different altitudes.

To make a database containing every single variable for every single plant on earth would be near impossible, therefore for this design variables chosen were those that are most commonly found amongst plants that are usually grown for human consumption and are found in almost every part of the world, such as tomatoes, carrots, lettuce and leaks. These variables are luminosity, wind, water and nutrients.

- Luminosity.

Light is the single most essential resource a plant needs in order to grow. In laboratory environments light is produced by using special lights that replicate the sun's rays. The advantage of using artificial light is that it gives us the control over the plant's phases such as the flowering phase.

- Water.

Water most the vast majority of plants is equally important to light. Most plants need a steady supply of water from which they absorb minerals and other essential elements not found in any other way that is accessible to the plant.

- Wind.

Wind creates a steady condition that the plant needs to constantly fight. Through this gentle training process, the plant acquires the ability to be stronger leading in thicker main bodies and therefore more leaves, which in turn allow it to absorb more light and provide a better yield. Wind acts as a constant gentle training throughout the plant's life cycle.

- Nutrients.

In laboratory environments such as the one proposed in this thesis, the plants can be fed artificial supplements like phosphorus in order to promote a more linear growth.

4.2 Collecting data

As in many other examples, so in this attempt, everything starts at the sensors. Data is one of the most valuable commodities that shape the decision-making process and lead to a better result. As shown in Figure 6, a sensor network has been designed to meet the needs of the system. Sensors have been placed in as much as possible optimal positions since their collected data directly affect the end result.

As shown in Figure 6, each type of sensor feeds information into a specific hub, which in turn pass the information to a central sensor hub. The need for this design comes from the hardware limitations of today. Commercially available sensors can be found on the market with minimal cost, however a central platform for them is needed. For this problem a device like the Arduino serves the purpose perfectly, since it is extremely customizable.

The proposed communication protocol for this thesis is the Event-to-Sink-reliable-transport protocol (ESRT). There are two predominant architectures, the one can be seen in the wind sensors, where four different sensor units lead to one hub and the other can be seen in the humidity sensor, where different sensors feed information to two different hubs working separately. Due to this, the ERTS's ability to not clog information or avoid overlaps seems to the most ideal sensor communication protocol. Although primarily used for wireless sensor networks, it can be used in this practical example as well and its innate congestion control mechanisms will prove to be the ideal and definitive choice.

For this exercise, the thesis opts for four different wind sensors that all feed information to one hub. The purpose of this is to receive accurate measurements from all corners of the growing environment, since wind is a variable which is extremely easily affected by distance and obstacles. Since resistance generated by wind is such a crucial variable in the progress of a plant, the wind generated needs to be of the same magnitude across all specimens. From the hub the data collected by the sensors are fed into the central sensor hub and in turn to the control suite where the algorithm uses this information to make decisions based on the knowledge-base that the user has created. This process is similar to all other sensor hubs regardless of the sensor's field of operation.

The supplement sensors are dug inside the ground of grow station one and two and monitor the ground for the percentage of nutrients and supplements it contains. Water sensors work in the same manner but measure the ground's humidity. Those two groups of sensors share the same technology but serve different purposes. The proposed technology is the Dielectric Soil Moisture Sensors which assess moisture levels by measuring the dielectric constant in the soil. The dielectric constant is an electrical property that changes depending on the amount of moisture present. Another type of sensor that can be used for the purposes of this thesis are the Airflow sensors which measure soil air permeability. The air flow sensor is disclosed, which uses a dielectric diaphragm providing good thermal isolation for thin-film heating and temperature sensing elements, resulting in high flow sensitivity and low current operation of the heating element. (Sensor construction patten, 1989).

Finally, two light sensors are placed between the two grow stations and to either side. Those sensors constantly measure the presence of light and its magnitude and similarly to the other sensors, the information is passed on through the information pipe to the control suite.

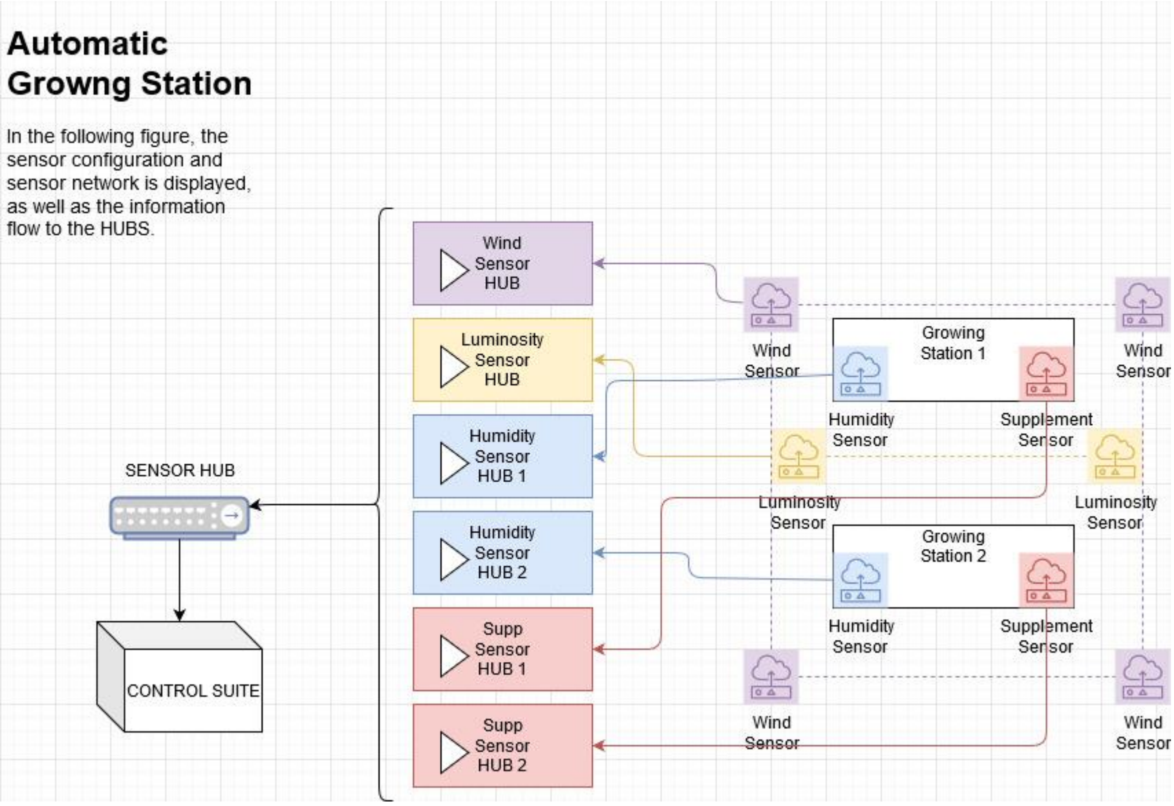

Figure 9. Automatic growing station sensor network architecture

4.3 Decision implementation

Similar to sensors, a system needs to be in place in order to implements any changes the control suite may decide to do. As seen in Figure 7, such a system was designed with various control units that are directly connected to the control suite and left at the control suite's discretion as to when to operate. Such a system is easy to design as it involves just a simple ON/OFF gate.

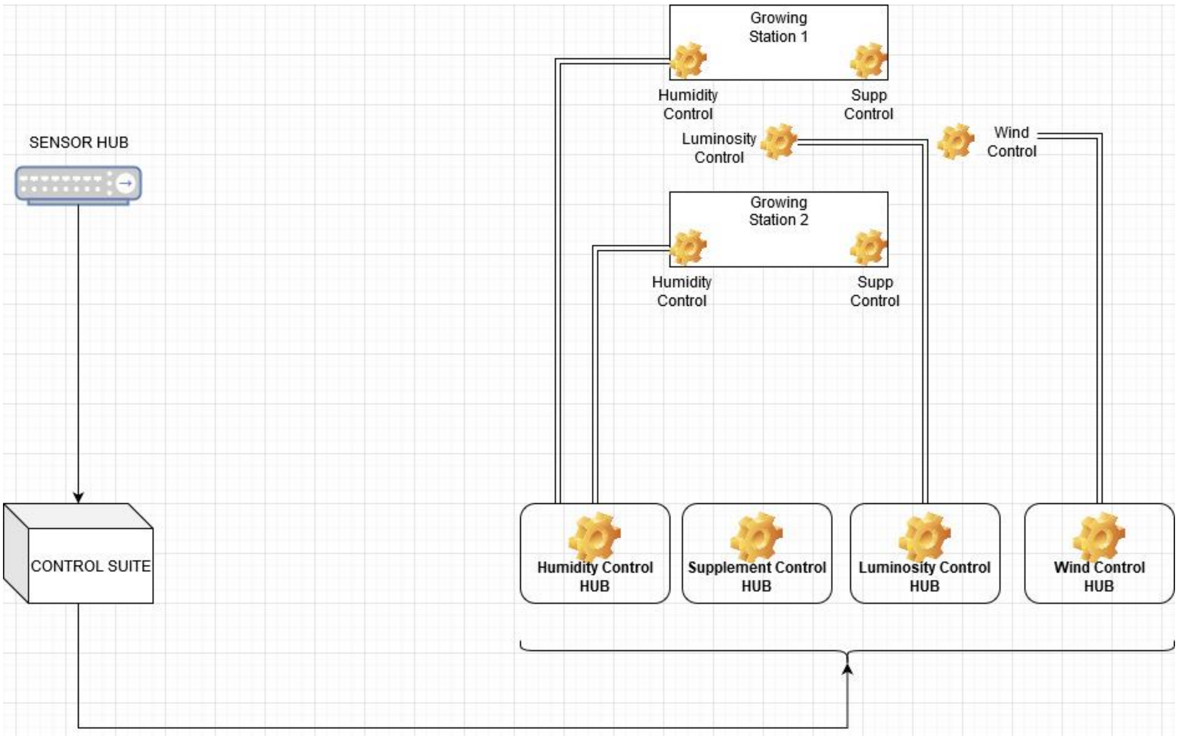

Figure 10. Variable Control hub architecture

After the flow of information passes from the central sensor hub to the control suite, the algorithm working within will compare the findings to the user established knowledge-base and decide whether or not to enable the variable control mechanisms in order to bring the associated value to acceptable measurements. An easy and fail-safe method would be to force the control suite to immediately request re-measurements from the sensor network after any variable control hub was activate, thusly ensuring the normal levels of operation.

When the control suites decide to do so, the appropriate hub is activated, switched the light on or off, injecting more water into the soil or more supplements or switching on or off the wind generator.

4.4 Decision making, the control suite

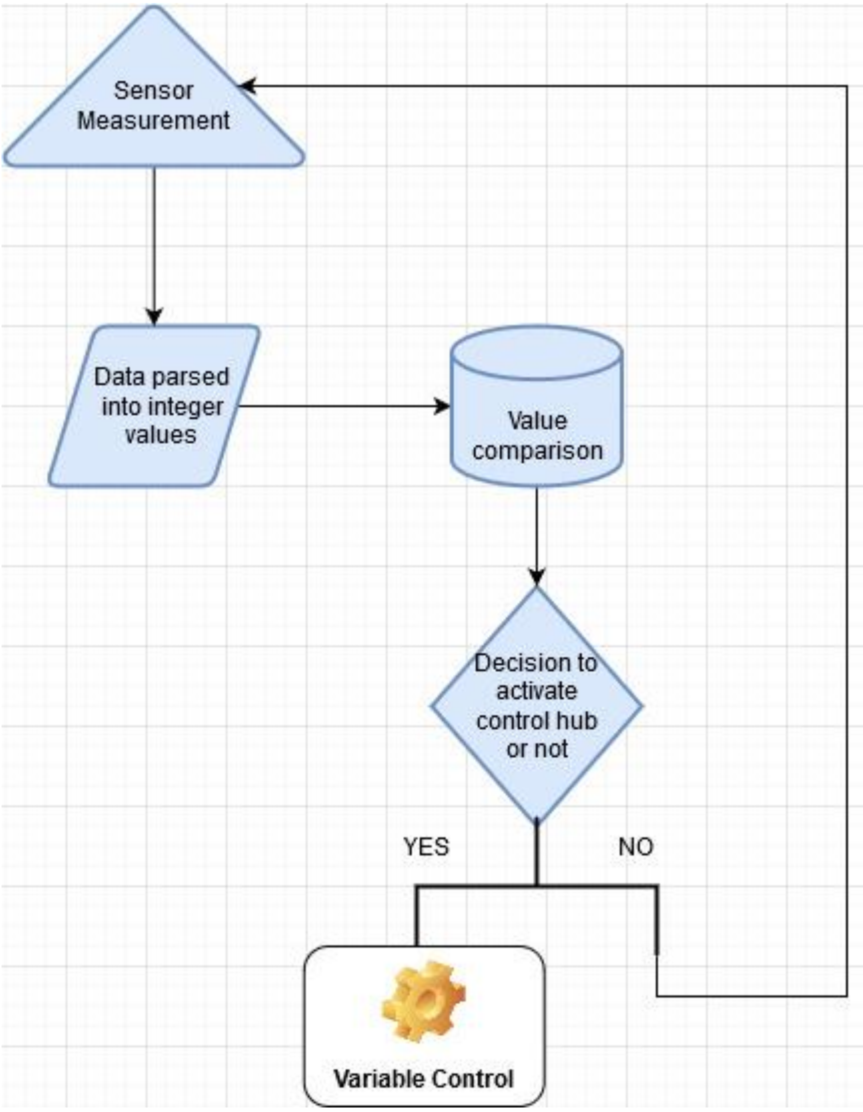

Figure 11. Decision algorithm flowchart

The control suite is the brain of the operation. This is where all the data is stored and measured against the knowledge-base and where the algorithmic operations are taking place. For the purposes of this thesis in Figure 8 an algorithm was created to demonstrate how the system will make its decisions.

After the control suite receives the data, it will be parsed into numerical values and compared against the knowledge base. In pseudo code the process will look as such:

if X < A….

then activate hub1; …

….
Of course, depending on which coding language is used, the appropriate method must be used. This thesis proposes the construction of the control suite in the C programming language mainly due to the unrivalled customizability it offers.

The knowledgebase needs to be manually established in the control suite's code and stored in a database for easy access. The following data give an exact guideline that the sensor measurements will be compared against.

- Carrots.

Optimal temperature: 15 to 20 C

Nutrients: Lime 6.0 to 6.8 pH, Boron 0.2 to 0.3B, Copper sulphate 50kg per hectare, sodium or ammonium molybdate 5kg per hectare.

Water: constant supply to maintain 58% soil humidity

Values taken from the "Vegetable Crops production guide" prepared by the ADVISORY COMMITTEE ON VEGETABLE CROPS (ACVC) and published by authority of the ATLANTIC PROVINCES AGRICULTURE SERVICES CO-ORDINATING COMMITTEE (APGSCC).

- Onions.

Optimal temperature: 24 to 29 F

Nutrients: nitrogen, potassium

Water: optimal humidity 67%

(https://pss.uvm.edu/ppp/articles/growonions.html)

However, the knowledgebase can be adjusted accordingly and the above act as a mere example as to how the values are measured. Since there has been extensive research on most different plant strains, it is safe to assume that most values have a margin of error within one degree.

It is evident that there exists plenty of information on the thesis relevant knowledgebase, making it easy to determine the values and built a reliable database upon which the system will make decisions.

5 Evaluation of system design and recommendations

The practical part of this thesis attempts to design an automatic growing station using the proposed methodology of the theoretical part. Using software like HYDRA for sensor communication with the control suite and knowledgebase specifically created for the task, as well as the appropriate protocols for sensor communication, the task should be completed successfully and could be yielding produce unattended.

The system is modular, having a certain degree of independence between its components and that makes it open-ended. Improvements can be implemented after the initial system implementation with minimal cost and without the need to completely redesign the system from start. This is an asset extremely valuable to any institution since it lower labour cost and time.

However, it is difficult to exactly pinpoint the system’s productivity without actually implementing it in laboratory conditions.

The usefulness of the system will be measured against its actual yield at the end of the grow cycle. If the yield matches of exceeds that of the manual labour yield, the system can be safely judged as a success. Given the fact that it is also a system that requires minimum human intervention, a slightly lower final yield might also be accepted, however there is always room of improvement and as technology advances, so will the system too.

5.1 Improvements recommendation

By deliberate design, the nature of the proposed system is open-ended therefore it is easy to make modular changes throughout the system. This decision has been made in order to accommodate the fast-changing technological field. Some suggestions would be the following:

Although C programming language is the chosen language due to its customizability, other more modern language could be used to complete the same tasks, that provide already implemented methods of communication between the hardware. A good alternative would be Python.

The sensor network can be improved by utilizing sensors that are designed not for commercial use, that are more accurate, consume less power and allow for dynamic measurements. Dynamic measurements require a moving platform where the sensor is mounted and able to cover the entirety of the grow station. Something that after the initial implementation of the system, would be something that should be prioritized since it will lead to a different more optimal sensor configuration.

The knowledgebase can also be improved upon by adding more controlling variables which will in turn increase the final yield. However, the knowledgebase increase is not independent as the sensor network is directly affected by it, therefore increasing the knowledgebase variables, the monitor nodes are increased as well, leading to a re-design of the sensor network. More variable might also be taken into consideration, such as atmospheric pressure or even symbiotic relations between the plants, which will lead into a greater variety of strains that can be used in the growing stations.

6 Conclusion

This bachelor thesis deals with the technology that takes place in the design and implementation of a Smart Environment and AmI methodology. Specifically, using custom middleware and object-oriented hardware communication methods such as ESRT communication protocol or the HYDRA middleware. Different applications of that technology are also examined specifically in the agricultural sector. The most important components of building such a system are also examined, in particular the knowledgebase and briefly, the algorithmic calculations.

The practical part of this thesis is focused on designing an Automatic plant growing station using the theoretical framework and the technology examined. The criteria established during the problem examination, helped the decisions on where the sensors should be placed, how many sensors should be used and how they communicate with each other and with the control suite as well. Furthermore, after examining the problem, a knowledgebase was created that is specific to the task and examples on how the software will be built are given, as well as considering the advantages and disadvantages of different programming languages and methods. This thesis also provides improvements on different aspects of the proposed system that consider advancements in technology, different or more efficient programming methods, a different sensor configuration and the choice of a wide variety of plant strains.

Finally, this thesis has found that the implementation of a proposed system is possible with today's technology and would lead to more cost effective and less time-consuming agricultural processes, that could potentially lead to a greater production yield.

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