DEGREE PROJECT IN TECHNOLOGY,
FIRST CYCLE, 15 CREDITS
STOCKHOLM, SWEDEN 2017

Automated hydroponics greenhouse

Regulation of pH and nutrients

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TRITA MMK 2017:15 MDAB 633

Abstract

The purpose of this project is to create a fully automated greenhouse that can produce year-round crops, using sensors and actuators. Temperature in both water and air, relative humidity, water level, nutrient level and pH are all measured with different sensors. Though only water level, pH and nutrients will be regulated. The greenhouse will be relying on a hydroponic growing technique, meaning that the growing is soil-less and will be done in water. This makes measuring and controlling said levels easier and also minimizes water waste and makes for a more environmental system. The main focus of this project is on regulating pH and nutrient levels of the water. The system has shown to be stable and self regulating within the desired intervals for nutrient concentration and pH for growing basil.

Referat

Automatiserat hydroponiskt växthus

Syftet med det här projektet är att skapa ett automatiserat växthus som kan producera grödor året runt med hjälp av sensorer och aktuatorer. Med olika sensorer mäts temperaturen i både vattnet och luften, relativa luftfuktigheten, vattennivå, pH- och näringsvärden. Dock kommer endast vattennivå, pH- och näringsvärden regleras. Växthuset använder sig av så kallad hydroponisk odling, vilket innebär att odlingen inte sker i jord utan i vatten. Detta underlättar bland annat mätningar och kontrollering av systemet men minimerar även vattenkonsumptionen och bidrar till ett mera miljövänligt system. Projektet kommer i huvudsak inrikta sig på reglering av pH och näringsnivåer av vattnet. Systemet har visats stabilt och har förmågan att reglera sig självt inom önskat intervall för näringskoncentration och pH för att odla basilika.

Acknowledgements

We would like to thank Nihad Subasic for inspiring and motivating us during the project. We would also like to thank Staffan Qvarnström and all of the patient and supportive lab assistents for helping us with practical dilemmas we stumbled upon during the course. Masoumeh Parseh has helped us with the thesis and giving constructive feedback which has been crucial for the quality of this paper.

Nomenclature

Abbreviations

AC .... Alternating current

ATC .... Automatic Temperature Control

EC .... Electric Conductivity

GMO .... Genetically Modified Organism

ppm .... parts per million

RH .... Relative Humidity

S .... Siemens

LDPE .... Low Density Poly-Ethylene

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Chapter 1

Introduction

This chapter introduces the background, purpose, scope and method of the project.

1.1 Background

Eating fresh, locally and organically produced vegetables and herbs has become a major topic in this day and time. We want to be able to consume seasonal vegetables all year. But here in northern Europe it isn't possible to grow crops all year because of the cold winters. This means buying vegetables and fruits from supermarkets that sometimes have been shipped halfway around the globe, increasing the already high prices. In the Nordic countries 70% of the fruits and vegetables are imported [1], often picked before ripe and left to sit on the shelves which tend to lower nutrient values[2]. As a result of the strong, and increasing urbanization, growing your own crops is a rarity, but with a compact system that would require minimal to no manual labour to maintain the issue of time would be a problem of the past [3].

1.2 Purpose

The purpose of this project is to make an automated greenhouse using hydroponics to grow fresh and organic herbs and lettuce for indoor urban environments as the aim is to make fresh and organically produced vegetables and herbs with the help of sensors and actuators to control water level, pH and nutrient levels. The system shall be able to do this without manual input. Our research questions are:

- Within what range can an automatic hydroponic system regulate the pH and nutrition levels?
- What are the limiting factors to the precision of the system?

1.3 Scope

This projects target is to automate the maintenance of a closed hydroponic system in the shape of a greenhouse. The system shall be able to measure and control:

- The water level
- The pH level
- The nutrient concentration

The greenhouse will also have an artificial light source, however the lights won't be controlled by sensors. Plants will be introduced into the system to have as an indicator that it is functioning properly. Since the purpose is not to optimize plant growth and thus precise measurement of the nutritional values in the plants will not be made. If plants appear healthy, they will also be considered as such with no further evaluation. The system will only be demanded to sustain itself during a timescale of under a month and in a controlled environment, so problems concerning long time pollution (e.g. due to dead plant parts [4]) will not be taken into consideration.

1.4 Method

1.4.1 Implementation of system

The completed system shall be able to maintain itself with no to minimal manual input. Considering the relatively long time span needed for plant growth, plantation in the greenhouse is initiated before the automated system is ready which is maintained manually during a period until a transition to automation can be made. The seeds are planted in a passive hydroponic system with a base of rockwool, a mixture of basalt and chalk shaped as a porous cubes, as fixating substrate. When reaching maturity cutlings are taken from them and transferred to the greenhouse.

When a functioning control system for the water level has been installed plantation in the actual greenhouse can be performed. The system will not be self maintaining at this point, and control of system, except for the water level, must be made manually. Plants are first introduced into the system on April 22 with functioning sensors and water pump installed, shown in Figure A.2). An Aruino UNO microcontroller which is connected to all installed sensors is used. While actuators for pH and nutrient solution are awaiting installation, daily measurements of the nutrient concentration and pH value will be performed and ensured to be kept within desired limits, as well as inspection of the plants growth and wellbeing. Dosers were installed May 5th and have been used to control system since.

1.4.2 Experiments

Nutrient and pH solutions effect on pH and EC

To get an understanding of how the pH and EC, electric conductivity, value is affected when adding nutrient solution, a small system in a 1:10 scale is created to see how they are impacted. Two different test are conducted. For the first test a solution consisting of seven parts nutrient solution to thirteen parts tap water is added two ml at a time to a two liter water tank, thereby simulating adding two cl to a 20 liter tank which will be done for the full system. The second test, for measuring correlation in pH, a solution of one ml of pH down is added to 30 cl of water is used and added two ml at a time to the two liter water tank.

Testing robustness of system

The robustness of the system is judged by its ability to steer pH and nutrient values to the desired levels. To test the robustness the system is exposed to disturbances, here in the form of either adding tap water or adding pH increasing buffer, to alter the levels. Tap water is expected to increase the pH value and lower the EC value while pH increasing buffer is expected to increase only the pH. Measurements are continuously logged. The experiment was conducted twice with similar disturbances on two different days, to observe the predictability of the system. The first time the test was executed, the pH doser was filled with a concentration of five ml pH down solution and 300 ml tap water. First five liters of water is added and system is left to stabilize. pH increasing buffer is then added and system is left to stabilize. Before starting the second time of testing the system was brought to the same levels as they were the previous day before testing began. The second time of testing, the pH doser was filled with a concentration of two ml pH down solution and 300 ml tap water. The test was designed with the ambition to stabilize the values within a range of 0.1 from the threshold value. When test was initiated the threshold value for EC was set at 2.0 Siemens, which has later been adjusted downwards to 1.6 Siemens. The threshold for pH was 5.8 for the first test and 6.2 for the second. The nutrient doser was filled with 70 ml of nutrient solution and 130 ml of tap water.

Long term experiment

As a final experiment the greenhouse was left to see how well it would perform under a longer time span, three days to be specific. To have theoretical limits for as what the pH and EC should be kept within, basil is grown in the greenhouse. As will be mentioned in the Theory section of this thesis, preferred pH levels for basil is around 5.5 to 6.5, and EC from 1.4 to 1.8 Siemens [5][6] and the system automatically lowers the pH when it is over 6.2 to keep it within the desired range. Nutrient solution is added when levels drop below 1.6 Siemens.

Chapter 2

Theory

This chapter explains the theory of the components needed for a hydroponic system.

2.1 Hydroponic systems

Hydroponic systems can be both passive and active, the difference is that active systems have some type of automated parts, such as sensors or actuators. All hydroponic systems are similar in the way that they all need a source of light, a supply of water, oxygen for cell respiration and nutrients, that are administered in the water. The benefit of hydroponic systems is that it is easier to measure nutrient and pH levels but also that the system uses much less water than conventional soil cultivation, as well as having natural resistance to parasites and diseases [7].

There are a few different types of hydroponic system, e.g. deep water culture, aeroponics, drip systems and systems using a nutrient film technique [8]. This project is using a so called ebb and flow system, also known as a flood or drain system, which is meant to act like the same natural concept. Meaning that the growing tray with the plants, is temporarily flooded with water and then drained. This way the roots get nutritional solution through the flow but is also exposed to oxygen during the ebb periods. The water flow is managed by a water pump. A water level sensor ensures that water rises to desired level. The level is not controlled by the system, but by the user and can be changed over time simply by moving them to satisfy the need of the plants.

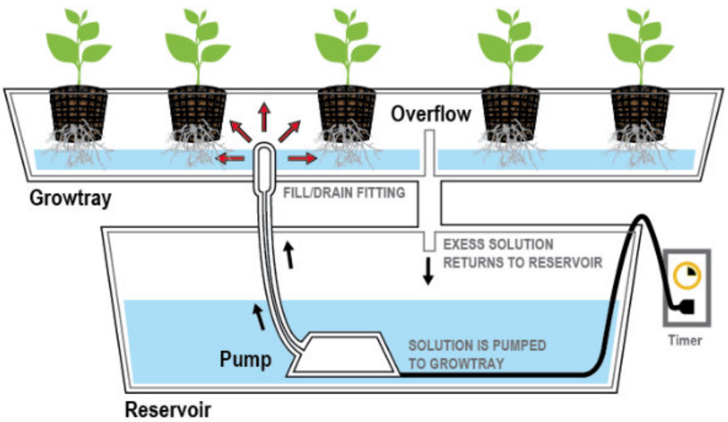

Figure 2.1: Ebb and Flow System (Flood and Drain) [9].

2.2 Temperature and humidity

Temperature can be measured with either contact or non-contact sensors, contact sensors are used in this project.

In this project a temperature and humidity sensor called DHT22 (also known as RHT03 or AM2302) which uses a thermistor to measure the temperature is used.

Thermistors are thermally sensitive resistors that shows a change in electrical resistance when exposed to a corresponding change in temperature [10].

A hydrometer is used to measure the moisture content in the air. The measurements in humidity are usually obtained indirectly by measuring temperature, pressure, mass or a electrical change in some substance as moisture is absorbed.

The DHT22 uses a capacitive sensor to measure the relative humidity, RH, in the air. Relative humidity is the proportion of the partial pressure (P_w) of water vapor to the equilibrium vapor pressure [$P_{ws}(t)$] of water at a given temperature [11].

$$RH\,[\%] = 100 \cdot \frac{P_w}{P_{ws}\,(t)} \tag{2.1}$$

2.3 Plant Nutrition

All plants need a composition of a range of nutrients to grow. The amounts of nutrients vary among different kinds of plants as well as over the life cycle of the plant. Low values may lead to deficiency related diseases while high levels leads to excessive algae and bacteria growth. The nutrients therefore needs to be kept within a certain range to ensure the well being of the plants. The most important nutrients for a wide range of plants are divided into macro nutrients, needed in relatively large amounts, and micro nutrients needed in much smaller quantities. However, since many plants have a similar range in which they thrive a system with healthy plants may be implemented without particular attention to these differences [6]. Since this project focuses not on optimization of plant growth, an average allowing relatively healthy growth is considered sufficient. For this project, a mixture of these is used by administering an "IONIC Hydro Grow nutrient solution" [12].

An ideal nutrient concentration as an EC between 1.4-1.8 Siemens [5], and a system reacting as soon as EC value drops below 1.6 Siemens has been implemented. The other plants are assumed able to grow as well with these values. The concentration of nutrients in a solution will decrease over time as they are absorbed by the roots of the plants, and thus need to be replenished continuously. The nutrient concentration shall be measured and added continuously. It must be noted that the nutrient value should ideally be added and measured individually, however only the combined amounts will be measured to fit in the scope of this project. The measuring of nutrient concentration is conducted through the electrical conductivity of the water-nutrient solution. Since nutrients are largely built up of molecules which fission to ions when dissolved in water, the conductivity increases with the concentration of nutrients, thus the level of concentration can be measured implicitly. However other factors will affect the conductivity and must be measured together to receive a correct value. The main factors are temperature and pH value, as well as the naturally occurring concentration of ions in the water [13]. To ensure this, calibrations will be performed.

2.4 pH

The pH value represents how many hydrogen ions there are in a specific volume of a substance. More accurately the pH value is given by the negative logarithm of the correlative hydrogen ion activity (H^+) in a solution [14].

$$\mathrm{pH} = -\log_{10}\left(\mathrm{H}^+\right) \tag{2.2}$$

So as can be seen from Equation (2.2) a lower concentration of hydrogen ions will result in a higher pH value. The pH scale goes from 0 to 14 where 1 is strongly acidic and 14 strongly alkaline, with 7 indicating a neutral pH value, meaning that the concentration of H^+ and OH^- are equal. Changes in pH level is highly non-linear and attempt of controlling it should be performed carefully to avoid instability [15].

This project will use a digital pH sensor which measures the change in an electrical potential between a pH electrode and a reference electrode. The electrode is usually made from glass. There are analog and digital meters, with the latter having the benefit of using a computer interface to analyse data. Digital pH meters can be sensitive to temperature. But most digital pH meters have Automated Temperature Compensation (ATC) that will compensate for the effect of temperature. It is important to calibrate the meter, regardless of it being analog or digital.

Since plants prefer a specific pH value to grow in a optimal way, it's important to get a good reading of the pH value in the nutrient solution. There are a few factors that will affect the pH; mainly adding too much nutrients to the water reservoir is expected to lower the pH value.

As this project will focus on growing basil the optimal pH range is 5.5-6.5 [6].

Chapter 3

Demonstrator

This chapter will focus on the construction of the automated system and assembling the sensors and actuators. The greenhouse is built on the base of a IKEA Krydda greenhouse module positioned on top of a plastic container to hold the nutrient solution. To keep the relative humidity at a higher percentage and more constant, a plastic sheet has been added to create a closed environment for the plants. This also increases the temperature in the greenhouse as the lights emit heat, which is desirable. The systems final design is shown in Figure A.1.

3.1 Hardware

The greenhouse relies on a number of sensors to give accurate measurements, e.g. water level, pH and EC. With different actuators like pH and nutrient dosers, and a waterpump the levels for the respective values are kept within their theoretical ranges. The sensors and actuators used in this project are shown in Figure 3.1 and are explained below.

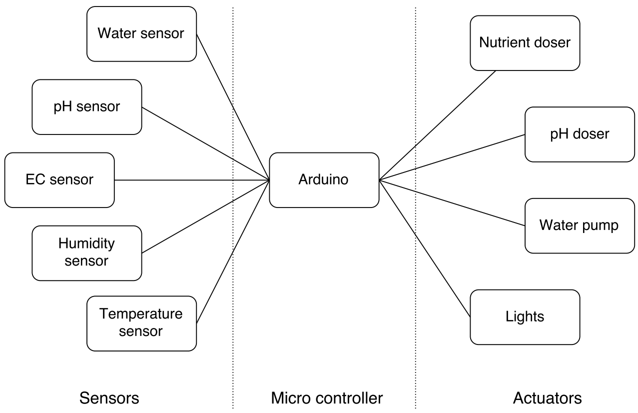

Figure 3.1: Schematic of sensors and actuators to and from the microcontroller, drawn in Draw.io.

3.1.1 Sensors

pH sensor

The pH value of the nutrient solution is measured using a digital industrial grade pH probe seen in Figure A.3. The pH probe is made by DFRobot and is sold under the name Gravity: Analog pH Sensor / Meter Pro Kit For Arduino [16].

Unlike most pH sensors the one used is made to be submersed for long periods of time at once. This has to do with the glass electrode used in measuring the pH value being more robust.

Calibration was done by submersing the probe in both 4.00 and 7.00 pH solution specifically made for calibration and compensating for possible loss or gain.

The pH probe is very sensitive to electric leakage. Due to this it is important that no other electrical device is turned on the tank at the same time as the pH probe to get accurate readings [17].

To furthermore get stable and faster readings the probe should be submersed in a stationary solution, meaning that the water pump should be turned off. Because of this reason the drain outlet for the grow tank is placed at the other end of the tank.

Measurements vary in time, depending on the pH value measured. The closer the pH value is to neutral, 7.0, the longer it will take to measure. Since this project is aiming at keeping the pH levels in the range of 5.5-6.5, measurements will have to be taken with intervals of at least 5 minutes which is the time until system stabilizes after a disturbance, shown in Figure 3.2.

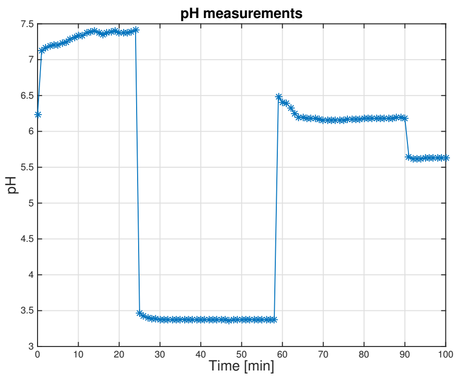

Figure 3.2: pH as a function of time to show stability of pH sensor, drawn in MATLAB R2014.

In Figure 3.2 the pH probe has been submersed in ordinary tap water at the start of the test. After stabilization a pH lowering buffer was added, containing 81% phosphoric acid. When the pH value had stabilized again, a pH increasing buffer was added, containing 50 % potassium hydroxide and later a nutrient solution was added. Based on this the time for taking measurements could be decided, as seen how long it takes to stabilize the pH value. It can be seen from Figure 3.2 that it takes longer for the pH to stabilize when it's closer to 7.0. After 10 minutes the values are stabilizing. The test also concludes that adding nutrients to the water, will lower the pH value of the solution and might therefore have to be increased using a buffer.

EC sensor

The idea used for measuring the concentration of the nutritional values in the water is based on its electrical conductivity. Pure water naturally has an ability to conduct electricity, although very low, however this ability can be increased by adding charged particles into it. When two electrodes are introduced in the solution, the ions will be able to conduct a current between them briefly. The nutrients needed for the plants to grow have the same ability and through measuring the conductivity of the solution, the concentration of nutrients can be measured. This method is only able to measure the conductivity of all nutrients together, and is unable to separate between them. To get precise results the conductivity must first be calibrated through measuring the change in conductivity by other factors and adjusted accordingly. The main factors to be considered are:

- The temperature of the water.
- The naturally occurring concentration of particles in the water.
- The pH solution.

To get precise readings the effect of these factors as well as the nutrient solution are measured and calibrated based on the readings from them.

The EC meter used here is a normal power plug with the head immersed in the solution to control conductivity. The power plug has the benefit of having the desired properties, as well as being cheap and can be found almost everywhere. The theoretical resolution of the probe is at 0.0058 EC units (or about 4 ppm) for the EC value [18]. Own calibrations of the probe was performed through using a table salt-pure water (with negligible EC, circa 5μS) where initially 1 ml was added to 250 ml pure water and then diluted 4 and 8 times using pure water. The factor was corrected for the first solution and controlled for resolution using the diluted solutions. Results are provided in Table 3.1. The conductivity resolution is of at least 0.2 for the probe used, although the larger error is measured at a level far below the desired for the system. For the values closer to the desired the error can likely be considered better. The EC meter, installed in water tank shown in Figure A.4 with corresponding circuit in Figure A.5.

Theoretical salt conc. [ppm]	Measured Value [ppm]	EC [S]	Error [%]
4600	4600	7.19	0
1150	1140	2.05	1
575	527	1.09	17

Table 3.1: Calibration constant determined using first measurement of 4600 ppm and then controlled using diluted fluids.

Water level sensor

The water level sensor is a simple flotation-based on/off switch, which sends a signal to the system that the solution level has reached the desired value and thereby interrupts pump.

Temperature and humidity sensor

To measure the temperature and humidity in the greenhouse, a DHT22 sensor is used. It is placed in the middle of the greenhouse to get stable readings. The DHT22 is not waterproof but can withstand up to 100% RH.

Because the EC and pH sensors are sensitive to temperature, a DS18B20, waterproof temperature sensor is placed in the water tank to compensate for possible temperature drifts.

3.1.2 Actuators

Lights

As an artificial light source the greenhouse uses an Ikea VÄXER LED light [19]. The lights emit 100 $\mu mol/m^2/s$ with 16 watts, which is sufficient for the plants, considering the size of the greenhouse and the number of plants. The lights used are chosen both because they are made to fit with the Ikea Krydda greenhouse frame used in this project and because LED lights are energy efficient and have a long lifespan.

Water pump

The water pump used in this project is of the model Hailea HX 1500 [20]. It has the capacity to pump up to 400 liters per hour to a maximum height of 0.7 meters. The pump runs on 230 V AC and is thereby controlled by a relay.

The pump is placed in the left corner of the water tank and pumps to a height of 0.3 meters. Water is pumped through a 13 mm LDPE, Low Density Poly-Ethylene, hose. It takes around 3.3 minutes to flood, and around 45 minutes to drain the grow tray.

Nutrient and pH dosers

The dosing of pH and nutrient solution is based on an on/off switch using 8A8321 90F solenoids controlled through the Arduino using IRFB7446 transistors, see figure A.6 and circuits figure A.7. Although the system has a feedback loop, it will not rely on a proportional controller and instead just add the same value each time, no matter the magnitude of the disturbance. When readings are taken from either the pH or the EC-probe and value is below threshold level for respective value a signal is sent to open corresponding switch. The nutrient solution is mixed 14 cl +26 cl tap water and the pH solution is mixed 30 cl tap water +2 ml pH lowering buffer. The dosage is determined by solenoid activation time so that 3 cl of nutrient solution and 2 cl of pH solution is released at each respective activation. After activation a minimal timespan of 12 hours must take place before doser may be reactivated.

3.1.3 Microcontroller

This project uses an Arduino UNO that is based on the ATmega328P microcontroller [21]. The Arduino is powered by a 9 volt power supply.

3.2 Software

The overall behaviour of the system is described by a flowchart shown in Figure 3.3.

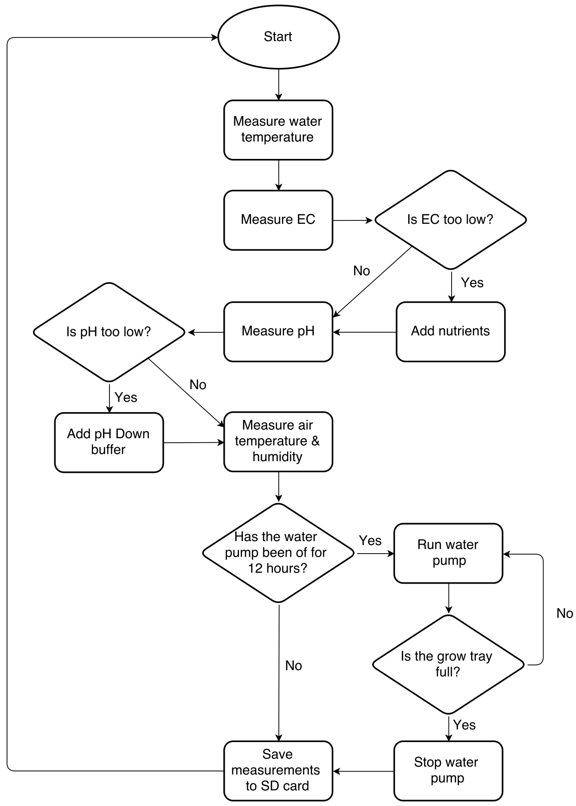

Figure 3.3: Software diagram of Arduino script, drawn in Draw.io.

The Arduino script starts by collecting measurements from the DS18B20 waterproof temperature sensor, to compensate for possible temperature changes for the EC sensor. EC measurements are then gathered to the arduino using code based on *3 Dollar EC-PPM meter* [18]. If the readings are too low the nutrients are added to the water tank to increase the EC. If readings are within the predefined range, no nutrients will be added and pH measurements will be taken. Again, if pH readings are too high, a pH down buffer will be added to lower the pH. After that the DHT22 sensor will give air humidity and temperature readings. After which the code checks if the water pump has been off for more than the predefined amount of time and that the grow tray is drained. If this is the case, a relay will turn on the pump until the water sensor sends back a signal that the grow tray is full or when 250 seconds have passed. The latter timing is a backup function if the water level sensor would stop functioning for some reason so the grow tray won't flood over.

Chapter 4

Results

4.1 Nutrient and pH solutions effect on pH and EC

The testing of nutrient solutions effect on pH and EC in a scaled down version shown in Figure 4.1 and in a logarithmic scale on the vertical axis in Figure 4.2. Although there is a difference in rate of increment between the lower (EC $\in (0, 1)$) and the higher (EC $\in (1, 2)$), system should never reach as low as EC< 1, thus in the interval of EC around 1-2 where it is expected to stay normally, the EC has a linear and predictable relationship.

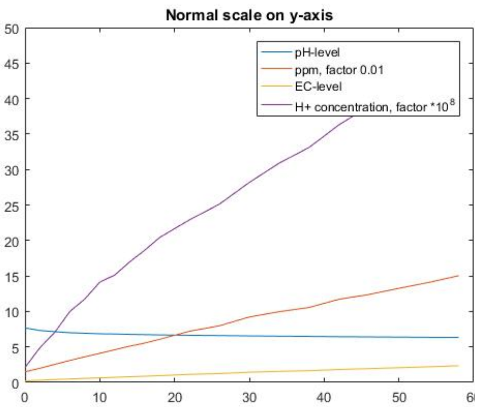

Figure 4.1: Test of nutrients solutions effect on pH, ppm and EC, drawn in MATLAB R2014.

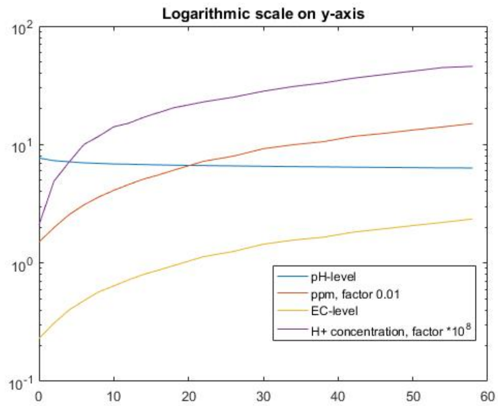

Figure 4.2: As 4.1 with logarithmic scale on y-axis, drawn in MATLAB R2014.

The testing of the pH solution showed a clear correlation in increased acidification with an increase in added solution. However the acidification appears to be strongly non linear, and a precise correlation was not found, test result shown in Figure A.9.

4.2 Testing robustness of system

The system contains 20 liters of water before the test. The experiment was conducted as follows (with times given in hours:minutes):

00:00 - 5 liters of tap water is added to the system.
04:50 - 3 ml of a pH increasing buffer is added
13:00 - pH increasing buffer is added to increase pH value above 6.2.
26:10 - 5 liters of tap water is added to the system.
30:10 - 0.5 ml of a pH lowering buffer solution consisting of 81% phosphoric acid is added.
30:40 - 1 ml of a pH increasing buffer solution is added.

The first part part of the experiment, shown in Figure 4.3 and Figure 4.4, led to a crash downwards in the pH value below 3 and also a large increase in the EC value, shown in Figure 4.4. The 3 ml of pH up that was added gave no notable response in the system. The pH was then brought up using additional pH up buffer which led to pH stabilizing at about 6.5 which also brought the EC value down. Test was then repeated with adjusted solution of pH down buffer and pH threshold value. From this time the system stayed within desired values and appeared stable both for the pH and the EC value until the end of the test period, extended image of EC values are shown in Figure A.15.

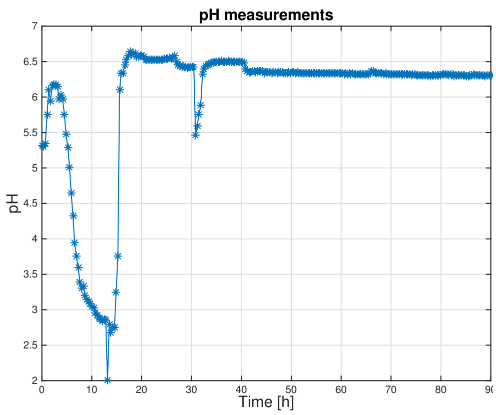

Figure 4.3: pH measurements, drawn in MATLAB R2014.

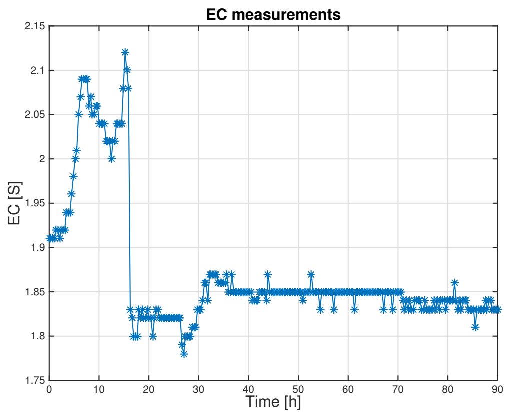

Figure 4.4: EC measurements, drawn in MATLAB R2014.

4.3 Long term experiment

During the first part of the test, the first 15 hours, the pH value sunk below accepted and the concentration of the pH solution was lowered for the remainder of the test. With the new concentration, pH lowering buffer solution was first added every second hour if needed for roughly 15 hours. After initial measurements showed that the system acted in a stable manner, pH solution was added only every 12 hours for three days. The system is as mentioned programmed to lower the pH as long as it is over 6.2. A clear correlation can be seen in pH lowering solution added and pH levels dropping, as shown in Figure A.13 and Figure A.14. The experiment also shows that the system can keep the pH within a predefined range in a stable manner without fluctuating for a longer time. If only for 3 days it still gives a good representation of a balanced system that can preform long-term.

At the final stages of testing, when pH and EC is added every 12th hour, the functions of the finished system is better represented as times periods are adjusted to the intended normal length for the final product. Since the EC is less prone to fluctuation, and since the EC-value already is over the recommended for basil (1.4-1.8 Siemens) no nutrients are added.

If the pH, or EC solution is too diluted there is a risk that the dosers keeps adding pH buffer solution or nutrients without reaching the desired limits defined by the system. Resulting in that the solution could possibly run out. The problem that emerges is that the system has no way of knowing this, which is a limiting factor.

Chapter 5

Discussion and conclusion

This chapter includes a discussion of the results and a conclusion as well.

5.1 Discussion

5.1.1 Calibration of EC meter

Calibration of EC meter was performed resulting in a 20 % error margin. A better approximation could possibly have been achieved through more measure points, but was limited to running out of pure water to use. The theoretical value of 0.0058 EC units of the resolution is still unlikely to reach considering other factors such as an uneven distribution in the tank, influence of other instruments and degradation over time.

5.1.2 Drop of EC and pH

Drastic drops in pH, see Figure 4.3, cannot be definitively explained. One possible explanation is that a poor mixing of pH lowering buffer solution resulted in a high concentration solution being added at one time. The system also has bad circulation of water when the water pump is turned off. Therefore it takes a fairly long time before the pH solution is properly mixed into the tank. This could also be a possible explanation, suggesting that a lot of pH lowering buffer solution was added to the water tank before it got mixed and could be measured. Additional possibilities could be sensor malfunction, although this behaviour has not been seen in other experiments. The increase in EC which occurred at the same time, shown in Figure 4.4, indicates a larger correlation than assumed. It is therefore possible that nutrient readings taken without accounting for the pH value has a larger error than assumed.

5.2 Conclusion

Based on the experiments conducted in this project, it can be concluded that the system can hold stable values for both pH and EC and stay within predefined ranges as described earlier. The interval had to be adjusted upwards to avoid the large drops and could not be shown to keep the values within a smaller interval as presumed. As plants consume nutrients relatively slow it is easy to control the EC, as long as not too much nutrients are added. pH is somewhat more sensitive, but with a better concentration of pH buffer solution the system appears to be able to keep the pH levels within the predefined ones without any problems for longer time spans. With further testing the system is believed to be able to maintain the values within a range of 0.2 rather than the 0.5 now used.

Chapter 6

Recommendations and future work

To reduce the influence of uneven distribution a system with better circulation could have been constructed, e.g. placing the pump base close to the outlet of the dosers, thereby pumping them through the system, or installing an extra pump for stirring.

The lighting used for this project was chosen because they fit in the greenhouse. As described in the theory there are LEDs with different wavelength that are better suited for plant optimization. Another idea is to use a light sensor measuring the light intensity in surrounding room. By doing this the LEDs could be turned off when the sun is shining with enough intensity, provided that the greenhouse is placed in a room with enough sunlight.

The dosers used in this project are relatively consistent with the dosing amount, but can at occasion also dose less than they are designed for. Industrial dosers of this kind often uses peristaltic pumps that are very precise. The downside is that they are quite expensive compared to solenoids.

Another thing to reflect upon is the size of the greenhouse. The system as a whole could be designed more compact. The lighting could also be set higher as the basil used in this project provides big yields very fast. Pruning of the plants has been done every second or third day to avoid leaf burn when the plants grow into the LEDs.

In the early stages of this project a fan was used to control air humidity. But since the project focuses on regulation of pH and nutrient levels the fan was removed due to lack of space and was not used in the final system. This is something that could have been considered in the main design.

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Appendix A

Images

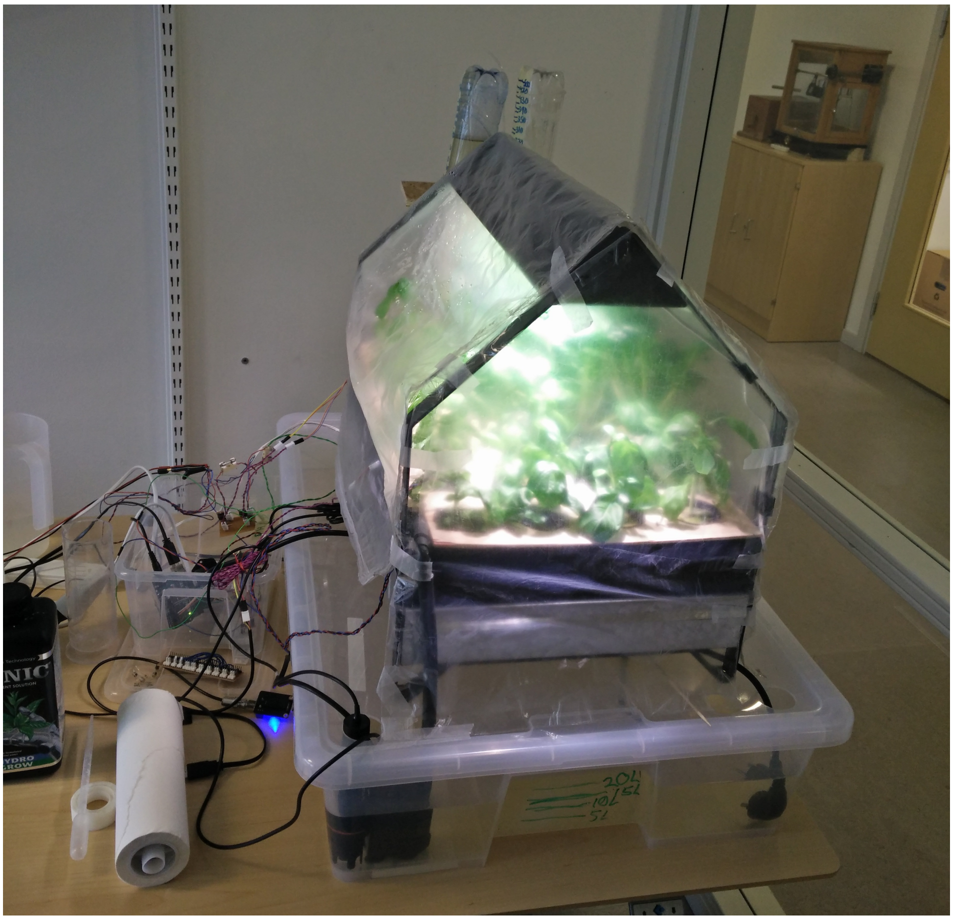

Figure A.1: Image of the greenhouse.

Figure A.2: First plantation in semi self-controlling system

Figure A.3: pH sensor used in project [16].

Figure A.4: EC sensor.

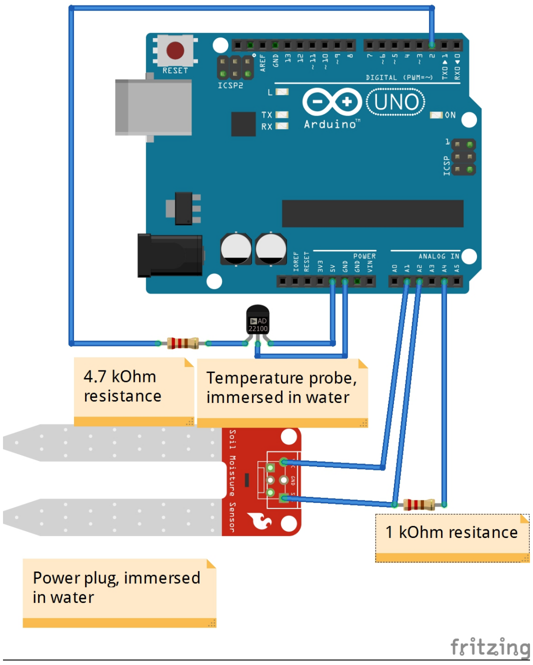

Figure A.5: Circuit for EC sensor, drawn in Fritzing.

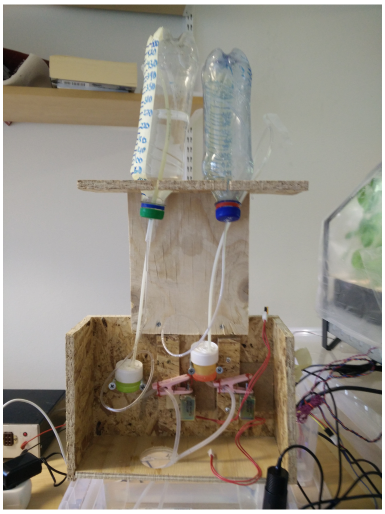

Figure A.6: Dosers, pH-solution left and nutrition solution right

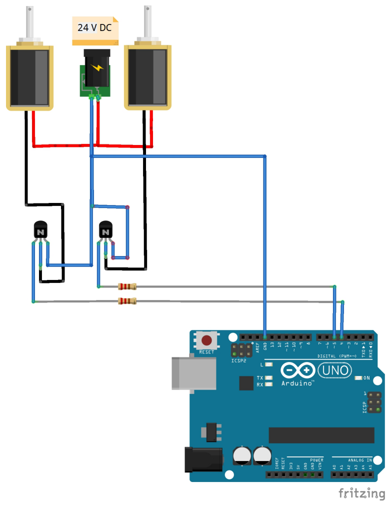

Figure A.7: Circuits for dosers, power cell indicating 24V DC, drawn in Fritzing.

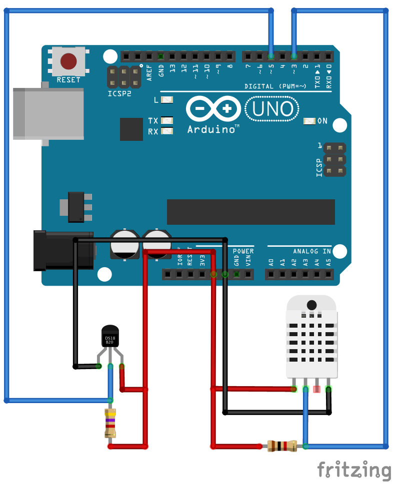

Figure A.8: Circuit for temperature sensors DS18B20 and DHT22, drawn in Fritzing.

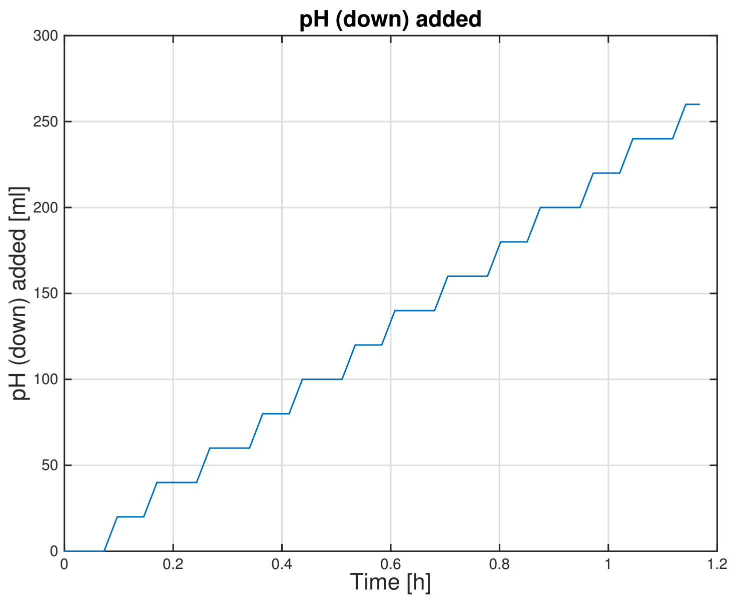

Figure A.9: Amount of pH solution added to small test tank (2 liters), drawn in MATLAB R2014.

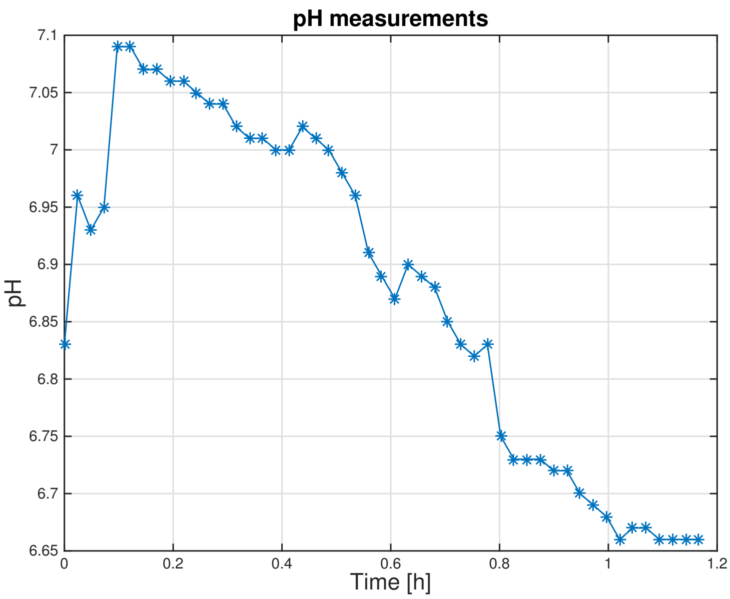

Figure A.10: pH measurements corresponding to Figure A.9, drawn in MATLAB R2014.

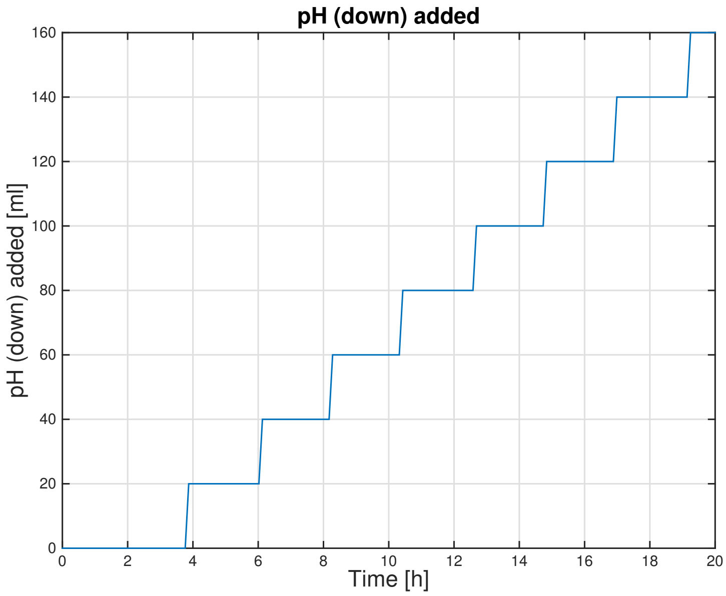

Figure A.11: Amount of pH solution added to main tank (20 liters), drawn in MATLAB R2014.

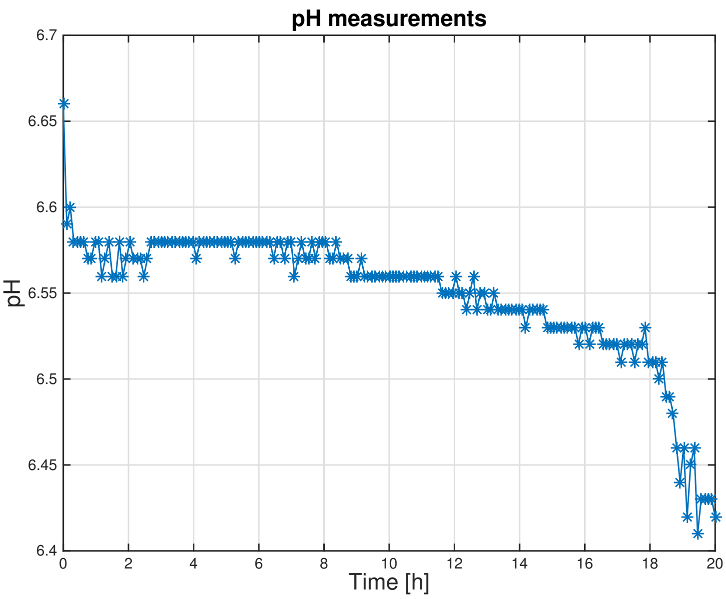

Figure A.12: pH measurements corresponding to Figure A.11, drawn in MATLAB R2014.

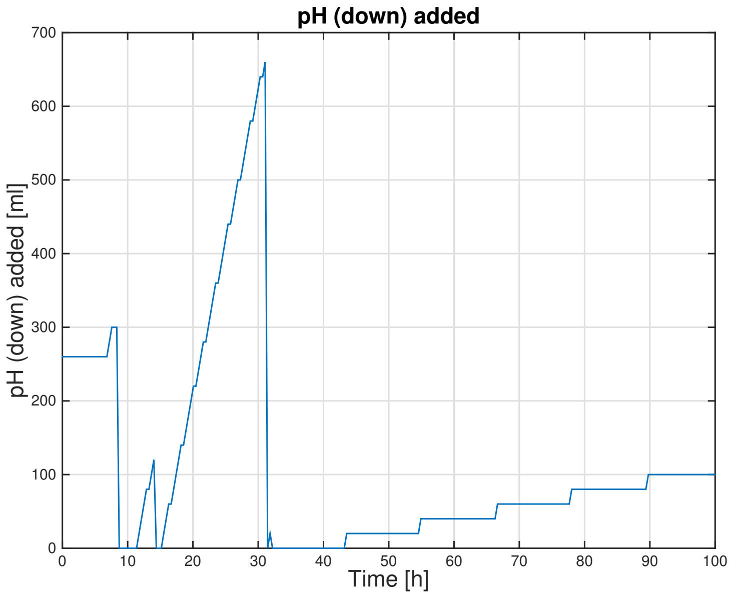

Figure A.13: Amount of pH lowering solution added to the test tank, drawn in MATLAB R2014.

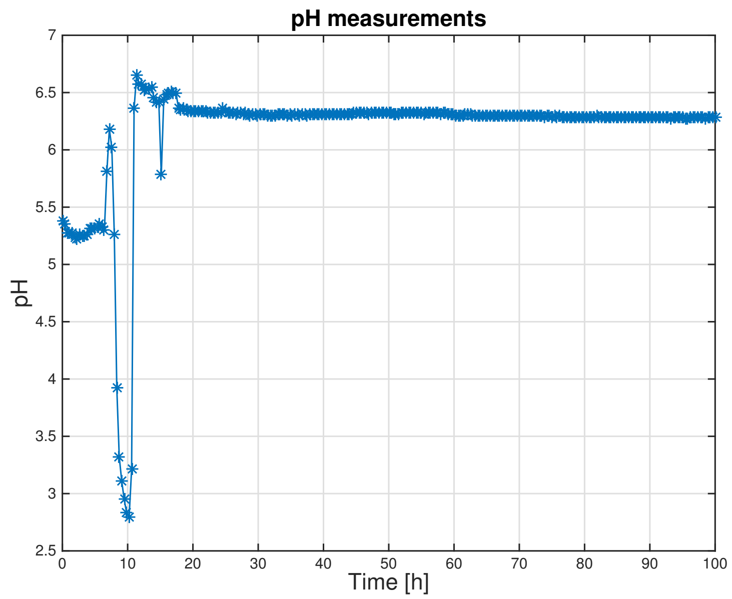

Figure A.14: pH measurements corresponding to Figure A.13, drawn in MATLAB R2014.

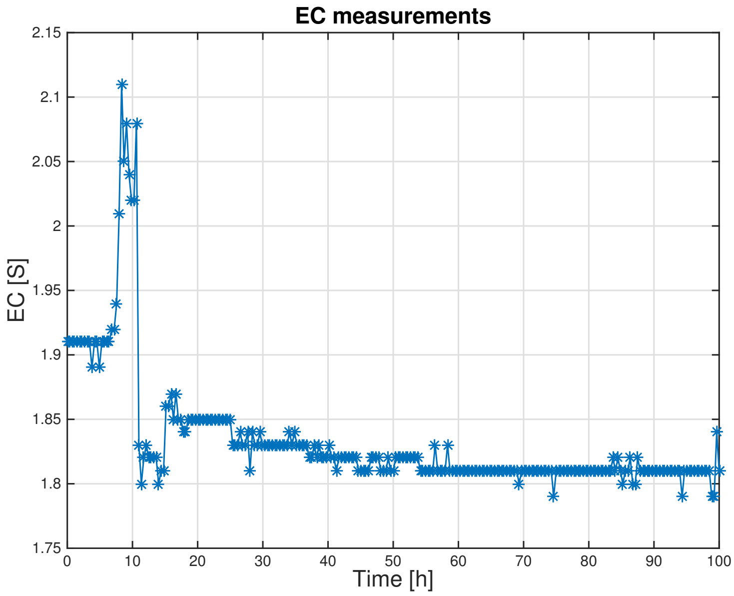

Figure A.15: EC measurements corresponding to Figure A.13, drawn in MATLAB R2014.

Appendix B

Arduino Code

```
# Oscar Olli & Karl Lundin
# TRITA MMK 2017:15 MDAB 633
# Arduino code for bachelor project in mechatronics for pH and
# EC regulation for automated hydroponic greenhouse
# using different sensors.

#include "OneWire.h"
#include "DallasTemperature.h"
#include "SPI.h"
#include "SD.h"
#include "dht.h"

// Do not replace R1 with resistor lower than 300 Ohm
int R1 = 1000;
//Resistance of powering Pins
int Ra = 25;
int ECPin = A0;
int ECGround = A1;
int ECPower = A4;

// SD card datalogger
const int chipSelect = 10;

//pH meter Analog output to Arduino Analog Input 5
#define SensorPin 5
//Store the average value of the sensor feedback
unsigned long int avgValue;
float b;
int buf[10], temp;
float phValue = 0;
float testvariable = 0;

int in1 = 7;
unsigned long previousMillisPump = 0;
unsigned long intervalPump = 46800000; // 3 hours

int WaterlevelPin = 6;
float waterlevel = 0;
```

```
#define DHT22_PIN 3
dht DHT;
float airtemp = 0;
float airhum = 0;

//************************* DOSER *************************
int pHDoserPin = 5;                    // Pin for pH-doser logic input
int ECDoserPin = 4;                    // Pin for EC-doser logic input
int pHDelay = 6500;//650;              // Time that pH-doser is open
int ECDelay = 8000;//800;              // Time that EC-doser is open
// Initialize value for amount of pH buffer administered
float pHAdministered = 0;
 // Initialize value for amount of nutrients administered
float ECAdministered = 0;
//1800000;   // (Change to 2 hours) (Later 1 day?)
unsigned long intervalDoser = 43200000;
// millis() returns an unsigned long for pH
unsigned long previousMillispH = 0;
// millis() returns an unsigned long for EC
unsigned long previousMillisEC = 0;

float PPMconversion = 0.64;

float TemperatureCoef = 0.019;

float K = 3.5;

// Data wire For Temp Probe is plugged into pin 10 on the Arduino
#define ONE_WIRE_BUS 2

// Setup a oneWire instance to communicate with any OneWire devices
OneWire oneWire(ONE_WIRE_BUS);
// Pass our oneWire reference to Dallas Temperature.
DallasTemperature sensors(&oneWire);

float Temperature = 10;
float EC = 0;
float EC25 = 0;
int ppm = 0;

float raw = 0;
float Vin = 5;
float Vdrop = 0;
```

```
float Rc = 0;
float buffer = 0;

void setup()
{
  Serial.begin(9600);
  pinMode(ECPin, INPUT);
  //Setting pin for sourcing current
  pinMode(ECPower, OUTPUT);
  //setting pin for sinking current
  pinMode(ECGround, OUTPUT);
   //We can leave the ground connected permanantly
  digitalWrite(ECGround, LOW);

  delay(100);// gives sensor time to settle
  sensors.begin();
  delay(100);
  //** Adding Digital Pin Resistance to [25 ohm] to the static Resistor
  // Consule Read-Me for Why, or just accept it as true
  R1 = (R1 + Ra); // Taking into acount Powering Pin Resitance

  pinMode(13, OUTPUT);          // pH sensor

  SD.begin(chipSelect);         // SD card

  pinMode(in1, OUTPUT);         // Water pump
  // Standard value for water pump relay is ON (HIGH)
  digitalWrite(in1, LOW);

  pinMode(pHDoserPin, OUTPUT);           // pH doser
  pinMode(ECDoserPin, OUTPUT);           // EC doser
  digitalWrite(pHDoserPin, LOW);         //
  digitalWrite(ECDoserPin, LOW);         //

};

void loop()
{

  GetEC();
  GetPH();
  GetTH();
  SaveDataToSDCard();
  //WaterSensor();
```

```
  WaterPump();
  PrintReadings();

  delay(5000);

}

void GetEC() {

  //*********Reading Temperature Of Solution *******************//
  sensors.requestTemperatures();// Send the command to get temperatures
  Temperature = sensors.getTempCByIndex(0); //Stores Value in Variable
  //Temperature = 22;

  //************Estimates Resistance of Liquid ****************//
  digitalWrite(ECPower, HIGH);
  raw = analogRead(ECPin);
  raw = analogRead(ECPin);
  digitalWrite(ECPower, LOW);

  //***************** Converts to EC **************************//
  Vdrop = (Vin * raw) / 1024.0;
  Rc = (Vdrop * R1) / (Vin - Vdrop);
  Rc = Rc - Ra; //acounting for Digital Pin Resitance
  EC = 1000 / (Rc * K);

  //*************Compensating For Temperaure*******************//
  EC25  =  EC / (1 + TemperatureCoef * (Temperature - 25.0));
  ppm = (EC25) * (PPMconversion * 1000);

  unsigned long currentMillisEC = millis();

  if (EC25 <= 1.6 and (currentMillisEC - previousMillisEC)
  >= intervalDoser) {
    delay(1000);
    ECAdministered += 25;          // milliliters
    DoserControl(ECDoserPin, ECDelay);
    previousMillisEC = millis();  // Save the "current" time
  }

  delay(10000);
  ;}

void GetPH() {
```

```
  //Get 10 sample value from the sensor for smooth the value
for (int i = 0; i < 10; i++)
{
  buf[i] = analogRead(SensorPin);
  delay(10);
}
for (int i = 0; i < 9; i++) //sort the analog from small to large
{
  for (int j = i + 1; j < 10; j++)
  {
    if (buf[i] > buf[j])
    {
      temp = buf[i];
      buf[i] = buf[j];
      buf[j] = temp;
    }
  }
}
avgValue = 0;
 //take the average value of 6 center sample
for (int i = 2; i < 8; i++)
  avgValue += buf[i];
//convert the analog into millivolt
float phValue = avgValue * 5.0 / 1024 / 6;
//convert the millivolt into pH value
phValue = 3.5 * phValue + 0.05;
testvariable = phValue; // Kompensering = 0.05
Serial.print("    pH:");
Serial.print(phValue, 2);
Serial.println(" ");
digitalWrite(13, HIGH);
delay(800);
digitalWrite(13, LOW);

unsigned long currentMillispH = millis();

if (testvariable >= 6.2 and (currentMillispH -
previousMillispH) >= intervalDoser) {
  delay(1000);
  pHAdministered += 20;          // milliliters
  DoserControl(pHDoserPin, pHDelay);
  previousMillispH = millis();     // Save the "current" time
}
;
```

```
}

void PrintReadings() {
  Serial.print("Rc: ");
  Serial.print(Rc);
  Serial.print(" EC: ");
  Serial.print(EC25);
  Serial.print(" Simens  ");
  Serial.print(ppm);
  Serial.print(" ppm  ");
  Serial.print(Temperature);
  Serial.println(" *C ");
  ;
}

void GetTH() {

  // READ DATA
  Serial.println("Type,\tstatus,\tHumidity (%),\tTemperature (C)");
  Serial.print("DHT22, \t");
  int chk = DHT.read22(DHT22_PIN);
  switch (chk)
  {
    case DHTLIB_OK:
      Serial.print("OK,\t");
      break;
    case DHTLIB_ERROR_CHECKSUM:
      Serial.print("Checksum error,\t");
      break;
    case DHTLIB_ERROR_TIMEOUT:
      Serial.print("Time out error,\t");
      break;
    default:
      Serial.print("Unknown error,\t");
      break;
  }
  // DISPLAY DATA
  Serial.print(DHT.humidity, 1);
  Serial.print(",\t");
  Serial.println(DHT.temperature, 1);

  // SAVE DATA FOR SD CARD
  airtemp = DHT.temperature;
  airhum = DHT.humidity;
```

```
  delay(1000);

}

void WaterSensor() {

  waterlevel = digitalRead(WaterlevelPin);

}

void WaterPump() {

  unsigned long currentMillisPump = millis();
  if ((currentMillisPump - previousMillisPump) >= intervalPump) {
    delay(1000);
    digitalWrite(in1, HIGH);      // Water pump ON
    previousMillisPump = millis();   // Save the "current" time

  int a = 0;  // Resetting counter every time pump has stopped
  // a <= 250
  // Pump until water sensor goes "ON" or
  //for a maximum time of 4:10 minutes
  while ((waterlevel == 0) and (a <= 250)) {

    WaterSensor();

    a += 1; // Counter

    // Serial.println(a);

    delay(1000);
  }
  }
  digitalWrite(in1, LOW);    // Water pump OFF

  //   delay(7200000);             // Delay for 2 hours to drain grow tray
  //   delay(10800000);            // Delay for 3 hours to drain grow tray

  // This if-loop is useless?!
  if (waterlevel == 1) {
    Serial.println("tank full");
  }
```

```
}

void DoserControl(int DoserPin, int DoserDelay) {

  digitalWrite(DoserPin, HIGH);
  delay(DoserDelay);
  digitalWrite(DoserPin, LOW);

}

void SaveDataToSDCard() {

  String dataString1 = "";
  String dataString2 = "";
  String dataString3 = "";
  String dataString4 = "";
  String dataString5 = "";
  String dataString6 = "";
  String dataString7  = "";

  dataString1 += String(EC25);
  dataString2 += String(Temperature);
  dataString3 += String(testvariable, 2);
  dataString4 += String(airtemp, 1);
  dataString5 += String(airhum, 1);
  dataString6 += String(ECAdministered);
  dataString7 += String(pHAdministered);

  File dataFile = SD.open("datalog.txt", FILE_WRITE);

  // if the file is available, write to it:
  if (dataFile) {
    dataFile.println(dataString1);
    dataFile.println(dataString2);
    dataFile.println(dataString3);
    dataFile.println(dataString4);
    dataFile.println(dataString5);
    dataFile.println(dataString6);
    dataFile.println(dataString7);
    dataFile.close();

    // print to the serial port to debug:
    // Serial.println(dataString6);
```

```
  }
  // if the file isn't open, pop up an error:
  else {
    Serial.println("SD ERROR: Insert SD card and reboot Arduino");
  }
}
```

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