

Automatic Plant Water System - Project

by Andrew Stanford

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Automatic Plant Watering System

By
Andrew Stanford

A project submitted in partial fulfilment for the
Degree of BEng. (Hons) Electrical and Electronic Eng.

In the
School of Applied Computing
Faculty of Architecture, Computing and Engineering

Supervisor: Gareth Jones

April 2016

Declaration of Authorship

I, Andrew Stanford declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

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Form of Consent

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Abstract

The purpose of this project is to research, design and build an automatic plant watering system. The concept of the plant watering system is to automatically water the plants when the moisture content of the soil drops below a certain percentage, alongside this the design also records data on the temperature, the sunlight and the humidity of the environment in which the plant is in. The outcome of this data can then be analysed to determine the most amendable environment for the plant to thrive.

The full content of this report includes:

- Research into the market to establish other similar systems related to that of the proposed idea.
- Research into different sensors finding the most appropriate for the application.
- A PCB design.
- Code written for the microcontroller.
- A prototype build and a cost list.
- Analysis of data gathered from working module.
- Evaluation of the project.
- Overall conclusion
- Personal Reflection

The different software packages used to design and build the project are as follows:

- Proteus.
- CCS Compiler.
- MpLab.
- Microsoft Word.
- Microsoft Excel.
- LabView.
- Arduino Software.

Faculty of Architecture, Computing and Engineering
School of Applied Computing

BEng.(Hons) Electrical and Electronic Eng.

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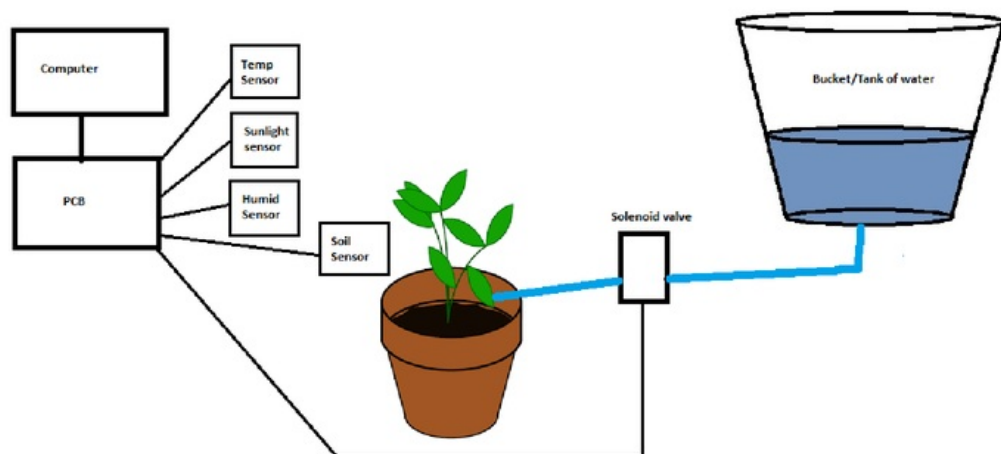
Chapter 1 – Introduction

The project that has been proposed is an automatic plant watering system or better known as an irrigation system. The concept of the project is to design a system which enable a plant/plants to be watered when their soil moisture content drops below a pre-determined level. The ultimate aim is to allow the plant to grow with very little human intervention. The system will be further developed to log data on the following points:

The soil moisture content.

- The ambient temperature.
- The humidity.
- The sunlight brightness.

The logging of the data listed above will facilitate the user to monitor the growth of the plant in order to determine the perfect positioning for the plant to reach its maximum growth potential. Below is a diagram of the proposed system:



The system will transfer the data straight to the PC. This diagram is currently showing the PC directly connected to the PCB but the desired final design will transmit the data wirelessly depending on time. The bucket/tank of water will be used for the prototype design but the system could also be connected to an outside water tap, depending on the user's requirements. There are a number of factors that need to be considered and researched for this project to be successful:

- The flow rate of water.
- The correct sensors required for the project
- Data transmission.
- Data logging.

The above factors will be looked at and achieved through the project research.

Chapter 2 – Planning

2.1. Objectives

In order to meet the requirements and produce an accurate report/design then the following objectives need to be met.

Planning	A plan needs to be constructed in order to meet all project requirements. The plan needs to include a Gantt chart to give a rough timescale and a rough guideline in order to meet deadlines; a specification also needs to be written to clarify the requirements.
Investigation	A research methodology needs to be produced to find the best method needed to research the required information. Research into the design then takes place in order to find the right and correct components to undertake the job that is necessary.
Implementation	Create a design from the research and information gathered that will meet the requirements. Once design is done on proteus the code can be written on CCS and a prototype design can be built in order to test functionality.
Analysis	Annalise results from test and make changes if necessary, write report to explain results and check that the design has met the requirements.
Evaluation	Evaluate project from results of design, discuss further future developments and what was learnt from project and how to improve if needed to.

Table 1 – Project Objectives

2.2. Project Milestone Dates

The dates shown in the table below show a rough timescale for the project to be successful. It gives a guide to help the Author keep on track with the project and to ensure it stays within the time constraints, therefore making the project achievable.

Task:	Due Date:
Project Start Date:	01-09-2015
Project Plan	28-09-2015
Investigation	04-12-2015
Implementation	21-01-2016
Analysis	21-02-2016
Evaluation	14-03-2016
Viva Part 1	19-11-2015
Viva Part 2	21-01-2016
Final Viva	28-04-2016

Table 2 – Project Milestone Dates

2.3. Project Breakdown

The following tables show the breakdown of the proposed project plan

Project Plan Tasks			
Breakdown of project plan	Brief description	Start date	Due date
Project proposal	Think of project idea and create proposal including reason for project and research involved in project	01-09-2015	04-09-2015
Produce gantt chart	Produce a timeline for project with breakdown of what needs to be done	07-09-2015	14-09-2016
Technical Specification	Create a technical specification explaining what the project is with block diagrams of how design should look.	15-09-2015	28-09-2015

Table 3 - Plan

Breakdown of Investigation	Brief description	Start date	Due date
Feasibility Study	Research the market to see if project is already available.	01-10-2015	07-10-2015
Risk assessment	Produce a risk assessment - what risks are involved when building – environmental factors need to be considered	01-10-2015	07-10-2015
Benefit analysis/Market research	What benefit will the project have for the public. What systems are already available on the market.	08-10-2015	12-10-2015
Research	Research different sensors to find which ones would best suit the project.	12-10-2015	30-11-2015
Cost analysis	Create cost analysis sheet showing how much the sensors will cost and how much the project costs are at.	30-11-2015	04-12-2015

Table 4 – Investigation

Breakdown of Implementation	Brief description	Start date	Due date
Design Circuit	Design a prototype circuit using simulation software such as proteus	05-12-2015	14-12-2015
Write firmware for PIC	Produce system flow diagram to explain how the code is going to work and how it needs to be set out.	14-12-2015	28-12-2015
Produce PCB layout	Build design on bread board following schematic design which was created on proteus.	28-12-2015	07-01-2016
Put firmware on to microcontroller	Put code created, on to microcontroller and place microcontroller in the circuit.	07-01-2016	14-01-2016
Test	Power board and test design.	14-01-2016	21-01-2016

Table 5 - Implementation

Breakdown of Analysis	Brief description	Start date	Due date
Analyse data	Analyse data from implementation stage	21-01-2016	25-01-2016
Feedback data into design	Check results are correct and design matches specification and delivers what is required.	21-01-2016	01-03-2016
Make changes if needed	Are changes needed to be made if so create new prototype and re-test.	21-01-2016	01-03-2016
Build completion design	Build final design within enclosure and produce a PCB layout on easy PC to get PCB produced.	01-03-2016	21-03-2016

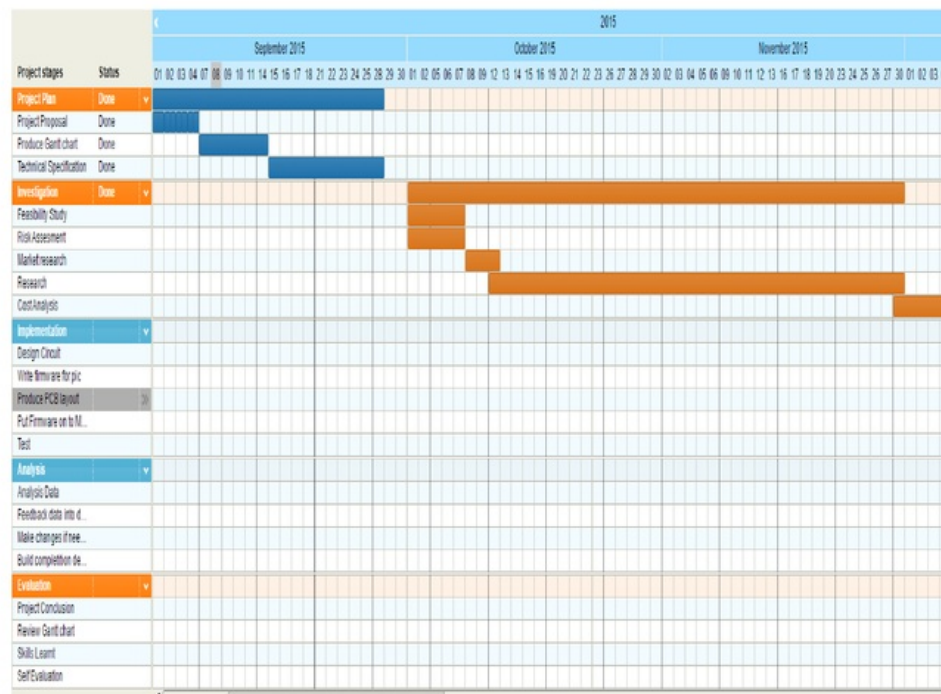
Table 6 - Analysis

Breakdown of Evaluation	Brief description	Start date	Due date
Project conclusion	Conclude project –outcome of project design	21-03-2016	31-03-2016
Review Gantt chart	Review gantt chart – was timescales followed and met or where they changed often	01-04-2016	07-04-2016
Skills learnt	What was learnt from doing the project – what new skills were acquired.	07-04-2016	11-04-2016
Self-evaluation	Write a self-evaluation.	11-04-2016	14-04-2016

Table 7 - Evaluation

2.4. Gantt Chart

Below shows a print screen of the Gantt chart created on tomsplanner.com.



2.5. Research Methodology

Research methodology underpins the research that needs to take place in order to make the project successful. The methods used to source information help give a clear understanding of what needs to be achieved and keeps the researcher on the right track. The best way to view research methodologies is by looking at the research onion as this breaks down the different methods and shows that if you start on the outside of the onion and begin peeling back each layer then you will reach the core of the research. The research onion is shown below [1] and each segment is broken down and detailed further below the research onion:

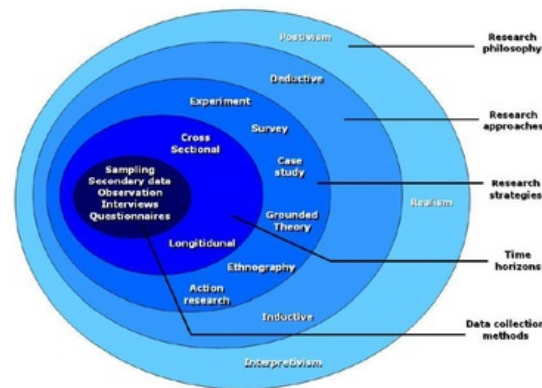


Figure 1 – Research Onion

2.5.1. Research Philosophy

The first layer of the onion is research philosophy. This first layer helps give the researcher an idea of how they would think about the research that needs to be obtained. Each of the choices at this level need to be carefully thought about as it will give the project structure, guidance and possible limitations to following decisions. The layer is comprised of three different views, positivism, realism and interpretivism.

Positivism research is described as taking the facts and searches for the truth, it believes that there is an answer to the question that can be justified by scientific experiments and hard evidence rather than going on hunches or someone's experience and intuition. Although this type of research is good people argue that it is heavily influenced by a person's world-view and or perception.

Interpretivism is described as the opposite of positivism as it looks more into people's experiences and to interpret their subjective understanding of reality. It therefore allows the author to capture data on expectations and doesn't really take the scientific approach.

Realism is the mixture of both interpretivism and positivism as it looks at what the actual result is and then compares it to what it should be, for example a calculation could be made and mathematically it is correct but when a test is done in the real world due to external factors things would have changed. The realism takes into account both different types, the real and the calculated.

2.5.2. Research approaches

The second layer of the onion is research approach this section determines how the author will approach the research and what they plan to achieve from the research which they have chosen to undertake. This layer contains two different ways to approach the research, deductive and inductive.

Deductive research is the aim to test theory and links in with positivism, the idea of deductive is to research and develop a theory/answer to the question and to then prove this theory by designing a strategy to test the theory, the idea is to then analyse and use these results to either adjust the theory that was obtained or confirm the theory was correct. This test also needs to be repeatable so that enough data can be gathered in order to provide evidence and support the research carried out.

The inductive approach is referred to as working from the bottom up. This approach aims to build theory by gathering data and then developing theory from the data retrieved. The main difference between inductive and deductive is that inductive doesn't set out to achieve an exact answer and conclusion; instead it gives a broader view of the subject in question and adds knowledge to that area of work so others can derive from it what they wish.

2.5.3. Research strategies

The third layer in the research onion is research strategies; this section concentrates on how the data is going to be gathered and how the research objectives will be achieved. There are a few different research strategies available:

- Experiment
- Survey
- Case study
- Grounded theory
- Ethnography
- Action research

Experiment: experiments are conducted to examine relationships between two factors. This is usually achieved by manipulating one factor in order to see the change in the other. It is done in order to gather data and analyse the results. Experiments generally involve definition of theoretical hypothesis, allocation of samples, selection of samples and control on variables.

Survey: Surveys are a method of gathering data from questionnaires to get an average opinion from the public about the research in question.

Case Study: A case study is a process that is carried out over a period of time to look at an area of development of a person or group. It is a study that requires constant monitoring.

Action Research: This is research that is taken as part of a group or community that solves a problem in order to improve the way processes are performed and services are delivered.

Grounded Theory: This type of research involves analysing data and observing other research in order to develop new theories surrounding a question.

Ethnography: This is the study of people or different cultures. The researcher will observe groups or individuals in order to explore different culture phenomena depending on the question of study.

2.5.4. Time horizons

The forth layer of the onion is time horizons, this is important when planning research as there are two different types of time horizons, longitudinal and cross-sectional. Depending on the time aloud for the research depends on which method is used. Cross-sectional is used when there are time constraints and there is no sufficient time for research, this is usually just a 'snap shot' of research. Whereas longitudinal studies is researching the same thing in different time periods and is extended over a long period.

2.5.5. Data collection methods

The last section and core section of the onion is data collection methods. There are two main types of data collection, primary data and secondary data. Primary data is data that is collected by the researcher and evaluated, for example questionnaires, interviews, tests, market research etc. Secondary data is looking at primary data that has already been collected by a different source and then used again by the researcher to gain the information they require from it, using secondary data saves a lot of time as the information is already there but it cannot always be trusted.

2.5.6. Research Methodology Conclusion

After analysing the different methods available for research it has been decided that the related methods and the ones chosen for the project are as follows:

- Research Philosophy – Positivism is the best method for the engineering project as it requires mathematical equations and exact answers.
- Research approaches – Deductive is chosen as this project involves some research in order to design the final prototype which will then be tested to prove that the research and design stage was successful.
- Research strategies – The strategies which will be used for the project are experiments and grounded theory as these relate to the project.
- Time horizons – As this project is over 2 years, the research will be continuous and therefor a longitudinal approach will be taken.
- Data Collection – The data collection will have a mixture of primary and secondary research done as theories and methods will be taken from research that has been previously done and new methods will also be used based on knowledge acquired.

Chapter 3 Investigation - Market Research

Market research needs to be carried out to determine if the project will be marketable and to identify the nature of the competition. The benefit of market research is to find other ideas similar to the one that has been proposed and to then either try to modify the proposed design to make it unique to the market or to make the product cheaper. Further advantages of the market research is to find the advantages/disadvantages and benefits of the project and if there is a big demand for an automatic watering system.

When researching on the internet for an automatic watering system the author found the following similar products:



Figure 2 – ClaberINC.[2]

Indoor Automatic Dripping Watering System

The picture of the system on the left is of an indoor irrigation automatic dripping watering system; this system was found on a website called claberinc [2]. This product can water plants for up to 1 year, it works on a 9V battery and has a timer that has 4 program settings which are 10, 20, 30 or 40 days and will water up to 20 plants. This system works on a gravity feed and comes with a 6.6 gallon polypropylene reservoir, 33 feet of PVC hose, 20 drippers and 20 spikes. This system is priced at £101.24

Self-watering Vertical Hanging Garden

This system was found on a website called ecrater [3] which supplies home and garden products. The name of this product is a free standing self-watering vertical hanging garden. It has been designed for indoor use and grows hydroponic plants which mean it doesn't require the plants to be in soil as it uses a mineral nutrient solution which is contained within the water.

The system has 30, two litre pockets; it includes a drip basin and a recirculation pump on a timer so the plants can be kept well-watered. It can be used to grow a variety of different plants like vegetable

plants, fruits, herbs or flowers. It is priced at £149.62 which is including VAT.



Figure 3 – Ecrater.[3]

Halls Vanlet Automatic Irrigation Unit



Figure 4 – Halls Green house [4]

Claber Hydro Programmable Timer Unit

This is one of the most expensive automatic plant watering systems available on the market, but is also more advanced than the others; it is priced at £175. It is called claber hydro programmable irrigation timer unit and is available on ebay [5]. This unit comes as a preassembled valve box which has a timer incorporated within it. It is powered by two 1.5V AAA batteries which provide enough power to keep the unit going through a season. The system has on/off control for 4 underground or drip irrigation lines; it has an easy programming procedure with only three buttons and a large visible display to make it easier for the user. The watering time can be programmed between 1 to 60 minutes and 2 programs can be written for each outlet with up to 4 watering cycles per day. The unit is sealed and is tested to IP68. It has the ability to be

This system is available in a range of different stores and seems to be the most popular, it is called halls vanlet automatic irrigation unit and is used mainly within green houses. The cheapest one found was on a site called Halls Greenhouse [4] and was priced at £84.99. This is a gravity fed system so the tank needs to be at height in order for the water to flow, the water and fertiliser is added and mixed in the tank and is then distributed to the plants via a system of Y connectors, hoses and drip pins. Each drip pin can be adjusted so that each plant can receive different amounts of water depending on the plant's needs. This system can be adjusted to deliver between 10 and 150 litres of water over a 24 hour period and the tank can then be refilled via the automatic fill system. For £84.99 the gardener will get a vanlet tank, 30 drip pins, 35 Y connectors, 25 metres of transport hose and a fitting bracket.



Figure 5 – Claber Hydro [5]

connected to a wireless radio frequency rain sensor, which is sold separately, and has 4 solenoid valves within the system. Its watering flow rate is 25l/min at 2.5 bar, the operating pressure is between 0.2 and 12 bar, and can operate between 3-60 degrees.

3.1.1 Market Research Conclusion

From the market research done it is clear to see that there are products already available that can do almost the same as what the proposal is suggesting but there isn't a single device that can do everything at once. The closest product to that being proposed is the Claber Hydro Programmable Timer Unit as it can link to sensors via radio control and it uses solenoid valves allowing the system to work off a mains water supply rather than a gravity fed system.

The system that is proposed is to have an automatic watering system that will water the plants depending on the soil humidity therefor eliminating much user need. The device will also monitor the environment in which the plant is growing in so that its growth can be monitored. The proposed unit will be much more sophisticated than those that are currently available on the market. However in order for the unit to be marketable it needs to be within the price range of those that are already available so that it will be more attractive to customers. The aim will be to produce the system within the same price range as the existing commodities but with more features than the others. The highest price of an automatic system found was £175 and the lowest was £84.99, to compete within the market it would be ideal if the product could be retailed at around £150. An estimated build cost will be drawn up later in the project.

3.2 Investigation - Sensor Research

The success of the project is dependent on keeping costs low whilst still using effective equipment. Sensor research is required to enable the researcher to select the correct sensors to meet the specification and fulfil the requirements of the system. The following is a list of parameters that need to be measured and or controlled:

- Water flow
- Temperature
- Humidity
- Soil moisture
- Sunlight

Each bullet point needs to be broken down and researched in order to find suitable sensors.

3.2.1. Water Flow

In order for the system to water plants a valve is required to turn the supply on/off. The best proposed way of doing this is by using a solenoid valve. The valve will be controlled via the microcontroller and will open and close depending on the moisture level of the soil. It does this by energising a coil which creates a magnetic field which will then in turn raise or lower the plunger which sits in the valve housing. The picture below shows the operation of a solenoid valve.

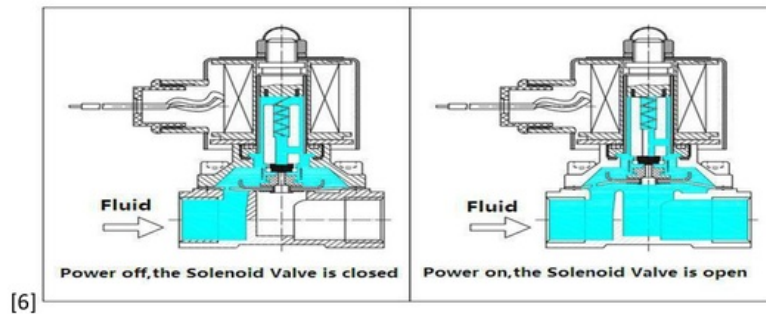


Figure 6 – Solenoid Operation

There are 3 main types of solenoid valves, direct-acting valves, in-direct acting valves and forced lift valves. The direct acting valve will only allow flow once the coil is energised; these valves are very robust and are used in a process line for simple isolation or safety purposes.

The in-direct acting valve requires a differential pressure across the inlet and outlet to allow them to stay in their rest state; if the valve didn't have the differential pressure then it could be intermittent and could change state without being energised. These valves are only used if the pressure levels are within that specified on the data sheet.

The forced lift valves can deal with high pressure, unlike the other two, it can deal with pressures from 40 bar and above. It has a much bigger and higher powered coil to open/close the valve and is connected directly to the bottom of the piston/plunger assembly which in turn disregards the need for a diaphragm.

The direct acting valve would be the most suitable for the project as it will only open if the coil is energised which is what is required. Most solenoid valves sourced stated that they required a minimum of 0.2bar of pressure to be able to operate as most contain a gasket and the pressure is required to open the main manifold. Although this may be fine for the final design as it could work off a mains water feed which has a pressure usually between 1.5 and 4 bar, it would be hard to achieve for the prototype.

The prototype design will have water flowing from a bucket. The problem identified through the research found that the pressure of water flowing from a height of 1 foot above the valve would be 0.434psi which is equivalent to 0.02bar, this was calculated by using a formula found on a website called kylesconverter [7]. So in order to get the flow to reach 0.2 bar the tank would need to be raised 7 feet above the valve, and as a prototype this would not be plausible. Therefore a solenoid valve needs to be sourced that will work at 0 pressure.

Water Flow Conclusion

The picture of the solenoid valve shown below was found on adafruit, it can work between 0 and 10 bar of pressure therefor making it an adequate choice for both the prototype and for final design. The valve is in a normal closed state and will open when 12V is applied to it, this is perfect for the design as power consumption is a main factor in the design. The item is priced at £22 which is rather expensive but as it is ideally suited then it will be used.



[8]

Figure 7 – Solenoid Valve

3.2.2. Temperature

In order to measure the temperature of the environment in which the plant is growing then a temperature sensor needs to be sourced. The idea of monitoring the temperature is to collect data which can then be recorded to enable the user to determine how the environment affects the growth of the plant. The user can then experiment and try to find the perfect environment to get maximum growth potential from the plant. There are a range of different types of temperature sensors available on the market that will do the job that is required. The three main types that are going to be research are:

- A thermocouple
- A thermistor
- A resistance thermometer
- Thermocouple

Thermocouple

A thermocouple is a durable temperature sensor that is made up of two conductors of different materials that are joined at one end and open at the other with the open ending being the output. The output has a voltage generated which is proportional to the heat that is being measured or monitoring. When the temperature drops a lower voltage is produced and vice versa if the temperature increases a higher voltage is produced. Therefore the temperature can be calculated by the output voltage that is given off, and a reference point is used for the calculation to be made. This is known as the 'see back' effect, this explains that the temperature difference between two different dissimilar metals in a circuit converts into an electrical current [9]. The main advantage of thermocouples, and why they are used quite regularly, is that the temperature measurement range can be between -270 and +1800 degrees Celsius and they are reliable and accurate.

Thermistor

A thermistor is basically a variable resistor, the resistance will change as the temperature increases or decreases. All resistors will vary will vary with temperature but the thermistor is different as it is made up of a semiconductor material that is specifically designed to measure temperature as it is very sensitive to temperature. There are two types of thermistors, a positive temperature coefficient (PTC) and a negative temperature coefficient (NTC). The NTC resistance will decrease as the temperature increases, and the PTC resistance will increase as the temperature increases. The temperature is calculated using the output voltage, within the data sheets of thermistors it will give the resistance of the thermistor at a certain temperature, by using this information and using Steinhart-Hart temperature calculator [10] the temperature can be determined. The main advantages of the thermistor is that it is cheap and rugged.

Resistance thermometers

The resistance thermometers, which are also known as resistant temperature detectors (RTD's), are sensors that are used to measure temperature by correlating the resistance of the RTD element with temperature. The RTD is very similar in operation of the thermistor as it also requires a small amount of current to be passed through it is order to determine the resistance. The difference between the two is that the thermistor is made of a different material and the thermistor has a much higher sensitivity to temperature than the RTD does. The main advantage of the RTD is that it has a small drift and is good for precision applications.

Temperature Sensor Conclusion

From the three different types of temperature sensors researched a table has been created showing the temperature range of the sensors, the advantages and the disadvantages. From this it has been determined that a thermistor is going to be used to measure the temperature as it is accurate and cheap, it also falls within the required temperature that needs to be measured. The lowest temperature recorded in the UK is -27.2 degrees, according to the met office which was taken on the 12th January 1982 in East Scotland [11] and the highest temperature recorded was 38.5 degrees, according to the met office, the reading was taken on the 10th August 2003 in Kent [12]. Therefore the thermistor will be sufficient for what is needed.

Sensor	Description	Temperature Range	Advantages	Disadvantages
Thermocouple	Temperature is calculated by output voltage	-270 to 1800 degrees	-Rugged -Fast in response to change in temperature	- Used in ways that require special attention due to rugged design. -Nonlinear devices
Thermistor	Temperature calculated by change in resistance	-55 to 250 degrees	- Cheap to buy -Rugged	-Doesn't work well at high temperatures. -Linearity isn't good.
Resistance thermometers	Temperature calculated by change in resistance	-200 to 500 degrees	- Suitable to precision applications -Low drift	-Slow response time. - Can be expensive.

Table 8 – Temperature Sensor

The thermistor chosen to be used for the application was sourced and found on RS. It can read temperature between -40 degrees and +250 degrees. This temperature is more than sufficient for the system being designed. The resistance value of the thermistor at 25 degrees is 100KOhm and is priced at £1. There is no data sheet found on RS for this thermistor so a print screen of the information supplied is shown below and the website can be found in the references section [13].

RS 100kΩ DO-35 Measurement NTC Thermistor, 7s, 2 Dia. x 4.2mm

RS Stock No. 998-961
Brand RS




Image representative of range

Specifications

What you're looking for? Select the attributes you require, then click the button below

☐ Temperature Coefficient Type	NTC
☐ Thermal Time Constant	7s
☐ Resistance @ 25 °C	100kΩ
☐ Tolerance	±10%
☐ Application	Measurement
☐ Package/Case	DO-35
☐ Length	4.2mm
☐ Dimensions	2 Dia. x 4.2mm
☐ Maximum Operating Temperature	+250°C
☐ Minimum Operating Temperature	-40°C
☐ Select all	

Figure 8 – Thermistor [13]

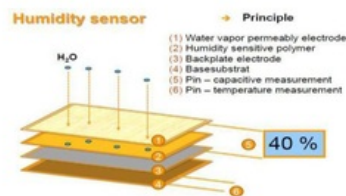
3.2.3. Humidity

To measure the humidity in the environment in which the plant is situated, then a humidity sensor is required. Like the temperature sensor the humidity sensor will be used to inform the user of the humidity in the air, helping them determine how the humidity effects the plant growth. There are two different types of humidity sensors:

- Capacitive humidity sensor.
- Resistive Humidity sensor.

Capacitive Humidity Sensor

A capacitive humidity sensor is made up of a hydroscopic dielectric material which is deposited between two electrodes which forms a small capacitor. The dielectric material used for capacitive sensors is usually a plastic or polymer which has a typical dielectric constant ranging from 2 to 15. When there is no presence of moisture, the sensor geometry and the dielectric constant of the hygroscopic dielectric material determines the value of the capacitance. As the dielectric constant of water vapour is around 80, which is a value much higher than that of the constant of the sensor dielectric material, then any water vapour that is absorbed by the sensor will change the sensor capacitance usually increasing it. This therefor will allow the room humidity to be calculated from the change of capacitance. Below is an image showing the capacitance sensor.

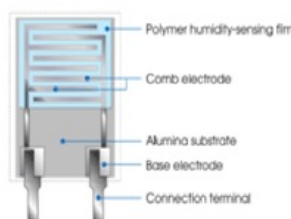


[14]

Figure 9 – Capacitive Humidity Sensor

Resistive Humidity Sensor

The resistive humidity sensors work similar to the capacitive sensors as like the capacitive sensors it measures a change from its usual state. The capacitive sensor measures humidity by monitoring the change of capacitance when it is exposed to moisture, whereas the resistive sensor measures the humidity depending on the change of resistance when it is exposed to moisture. The construction of the resistive humidity sensor is shown in the diagram below:



[15]

Figure 10 – Resistive Humidity Sensor

[26]

As both types are similar in operation and would both suit the application then there is no need to make a choice on which one is better. Three humidity sensors have been sourced, and are shown below:

TDK Corporation – Humidity Sensor



[16] *Figure 11 – TDK Humidity Sensor*

The humidity sensor shown to the right was found on digikey. Its operating voltage is between 4.75V and 5.25V and it gives an analogue voltage output. At 50%RH the output voltage is 500mV and it has a 60s response time with a humidity range between 5% and 95%. It is a through hole component and its operating temperature for best results is between 0 and 50 degrees Celcius. This component is priced at £69.38.

HoneyWell Sensing and Productivity Solutions

This humidity sensor was also found on Digikey [17]. It has an operating voltage of between 4V and 5.8V. Its humidity range is between 0 and 100% and produces an analogue output voltage, its output voltage at 75.3% RH is 3.198V. It has a response time of 50 seconds and is priced at £78.61.



[17] *Figure 12 - DigiKey Humidity Sensor*

HONEYWELL S&C HIH-4000-002



[18]

This sensor was found on Farnell [18], it is priced a lot cheaper at £14.58. It has an operating voltage of between 4V and 5.8V and has a typical current draw of 200uA. It has on board signal conditioning; it is accurate to $\pm 3.5\%$ RH with a response time of 15s. It can operate in temperatures between -40 degrees and 85 degrees. Its humidity range is between 0% and 100%.

Figure 13 – Honeywell Humidity Sensor **Humidity Sensor Conclusion**

The sensor that best suits the application is the Honeywell HIH-4000-002 as it is the cheapest and will suit the needs of the project. As the system could be used outside in a green house where the temperature can range from -15 to +28 degrees then this sensor will be able to comfortably work in these temperatures. It has a good humidity range of between 0% and a 100% and the accuracy will be sufficient enough as it is only being used as a reference.

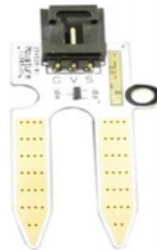
3.2.4. Soil Moisture

Soil moisture is important in the growth of plants as too little water means the plant doesn't have enough to survive and will begin to get stressed and will eventually wilt and die. If the soil is water logged then there is no air or oxygen in the pore spaces for the roots to extract and use and so the roots will begin to die. Therefore the soil moisture has to be kept to the requirements of the plant in order to increase its life and get its full growth capacity.

Soil moisture is measured as a percentage between 0% to 100%. In order to measure the soil moisture a soil moisture sensor is required. The sensor works by calculating the resistance between two prongs, if the soil is wet the resistance is low and therefore it will output a high level and when the soil is dry the resistance is high and so it will output a low level. The sensor is used so that when the soil moisture levels drop below a certain level it will activate the solenoid valve so that water will be released into the soil and once the moisture has increased the valve will shut off, stopping the flow of water. The limits for the activation will be changeable so that the system can work with a variety of different plants depending on what the user is growing, as all plants will require different moisture content.

Three different soil moisture sensors have been sourced and are shown below:

Octopus Soil Moisture Sensor Brick



[19]

Figure 14 – Octopus Soil Moisture Sensor

This soil moisture sensor was found on a website called robot shop [19]. It is ideal for monitoring an urban garden; it requires a supply between 3.3V and 5V. The output signal is between 0V and 4.2V and has a current consumption of 35mA. This sensor is priced at £3.76 which is inclusive of VAT.

Soil Hygrometer Detection Module + Soil Moisture Sensor

This sensor was discovered on a website called light in the box [20]. This soil moisture sensor comes with a hygrometer detection module. The module is used to control the output of the sensor, it has a potentiometer which can be adjusted so that the device will only output when it gets to the adjusted level. It gives a high digital output if the soil is too dry and a low output when the soil is moist. This sensor is priced at £2.09 and has an operating voltage between 3.3V and 5V.

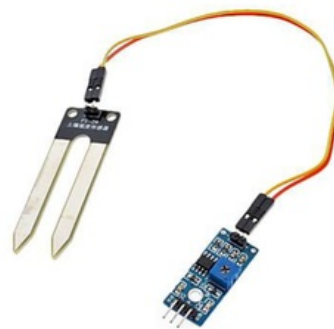


Figure 15 – Hygrometer Soil Moisture Sensor [20]

Soil Moisture Sensor Ground Humidity Sensor Module



This soil moisture sensor was also found on light in the box [21]. This sensor is similar the first one sourced but it is priced at only 0.69p. It requires a power supply of between 3.3V and 5V, it has a working current of less than 20mA and has an analogue output voltage between 0V and 2.3V (2.3V when sensor is completely soaked in water). The surfaces of the sensor have gone through a plating process in order to enhance the electrical conductivity and the corrosion resistance. The approximate service life of this sensor is 1 year depending on the conditions it is used in.

[21] *Figure 16 – Soil Moisture Sensor – Light in the box*

Soil Moisture Conclusion

From the sensors sourced it is clear to see that all work in a similar way and have the same construction to them. The soil hygrometer detection module is slightly different to the other two as it comes with a control module although this is not required for the project as the microcontroller will be providing the output depending on the information received from the sensor as it will be written into the code. This will be more accurate than using the potentiometer as the exact percentage of moisture can be set instead of using the potentiometer to estimate what is required.

The sensor chosen is the soil moisture sensor found on light in the box for 0.69p as it is almost identical to the one found on robot shop but is a lot cheaper making it more appealing. The photo and specification of the chosen sensor is shown below:



- Material: RF4.
- Power Supply: 3.3V – 5V.
- Working Current: less than 20mA.
- Output Voltage: 0V-2.3V.
- Sensor type: Analogue output.
- Service life: 1 Year approximately.
- Weight: 7.0g.
- Packaging dimensions: 120x70x10.
- Colour: Red and Silver.

3.2.5. Sunlight Sensor

A sunlight sensor will measure the intensity of the sunlight. Sunlight is measured in lux so the voltage output of the sensor will need to be converted to lux. According to a table found on Wikipedia, the brightest sunlight would be 120,000 lux and the extreme darkness like storm clouds or sunset/sunrise on a cloudy day would be less than 1 lux. The table is shown below [22]:

Illuminance	Example
120,000 lux	Brightest sunlight
110,000 lux	Bright sunlight
20,000 lux	Shade illuminated by entire clear blue sky, midday
1,000 - 2,000 lux	Typical overcast day, midday
<200 lux	Extreme of darkest storm clouds, midday
400 lux	Sunrise or sunset on a clear day (ambient illumination).
40 lux	Fully overcast, sunset/sunrise
<1 lux	Extreme of darkest storm clouds, sunset/rise

Table 9 – Sunlight Intensity

This table helps give a rough indication of what will be expected at different times of the day and can show the user what the data they are receiving equates to. Three sensors have been sourced that would be sufficient for the project:

Phidgets light sensor



[23]

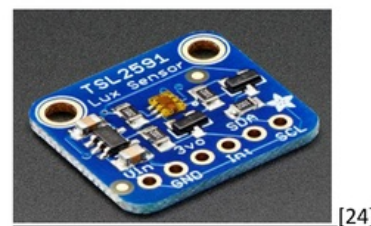
Figure 17 – Phidgets Light Sensor

TSL2591 High Dynamic Range Digital Light Sensor

The TSL2591 luminosity sensor is a digital advanced light sensor. It can measure exact lux calculations and can be configured for different gain/timing ranges to allow it to detect light between 188 lux and up to 88000 lux. The sensor allows the ability to measure infrared, full spectrum or human visible light separately. This sensor can operate within -30 and + 80 degrees Celsius and requires a voltage of between 3.3V and 5V in order to operate. It has a low current draw of 0.4mA when actively

The light sensor shown was sourced and found on a website called robotshop [23]. The sensor can measure between 3 and 70,000 lux and can measure incandescent and fluorescent light. It has a response time of 0.5ms with a maximum current consumption of 500uA. The supply voltage needed for correct operation is between 4 to 5.5 VDC and can operate within the temperature of -40 to 85 degrees Celsius. This sensor is priced at £5.46.

sensing and 5uA when in power down mode. The TSL2591 is priced at £4.93



[24]

Figure 18 – Dynamic Light Sensor

[30]

GA1A12S202 Log-scale Analog Light Sensor

The GA1A12S202 light sensor was also discovered on adafruit and has a different operation to the TLS2591. This sensor has a large dynamic range of between 3 and 55000lux and can be used both indoors and outdoors without the need to recalibrate the sensor. It provides an analogue output which increases as the light intensity increase, the analogue output ranges between 0 and 3V. The operating voltage of this sensor is anywhere between 2.3V and 6V. The GA1A12S202 is priced at £2.80.



[25] *Figure 19 - GA1A2S202 Light Sensor*

Sunlight Sensor Conclusion

The chosen sensor for the application is the GA1A12S202. This sensor has been chosen because it is the cheapest and matches the requirements of the project. The sensor can detect sunlight between 3 and 55000 lux which is a lot lower than the other sensors sourced but from the table found on Wikipedia it shows that anything over 20000 lux is classed as bright sunlight. For the intended application the sensor will only need to determine when the plant is in direct sunlight, cloudy sunlight or darkness. Below shows the specifications of the chosen sensor:

- Power with 2.3-6V
- Onboard 68K load resistor for max 3V analog output
- Lux range 3 lx – 55Klx
- 0.2 grams
- 0.4" x 0.5" x 0.06" (10mm x 13mm x 1.5mm)
- 0.1" (2.5mm) mounting hole
- £2.80

3.2.6. Sensor Research Conclusion

To conclude the sensors chosen for the project and their parameters are shown below:

Sensor Required	Chosen Sensor	Supplier	Cost	Operating Voltage	Analogue or Digital output	Output voltage range
Water valve	Solenoid Valve	Adafruit	£22	12V	Digital Pin required	-
Temperature	Thermistor	RS	£1	3.3V	Analogue	0-3.3V
Humidity	HIH-4000-002	RS	£14.58	4V – 5.8V	Analogue	0.84V – 3.4V
Sunlight	GA1A12S202	Adafruit	£2.80	2.3V – 6V	Analogue	0 – 3V
Soil Moisture	Ground humidity sensor	Light in the box	0.69p	3.3V – 5V	Analogue	0-2.3V

Table 10 – Sensor Research Conclusion

3.3 Investigation - Battery Selection

The automatic plant watering system will be powered by a 12V battery. Powering the system from a mains supply was considered but as it may be used in a green house, or a garage or somewhere it may be difficult to find a mains supply, it was found that a battery would better suit the application. The table below shows the current consumption of the sensors, this will help determine the size of the battery:

Sensor	Current Consumption over 1 hour
Soil Moisture Sensor	20mA
Humidity Sensor	200uA typical supply current
Thermistor	2.4mA
Sunlight Sensor	70uA typical supply current
Solenoid	1.5A – When opened
Total current consumed when valve open	1.70267A
Total current consumed when valve closed	0.02267A

Table 11 – Battery Specification

The total current consumed when the solenoid valve is open is 1.70A, this will only happen two maybe three times a day depending on how quickly the soil will dry up. The main operating current that will be constant when the system is on is 22.67mA. The battery selected needs to be small in size so that it can fit into small enclosure and also be rechargeable so that the user never needs to remove the battery from the enclosure. The battery selected is shown below:

[26]



- Input: DC 12.6V
- Output: DC 12V 4500mAh
- Fit for Security CCTV Camera, cellphone, digital camera, outdoor use etc.
- Comes with 110~240V power adapter (2-flat-pin plug)
- Dimensions: 3.46 in x 2.01 in x 0.75 in (8.8 cm x 5.1 cm x 1.9 cm)
- Weight: 9.45 oz (268g)

Figure 20 – 12V Battery

This battery was found on deal extreme, it is priced at £17.31. The battery is small in size and is rechargeable. It can deliver power up to 4.5Ah, if the solenoid isn't active the battery can run for up to 198.5 hours which is around 8 days, as the solenoid won't be active for very long the predicted life of the battery is 6 - 7 days. This battery will be sufficient for the application.

3.4 Investigation - Enclosure

The enclosure will need to be used to house the battery, the PCB and the sensors apart from the soil moisture sensor which will be outside the enclosure. The main specifications for selection are:

- Needs to be waterproof/splash proof.
- Needs to be small and easily transportable.
- Needs to have a transparent lid for the sunlight sensor to detect light.
- Needs to be able to house the battery and PCB and sensors.
- Needs to be robust and durable – Can't be metal as it may rust.

Based on the specifications the most suitable enclosure found is the peli case. This enclosure is designed to be waterproof and robust. An image of the selected peli case is show below. It has a transparent lid to allow for the sunlight sensor to operate and it is small and easy to transport. The case is fully waterproof put holes will need to be made to allow for connections to the solenoid and the soil moisture sensor. The enclosure will therefore still be splash roof and will still protect the PCB and battery.



[27]

Figure 21 - Enclosure

Internal Dimensions (mm)					External Dimensions (mm)		
A	B	C	D	E	A	B	C
Length	Width	Depth	Lid Depth	Base Depth	Length	Width	Depth
209	108	55	18	37	238	141	67

The dimensions above show that the battery and the PCB will fit comfortably within the enclosure. The Peli case is priced at £22.39, as this seems expensive it is felt that it is worth the money as it matches the criteria and Peli is well known for making hard wearing durable enclosures and offer a life time guarantee.

[34]

3.5 Investigation - Microcontroller Selection

In order for the project to be successful an appropriate microcontroller selection needs to be done. The microcontroller needs to measure 4 analogue input signals (Sunlight, temperature, humidity and soil humidity) it also needs to control the opening and closing of a valve. In order to make a suitable microcontroller selection, the following need to be considered:

- How many pins are required
- How many digital and analogue pins are needed
- How much RAM is needed
- Does it need to have UART, SPI or I2C
- How is the data going to be stored
- The cost of the microcontroller

The points set above give an approximate indication thought needs to take place before a selection can be made. Each sensor selected has been broken down and detailed further below:

Temperature sensor

From the data sheet of the thermistor it shows that the temperature can be detected between -40 and 250 degrees, this give the range of 0 to 290. In order to get an accurate reading the minimum step should be 0.5 degrees, therefor giving 380 steps, which means a minimum resolution requirement of 9 bit. As temperature rises quite slowly the data will only be taken and displayed every 5 minutes. This sensor will need require 1 analogue pin.

Soil Moisture sensor

The humidity of the soil is measured as a percentage and so is measured between 0 and 100%. In order to get an accurate reading it has been decided to go up in steps of 0.1%, therefor between 0 – 100 there will be 1000 steps, this will require a minimum resolution of 10 bit. As the soil moisture is the most critical within the project it is going to be measured and stored every 1 minute but will be displayed as a live feed. The soil moisture sensor will need 1 analogue pin.

Room/outside Humidity sensor

The room/outside humidity is measured in the same way as the soil humidity and will therefore also require a minimum resolution of 10 bits. Humidity is generally linked to temperature, so if the temperature changes the humidity will change, therefore the humidity will be recorded and stored once every 5 minutes to link in with temperature. One analogue pin is needed.

Sunlight/light sensor

The sunlight sensor will detect sunlight between 0 and 55000 lux. Anything close to 100 lux would be considered an accurate reading when measuring the suns intensity, therefore going in 100 lux steps would require a 10 bit resolution as there would be a total of 550 steps. The brightness can change fairly quickly, if used outside then a cloud could pass over, if used inside the lights could be switched of. Therefore a reading is going to be taken and stored every 2 minutes. One analogue pin will also be needed for the light sensor.

The overall sensor requirements for the microcontroller are shown in the table below:

Input/ Outputs	Supply Voltage	Output voltage	Range	Steps	Bit requirement	How often readings are taken	Analogu e/Digital Pin
Light sensor	2.3V – 6V	0v – 3V	0- 55000lux	550 Taken in 100lux steps	10 bits	Every 2 minutes	1 Analogu e pin
Temp sensor	5V	0V -5V	-40 degrees to 250 degrees	580 steps taken in 0.5 degree steps	9 bits	Every 4 minutes	1 Analogu e pin
Soil Moistur e sensor	3.3V – 5V	0-2.3V	0 – 100%	1000 taken in 0.1% steps	10 bits	Every 1 minute	1 Analogu e pin
Humidit y Sensor	4V – 5.8V	0V to 3.2V	0 – 100%	1000 taken in 0.1% steps	10 bits	Every 4 minutes	1 Analogu e
Solenoi d Valve	12V						1 Digital output pin
LCD	5V						7pins

Table 12 – Sensor Specifications

The data is going to be displayed on a program called Tera term, putty or possibly on LabVIEW and the data saved into an excel spreadsheet. In order for this to be possible the data will need to be sent through the RS232, this means the microcontroller will need an additional 2 pins in order to transfer the data. As the microcontroller will also require power this will mean another 2 pins are needed. The program memory size and RAM needed is based on an estimate, this estimate has been made based on the knowledge acquired from other subjects studied. The minimum memory required is 16Kb and the minimum RAM required is 64 bytes.

The clock speed has been calculated based on how often the readings of the sensors are taken, as the longest time waited for a reading is 4 minutes then the total readings taken every 5 minutes needs to be calculated:

- Temperature – once every 4 minutes
- Soil Humidity – 4 times every 4 minutes
- Room Humidity – once every 4 minutes
- Light sensor – 2 times every 4 minutes

Therefore the total readings taken every 4 minutes is 8, so the total readings taken every 1 second is $(8/4)/60=0.033$. If on average it takes 30 instructions on order to take one reading then $0.033 \times 30 = 1$. The clock needs to pulse 4 times for each instruction, so the total clock speed would be 4Hz. As this calculation is a very rough guide it is best to choose a microcontroller with an internal clock much higher than that calculated, also there is information that has not been included in the calculation, therefore the microcontroller needs at least a minimum speed of 1Mhz. by choosing a clock speed much higher than required will also prolong the life of the microcontroller will be prolonged as it will not over exert itself.

3.5.1. Microcontroller Conclusion

From the calculations made the minimum specifications required for selection are:

Minimum Specification Requirements	
Analogue pins	>4
Digital pins	>1
RAM	>64bytes
Programming memory	>16Kb
Clock speed	>1Mhz
Additional Pins	>11
A/D resolution	>10 bit

Table 13 – Minimum Microcontroller Specifications

A search was done on microchip.com [28] to find a suitable microcontroller to suit the requirements. The microcontroller selected is the PIC18F24J50, it was selected as it exceeds all the requirements which will allow for any future developments or any missed calculations, the specifications for the PIC18F24J50 are shown below:

PIC18F24J50 Specifications	
Price	
Memory Size	16Kb
RAM	3800 bytes
Pin count	28
Internal oscillator	8Mhz
A/D Channels	10
A/D resolution	10 bit
Operating voltage	2V - 3.6V

Table 14 – Chosen Microcontroller

3.6 Investigation - RC Filter Network

'An electrical filter is a circuit that can be designed to modify, reshape or reject all unwanted frequencies of an electrical signal and accept or pass only those signals wanted by the circuits designer. In other words they "filter-out" unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency.' [29]

As described in the quote above an RC circuit can be used to eliminate any unwanted noise. There are three different types of filter circuits, low pass filter, high pass filter and band pass filter. A low pass filter will allow any frequency below a certain threshold to pass and anything above the threshold it attenuates the signal. A high pass filter works the opposite to the low pass and allows any frequency above the threshold to pass and attenuates any frequency below the threshold. The band pass filter is a combination of both high pass and low pass filters, it allows a frequency within a certain range to pass and any frequency above or below that range is attenuated. A diagram of the different types of RC networks is shown below:

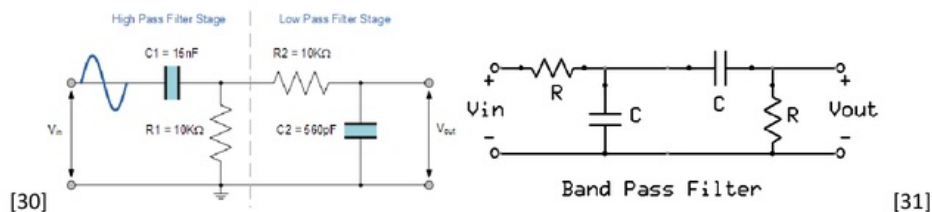


Figure 22 – RC Network Examples

All the sensors used will require an RC filter network in order to eliminate any possible AC noise that may be picked up from in the circuit or from any noisy devices that may be surrounding the circuit. All the sensors data sheets state that they have an analogue output but the frequency of the output is so slow that it could be suggested that they have digital outputs. The frequency of the sensors at an estimated would all be well below 1Hz. Therefore the best choice of RC circuit would be a low pass filter circuit, it would block out any unwanted noise that is above a certain threshold. As mains frequency is 50Hz then the filter circuit would need to ensure it blocks out any frequencies at least above 40Hz. the resistor value chosen is 1kOhm and the capacitance value is 10uf. These values have been chosen as they were used in a previous design and were satisfactory. The formula used to calculate the frequency cut-off threshold is:

$$F_c = 1 / (2\pi R C)$$

$$F_c = 1 / (2\pi \times 1000 \times 0.000010)$$

$$F_c = 15.92 \text{ Hz 2.d.p}$$

The cut off frequency calculated is roughly 16Hz which would be sufficient for the application, it would eliminate any possible mains noise and would limit any potential noise that may be surrounding the circuit. This RC circuit will be implemented into the final design and will be on the output of all the sensors being used.

Chapter 4 Implementation – Sensor Testing

In order to ensure the sensors are operating correctly, they will be tested using an Arduino board and a program called LabVIEW. 'LabVIEW is a highly productive development environment for creating custom applications that interact with real-world data or signals in fields such as science and engineering' [32]. The LabVIEW program will allow the data being sent from the sensors to be display in a graph in real time and will save the data into an excel spreadsheet with a time stamp against each reading. A print screen of the program written in LabVIEW is shown below:

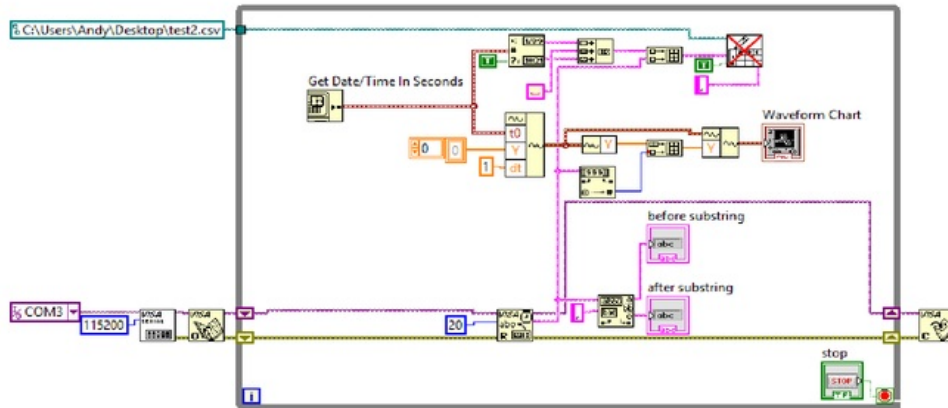


Figure 23 – LabVIEW Software Design Print Screen

The data is being seen coming through COM port 3 and the baud rate is set to 115200 as that is the baud rate that the Arduino board is set to. The VISA then reads the number of bytes being sent from the Arduino and returns the data in read buffer, the data is then timestamped according to the time and date that is set on the computer and then displayed in a waveform chart and also printed into an excel spreadsheet where the data is then stored.

A simple Pseudo code is written for the Arduino board, in order for the Arduino board to communicate with the sensor and send the data to the PC. This is shown below:

```

void setup() {
  Serial.begin(115200);
  pinMode(A0,INPUT);
}

void loop() {
  float variable=analogRead(A0);
  Serial.print(variable);
}
  
```

The 'void setup' sets the baud rate and sets pin A0 as an analogue input, the data is then read and printed to the serial port. This code will be sufficient for gathering sensor data.

4.1 Soil Moisture Sensor Test

The soil moisture sensor was connected to the Arduino board as shown in the picture below. The data sheet of the soil sensor specifies that it requires a 5V supply voltage in order for it to work effectively. This sensor is being powered from the Arduino board as it provides a 5V output from the USB.

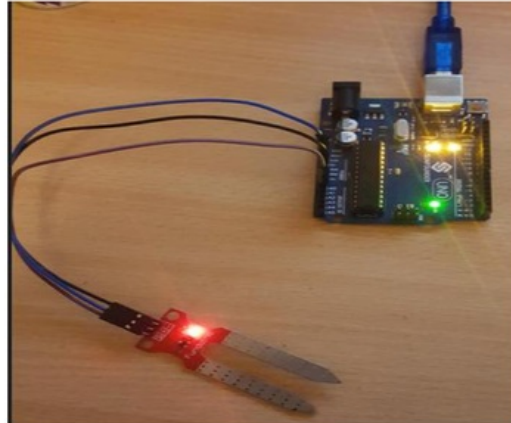


Figure 24 – Print Screen – Soil Moisture Sensor Test

The data sheet of the sensor also specifies that the output voltage is between 0 and 2.3V (2.3V when the sensor is fully submerged in water). The Arduino analogue inputs are 10 bit which is the same as the microcontroller that has been chosen but the voltage of the input works between 0 and 5V whereas the microcontroller will work between 0 and 3.3V. Therefore the expected values that should be displayed from the sensor through the Arduino board will be between 0 and 470.58 bits. The calculation for this is shown below:

$$1023 \text{ bits} / 5 = 204.6$$

$$204.6 \times 2.3 = 470.58$$

The print screen of the graph below shows the output of the sensor when it is powered and not submerged in water:

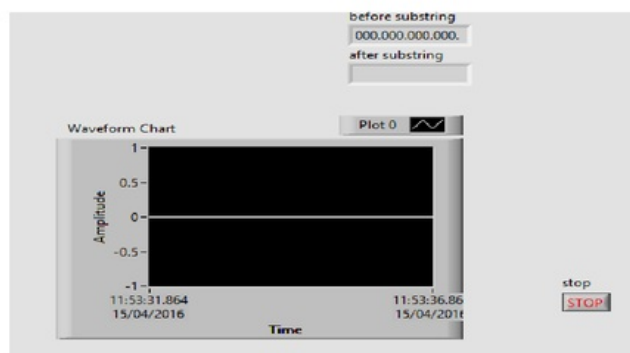


Figure 25 – Print Screen – Soil Moisture Sensor Results 1

As expected there are 0 bits being received as the sensor has no contact to any moisture.

The graph below shows the output of the sensor when it is fully submerged in water:

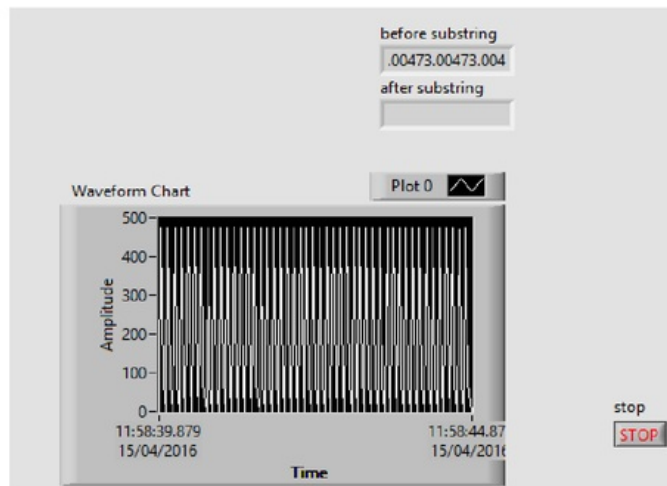


Figure 26 – Print Screen – Soil Moisture Sensor Results 2

As can be seen from the graph the sensor works correctly and as predicted the maximum bits being received when the sensor is fully submerged is between 470 and 480 bits, this means that the output voltage of the sensor is between 2.3V and 2.4V. A snapshot of the data stored in excel has been shown below:

	A	B	C	D
1	15/04/2016 11:59	1.00480.00480.00479.		
2	15/04/2016 11:59	00480.00480.00480.00		
3	15/04/2016 11:59	480.00480.00480.0048		
4	15/04/2016 11:59	0.00480.00480.00480.		
5	15/04/2016 11:59	00480.00480.00480.00		
6	15/04/2016 11:59	481.00480.00480.0048		
7	15/04/2016 11:59	0.00479.00480.00480.		
8	15/04/2016 11:59	00480.00479.00480.00		
9	15/04/2016 11:59	480.00480.00477.0048		
10	15/04/2016 11:59	0.00480.00479.00480.		
11	15/04/2016 11:59	00479.00480.00480.00		
12	15/04/2016 11:59	480.00480.00480.0048		
13	15/04/2016 11:59	0.00480.00480.00480.		
14	15/04/2016 11:59	00481.00481.00480.00		
15	15/04/2016 11:59	480.00479.00480.0048		

Figure 27 – Print Screen – Soil Moisture Sensor Results 3

As the sensor is slowly removed from the water it can be seen in a print screen of the data below that the values start to descend, showing that the sensor can determine between high volumes of moisture and low volumes:

	A	B	C		
1008	15/04/2016 11:59	281.00280.00279.0028		1027	15/04/2016 11:59 5.00235.00233.00232.
1009	15/04/2016 11:59	0.00280.00282.00280.		1028	15/04/2016 11:59 00231.00230.00228.00
1010	15/04/2016 11:59	00281.00280.00279.00		1029	15/04/2016 11:59 226.00224.00222.0022
1011	15/04/2016 11:59	277.00274.00272.0027		1030	15/04/2016 11:59 5.00220.00217.00214.
1012	15/04/2016 11:59	1.00269.00268.00267.		1031	15/04/2016 11:59 00212.00210.00209.00
1013	15/04/2016 11:59	00266.00263.00264.00		1032	15/04/2016 11:59 209.00209.00207.0020
1014	15/04/2016 11:59	263.00260.00257.0025		1033	15/04/2016 11:59 3.00198.00192.00187.
1015	15/04/2016 11:59	5.00252.00249.00247.		1034	15/04/2016 11:59 00183.00177.00176.00
1016	15/04/2016 11:59	00245.00246.00247.00		1035	15/04/2016 11:59 171.00168.00162.0015
1017	15/04/2016 11:59	248.00249.00250.0024		1036	15/04/2016 11:59 4.00151.00148.00145.
1018	15/04/2016 11:59	9.00248.00245.00243.		1037	15/04/2016 11:59 00140.00140.00136.00
1019	15/04/2016 11:59	00241.00237.00242.00		1038	15/04/2016 11:59 132.00129.00125.0012
1020	15/04/2016 11:59	242.00244.00245.0024		1039	15/04/2016 11:59 4.00123.00121.00121.
1021	15/04/2016 11:59	6.00247.00247.00247.		1040	15/04/2016 11:59 00116.00107.00094.008
1022	15/04/2016 11:59	00245.00245.00245.00		1041	15/04/2016 11:59 1.0068.0055.0036.000
1023	15/04/2016 11:59	245.00246.00244.0024		1042	15/04/2016 11:59 .000.000.000.000.000
1024	15/04/2016 11:59	4.00243.00241.00238.		1043	15/04/2016 11:59 .000.000.000.000.000
1025	15/04/2016 11:59	00237.00236.00235.00			
1026	15/04/2016 11:59	235.00234.00235.0023			

Soil Moisture Test Conclusion

The soil moisture sensor works as per data sheet and is clear to see from the results that the output voltage does work within 0 – 2.3V. This therefore means that because the microcontroller analogue input is between 0 – 3.3V the output of the sensor will need to be amplified in order to get the full range of bits available and to make the programming easier.

To increase the output voltage a non-inverting operational amplifier is used. The calculation needed to get the correct gain is:

$$V_{out} = V_{in} \times (1 + R_2/R_1)$$

As V_{out} needs to equal 3.3V, to calculate the resistor values needed the equation is rearranged:

$$(V_{out}/V_{in}) - 1 = R_2/R_1$$

$$(3.3/2.3) - 1 = 0.43$$

Therefore the resistor values chosen are:

$$R_2 = 220\Omega \text{ and } R_1 = 500\Omega \text{ as } 220/500 = 0.44$$

The circuit was designed and tested on Proteus and is shown below, this circuit will be integrating into the final design and the output of the op amp will be connected to the analogue input of the microcontroller.

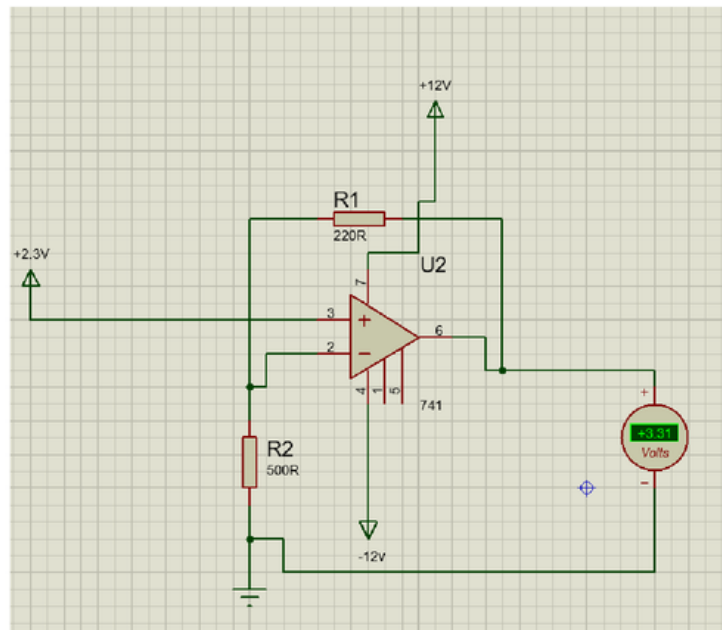


Figure 28 – Print Screen – Soil Moisture Circuit Design

4.2. Sunlight Sensor Test

The sunlight sensor was connected to the Arduino board in the same way as the soil moisture as it also requires a 5V supply. A picture of the connection is shown below.

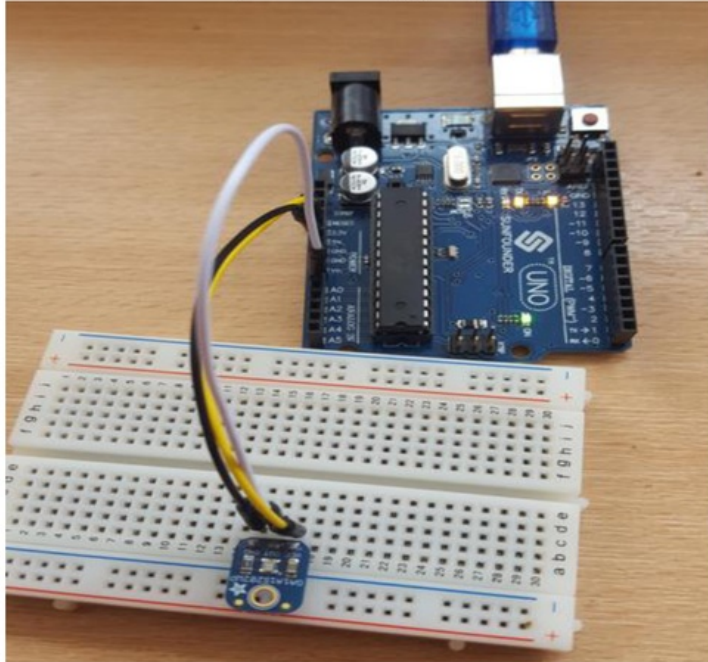


Figure 29 – Photo of Sunlight Sensor - Arduino

The data sheet states that the output voltage of the sensor ranges between 0 and 3V (3V being bright sunlight). Therefore the maximum bits which will be received through the Arduino board will be 613 bits. The sensor was covered by a box to simulate complete darkness and the results are shown below:

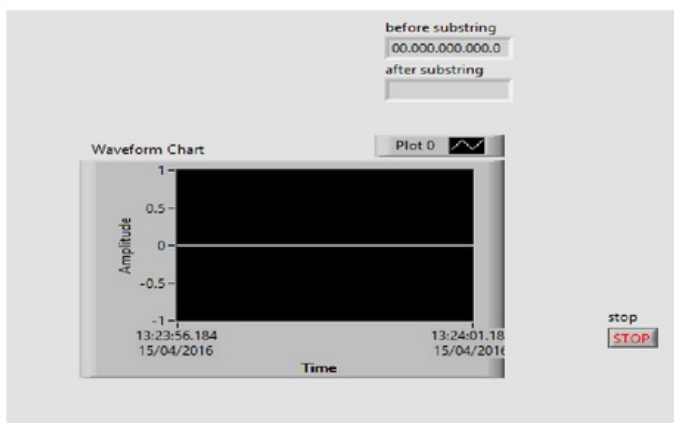


Figure 30 – Print Screen – Sunlight Sensor Results 1

As expected 0 bits of data are being received, proving that the sensor is in complete darkness and will not output any voltage.

The graph shown below is data being received from the sensor when there is bright sunlight, this I simulated by placing a bright light above the sensor:

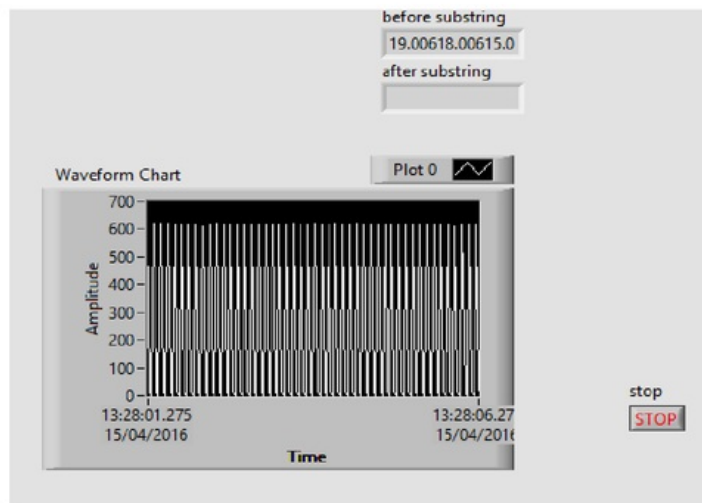


Figure 31 – Print Screen – Sunlight Sensor Results 2

The maximum bits being receive is between 610 and 620, showing that there is approximately 55000 lux of light being detected. The data which was stored in the excel spread sheet is shown below. The maximum sunlight being detected on the day of testing was 426 bits which equates to around 37,390 lux.

15/04/2016 13:34	.00619.00619.00619.0
15/04/2016 13:34	0620.00621.00623.006
15/04/2016 13:34	21.00618.00623.00620
15/04/2016 13:34	.00621.00619.00622.0
15/04/2016 13:34	0620.00620.00621.006
15/04/2016 13:34	20.00620.00620.00622
15/04/2016 13:34	.00622.00619.00618.0
15/04/2016 13:34	0619.00621.00620.006
15/04/2016 13:34	21.00621.00618.00620
15/04/2016 13:34	.00622.00614.00617.0
15/04/2016 13:34	0621.00620.00620.006
15/04/2016 13:34	21.00623.00620.00619
15/04/2016 13:34	.00620.00620.00618.0
15/04/2016 13:34	0620.00620.00619.006
15/04/2016 13:34	20.00620.00619.00622
15/04/2016 13:34	.00619.00620.00614.0
15/04/2016 13:34	0619.00619.00618.006
15/04/2016 13:34	18.00621.00620.00619
15/04/2016 13:34	.00620.00620.00622.0
15/04/2016 13:34	0621.00620.00621.006
15/04/2016 13:34	20.00619.00620.00620
15/04/2016 13:34	.00620.00619.00619.0
15/04/2016 13:34	0620.00622.00620.006
15/04/2016 13:34	21.00622.00618.00620
15/04/2016 13:34	.00620.00617.00619.0
15/04/2016 13:34	0619.00621.00621.006
15/04/2016 13:34	19.00619.00619.00622
15/04/2016 13:34	.00621.00621.00620.0
15/04/2016 13:34	0620.00619.00620.006

Figure 32 – Print Screen – Sunlight Sensor Results 3

Sunlight Sensor Test Conclusion

The sunlight sensor test was successful in proving that the sensor worked and the data sheet was correct. To step the voltage output from the sensor up to get the full sampling bit range, an operational amplifier will be used. The same formula and method used for calculating the output of the soil sensor will be used again:

$$V_{out} = V_{in} \times (1 + R_2/R_1)$$

$$(V_{out}/V_{in}) - 1 = R_2/R_1$$

$$(3.3/3) - 1 = 0.1$$

Therefore from this calculation the resistor values chosen are, $R_2=100\text{ Ohm}$ and $R_1=1\text{K Ohm}$. The circuit was designed and proven on Proteus and is shown below:

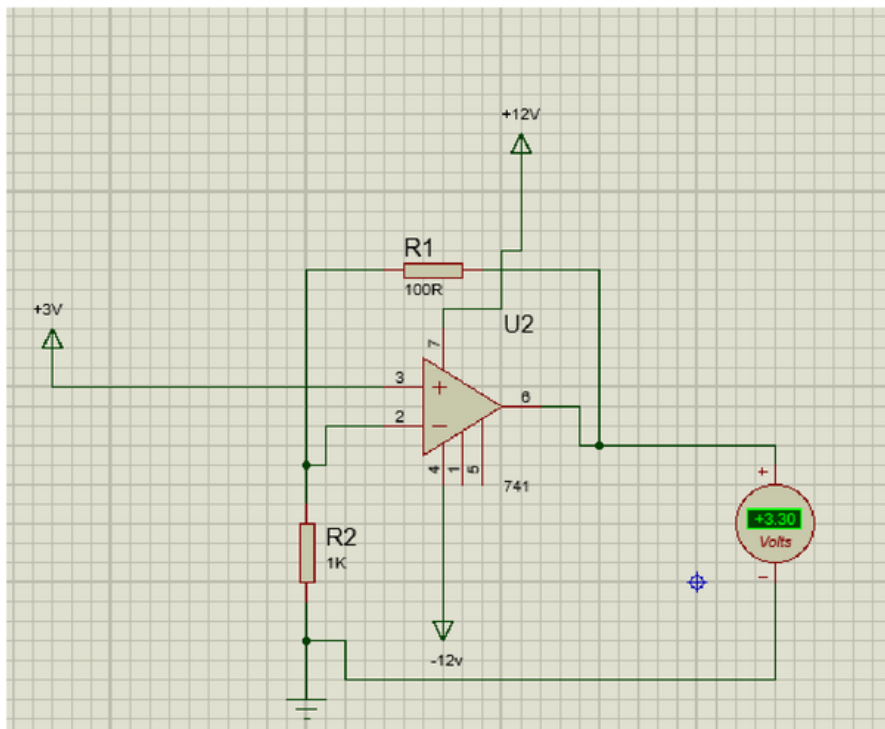


Figure 33 – Print Screen – Sunlight Sensor Circuit Design

This circuit is going to be implemented into the main design as per the soil moisture circuit. This will now give the full range output of between 0 and 3.3V making the results more accurate and giving a bigger sampling range.

4. 3. Humidity Sensor Test

The humidity sensor was connected to the Arduino board as seen in the photo below. The data sheet of the sensor specifies that its operating voltage is 5V and the output voltage is between 0 and 3.4V. Therefore with the Arduino board the maximum humidity shown in bits would be 695.64.



Figure 34 – Photo of Humidity Sensor - Arduino

When testing the sensors it was realised that it is not possible to get the maximum or minimum output from the sensor without the use of a humidity chamber. Therefore the test can only display what the possible humidity is at the time of the test. The results are shown

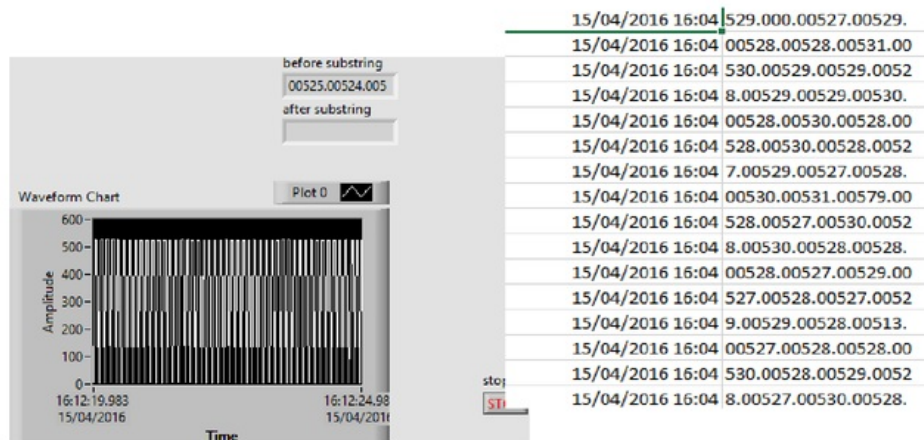


Figure 35 – Print Screen – Humidity Sensor Results 1

The graph shows that the sensor is operating and does give out an output voltage. It gives a constant stream of data of between 520 and 530 bits, which calculates to be around 75% humidity.

Humidity Sensor Test Conclusion

The results of the humidity sensor test determined that the sensor does operate but due to lack of correct testing equipment precision testing cannot be performed and the minimum and maximum data cannot be acquired.

As the test cannot be accurate, then it has to be assumed that the data sheet is correct and that the voltage output does range between 0 and 3.4V. Based on this information there is no need to amplify or reduce the output voltage as the microcontroller analogue input ranges between 0 and 3.3V. If the humidity sensor was to reach its maximum output then it would chop the signal losing 0.1V which is 30.09 bits of data which equates to around 3%, therefore making the sensor only accurate up to 97% which would be more than suitable for the purpose of its application.

To conclude the only additional circuitry required on the output of the humidity sensor will be an RC network to eliminate any possible AC noise.

4.4. Temperature Sensor Test

The thermistor temperature test is difficult to do using the Arduino board as it needs a 3.3V supply and the board cannot supply this, so the test is going to be simulated on Proteus to prove the calculations are correct.

For the thermistor to act correctly it needs to be placed in series with a fixed resistor therefore creating a voltage divider circuit. This will allow the voltage to change as the thermistor resistance increases or decreases depending on the temperature. By calculating the thermistors resistance at 0 degrees and placing a fixed value resistor in series the output voltage can be determined. The temperature can then be calculated using the change in voltage. The following formula will determine the thermistors resistance at 0 degrees and calculate the output voltage:

$$R_{new} = R_0 \cdot \exp\left(-B \cdot \left(\frac{1}{273 + T_{ref}} - \frac{1}{273 + T_{new}}\right)\right)$$

The beta value for the thermistor was found on the data sheet. By inputting the relevant information into an online calculator (shown below) which was found on the internet [32]. The resistance value of the thermistor at 0 degrees is 368639 Ohms. A 32Kohm Resistor was used as a reference point by also putting this into the calculator it gives out an expected output voltage of 0.26V:

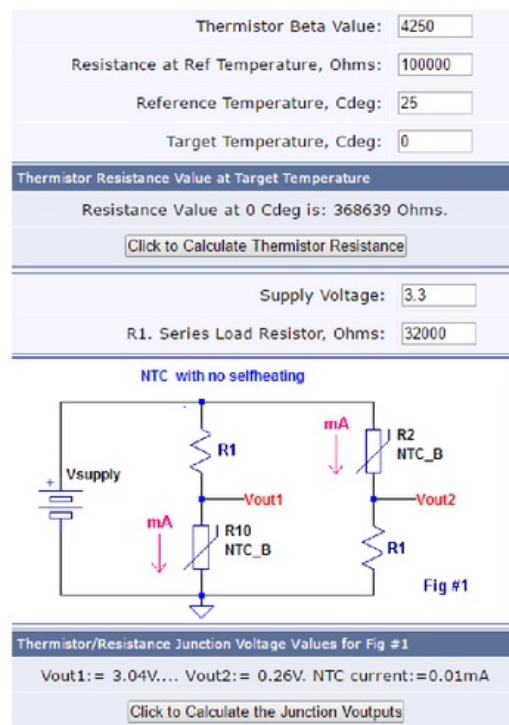


Figure 36 – Print Screen – Thermistor Calculator

Temperature Sensor Conclusion

The theory shown on the previous page was used to draw a circuit in Proteus to test and prove that the output voltage is the same as what was calculated. This is shown in the print screen below:

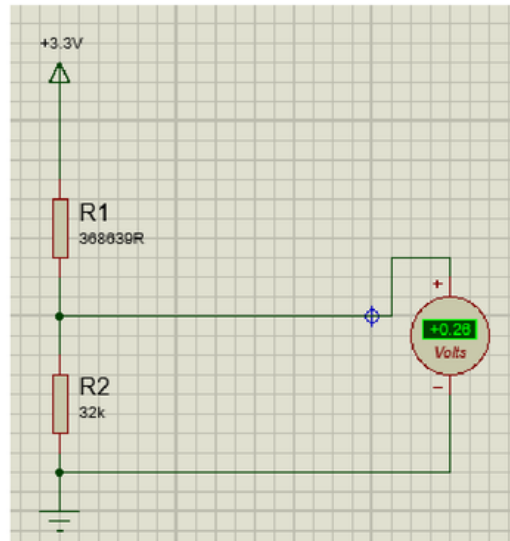
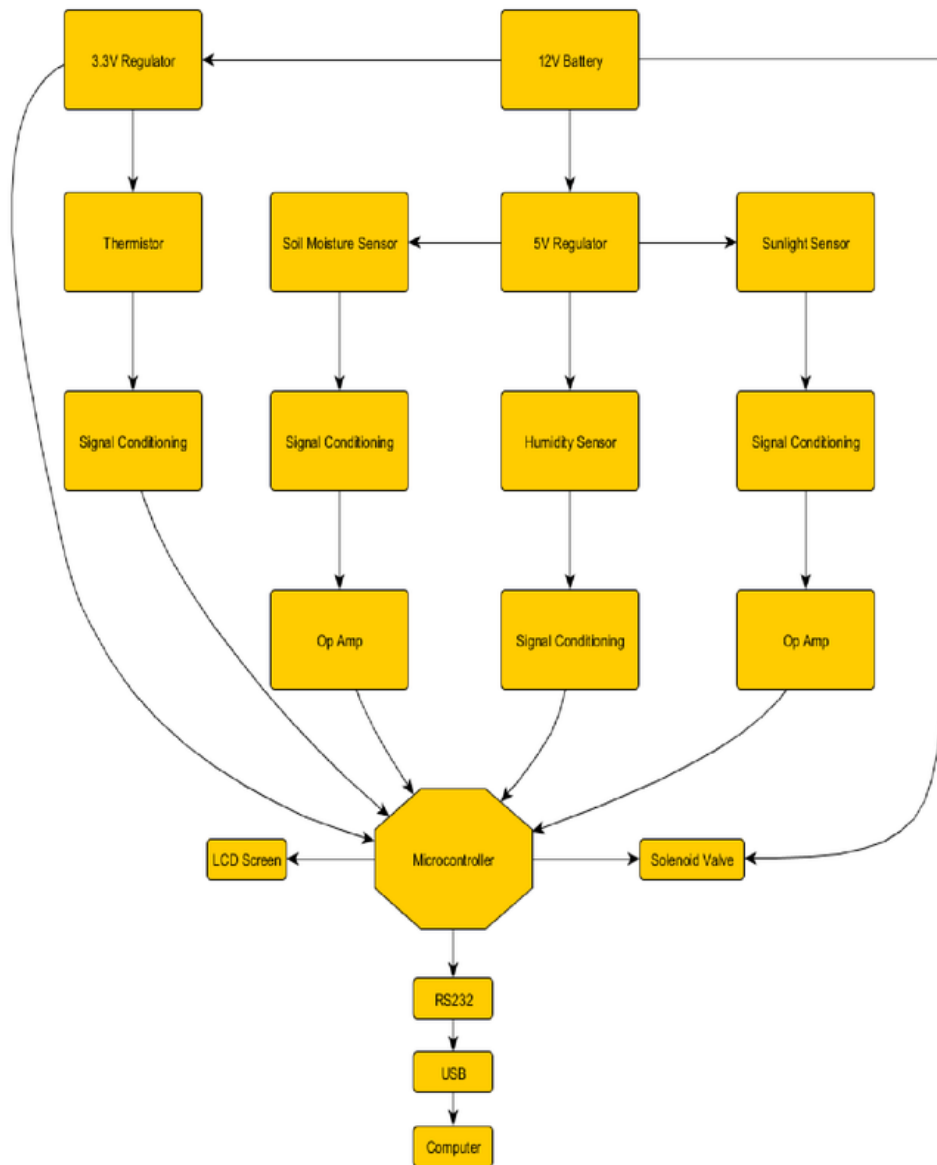


Figure 37 – Print Screen – Thermistor Circuit Design

R1 is the resistance of the thermistor at 0 degrees and R2 is the fixed resistor. As can be seen from the print screen the output voltage is the same as what was calculated thus proving the equation was correct. This circuit will be used in the main design and will be tested in the prototype build.

Chapter 5 - Design – PCB Structure Diagram

Using the results obtained from the sensor test a structure diagram of the circuit design was established, this is shown below:



5.5.1 PCB Schematic Design

The below image is a print screen of the design done on Proteus, the original file can be found in the appendix:

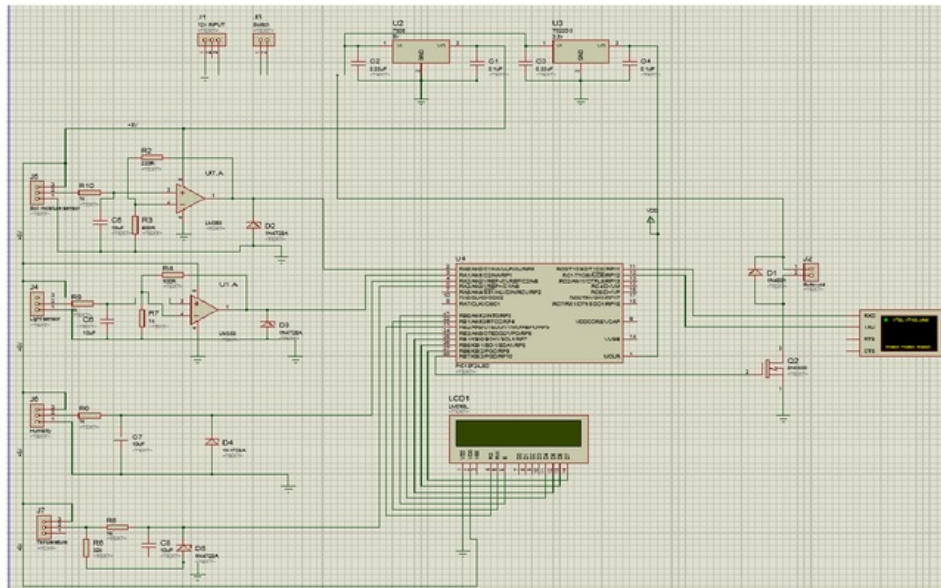


Figure 38 – Main Circuit Design

As you can see the design follows the flow chart. The 12V supplied by the battery is plugged onto J1 header, the 12V then goes through an on/off switch which is connected to J3. The 12V is then stepped down using a 5V regulator, the regulator not only steps the voltage down to 5V but also maintains a constant 5V, this is used to power the sensors and the LCD screen. A 12V supply is also connected to a 3.3V regulator in order to step the voltage down to 3.3V to power the microcontroller and put voltage across the thermistor. The final 12V line is used to power the solenoid, which will be connected to J2.

From the results of testing the sensors it was clear that the sunlight sensor and soil moisture sensors signals needed to be amplified. This has been done by using an op amp, please refer back to soil moisture and sunlight sensor testing for explanation on the amplification circuit.

The 1kOhm resistor and 10uF capacitor, as explained previously, is used to filter any unwanted frequency. It has a cut off threshold of 16Hz.

Each sensor output also has a 3.3V Zener diode between the output and ground, this is there to protect the microcontroller from any voltage spikes, and the Zener diode will eliminate any voltages seen above 3.3V. There is also a Zener diode placed across the positive and negative terminal of the solenoid valve, it is usually known as a fly back diode, it allows the electro-magnetic field in the coil to safely dissipate, preventing any possible back emf.

The Mosfet is used to switch the solenoid valve on when Pin B7 goes high.

The power and ground pins are hidden on the schematic but there will be a capacitor between the power and ground pins as specified in the PIC18F24J50 data sheet.

5.5.2 PCB Design on Easy PC

Once the schematic design was done on Proteus, it was then re-done on easy PC. Easy PC is software that allows a user to design a schematic with ease and design a PCB layout. The advantage with Easy PC is that it allows you to see the final design in a 3D image. A user's guide to Easy PC can be found in the appendix. Below are print screens of the final layout design, the design can also be found in the appendix labelled 'Easy PC Design'.

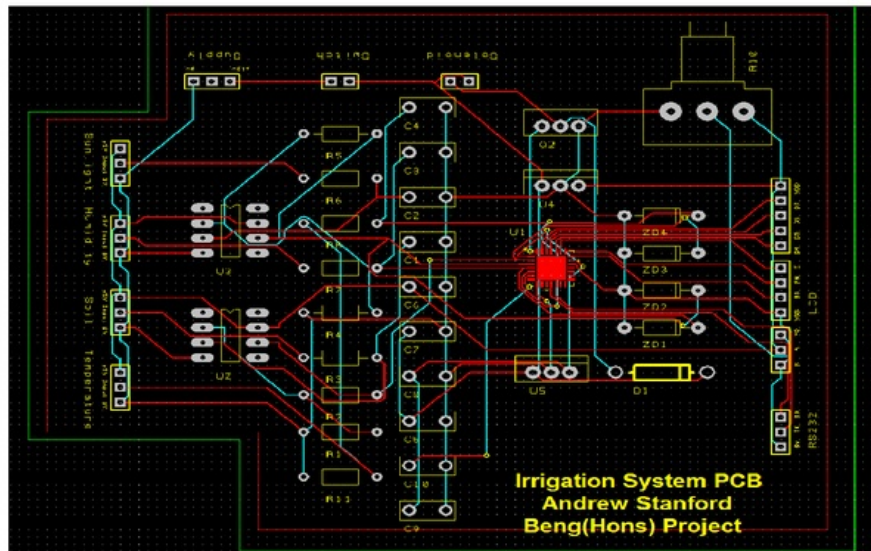


Figure 39 – Easy PC Schematic

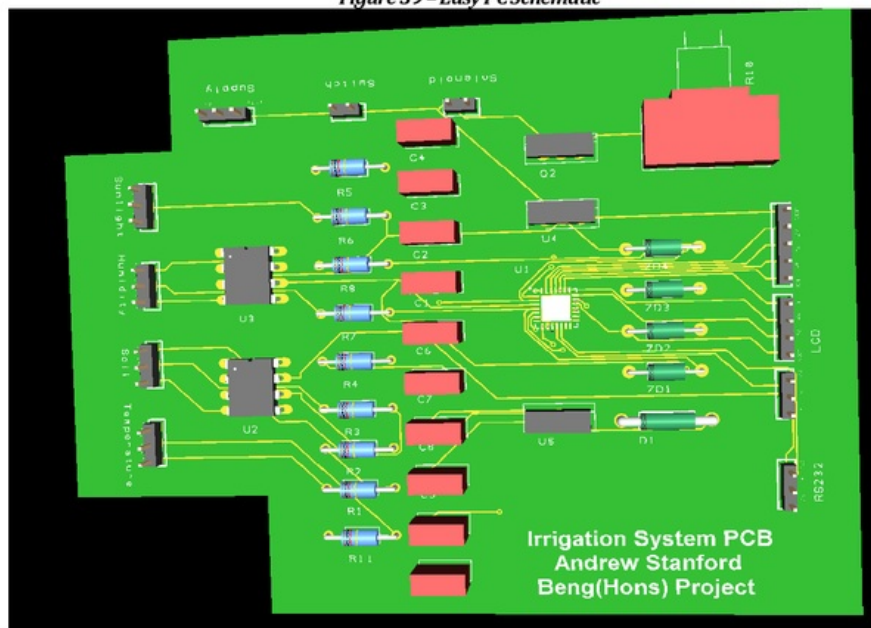


Figure 40 – Easy PC Board Layout

5.5.3 Parts List

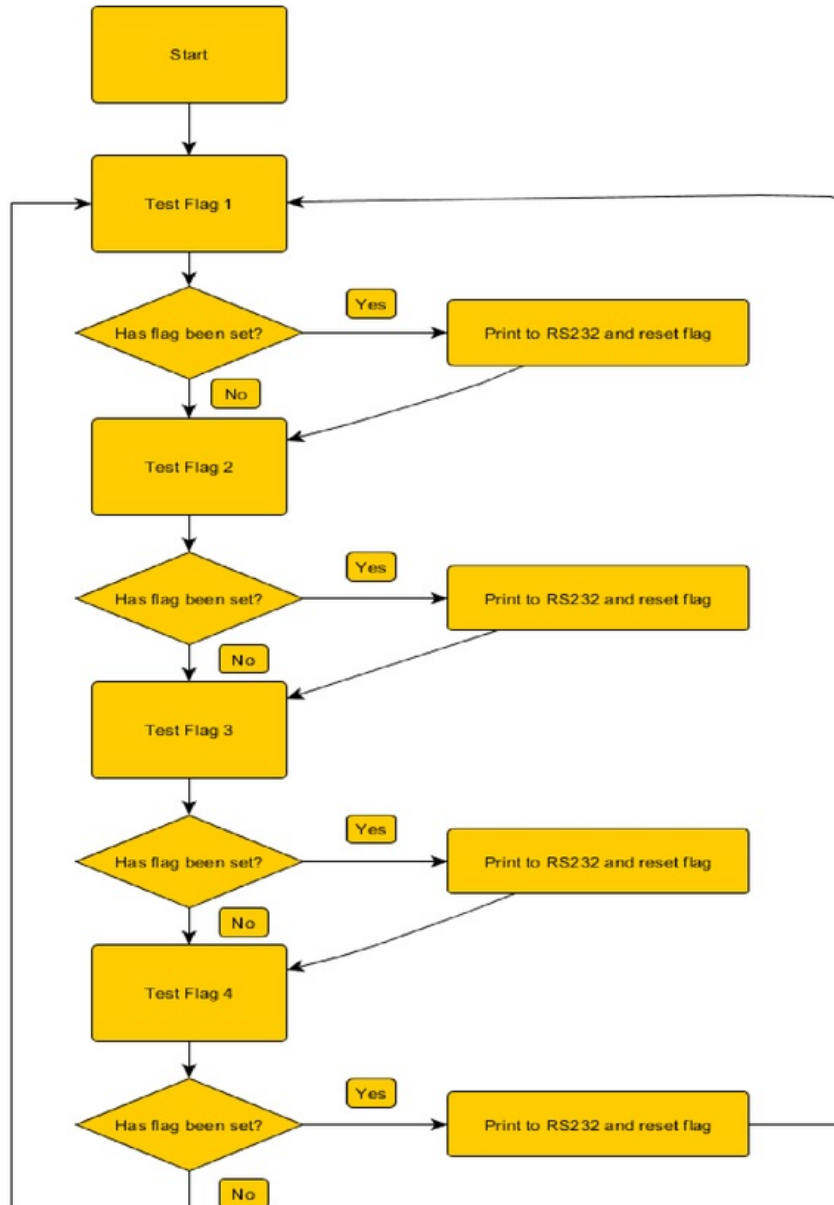
The parts required, supplier information and cost are shown below:

Part	Quantity	Supplier	Supplier PN	Price for 1	Total Price
Solenoid Valve	1	Adafruit	-	£22.00	£22.00
Soil Moisture Sensor	1	MinInTheBox	-	£2.09	£2.09
Humidity Sensor	1	Farnell	1187548	£17.50	£17.50
Thermistor	1	RS	198-961	£1.00	£1.00
Sunlight Sensor	1	Adafruit	1384	£2.80	£2.80
10uf Capacitor	4	RS	224-4325	£0.22	£0.88
0.1uf Capacitor	2	RS	721-5256	£0.08	£0.16
0.33uf Capacitor	2	RS	721-5274	£0.38	£0.76
1Kohm Resistor	5	RS	214-1131	£0.17	£0.85
100ohm Resistor	1	RS	148-269	£0.02	£0.02
220ohm Resistor	1	RS	148-348	£0.02	£0.02
500ohm Resistor	1	RS	849-8997	£0.88	£0.88
32Kohm Resistor	1	RS	701-7875	£0.45	£0.45
3.3V Zener diode	4	RS	544-3531	£0.07	£0.28
Protection Diode	1				
5V Regulator	1	RS	843-1566	£0.41	£0.41
3.3V Regulator	1				
Op Amp	1	RS	759-9392	£0.21	£0.21
Mosfet	1				
LCD Screen	1	Rapid Online	57-2226	£5.54	£5.54
PIC18F24J50	1	RS	666-9920	£2.19	£2.19
12V Battery	1	DX	80405	£17.31	£17.31
Total					£75.35

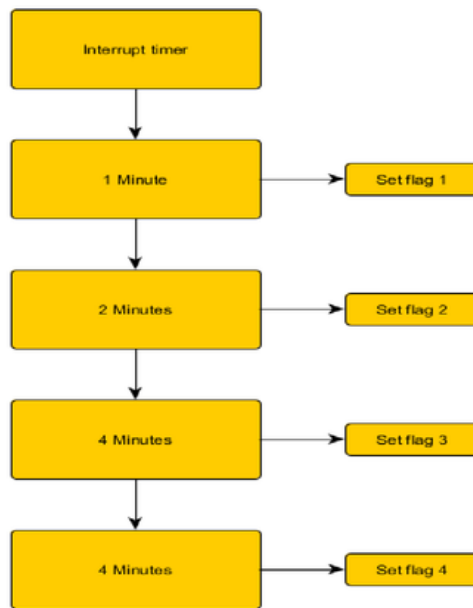
5.6 Design – Program Structure Diagram

The following flow charts give a breakdown of the microcontroller program. The structure diagram helps show what the program needs to achieve and will be useful when writing the program:

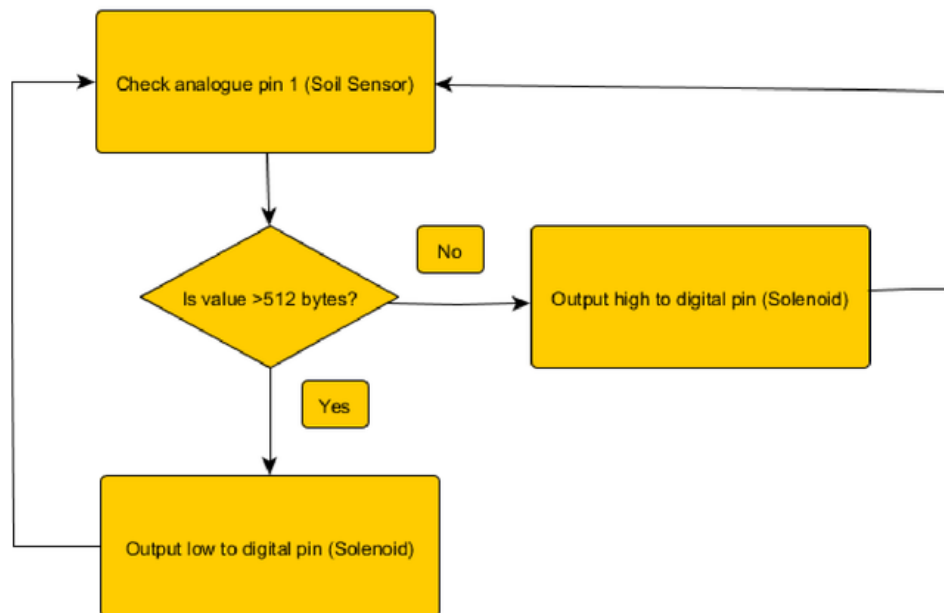
5.6.1 Main Program



5.6.2 Interrupt Timer



5.6.3 If statement



5.7 Design – Program

The following program was written on CCS and then tested on Proteus.

```
#include <main.h>

unsigned long int adc_value[4];
int channel=0,flag=0;

#INT_RTCC
void RTCC_isr(void)
{
    adc_value[channel] = read_adc(ADC_START_AND_READ); // read the adc for channel
    channel++;
    if (channel>3) {channel=0;flag=1;}
    set_adc_channel(channel); //set to read channel next channel
}

void main()
{
    int16 adc_value0,adc_value1,adc_value2,adc_value3;
    float SoilMoisture0, SoilMoisture1, Sunlight1, Humidity2, Temperature3;
    int i,secsoil=0,sectemp=0,sechumid=0,seclight=0;
    setup_adc_ports(SAN3|SAN2|SAN1|SANO);
    setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0);
    setup_timer_0(RTCC_INTERNAL|RTCC_DIV_16); //262 ms overflow
    set_adc_channel(0); //set to read channel a0 next
    delay_us(30);
    enable_interrupts(INI_RTCC);
    enable_interrupts(GLOBAL);
    lcd_init();

    // #include <lcd.c>

    while(TRUE)
    {
        if(flag)
        {
            flag=0;
            secoil++; //increment the seconds count
            seclight++;
            sechumid++;

            if(secoil==5) // 5 secs
            {
                secoil=0;
                SoilMoisture0 = (float)((adc_value[0])*5)/1023.0*20;
                printf(lcd_putc, "\f\n\r Soil: %3.2f",SoilMoisture0);
                printf("\n\r Soil: %3.2f",SoilMoisture0);
            }

            if(seclight==20) // 20 secs
            {
                seclight=0;
                Sunlight1 = (float)(adc_value[1])*53.76;
                printf("\n\r Sunlight: %3.2f",Sunlight1);
            }

            if(sechumid==20) // 20 secs
            {
                sechumid=0;
                Humidity2 = (float)((adc_value[2])*5)/1023.0*20;
                printf("\n\r Humidity: %3.2f",Humidity2);
            }

            if(sectemp==20) // 20 secs
            {
                sectemp=0;
                Temperature3 = (float)(adc_value[3]/3.53) -40;
                printf("\n\r Temperature: %3.2f",Temperature3);
            }
        }
    }

    ////////////////////////////////////////////

    if (adc_value[0]<512)
        output_high(PIN_B7);
    else
        output_low(PIN_B7);
}
```

Figure 41 – Print Screen – First Program

The program written on the previous page, is a test program and the data is therefore being printed every few seconds instead of in minutes. The program was tested using Proteus, and the results are shown below. The first print screen shows the program operating with the data being printed onto a virtual terminal, the soil moisture content is above 50% and so the solenoid valve is in the closed position, this is simulated using an LED. The second print screen shows the soil moisture content below 50% and so the solenoid is in the open position, as can be seen the LED is illuminated:

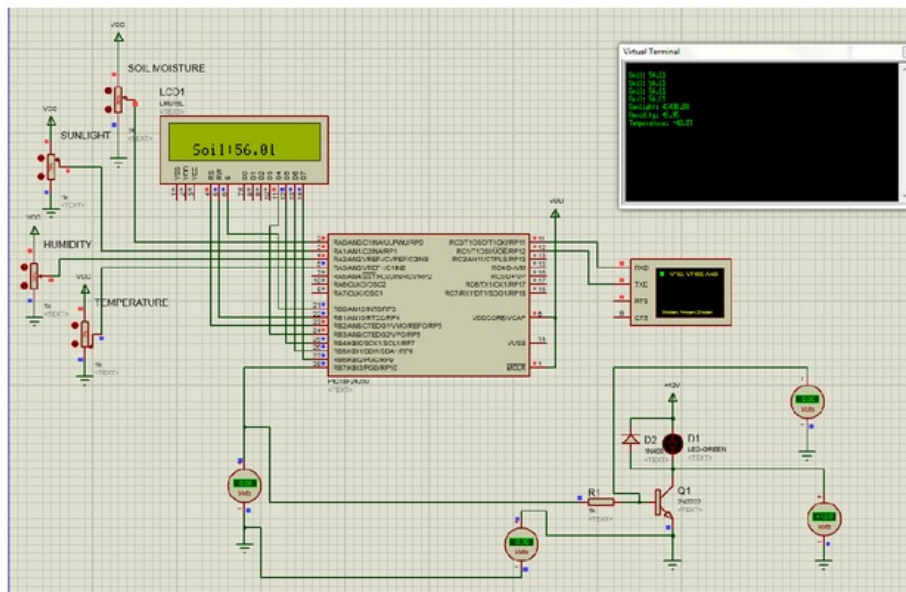


Figure 42 – Print Screen – Circuit Design for Testing Program 1

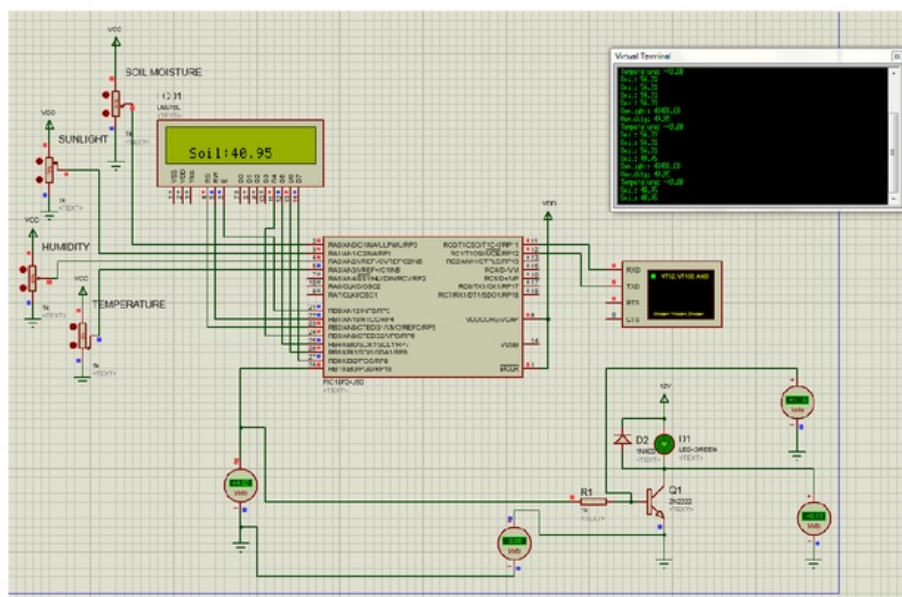


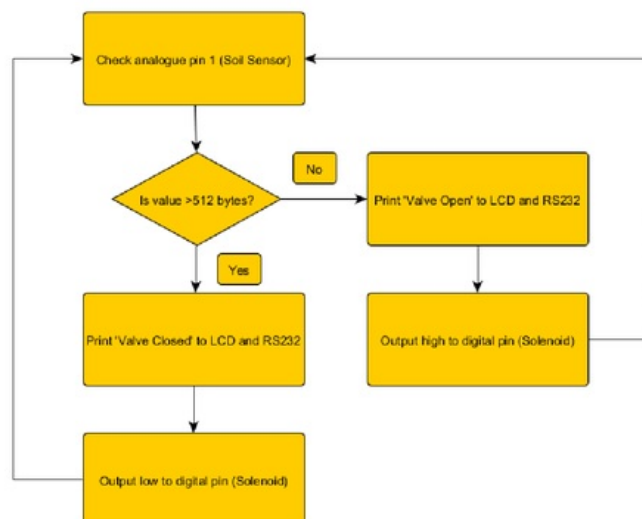
Figure 43 – Print Screen – Circuit Design for Testing Program 1

5.7.1 Explanation/Conclusion of First Design

The program that was written follows the flow chart. The first initial part of the code sets up the ADC channels to start and read them. The timer is also set at this stage. When secsoil reaches 5 seconds the data is printed to the RS232 and then the flag is reset to 0 and the count begins again. This happens for all the sensors at different times depending on what is set. This will continue to loop until the system is turned off. The secsoil data is also sent to the LCD screen and is refreshed every 5 seconds. The mathematical equations put in place are there to change the input bit data into a more readable value so the user understands what he/she is seeing. The equations are different for each sensor as the soil moisture needs to read between 0 – 100%, the sunlight sensor needs to read between – 55000 lux, the temperature needs to read between -40 and 250 degrees and the humidity sensor, like the soil moisture, also needs to read between 0 – 100%.

The IF statement towards the bottom of the program is there to turn the solenoid off and on. If the soil moisture value being read into analogue pin 1 reads less than 512 bits, or 50%, then output high to pin B7, if the Pin reads greater than 512 bits then it outputs low to pin B7.

This program worked successfully as it was designed to but after seeing the program and testing it, it was realised by the Author that it could be improved. The LCD screen printed the data every 5 seconds, which was fine for the test program but when the data is printed every 1 minute there would be a 1 minute delay on the LCD, whereas it would be better to show a live feed. Also when the data is printed there is no indication to show that the solenoid valve is on or off without assuming that it did activate when the soil moisture was below 50%. From a user's point of view he/she may want to monitor how often the plant is watered and for how long the solenoid valve was open for, therefore changes needed to be made to the program to implement these new findings. The IF statement needs to be changed to match the new structure diagram shown below:



5.7.2 Program 2

The following program is the new program showing the changes that have been made best on the previous analysis:

```
main.c main.h
1 #include <main.h>
2
3 unsigned long int adc_value[4];
4 int channel=0,flag=0;
5
6 #INT_RTCC
7 void RTCC_isr(void)
8 {
9     adc_value[channel] = read_adc(ADC_START_AND_READ); // read the adc for channel
10    channel++;
11    if (channel>3) {channel=0;flag=1;}
12    set_adc_channel(channel); //set to read channel next channel
13 }
14
15 void main()
16 {
17     int16 adc_value0,adc_value1,adc_value2,adc_value3;
18     float SoilMoisture0, Sunlight1, Humidity2, Temperature3;
19     int i,seccoil=0,sectemp=0,sechumid=0,seclight=0;
20     short int high_flag=1;
21     setup_adc_ports(&AN3,&AN2,&AN1,&AN0);
22     setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0);
23     setup_timer_0(RTCC_INTERNAL|RTCC_DIV_16); //262 ns overflow
24     set_adc_channel(0); //set to read channel a0 next
25     delay_us(30);
26     enable_interrupts(INT_RTCC);
27     enable_interrupts(GLOBAL);
28     lcd_init();
29     unsigned int count;
30
31
32     while(TRUE)
33     {
34
35         if(flag)
36         {
37             flag=0;
38             seccoil++; //increment the seconds count
39             seclight++;
40             sechumid++;
41             sectemp++;
42
43             SoilMoisture0 = (float) (((adc_value[0])*5)/1023.0)*20; // show moisture content between 0 - 100%
44             lcd_gotoxy(1,1);
45             printf(lcd_putc, "Soil: %3.2f",SoilMoisture0); // Print data to LCD screen
46
47             if(seccoil==4) // print to RS232 every 4 seconds
48             {
49                 seccoil=0;
50                 PRINTF("\n\rSoil: %3.2f",SoilMoisture0); // reset flag
51                 // PRINT TO RS232
52             }
53
54             if(seclight==20) // print to RS232 every 20 Seconds
55             {
56                 seclight=0;
57                 Sunlight1 = (float)(adc_value[1])*55.76; // reset flag
58                 printf("\n\rSunlight: %3.2f",Sunlight1); // Display data between 0 - 55000
59             }
60
61             if(sechumid==20) // print to RS232 every 20 Seconds
62             {
63                 sechumid=0;
64                 Humidity2 = (float) (((adc_value[2])*5)/1023.0)*20; //Reset flag
65                 printf("\n\rHumidity: %3.2f",Humidity2); // Display data between 0 - 100%
66                 //Print to RS232
67             }
68
69             if(sectemp==20) // print to RS232 every 20 Seconds
70             {
71                 sectemp=0;
72                 Temperature3 = (float)(adc_value[3])/5.55 -40; // Display data between -40 and 260 degrees
73                 printf("\n\rTemperature: %3.2f",Temperature3); // Print to RS232
74             }
75         }
76
77         ///////////////////////////////////////////////////////////////////
78         if (adc_value[0]<512) // IF soil moisture drops below 512 bytes (50%)
79         {
80             if(high_flag==0)
81             {
82                 high_flag=1;
83                 output_high(PIN_B7); // Set flag to 1
84                 printf("\n\rSolenoid operated"); // Output high to pin B7 to activate solenoid
85                 printf(lcd_putc, "Valve open"); // Print to RS232 screen Explaining valve is open
86                 lcd_gotoxy(1,2); // go to next line on LCD
87                 printf(lcd_putc, "Valve open"); // Print to LCD screen 'Valve open'
88             }
89         }
90         else
91         {
92             if(high_flag==1)
93             {
94                 output_low(PIN_B7); // Output low to turn solenoid off
95                 high_flag=0; // set flag to zero
96                 printf("\n\rSolenoid off"); // Print 'solenoid off' to RS232
97                 lcd_gotoxy(1,2); // go to next line on LCD
98                 printf(lcd_putc, "Valve closed"); // PRINT TO LCD 'Valve closed'
99             }
100         }
101     }
102 }
103
104
105
106
107 }
```

Figure 44 – Print Screen – Second Program

The Proteus print screens shown below, show the program operational with the new changes made. The first print screen shows the valve closed and the second print screen shows the valve open.

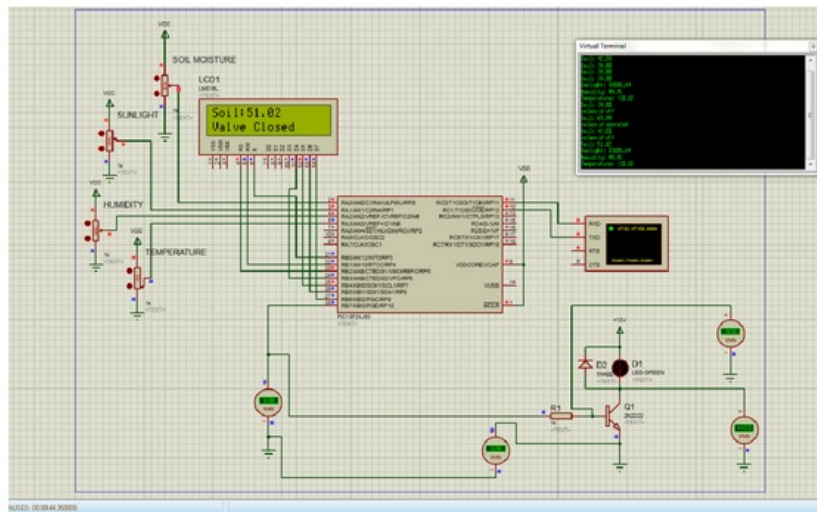


Figure 45 – Circuit Design for Testing Program 2

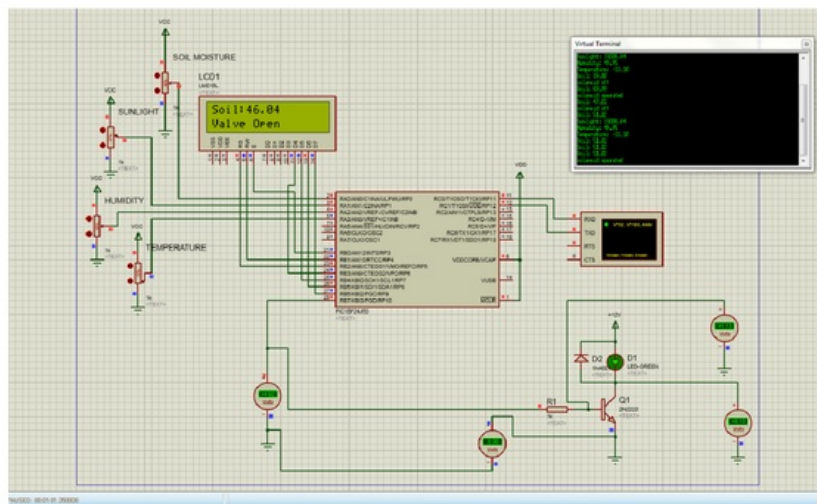


Figure 46 – Circuit Design for Testing Program 2

5.7.3 Explanation/Conclusion Design 2

The program was changed to match the findings from program 1. The new code has a few new additional lines. The LCD now shows a live feed off the soil moisture content, so when the moisture content changes the LCD value will change almost instantaneously. The LCD now also displays the state of the solenoid valve whether it is open or closed. The state of the valve is also now printed to virtual terminal so that a log of the information can be kept allowing users to see how often the plant has been watered through the day and shows that the IF statement is working correctly.

5.8 Design – Prototype Build

After simulating the program on Proteus, it was decided that the program written met the specification and the needs of the project. The program was then released in a .hex file and put onto the microcontroller using Mplab and the PICKIT3. Print screens of this evidence are shown in the appendix.

The circuit was then built on bread board, photos are shown below following the schematic design done on Proteus:

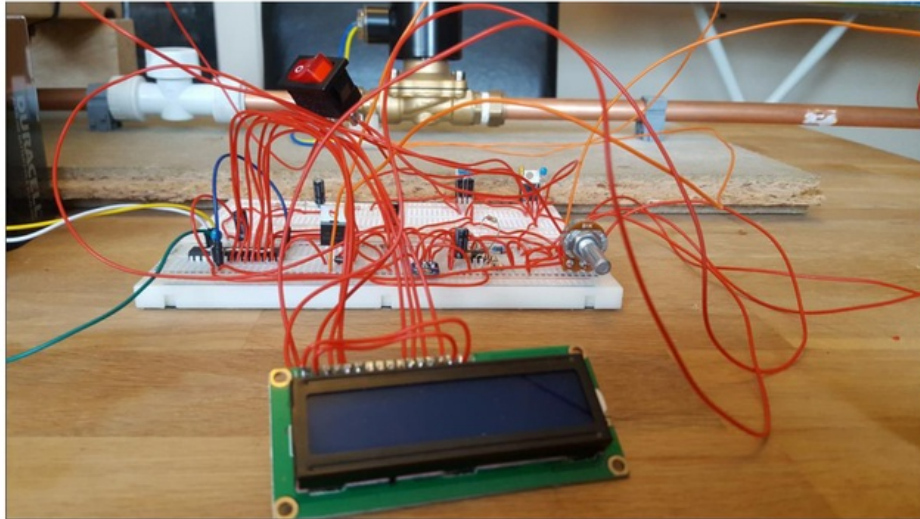


Figure 47 – Photo – Prototype Build

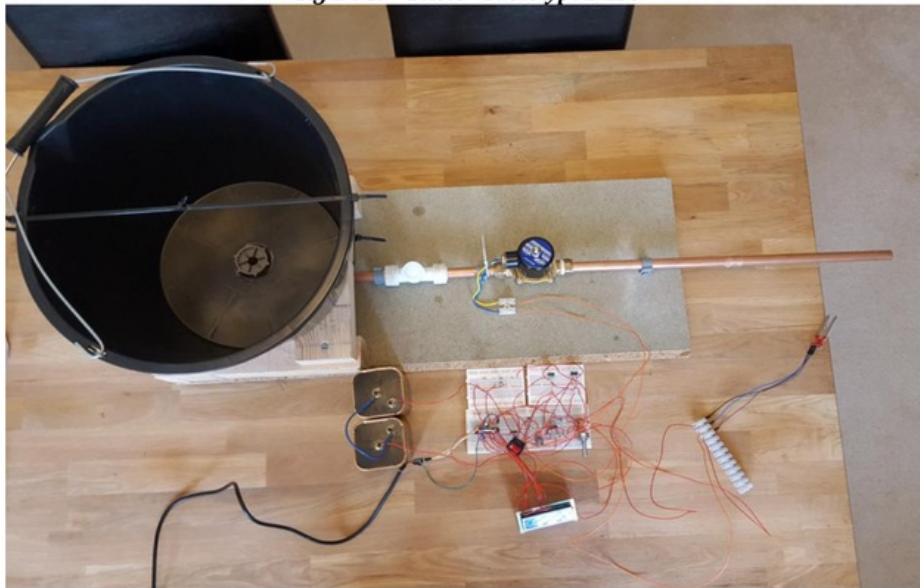


Figure 48 – Photo – Prototype Build

Chapter 6 - Analysis

6.1 Program 1 Test

There were two programs written. The first program was written to display the data in seconds, the soil moisture was printed every 5 seconds, sunlight was printed every 20 seconds and the temperature and room humidity also every 20 seconds. This was done to make sure the system was communicating properly and efficiently. The second program was written to display the data in minutes as per specification.

The prototype build was first tested using the first program. This was done to see the data being sent through quicker. Photos of the system operating are shown below:

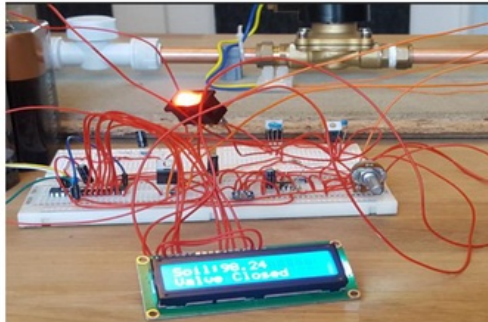


Figure 49 – Photo – Valve Closed Test 1

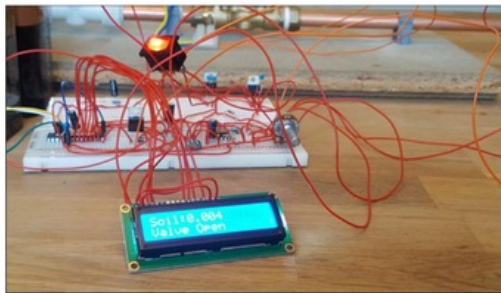


Figure 49 – Photo – Valve open Test 1

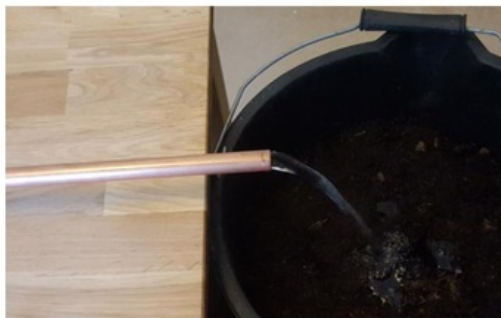


Figure 49 – Photo – Valve open Test 1

The data was first initially seen using teraterm as seen below in the print screen. This proves the data is being sent through the RS232. It can be seen that the soil moisture data is being printed 4 times more than the others, showing that it is being displayed every 5 seconds. It also shows the solenoid valve coming on and going off:

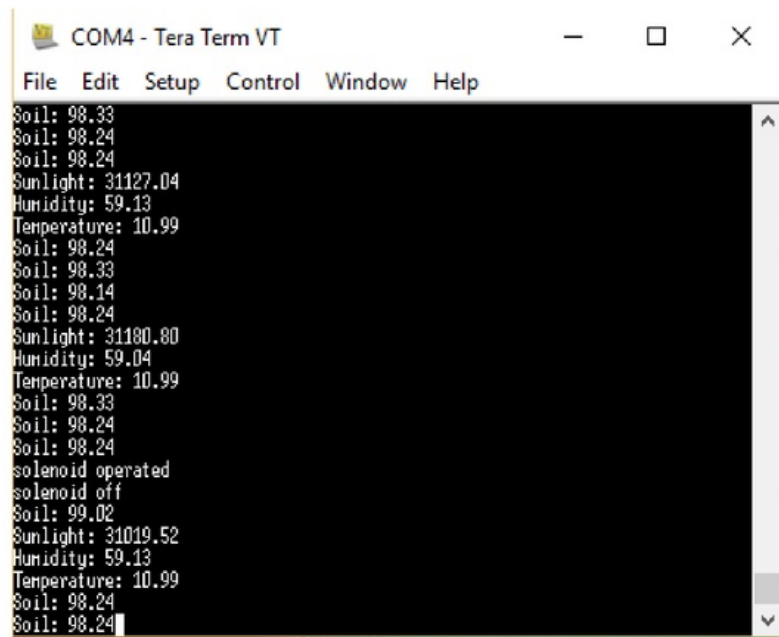


Figure 50 – Print Screen – Tera Term Results 1

In order to get the data to save in an excel spreadsheet and have a timestamp alongside each bit of data the Author used LabView. The Author changed the program slightly so that the data would be printed better visually for the user, a print screen of the program block diagram done in labView is shown below:

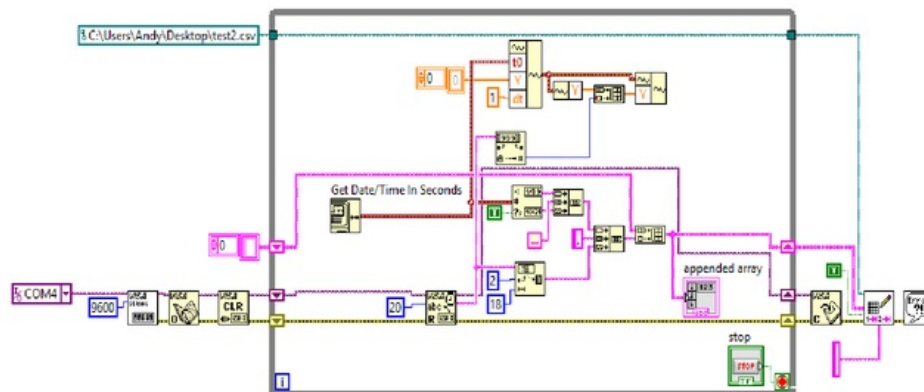


Figure 51 – Print Screen – LabView Program

The Visual display that will be seen by the user is shown below:

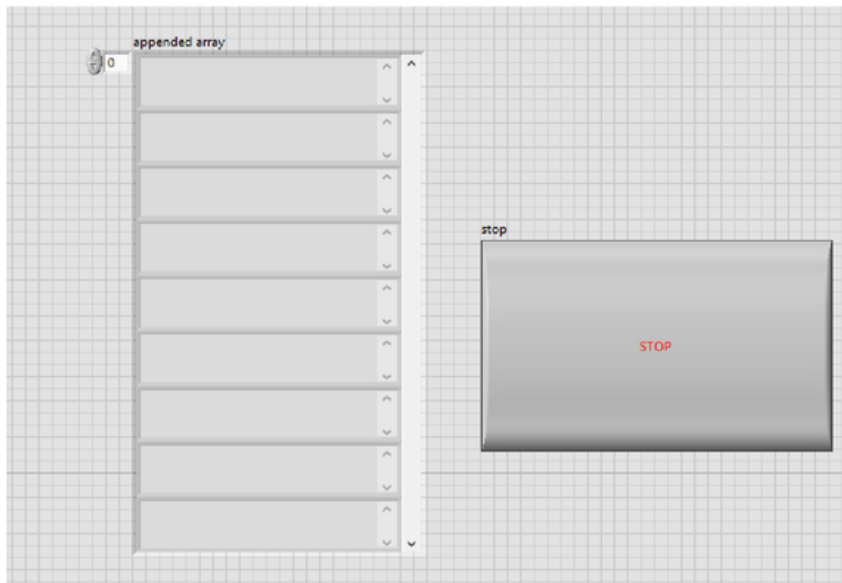


Figure 52 – Print Screen – LabView Display

The system was run and viewed in labview, a print screen of what was seen is shown below, as can be seen the time stamp proves that the data was coming through when expected, the soil every 5 seconds and the sunlight, humidity and temperature every 20 seconds:

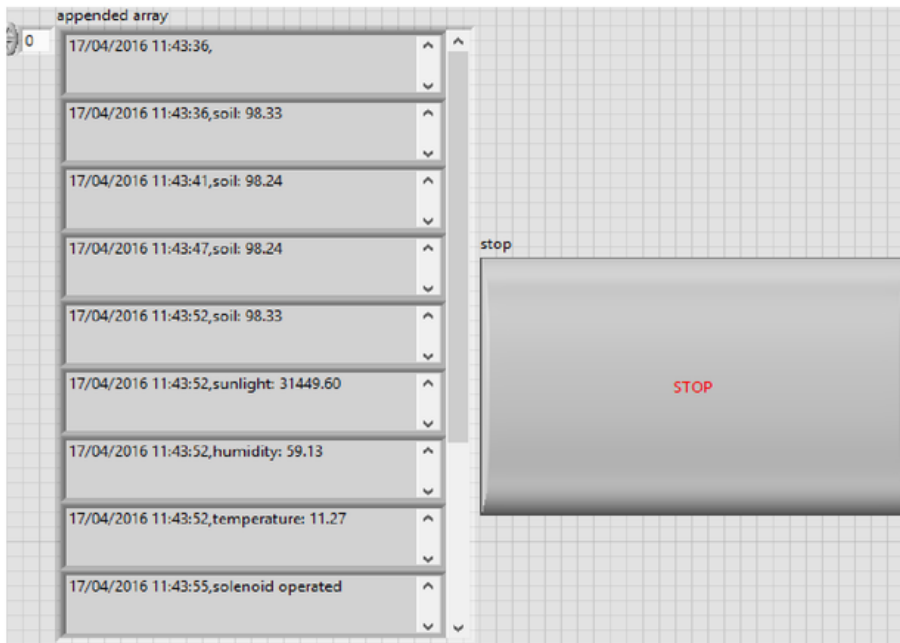


Figure 53 – Print Screen – LabView Display

The excel spreadsheet can be seen in full in the appendix, a print screen of it is shown below:

	A	B
1	17/04/2016 11:49	
2	17/04/2016 11:49	soil: 98.24
3		
4	17/04/2016 11:49	soil: 98.14
5		
6	17/04/2016 11:49	soil: 98.24
7		
8	17/04/2016 11:49	sunlight: 32739.84
9		
10	17/04/2016 11:49	humidity: 59.23
11		
12	17/04/2016 11:49	temperature: 11.27
13		
14	17/04/2016 11:49	soil: 98.24
15		
16	17/04/2016 11:49	soil: 98.24
17		
18	17/04/2016 11:49	soil: 98.33
19		
20	17/04/2016 11:49	soil: 98.24

Figure 54 – Print Screen – Results in Excel

Conclusion Program 1 Test

To conclude, the testing of program 1 was deemed successful. No errors were seen during the test and data was sent correctly to the excel spreadsheet using the LabView program. The solenoid valve opened when simulation of the soil being dry was performed and the valve closed when the moisture content went above 50%. The next stage of testing is to run the system for a 24 hour period.

6.2 Program 2 Test

As program 1 testing was deemed successful, the next stage of testing is to run the system for 24 hours using the second program. The only changes made between program 1 and program 2 is that the data is sent and logged in minutes rather than in seconds. Program 2 is the main program that meets the requirements set.

The test was done indoors as the system has not yet been put into an enclosure and if it rained the electronics would be damaged. Two 6V Duracell batteries were hooked up in series to give a 12V supply to the system, these batteries were used because the chosen battery from the research wouldn't arrive in time and these were easily bought off the shelf.

The expected outcome of the test is to see soil moisture being logged every 1 minute, sunlight data every 2 minutes and the temperature and humidity logged every 4 minutes. The solenoid may or may not be activated during test depending if the moisture content of the soil drops. The test setup is the same as program 1 test except this setup includes an ammeter to measure the current being drawn while the system is operating. Photos of the setup can be found in the appendix.

A print screen of the raw data captured from the test is shown below, full document of captured data can be found in an excel spreadsheet within the appendix:

Date	Time		Data
18/04/2016	05:59:38	Soil:	98.33
18/04/2016	06:00:41	Soil:	98.33
18/04/2016	06:00:41	Sunlight:	483.84
18/04/2016	06:00:41	Humidity:	59.13
18/04/2016	06:00:41	Temperature:	9.29
18/04/2016	06:01:44	Soil:	98.33
18/04/2016	06:02:47	Soil:	98.43
18/04/2016	06:02:47	Sunlight:	4354.56
18/04/2016	06:03:50	Soil:	98.33
18/04/2016	06:04:52	Soil:	98.33
18/04/2016	06:04:53	Sunlight:	5537.28
18/04/2016	06:04:53	Humidity:	59.23
18/04/2016	06:04:53	Temperature:	9
18/04/2016	06:05:55	Soil:	98.33
18/04/2016	06:06:58	Soil:	98.33
18/04/2016	06:06:58	Sunlight:	6773.76

Figure 55 – Print Screen - Test 2 Results in Excel

6.2.1 Plotted Results

The results from each sensor have been plotted into graphs to see how they responded over a 24 hour period and if there were any random anomalies, this was done on excel by using the filter function to view only the data needed for each sensor. The graphs are shown below:

Soil Moisture

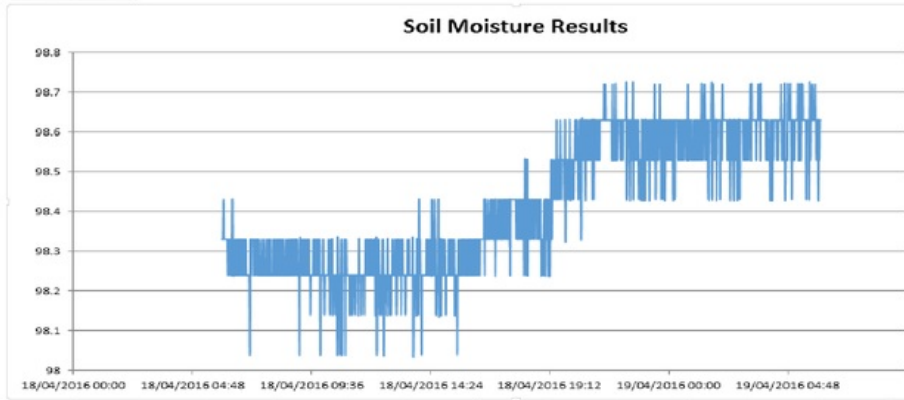


Figure 56 – Print Screen – Soil Moisture Graph

The moisture of the soil did not drop below 98% over the 24 hour period. The results fluctuated between 98 and 98.8%. This was expected as the soil was indoors and wasn't in direct view of the sunlight. This also shows that if the system was used for indoor plants the solenoid valve would not activate very often meaning that the battery life would last longer than expected.

Sunlight

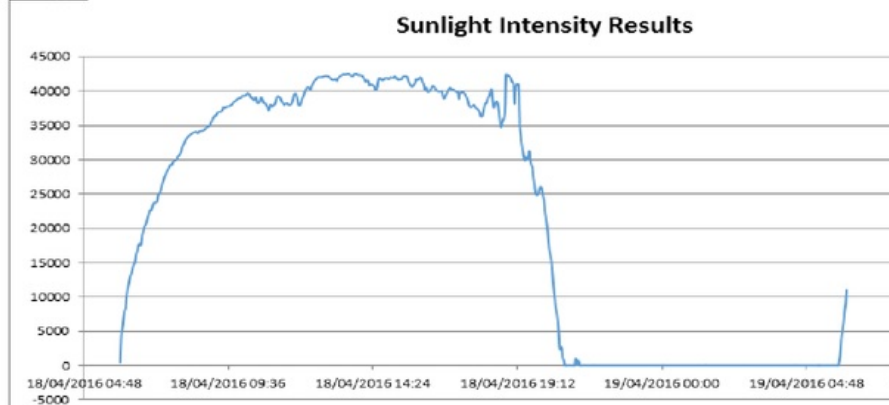


Figure 57 – Print Screen – Sunlight Intensity Graph

As can be seen from the graph, the test started at 6 o'clock in the morning of the 18/04/16 and ended at 6 o'clock in the morning on the 19/04/16. The curve on the graphs shows the sunlight becoming more intense as it rises and hits its peak at around 12 o'clock mid-day. As the sun begins to set the light intensity begins to fall and stays around 0 lux showing that it is night time. The sensor results have proven that the sensor works efficiently and it has given a really good indication to show when it is night time and when it is day time. If the Author had more time it would have been interesting to see the lux intensity the sensor picked up if it was out doors.

Humidity

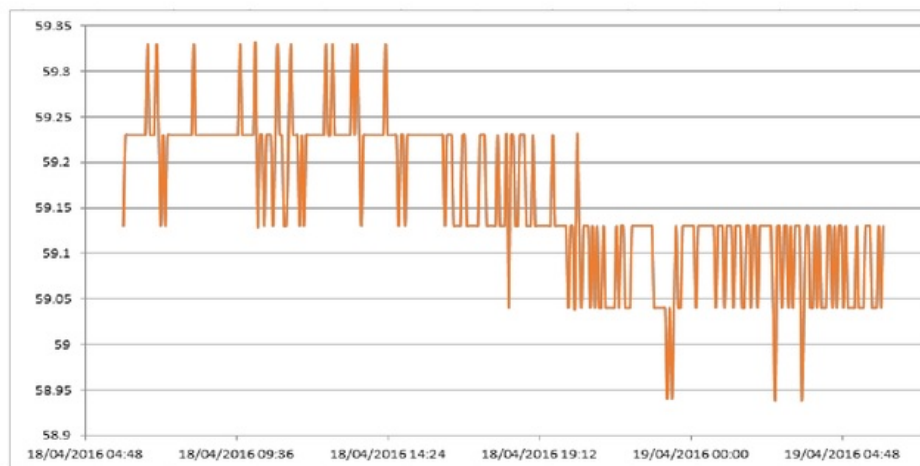


Figure 58 – Print Screen – Humidity Graph

There were no random anomalies found in the data given from the humidity sensor as it stayed fairly constant throughout the 24 hour period. Compared to the temperature graph shown below it can be seen that the humidity begins to drop as the temperature in the room increases. This shows that the sensor is working, as it is known that there is less moisture in the air when it is warmer. If the system was in a greenhouse it would be interesting to see how the humidity in the air and the soil moisture content changed and how they would interlink.

Temperature

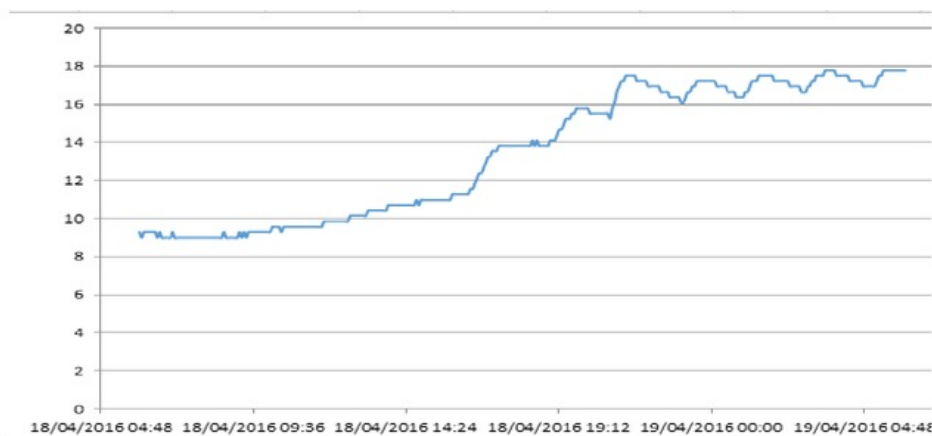


Figure 59 – Print Screen – Temperature Graph

The results from the thermistor have showed the temperature of the room between 9 and 18 degrees. The temperature began to rise at around 16:00 hours, this is because the heating was put on and was set at 19 degrees, the thermistor results were fairly accurate to that showing on the thermostat, there is no evidence to prove this but the results do show the increase of temperature. Therefore the thermistor has a tolerance of around +1 degree.



Figure 60 – Photo – Current Drawn

The two pictures shown above were taken to show the current being drawn when the system is operating. The photo on the left shows the current drawn when the solenoid is open, as can be seen it draws 1.12A. The photo on the right shows the current drawn when this system is operating with the valve closed, which is 107mA. The operating current for the system with the valve closed was calculated to be 22.67mA. This estimate was a bit out from the actual value and suggest that there are factors that haven't been taken into consideration, for example the LCD screen.

6.2.2 Program 2 Results Conclusion

The data gathered over a 24 hour period showed that soil moisture doesn't fluctuate as often as expected and maintains a fairly constant level. This data has been helpful as it shows that the solenoid won't be activate as often as predicted. However the current being drawn from the system operating is much higher than calculated and would therefore mean the battery would only last for around 48 hours which would deem this not suitable for the final design. The battery selection is classed as a minor issue as it just means a different choice would need to be made. The main test was to check the operation of the sensors and it has shown that all sensors operate within the desired expectation. It was good to see that the temperature and humidity data corresponded with one another, showing that both sensors can notice a slight difference in the environment, which is what is needed for the end user to decide on the best suitable environment for their plant/crop. The sunlight sensor also gave good feedback as it was able to measure the light intensity as it gradually changed throughout the day giving a nice smooth line graph with no random data. Overall the test was deemed a successful as it provided useful information and proved that the design is fit for functionality.

6.2.3 Wireless Communication

The project design does meet the specification but it was suggested in the plan that if there was enough time then wireless communication would be considered. The system currently transmits data through a USB to TTL lead, as so it always needs to be connected to a PC in order to record the data. This is would only really be plausible if the system is used in doors but if it was to be used outdoors or within a greenhouse this would prove to be difficult. Therefore it was decided to research to find a simple wireless data transmission module that could easily be incorporated into the design.

After searching the internet the Author came across a wireless USB to TTL module, it is called APC220 radio data module. It was available on a few websites but was found cheapest on a website called deal extreme and was priced at £19.94 [34]. The module is designed for easy setup for data transmission for UART to TTL. The price include 2 wireless RF module, 2 antennas, and 1 USB converter module. A picture of the package is shown below:



Figure 61 – Print Screen – Wireless modules

The modules have a working voltage of between 3.3V and 5V. a working frequency between 418 – 455Mhz and a transmission distance of up to 1000m, the full data sheet can be found in the appendix. This module sourced is perfect for the design, the transmission distance is more than sufficient for that needed and can simply be added on to the original design as it has the same operating voltage as the sensors. A photo is shown below of it connected to the bread board:

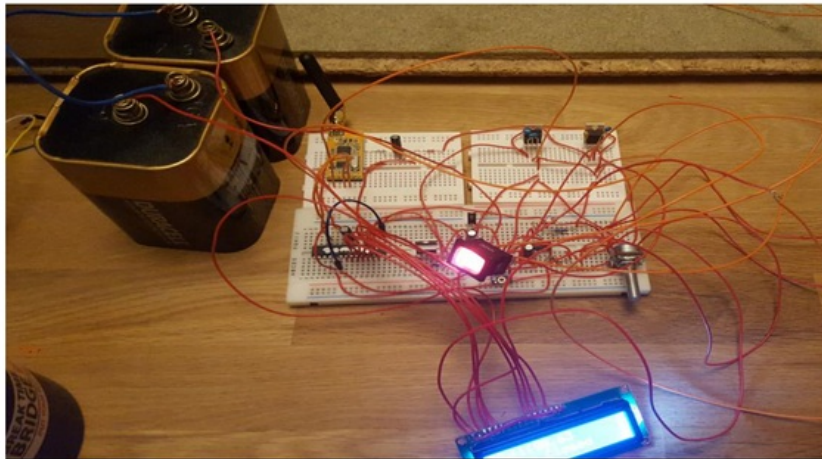


Figure 62 – Photo- Wireless Module implemented into Design

Wireless Communication Test

A quick test was done to check the full operation of the system and to see if the data transmitted successfully. In order to set the parameters up on the RF boards a software called truly magic was used, a print screen is shown below. The software was self-explanatory and needed little guidance as the default settings were accurate to what was needed.

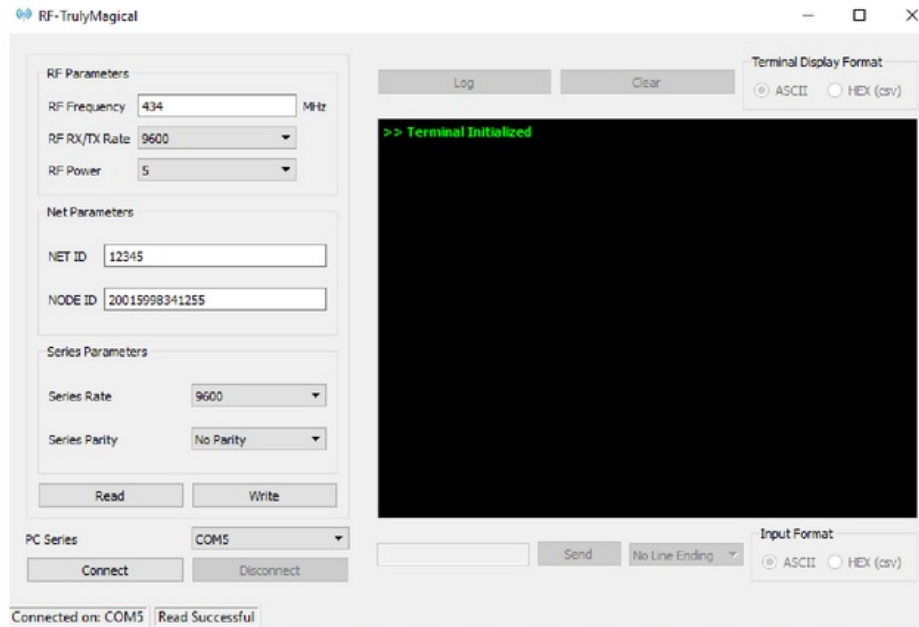


Figure 63 – Print Screen – Software used to Configure Wireless Modules

The print screen shown below shows the data being transmitted by the wireless RF module. A short video can be found in the appendix proving the system fully working to that specified.

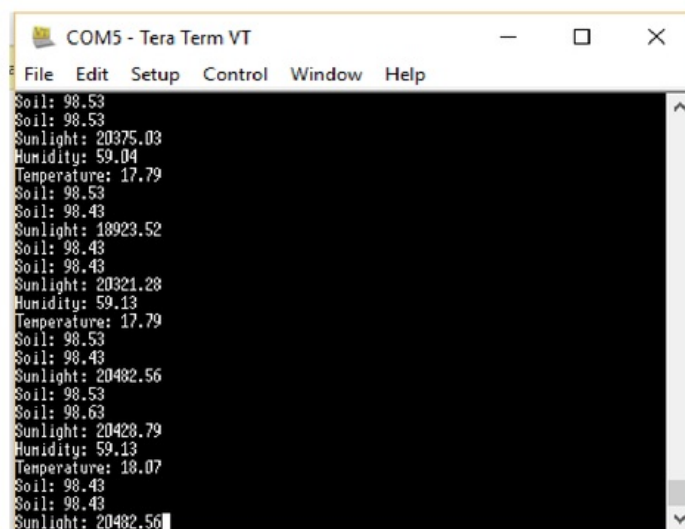


Figure 64 – Print Screen – Data Transmitted via Wireless Modules

Chapter 7 – Evaluation

The conclusion drawn from the analysis is that the system works to the specifications set within the planning stage of the project. The specifications set was to design an automatic plant watering system that would:

- Activate a solenoid valve when soil moisture dropped below a certain level.
- Record data on the temperature, Humidity, Soil moisture and sunlight intensity.
- Wirelessly transmit data to a PC.
- Display soil moisture content on an LCD.

All objectives set were met and accomplished. Although the final build for sale was not complete. The PCB was not made and the system was not built into a water tight enclosure.

The main research done was into the type of sensors required for the design. The sensors researched and chosen worked to the requirements set. The tests performed on the sensors gave an idea of what circuitry was required in order for them to operate effectively. The tests backed that of the data sheets and the only adjustments needed was to amplify the signals in order to get better results.

The main aim of the project was to design and develop a working automatic plant watering system. This goal was achieved. The biggest downfall of the project is that it wasn't built into the chosen enclosure and tested outdoors for a long period of time. Although it has been proven that the solenoid valve will operate by simulating the moisture level dropping, it would have been more satisfying to of run a test for a long period of time to see how often the solenoid valve would operate and if it managed to keep a plant alive.

Most of the results from the 24 hour test were as expected. The biggest surprise was seeing that the soil moisture level didn't drop and was assumed that soil dried out quicker than it actually does. There was not much research done in the project around how long it would take for soil to dry out and from the results it is felt that more research into this could have been done.

If the project was to be done again then a different approach would be used. It is felt that the design, build and test was left too late and therefore a bit rushed. More time needed to be set aside for designing the PCB and writing the program for the microcontroller. It was difficult to learn how to program in such a short period of time and for any future projects more time will be set aside for learning as this was never taken into consideration. Apart from poor time management and underestimating the difficulty of the project the Author feels that the overall outcome was successful and is very proud of what was achieved.

Chapter 8 – Conclusion

To summaries everything done in the project each chapter has been explained and concluded below its relevant heading:

Chapter 1 Introduction

The introduction chapter includes information on the proposed project and gives a good outline to the reader of what the project is hoping to achieve. It provides a list of research objectives along with a diagram showing how the system will operate to give a visual understanding to the reader of the final outcome. This introduction is brief and could have been expanded further but it is felt that it provide enough information to grasp the reader's attention.

Chapter 2 – Planning

This section provided a plan for the project, breaking down each chapter objectives and setting a timescale in order to give the author an idea of what needed to be achieved. A Gantt chart was also produced to show the time line. The project plan was similar to the one used within the project proposal although the project idea changed the plan was still almost the same except for the need for different dates. Parts of the plan were not achieved and it is because the project took a different scope and the need for such things like a risk assessment were not really required or necessary. The dates set for the plan were also out as a lot of the project was left to the last minute due to family and work commitments. Also some aspects of the project needed more time than predicted such as writing firmware and testing/analysing data.

Chapter 3 – Investigation

The investigation chapter includes information on similar products already available on the market, showing a comparison between each one and the difference between them and the proposed product. The investigation chapter also contains research into the sensors required and the different types of sensors available that could achieve the end goal. A description of each sensor was provided along with a reason of why a particular sensor was chosen for the job and the advantages and disadvantages over the other sensors researched.

The research then continues onto the requirements and selection of a battery, an enclosure and a microcontroller. Once the research was done on the sensors and one was selected for each job, the information then helped with selection of a battery as it was then known what power would be needed to operate the circuit. The enclosure could also then be specified along with the best suited microcontroller.

The overall investigation stage helped provided the ground work for the design of the project. More research could have been done into soil moisture and the moisture level different types of plants would require in order to grow to their full potential. It was felt however that the research done to provide enough information to make the project successful.

Chapter 4 – Implementation

The implementation stage was used to test the sensors capabilities and prove that the data sheets were correct. The outcome of the tests provided enough evidence to show that the data sheets were correct. This information was then used to provide a circuit diagram. Based on the results it was shown that some of the sensors output signals needed amplification in order to get the full use input voltage of the microcontroller which was 0-3.3V.

The implementation stage was useful and was required for the overall PCB design as it provided information that wasn't confirmed. The information was displayed on the data sheets but this is not always correct.

Chapter 5 – Design

Chapter 5 includes the full system design. The flow charts for the PCB design and program are included in this chapter. The flow charts helped provide a clear idea of what was needed from the PCB and program and provided a good stepping stone for the design stage.

Using the research, testing and flow charts done a PCB schematic was designed on Proteus and also a PCB layout was designed on Easy PC. A parts list for the prototype design was provided along with the cost of the build.

A program was then written in C and tested on Proteus using a test schematic with variable resistors used to simulate the sensors outputs. Once test was confirmed to be successful the program was then downloaded onto the microcontroller and placed onto the prototype PCB which was built up on bread board.

Chapter 6 – Analysis

Chapter 6 includes the full test of the system and final conclusion of the project outcome. The system was fully tested as a whole using both program 1 and program 2. Program 2 was run for a 24 hour period and the results were plotted into graphs. The data was then analysed and it was confirmed that everything worked to most of the specification. One part the specification was to get the system to transmit data wirelessly to a PC so that data could be logged without the need for a computer being directly present. As there was enough time left, this objective was then met by purchasing wireless modules. The system was then yet again tested to prove the operation of the wireless modules.

Chapter 7 – Evaluation

The evaluation sums up the results gathered during the test stage and concludes on the analysis. The evaluation points out the objectives and specifications set were met and that as a whole the project was successful.

Final Conclusion/Recommendations

To conclude it is felt that as a whole the project was a great achievement. The project has been left with avenues for further progression. More research and analysis can be done into automatic watering systems and plant growth. The system could be run for a longer period of time to gather more information on how the humidity of soil is influenced by the environment. It could also then be modified to suit any plant so that it is watered to the plant's needs, for example cactuses would need a lot less water compared to that of a rose bush.

Further development could be done to get the system to log and store data on an SD card rather than streaming it to a PC, this would therefore do away with wireless connectivity and the system would not need to really on a PC being within a 1000metres of its placement.

The system could also have the option to be powered by the mains to eliminate the possibility of the battery dying before the user is able to change it.

The suggestions above for further work/changes were unable to be implemented into the project due to lack of time. They were not considered until later on in the project and if the Author had more time they would implement these changes and research further into plant growth.

Chapter 9 - Reflection

I feel this has been a good and interesting project to work on. The knowledge and understanding that has been acquired throughout the project has been rewarding and satisfying. When the project first started it was hard to see the end, and I felt that I would never achieve the end goal as I didn't have the knowledge to be able to design and develop a working product. I have learnt to use a lot of different software packages to enable me to successfully complete the design, the software packages that I used are:

- Proteus
- Easy PC
- LabView
- CCS Compiler
- MpLab

I had very little/ no experience on these software packages but now feel that I have a much greater understanding of them and feel like the knowledge I have obtained can now be implemented and used in the future.

The one major point I have learnt when doing the project is time efficiency, I feel I underestimated how long the project would take to complete and left to much of it to the last minute. I changed the project I was originally doing in October when I was told that the project proposed didn't meet the criteria. I then didn't begin the new project till January and felt there was enough time to achieve what I needed to but underestimated the time it would take to learn the software packages and learn how to program.

Overall I feel like the project was a success I would of liked to of been able to build the final design within the enclosure and have the PCB made, so that I could of seen the final product but as the prototype worked as planned I am happy with what I managed to achieve in such a small space of time.

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