A Monitoring and Control System for an Accelerated Weather Test Chamber

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A Monitoring and Control System for an Accelerated Weather Test Chamber

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Declaration

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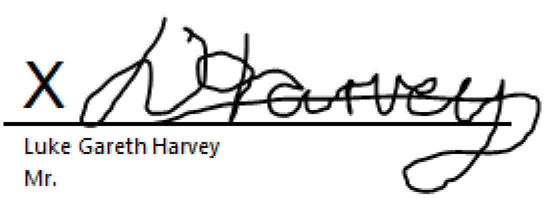

Copyright Statement

Abstract

In the Automotive Sector, weathering tests of components are of paramount importance. The most critical components to the overall comfort and durability of a vehicle are the interior components and thus is important to guarantee the quality of these components. The interior components are generally made of plastic, fabric, leather and various painted components. These components are prone to fading, cracking and distortion which is caused by natural factors such as solar radiation, temperature and moisture. This is known as natural weathering.

Over the years many weathering tests have been carried out on automotive components to address critical issues during the design process. Many of these tests are simulated in chambers to mimic real life cycles. Although these accelerated tests provide somewhat accurate results in much shorter periods, natural weathering is still essential as it is uncontrolled and unpredictable. This dissertation looks at the method of a metallic chamber used to carry out weathering tests on automotive components and to simulate the conditions inside a vehicle. It addresses the current state and improvement: accurate tracking, intelligent fuzzy logic control and cloud-based monitoring. Currently weather testing chambers are stationery, which does not allow for maximum exposer to solar radiation. Therefore, a system was designed to allow the weather testing chamber to track the azimuth and elevation of the sun to increase the solar radiation on the components tested, a GPS will achieve this.

Currently systems lack remote monitoring. A further shortcoming is the lack of controlling the temperature and humidity inside the chamber for sufficient tests. The use of a fuzzy logic controller was implemented to achieve this. The fuzzy logic was compared to other types of logic controllers. To further IoT integration, two main control devices were used, these control devices were two Arduino Mega's. One Arduino Mega was used for the intelligent fuzzy logic control and the second for solar tracking. The weathering system and controllers were powered by using solar power. The fuzzy logic controller was tested while tracking the sun and then not tracking the sun. The results obtained were compared and it was seen that the fuzzy logic performed very well in both instances, however, the

test with tracking the sun performed better. A second test was performed. The second test was similar to the previously mentioned test, but the fuzzy logic had a set point control. It was concluded that both tests performed as expected as the fuzzy logic controlled the temperature and humidity at the given setpoint, but during the solar tracking test the fuzzy logic control performed the best. The fuzzy logic worked well in general use as well as set point control, both for tracking and non-tracking. The tracking performed better than the non-tracking.

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Nomenclature

Symbols

δ	Declination
φ	Latitude
α	Angular acceleration

Explanation of Abbreviations

Shortcut	*Meaning*
LSTM	Local Standard Time Meridian
LST	Local Solar Time
LT	Local Time
EoT	Equation of Time
TC	Time Correction Factor
HRA	Hour Angle
FL	Fuzzy Logic
IoT	Internet of Things
DOF	Degree of Freedom
GPS	Global Positioning System
V	Volts
A	Amps
Ah	Amp Hours
P_F	Power of Fan
C_{PS}	Current from power source
V_S	Voltage Source
T	Torque
I	Mass moment of inertial

1. Introduction

In the Automotive Sector, weathering tests of components are of paramount importance. These tests show the behaviour of materials under adverse conditions-be-it high solar radiation, high humidity and high temperature or both. Many of these tests are simulated in chambers to mimic real life cycles. Although these accelerated tests provide somewhat accurate results in much shorter periods, natural weathering is still essential as it is uncontrolled and unpredictable. Currently automotive manufacturers use static temperature-controlled test boxes to expose components to solar radiation (Atlas, 2016).

Therefore, the purpose of this dissertation is to accelerate natural weathering by designing a system that always allows the test box to track and follow the azimuth and elevation of the sun to increase the solar radiation incident on the components tested. Azimuth is the angle between a celestial body (sun, moon) and to geographic North, measured clockwise around the observer's horizon (Pons, 2015).

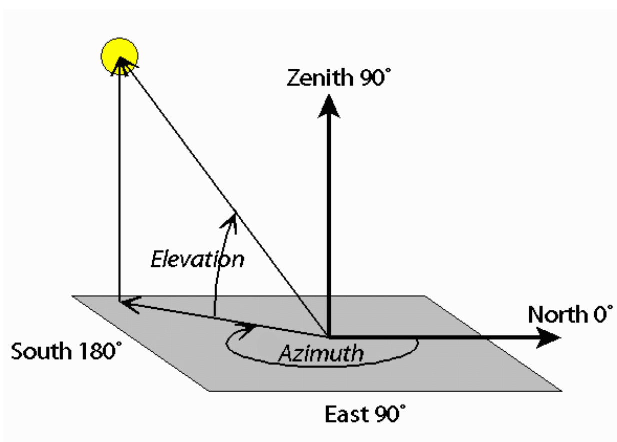

Figure 1-1 Azimuth and Elevation angles Source: (Anon., 2018)

The weathering testing chamber will be placed in hot dry areas, such as the desert, to simulate the effects on certain components of a vehicle to see how well the components can withstand the harsh natural environments. This type of testing is known as "accelerated weathering". An advantage of accelerated weathering is that the results from testing can be obtained quickly. Accelerated weathering, however cannot simulate the global radiation spectrum in total (Anon., 2001). Accelerated weathering provides test data quick enough to allow changes in the product design process which makes it compatible with time-to-market constraints. However, it does not accurately reproduce failure modes seen in real life (Haillant, 2011).

This project will also include: Solar tracking to track the sun's position to always receive the highest amount of solar radiation from the sun. The solar tracker will also be used for the solar panel, which will be added to the weathering testing chamber, to charge a 12V DC battery that will power the weathering testing chamber.

Two Arduino Mega's will be used as the microcontrollers to run the entire system. A fuzzy logic algorithm will be developed, which will control the temperature and the humidity within the box to allow the chamber to reach the desired range that would be needed for the certain tests to be conducted. An IT aspect that will be investigated would be cloud storage and networking. The data obtained from the testing chamber would be stored in the cloud and can be obtained from various PCs which could be in different locations. The Siemens IoT 2040 will be a good choice for this, because it is compatible with Arduino, but other IoT devices could also be investigated to find out which device would be the best to use.

1.1 Overall Aim

Weathering of components especially in the automotive industry has been a critical subject for many years. Many automotive manufacturers have several methods for carrying out weathering tests being done on their products, more specifically to the material of the products. These automotive manufacturers have many weathering testing chambers, which can simulate temperature and radiation, but do not have chambers that track the sun and simulate humidity. These tests are carried out by exposing test samples to the natural conditions or by simulating the natural conditions in a testing chamber in a laboratory (Anon., 2001).

The weathering tests that are conducted are very important, as it is important to guarantee the quality of the components. The automotive industry is required to continually improve the quality of vehicles, as it is the desire for every motorist to drive an exquisite vehicle

(Zindove, 2015). Many of these tests are conducted within the laboratory, thus, it is also crucial to have these tests conducted in the natural environment. This weathering testing chamber will be placed in the natural environment and the components will be placed inside the chamber.

Figure 1-2 Dashboard of a car damaged by sun exposure (Source: (unyyc, 2017))

The overall aim is to design a monitoring and control system with a solar tracking system for a temperature and humidity-controlled weathering chamber. The system must have the following characteristics:

- Power efficient
  - The whole system will run off 12V DC
  - Solar panels are used to charge the 12V battery, therefore this is using clean energy.
- Size
  - Compact
  - Easy mobility
  - Stable
- System
  - It is cost effective
  - Intelligent control system
  - User friendly
  - IoT (remote monitoring)

1.2 Objectives

The following objectives will form the backbone of this project. These will be the success measures, as well as the design guidelines.

1.2.1 Sub-Objectives

- Use and programming of a Microcontroller Board: Arduino
  - Using a cheaper Microcontroller board would make this project a cost-effective project. It is easier to interface with various sensors and devices.
- Mechanical Design
  - The design of the system should be strong enough and must be able to work with a load of around 35 kg. The system must be secure and stable, consideration of wind load must be explored.
- Tracking by calculating the sun's position
  - Tracking of the suns position should be done using a GPS module interfaced with an Arduino microcontroller. The GPS module and the Arduino can be used to find the current position and time of the system. From the found position and time, the suns azimuth and elevation can be calculated.
- A control algorithm that uses fuzzy logic
  - The fuzzy logic control algorithm should be implemented with an Arduino Microcontroller which would be used to control the temperature and humidity within the weather testing chamber. It should also be able to maintain the temperature and humidity of a given set point.
- Use of Solar energy to power the system
  - The entire system should be powered by means of solar power and battery. The battery should be charged via solar energy and the charge of the battery being controlled. To ensure continuous power use, an energy balance calculation must be performed to ensure enough supply power for the system to use.
- The use of an IoT system for cloud base storage and monitoring

    - An IoT aspect to be implemented into the system, to ensure data collection and monitoring of the temperature and humidity within the chamber throughout the day, every day, all year.
- Testing and validation of the system
    - The system should be tested to validate that it functions correctly and is reliable in its collection of data and performance.

1.2.2 Performance Requirements

- Tracking and control of the weather testing chamber at least every 15 minutes
    - The weathering testing chamber should track the sun and update its position at least every 15 minutes to ensure the component is exposed to as much solar radiation as possible.
- Positioning of the weather testing chamber
    - The weathering testing chamber must be able to move within a +180-degree range for horizontal movement for azimuth movement. The vertical movement must be a maximum of 35-degree range for elevation movement. Both horizontal and vertical movements must have a tolerance of 5 degrees.
- Fuzzy Logic Control
    - The fuzzy logic controller must be able to control and maintain the temperature and humidity within the weather testing chamber to a given set point or through normal everyday conditions. The controller must maintain a higher temperature, but not too high inside the weather testing chamber compared to the ambient outside temperature. The controller must also maintain a higher or lower Relative Humidity inside the weather testing chamber compared to the ambient outside Relative Humidity.
- IoT System
    - The IoT system must collect all the data from the weather testing chamber and store it in the cloud. The data collected must be done automatically through the cloud and no manual data must be collected. The data must be real-time data and must be monitored through the cloud.

1.3 Hypothesis

A weathering testing chamber that controls and maintains the temperature and humidity to a varying value defined by the user with a fuzzy logic algorithm. The system must be designed and built to be used to run tests on automotive components to simulate natural weathering conditions. The chamber is placed outdoors to run tests and thus is required to be water and dust proof. The design of the system to follow the sun can be developed using standard components. It is also possible to collect the measured data and store it in cloud.

1.4 Delimitation

- The weather testing chamber will be designed primarily to meet the required specifications
- The system will run in an outdoor environment.
- The system will need low power requirements.

1.5 Layout of Chapters

The layout of the chapters is as follows:

1. The first chapter consists of the introduction, overall aim, overall objectives, hypothesis and delimitations are presented in this chapter.
2. The second chapter is the theoretical research which describes any existing methods and practices that the system will be using or is currently using in various applications. The need for such methods and practices for the system is emphasized in this chapter.
3. The third chapter explains how the entire system was developed. It makes use of various design tools that were used to explain the decisions that were made in building the project. This chapter is broken down into three subsections, namely: Mechanical, Electrical and Software/IT design.

4. The fourth chapter describes the test setup and the procedure used to evaluate the built system and hence test its effectiveness. This will also describe the environment that the system was tested in and which parameters were measured.
5. The fifth chapter presents the results found from the various tests that were conducted. This chapter also presents possible causes of any failures or any unexpected results and provides suggestions to prevent these types of results.
6. The sixth chapter concludes the dissertation. This chapter describes in general the results from the project and any general remarks for any future developments of weather testing systems.

1.6 Chapter Conclusion

In conclusion the solar tracking and fuzzy logic systems have been described with how they will function together with the entire weather testing chamber. The project has been defined with the overall aim, requirements and functionality of the final system. In the next chapter the theoretical background will be explored, here the various methods for solar tracking, fuzzy logic control and IoT as well as their function will be presented.

2. Literature Review

When designing a weather testing chamber, there are two aspects that need to be established through calculation. They are the azimuth and elevation of the sun. Since the weather testing chamber needs to test the behaviour of components under solar radiation, the chamber needs to follow and track the sun throughout the day to get the most solar exposure of the component. This solar tracking will also be used for the solar panel, to ensure the solar panel receives the maximum energy from the sun as well as for the weather testing chamber.

There are two main types of solar tracking systems, namely (Anon., 2016):

- Single Axis Tracking Systems; and
- Dual Axis Tracking Systems.

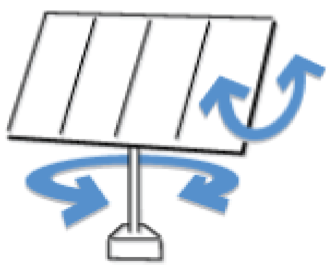

Figure 2-1 Dual Axis Tracking System (Source: (Anon., 2016))

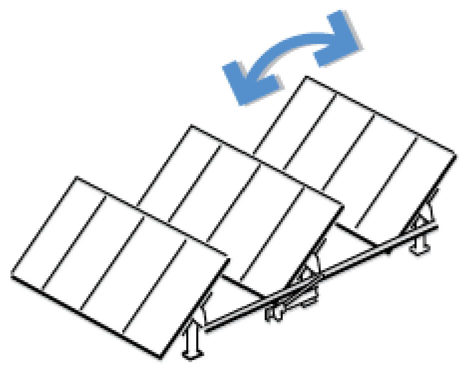

Figure 2-2 Single Axis Tracking System (Source: (Anon., 2016))

Each of these two systems have their own unique advantages and disadvantages when it comes to cost and solar exposure. Solar tracking systems are more beneficial compared to stationary mounted solar panels, as stationary mounts have their productivity compromised when the sun passes over the optimal angle (Bushong, 2016). The solar tracker compensates for this, as the solar tracker automatically moves to track the suns position throughout the day, therefore maximizing the output given from the sun (Bushong, 2016). These two types of tracking systems use two methods of tracking, either active or passive tracking. A passive solar tracker uses an algorithm to follow the sun and requires a GPS module for the location, current data and time of the system. This information is then used in equation 2.1 and onwards to calculate the azimuth and elevation angles at the specified location (Potgieter, 2014). The active solar tracker makes use of sensors to follow the sun based on the intensity of the sunlight. It follows the sun actively and responds to any changes that might arise in the position of the sun based on the reaction of the sensors. Active solar trackers are more accurate than passive solar trackers, but passive solar trackers are better when it is cloudy (Potgieter, 2014). This is because the place in the sky with the highest intensity is not always where the sun is. (Anon., 2016)

The position of the sun in the sky is a function of both the geographic coordinates and time for the observer on the surface of the Earth (Jenkins, 2013). To find the position of the sun for an observer at a given time, the following three steps must proceed (Jenkins, 2013) :

- Calculate the sun’s position in the ecliptic coordinate system.
- Convert to the equatorial coordinate system.
- Convert to the horizontal coordinate system.

The two key angles which are used to orient photovoltaic modules (Solar Panels) are the azimuth angle and the elevation angle at solar noon (Jenkins, 2013). However, to calculate the sun’s position throughout the day, the azimuth and elevation angle must be calculated throughout the day. These angles are calculated using “solar time’ (Meeus, 1991).

There are a few abbreviations that need to be known first, in calculating the sun’s position, namely:

- Local Solar Time (LST)
- Local Time (LT)
- Local Standard Time Meridian (LSTM)

Local Solar Time at twelve noon is defined as when the sun is the highest in the sky. Local Time usually varies from LST, because of the eccentricity of the Earth’s orbit (Pons, 2015). The Local Standard Time Meridian is a reference meridian used for a particular time zone and is like the Prime Meridian. Equation 2.1 illustrates the LSTM (Jenkins, 2013).

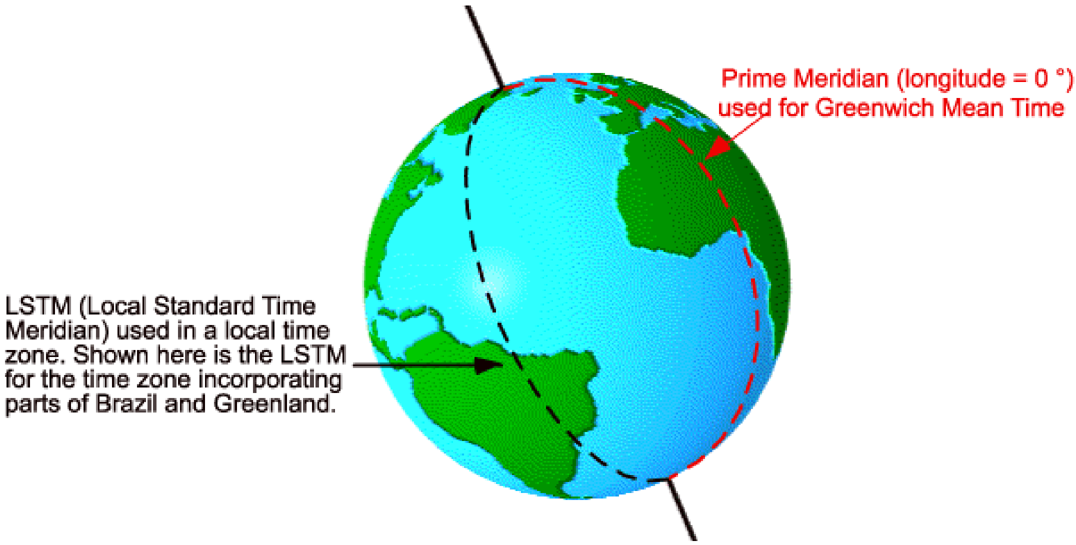

Figure 2-3 Illustration of the LSTM (Source: (Jenkins, 2013))

The (LSTM) is calculated according to the equation:

$$LSTM = 15^{\circ} * \Delta T_{GMT} \quad (2.1)$$

Where ΔT_{GMT} is the difference of the Local Time (LT) from Greenwich Mean Time (GMT) in hours.

2.1 Equation of Time (EoT)

The equation of time (EoT) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt (Jenkins, 2013).

$$EoT = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B) \quad (2.2)$$

Where

$$B = \frac{360}{365}(d - 81) \quad (2.3)$$

In degrees and *d* is the number of days since the start of the year.

2.2 Time Correction Factor (TC)

The net Time Correction Factor (in minutes) accounts for the variation of the Local Solar Time (LST) within a given time zone due to the longitude variations within the time zone and incorporates the EoT above (Jenkins, 2013).

$$TC = 4(Longitude - LSTM) + EoT \quad (2.4)$$

The factor of 4 minutes comes from the fact that the Earth rotates 1° every 4 minutes.

2.3 Local Solar Time (LST)

The Local Solar Time (LST) can be found by using the previous two corrections to adjust the local time (LT).

$$LST = LT + \frac{TC}{60} \quad (2.5)$$

2.4 Hour Angle (HRA)

The Hour Angle converts the local solar time (LST) into the number of degrees which the sun moves across the sky. The Hour Angle is 0° at solar noon. Since the Earth rotates 15° per hour, each hour away from solar noon corresponds to an angular motion of the sun in the sky of 15°. In the morning the hour angle is negative, in the afternoon the hour angle is positive (Jenkins, 2013).

$$HRA = 15^{\circ}(LST - 12) \quad (2.6)$$

2.5 Declination

The declination angle has been previously given as:

$$\delta = 23.45^{\circ}\sin(\frac{360}{365}(d - 81)) \quad (2.7)$$

Where d is the number of days since the start of the year.

2.6 Elevation and Azimuth

$$\alpha = sin - 1[sin\delta sin\varphi + cos\delta cos\varphi cos(HRA)] \quad (2.8)$$

$$Elevation = sin^{-1}[sin\delta sin\varphi + cos\delta cos\varphi \cos(HRA)] \quad (2.9)$$

$$Azimuth = cos^{-1}[\frac{sin\delta cos\emptyset - cos\delta sin\emptyset \cos(HRA)}{cos\alpha}] \quad (2.10)$$

Where φ is the Latitude of the current location.

2.7 Sunset and Sunrise

Throughout the year, there are different seasons and as a result, the sunrise and sunset times are different throughout the year. In the Southern Hemisphere the sun sets earlier and rises later in the winter and sets later and rises earlier in the summer. In the Northern Hemisphere it is the opposite. It is thus important to calculate the sunset and sunrise times to know exactly when the sun will set and rise throughout the year, so that efficient solar tracking can take place, to maximize solar exposure. To calculate the sunrise and sunset time the elevation is set to zero and the elevation equation above is rearranged to give (Honsberg & Bowden, 2018):

Sunrise Time:

$$Sunrise = 12 - \frac{1}{15^{\circ}} cos^{-1}\left(\frac{-sin\varphi sin\delta}{cos\varphi cos\delta}\right) - \frac{TC}{60} \quad (2.11)$$

Sunset Time:

$$Sunset = 12 + \frac{1}{15^{\circ}} cos^{-1}\left(\frac{-sin\varphi sin\delta}{cos\varphi cos\delta}\right) - \frac{TC}{60} \quad (2.12)$$

2.8 Fuzzy Logic

Two Arduino Mega's, which are microcontrollers, will be used to control the entire system. One Microcontroller will be used to control the rotation and tilt angle of the testing chamber and the other one will be used to control the temperature and relative humidity (RH) within the chamber itself. The algorithm that will be developed will use fuzzy logic to control the temperature and relative humidity. Fuzzy Logic (FL) is a method of reasoning that resembles human reasoning (Anon., 2017). Fuzzy Logic Systems produce definite outputs in response to ambiguous or distorted (fuzzy) inputs (Anon., 2016). The conventional logic that computers use to understand precise inputs which produces a definite output such as TRUE or FALSE, equivalent to YES or NO. With fuzzy logic the output range is greater than just yes or no and uses more of a human decision-making process, so the range of possibilities between yes and no could be as follows:

Table 2-1 Example of Fuzzy logic range possibilities

Certainly Yes
Possibly Yes
Cannot Say
Possibly No
Certainly No

With this general idea of fuzzy logic, it can be applied to temperature and humidity control, the output for such an example will be as follows:

Table 2-2 Example of Fuzzy Temperature Outputs

Temperature
Hot
Warm
Luke Warm
Cool
Cold

Table 2-3 Example of Fuzzy Humidity Outputs

Humidity
Very Moist
Moist
Slightly Moist
Slightly Dry
Very Dry

With Fuzzy logic algorithms comes fuzzy sets and these sets are the inputs or the outputs. There can be many inputs and outputs. For this project there will be two inputs, temperature and humidity and two outputs, the speed of the fans and the duration that the humidifiers must be on. These inputs and outputs are created by using membership functions. A membership function is a curve that defines how each point in the input or output space is mapped to a membership value which is between 0 and 1 (Matlab, 2018). There are different types of membership functions, they include:

- Piece-wise linear functions
- Gaussian distribution function
- Sigmoid curve
- Quadratic and cubic polynomial curves

Figure.2-4 shows examples of these functions.

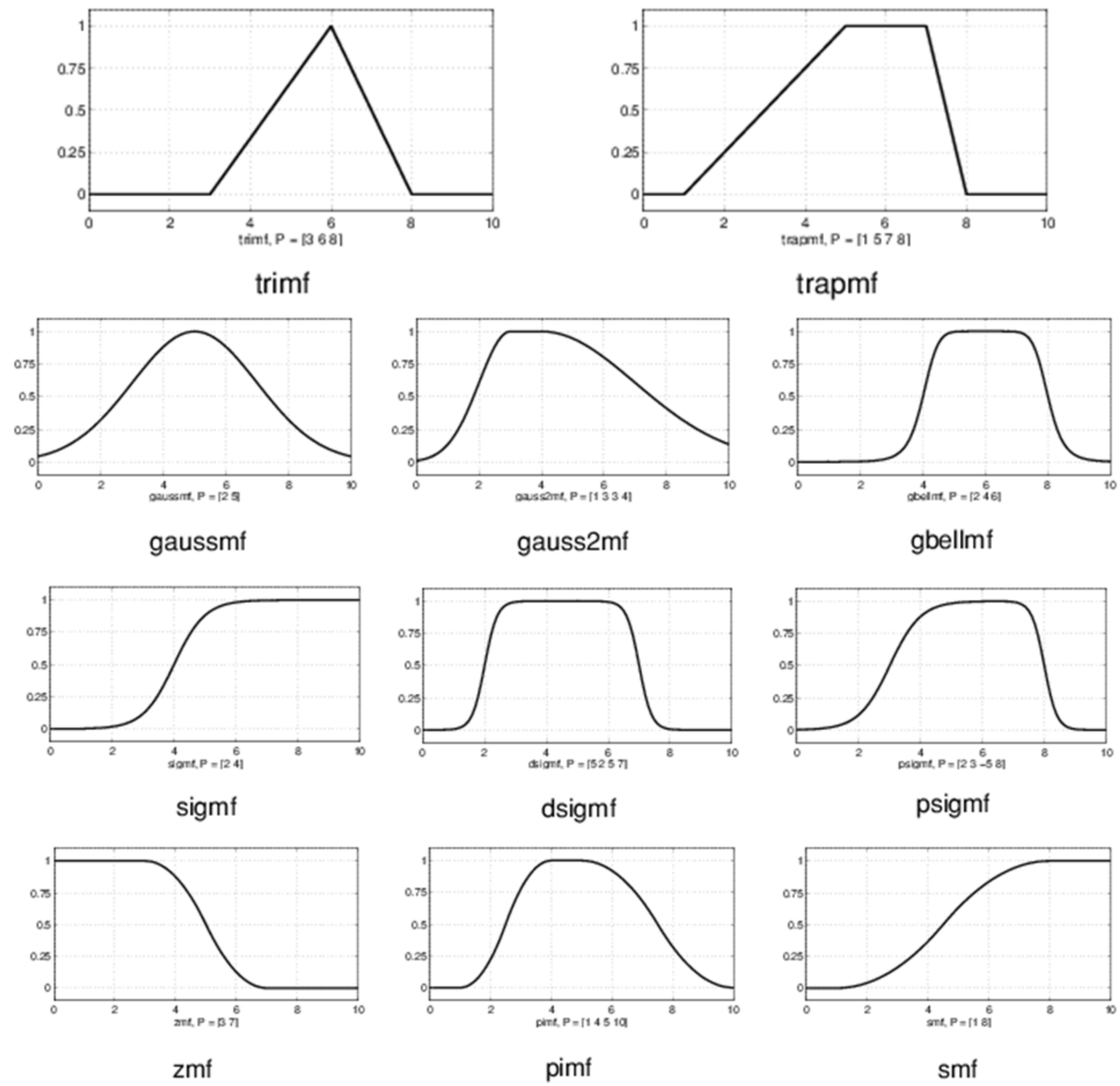

Figure 2-4 Different types of membership functions (Source: (Matlab, 2018))

The input of the membership functions is then passed into rules. The rules determine what the output should be. The rules are created using logic functions: IF THEN or AND.

With this logic the system will then be able to determine when to start cooling the chamber and at what rate. This is in addition to controlling the relative humidity by either increasing or decreasing the humidity and at what rate to do so.

Humidity is universal in nature and affects everything around us. Air contains varying degrees of moisture in it, depending upon location, season, time of day, etc. The current temperature is also affected by similar factors (The American Society of Heating, n.d.).

According to Washington State University (Humidity, 2010) Relative Humidity (RH) is the measure of the amount of water vapour which is present in the air compared to the maximum water vapour the air is able to hold. It is expressed as a percentage of the amount needed for the saturation at the same temperature. Relative humidity does not tell how much water vapour is actually in the air but, it tells how close the air is to being saturated (Skilling, 2009).

RH changes when temperatures change. The reason for this is that warm air can hold more water vapour than cool air, when the temperature rises, and no moisture can be added to the air, Relative Humidity falls. Thus, Relative Humidity (RH) is inversely proportional to temperature. Hence, if temperature increases the RH decreases and vice versa (The American Society of Heating, n.d.). Looking at Table 2-4 one can see the relationship between temperature and humidity (What is the relationship between temperature and humidity, 2017).

Table 2-4 Relationship between Relative Humidity and A Measured Temperature and what it would feel like

Relative Humidity	Air Temperature ˚C						
	21	24	27	29	32	35	38
0.0%	18	21	23	26	28	31	33
10.0%	18	21	24	27	29	32	35
20.0%	19	22	25	28	31	34	37
30.0%	19	23	26	29	32	36	40
40.0%	20	23	26	30	34	38	43
50.0%	21	24	27	31	36	42	49
60.0%	21	24	28	32	38	46	56
70.0%	21	25	29	34	41	51	62
80.0%	22	26	30	36	45	58	
90.0%	22	26	31	39	50		
100.0%	22	27	33	42			

The above table can be explained by the following: If the measured outside temperature is 29˚C and the Relative Humidity is 40% it would feel like 30˚C.

Ventilation is another important factor. Ventilation is the process of changing the current air in a space or room with new outside air to provide a high indoor air quality (Givoni, 1994).

There are three ranges of comfort with respect to humidity, they are (Humidity, 2010):

Comfortable: 30% - 60%

Recommended: 45% - 55%

High: 55% - 80%

2.9 Internet of Things

The Internet of Things may be defined as physical devices that are networked together. The physical devices include: Vehicles, home appliances and other items. These items are embedded with electronics, software, sensors, actuators and connectivity, allowing these objects to connect and exchange data (Brown, 2016). It is possible for each 'thing' to operate within an already existing internet infrastructure. This allows for direct integration of the physical world into the computer world. IoT has many advantages including improved efficiency, accuracy and economic benefits (Friess & Vermesan, 2013).

The devices that allows IoT to take place are known as IoT microcontrollers. These devices act as a gate-way to the internet/cloud for the item to send data to. IoT has the ability to connect to various sensors and actuators, when this takes place, IoT becomes a general class of cyber-physical systems. Cyber-physical systems consist of technologies such as smart grids, virtual power plants, smart homes, intelligent transportation and smart cities (Friess & Vermesan, 2013).

IoT makes use of various protocols to transmit information. One such protocol is Messaging Queuing Telemetry Transport (MQTT). MQTT is a messaging protocol that provides an easy way to distribute telemetry information. This protocol plays vital role in IoT. It makes use of a publish/subscribe communication pattern and is most commonly used for machine-to-machine (M2M) communication (Rouse, 2018).

The MQTT protocol works in the following way: Information is sent or published to a server from a resource-constrained IoT device about a specific topic. The server then acts as an MQTT message broker. Once this occurs, the message broker pushes the data to the clients who have subscribed to the specific topic. A topic resembles a hierarchical file path. It is possible for clients to subscribe to a level of a topic's hierarchy, alternatively a wild-card character can be utilised to subscribe to multiple levels (Rouse, 2018).

The MQTT protocol works best in environments where wireless networks experience fluctuating levels latency as a result of bandwidth constraints or poor connections. If the connection between a client and a broker gets lost, the broker will buffer the messages and push them to the subscriber when it is online/functional. It is possible for the broker to close the connection and send subscribers a cached message with instructions from the publisher if the connection between the publisher and client is disconnected without notice (Rouse, 2018).

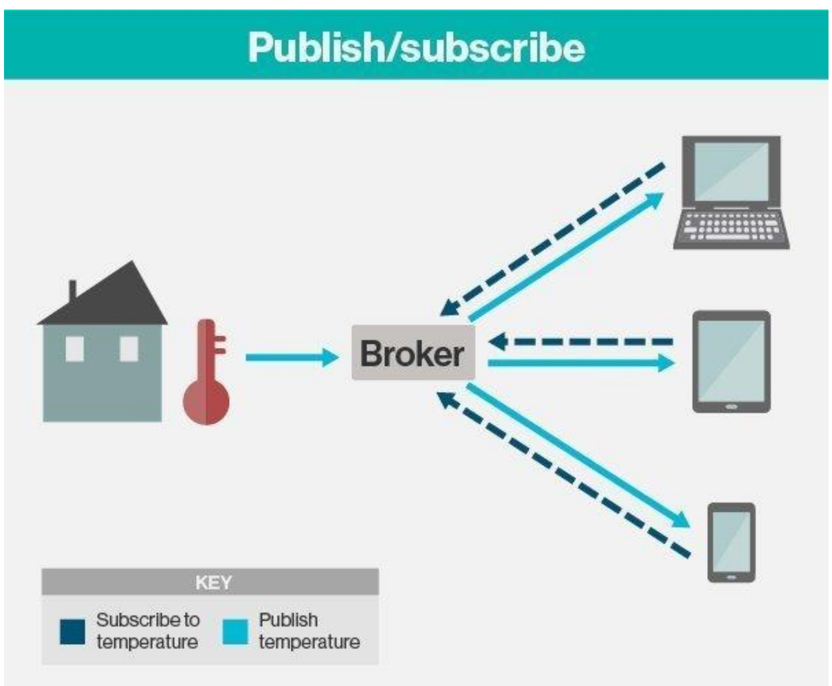

Figure 2-5 MQTT's publish/subscribe model (Source: (Rouse, 2018))

2.10 Research Methods

Research into this project will begin by conducting a thorough literature review into tracking the sun's position by using calculations and to determine what the best sensors are to use to track the sun. Research will also be done on using a solar panel to charge a 12V DC battery. This will be used to power the whole system. Once the fundamentals have been researched, ways on how to implement the fuzzy logic with an Arduino Mega and the different ways of implementing it will be explored.

A Matlab Simulink model will then be created to see how well the system runs and to fine tune it to have the best performance. Research will be done on how to track the sun using the researched sensors with the Arduino Mega and how to move the required motors which will change the rotation and elevation of the weather testing chamber.

More research will be done on which cooling methods will be used, which would be the best to use to control the temperature of the testing chamber, and how to control the humidity within the chamber. Once that has been completed, the fuzzy logic algorithm will be coded and implemented which will control the temperature and humidity from the user's desired settings.

The next aspect will be to research the data cloud storage. The results obtained from the testing chamber must be stored in the cloud and accessed remotely from another PC in a different location.

Once all the research has been completed, the next task will be to start building and implementing the final design of the testing chamber and once that is complete, the testing phase and verification of the chamber will begin, and any final adjustments will be made.

2.11 Research Activities

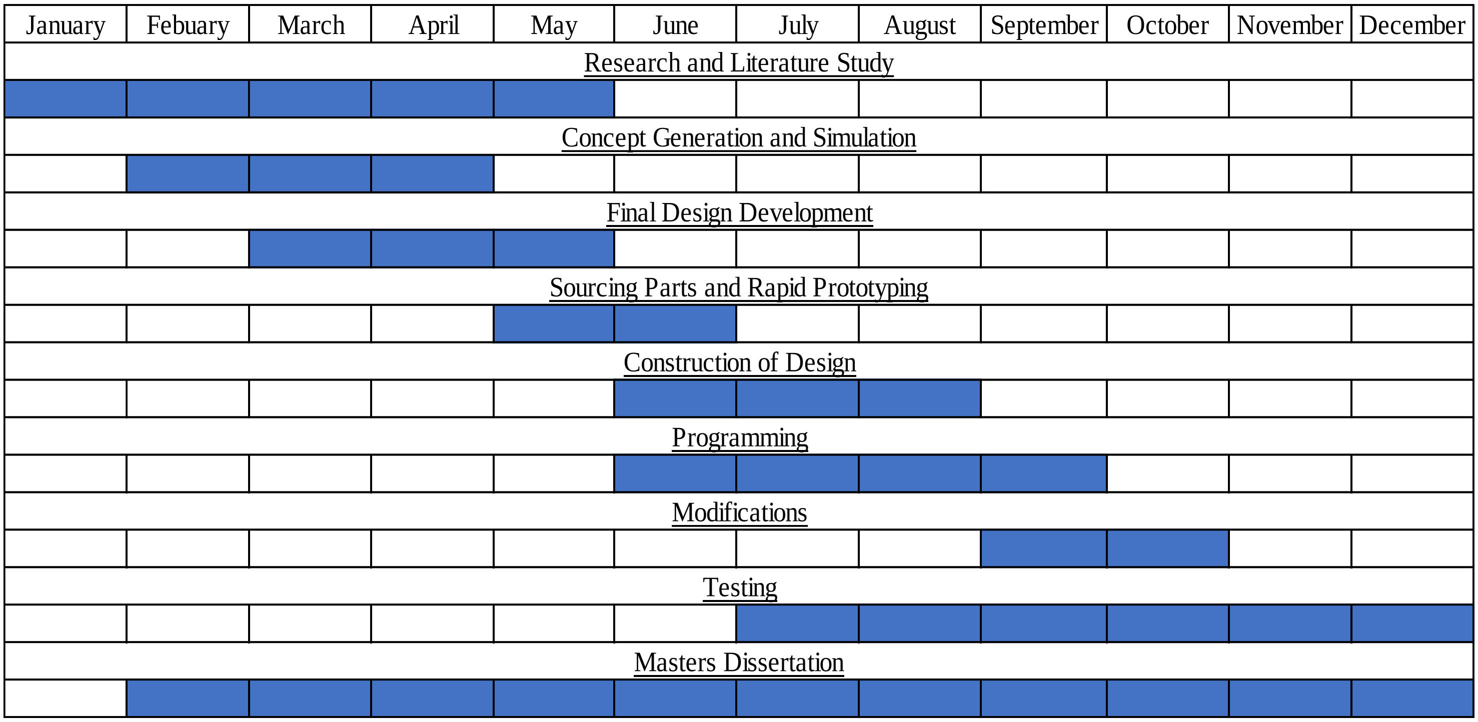

Figure 2-6 Proposed Research Timeline

2.12 Chapter Conclusion

Over the course of this chapter it can be seen that there are different methods with regards to solar tracking. Each of these systems have their own advantages and disadvantages. Two of these methods will be tested and compared to each other, this can be seen in Chapters 4 and 5. With regards to the fuzzy logic control, there are a lot of resources relating to how fuzzy logic works and how the different variants are used in specific tasks. The implementation of the fuzzy logic with an Arduino Mega will use this knowledge and be simulated with Matlab Simulink and the results of this simulation can be seen in the following chapter. The IoT system and implementation is straight forward as can be seen. The research shows that with IoT there are protocols that are used in order to send and receive data to and from the cloud, it shows that the MQTT protocol is the best as it is fast and depicts a real-time update of the data. The MQTT will still send the messages through to the subscriber if the connection between the client and broker gets lots, as it does this by buffering the messages and pushes them through to the subscriber when it is online.

In the next chapter, implementation and design of weather testing chamber will be discussed.

3. Implementation and Design of Weather Testing Chamber

The following chapter will cover the design process undertaken in developing the solar tracking weather testing chamber. This chapter will be split up into three sections describing the component selection and their implementation into the final system.

The first section will discuss the mechanical design of various components, focussing mostly on the frame that will hold the weather testing chamber during the solar tracking process and the mounting systems for the various components. This sub-section will look at the original design problems involving the tilting mechanism and the support frame for the weather testing chamber. This sub-section will also address various solutions to the above-mentioned problems.

The second section will discuss the electrical design of the weather testing chamber system. This sub-section will include the part selection, electric and electronic circuit design and their integration into the system. This sub-section will also look at the energy use or energy balance equations, to see how much energy is used and how much the energy is provided to the system. Since the entire system is powered via solar power and a battery, the above-mentioned needs to be included, to prevent the system from using too much power that is provided which may result in the system not lasting for a long time.

Finally, the programming design will be discussed. This sub-section will look at the programs used to code and implement the algorithms to the final control system. This sub-section will also discuss programs that were used to simulate the fuzzy logic control and compare it to other logic control. Simulations of the air flow within the weather testing chamber and how the temperature changes are included in this section. The program design will be split into three parts, the temperature and humidity control, the solar tracking control and the IoT/cloud-based monitoring.

3.1 Mechanical Design

The mechanical design will discuss, for the most part the design and implementation of the frame that will hold the weather testing chamber. The old frame design will be looked at and the new designs will be discussed.

Up until now, the weather tests that are conducted are done so in stationary weather testing chambers. As mentioned above a weather testing chamber that can track the sun on dual axis, increases the solar radiation onto the component being tested. This is beneficial, as it will provide a more accurate way of testing.

The original design of the frame had some problems. The first problem was that the pivot point on which the weather testing chamber would rotate was below the centre of mass, this means that a lot of force would be needed to rotate the chamber. A large amount of force would require a powerful motor to rotate the chamber. A solution to this problem was to design the frame so that the pivot point would be on the centre of mass, requiring very little force to rotate the chamber, this rotation could then be easily be done using a less powerful motor. The second problem was that the side arms of the frame were very tall, which means that the system was top heavy and would rock back and forth easily in slight winds. This was an issue as it could cause the entire system to tip over. This is a risk as it could cause damage to the entire system or cause harm to any persons working with the system. A solution to this problem, was to shorten the side arms, so the centre of mass would be closer to the ground and not be top heavy.

It is for this reason that the mechanical design will focus mainly on the frame and tilting, where various concepts are proposed in order to mitigate these potential risks in the future. This section will be discussed in two separate designs, one relating to the frame holding the chamber and the other relating to the tilting of the frame.

3.1.1 Original Design

The initial frame was designed and manufactured previously. The first step was to determine how the frame was designed and to determine what method was used to tilt the frame. There were a few issues that were noted, the first problem was that the pivot point was below and to the front of the weather testing chambers centre of mass. This made it difficult to rotate the chamber forward by 35 degrees (This was one of the requirements for the project) and then back to the initial position. A motor with a very high torque and holding torque would be required to rotate the weather testing chamber, this would be a problem as the system runs off 12V. A motor with such a high torque would not satisfy this requirement. The second problem was that the frame together with the weather testing chamber was quite tall, which made the entire system very top heavy and would thus sway back and forth if it were windy. The design solutions to these problems are discussed below. Figure 3.1 below shows the original design of the frame holding the weather testing chamber.

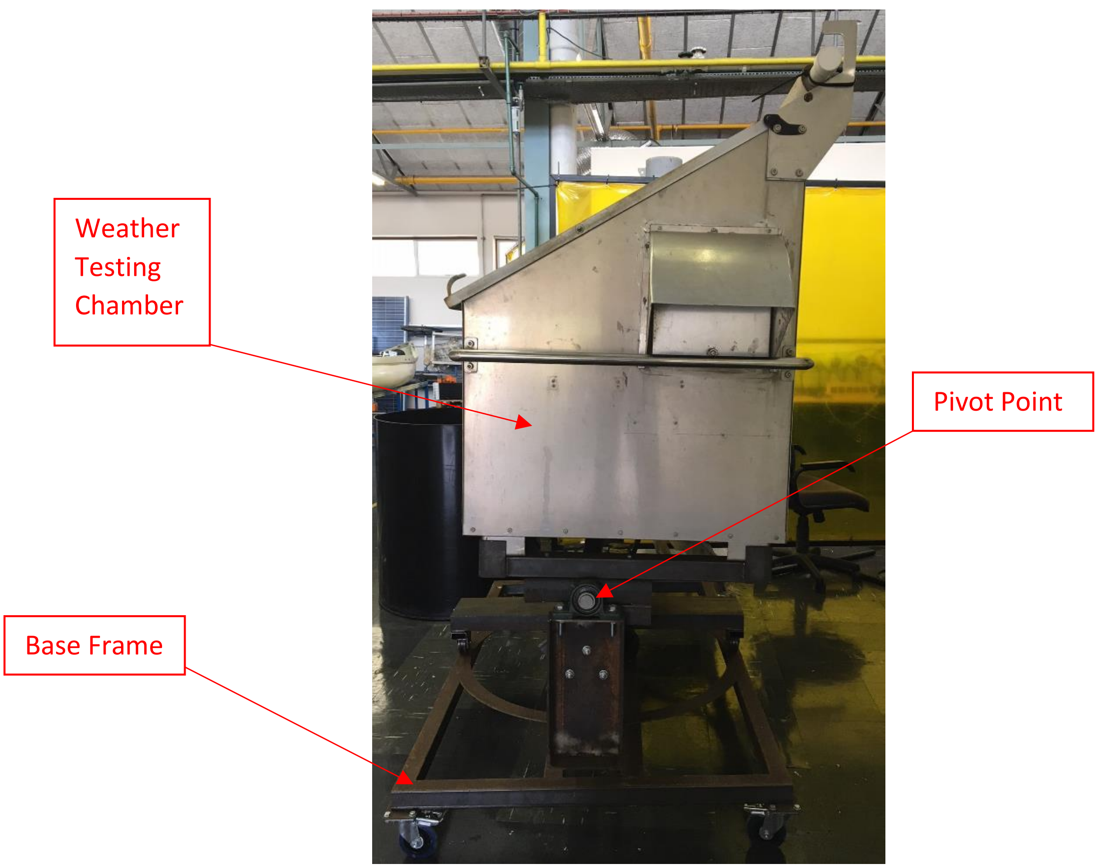

Figure 3-1 Side view of the original design of the Frame with chamber

Figure 3-2 Front View of the original frame holding the chamber

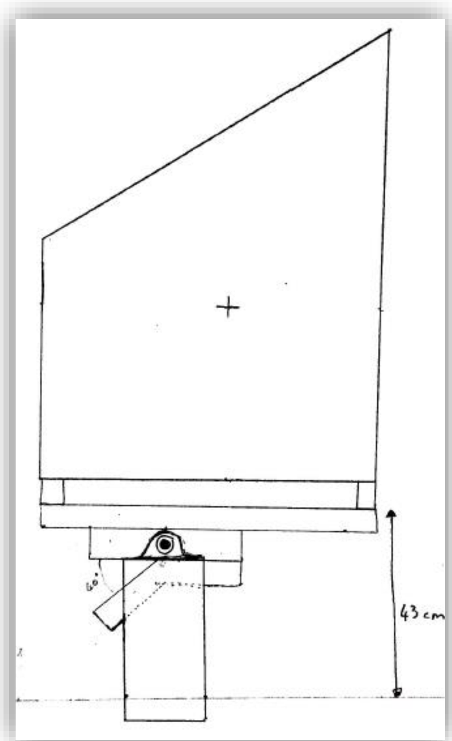

Figure 3-3 Side view showing the center of mass point and pivot point

3.1.2 Design Solution

The solutions to the problems that were mentioned above are discussed in this sub-section. The solution to the first problem regarding the pivot point, was to bring the pivot point to the centre of mass of the weather testing chamber. Having the pivot point on the centre of mass would mean that less force and holding torque would be required to rotate the weather testing chamber forward to the required position during the day and then back to the initial position at the end of day when no solar tracking is required. The reason for this is that the moment of inertia is the least, thus less force required to rotate the mass. Since the centre of mass is the best place for the pivot point, the centre of mass of the weather testing chamber must be calculated. The calculations used to determine the centre of mass can be seen below:

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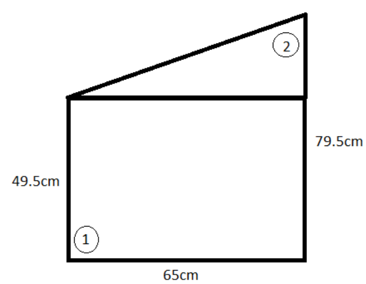


Shape 1:

$$A_1 = 3217.5cm^2$$

$$y = 24.75cm$$

$$x = 32.5cm$$

Shape 2:

$$A_2 = 975cm^2$$

$$y = 59.5cm$$

$$x = 43.33cm$$

Centroid:

$$y = \frac{(3217.5)(24.75)+(975)(59.5)}{3217.5+975} \quad (3.1)$$

$$y = 32.83cm$$

$$x = \frac{(3217.5)(32.5)+(975)(43.33)}{3217.5+975} \quad (3.2)$$

$$x = 35.0186cm$$

This is beneficial, because this means that a smaller less powerful motor could be used. A less powerful motor means less energy used by the entire system. The solution to the second problem was to redesign the frame that holds the weather testing chamber. The new design would bring the weather testing chamber lower which brings the centre of mass lower to the ground and in turn makes the weather testing chamber less top heavy and less susceptible to tip over. Figure.3-4 shows the new design of the frame.

The remainder of this chapter will discuss the three ideas that were thought of to find a method which would be the best to rotate the chamber forward, hold the chamber in the desired position during the day when solar tracking is required and back to the initial position at the end of the day and the advantages and disadvantages of each idea. The first idea was to have a linear actuator underneath the weather testing chamber. One end of the linear actuator mounted on the front end of the 'bed' that holds the chamber and the other end mounted on the back of the rotating frame. Figure.3-4 shows the components of the entire frame that holds, tilts and rotates the weather testing chamber.

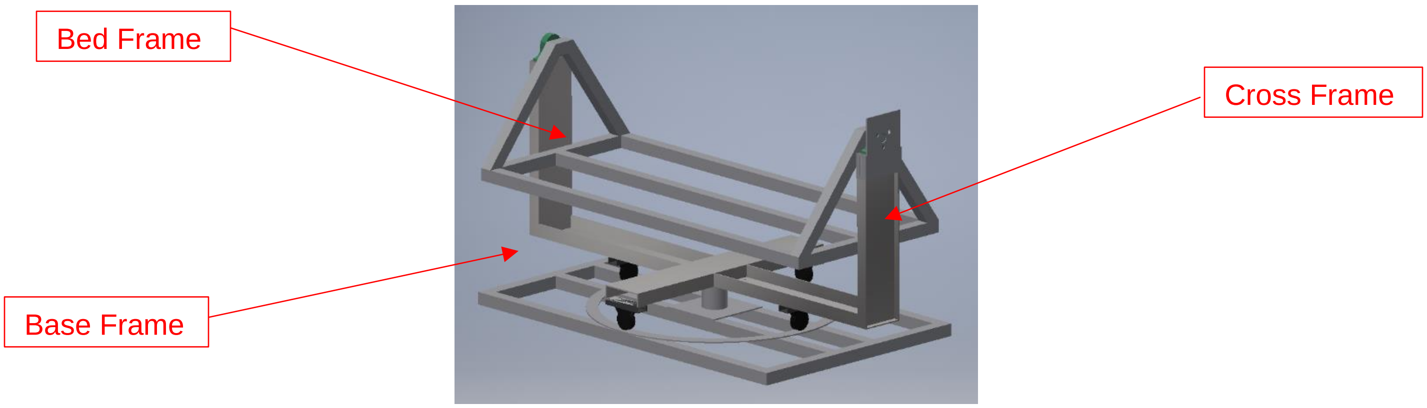


Figure 3-4 the entire frame

The linear actuator would be in its fully extended position when the weather testing chamber is in its initial/start position and would then rotate the chamber forward when the linear actuator would be retracted. Figure.3-5 shows the how the linear actuator would be mounted onto the frame.

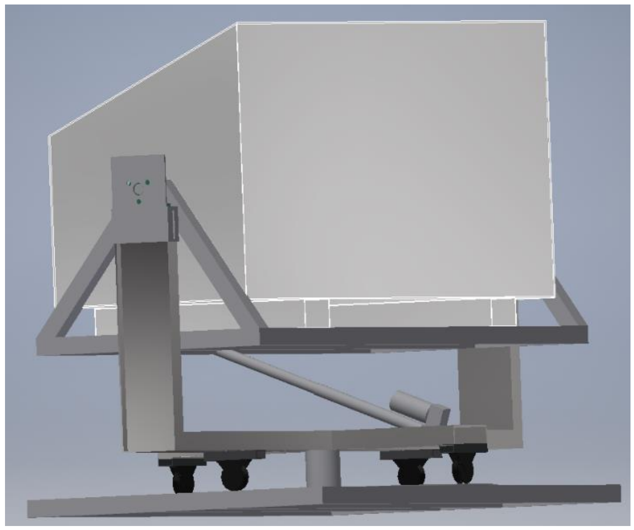


Figure 3-5 Linear actuator position

This type of method would be very beneficial, because it would be very efficient and would require minimal effort to rotate and hold the weather testing chamber in the required position. The only issue with using the linear actuator was getting the best linear actuator to have the correct stroke length and retracted length (Figure 3-6 shows what the stroke length, retracted length and entire length of the actuator is) to work in the space under the weather testing chamber.

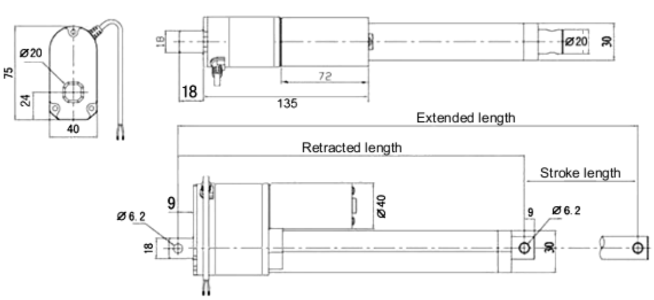


Figure 3-6 Stroke length and retraction length (mm) (Source: (Microbot, 2018))

The space underneath the chamber was very limited, because the side arms were shortened to bring the chambers centre of gravity closer to the ground. A custom-made linear actuator could be used so that it would fit and operate correctly underneath the chamber, but the cost of the linear actuator was very high, and the delivery time was very long, thus, it was decided that the linear actuator would not be used.

The second idea was to use a wiper motor that was provided from a supplier and have it connected directly to the side of the of the shaft which is connected to the 'bed' that is inserted inside the bearings that allow the chamber to rotate freely. A key slot was required to be made so that the wiper motor shaft would slot into the shaft of the 'bed'. This idea was beneficial because the wiper motors are readily available and a lot cheaper than the linear actuator and easy to mount onto the system. Since the wiper motor is a worm gear it has the required torque to rotate the chamber efficiently. The calculations below show that the motor has the required torque.

$$T = I * \alpha \tag{3.3}$$

The chamber is required to move at slow speeds, thus the angular acceleration can be small. The required angular acceleration can be the following:

$$80 = 39.519 kg.m^2 * \alpha$$

$$\frac{80}{39.519 kg.m^2} = \alpha$$

$$\alpha = 2.0243\, rads/s^2$$

The specifications of the motor can be found in Chapter 4. The only downside to the wiper motor is that it has a higher running current than the linear actuator, so a powerful motor driver would be needed to control the motor. The third idea was to use the wiper motor, but to have the motor mounted underneath the chamber onto the cross-section frame and have a gear on the shaft of the motor and then to have a curved-like electric gate track connected to either end of the 'bed'. Figure.3-7 shows the visual of this idea.

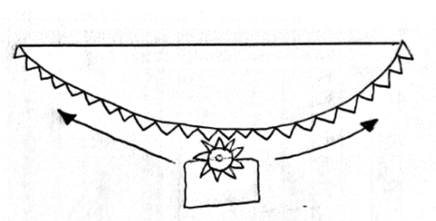


Figure 3-7 Gate motor concept

The benefits of this idea are the exact same as the second idea, but the disadvantage is that more effort would be required as additional components would be needed. The additional components include the curved track. The next sub-section looks at taking into account the above mentioned and forming the new design.

3.1.3 New Design

This sub-section will look at the final design and how the new design was made final. Two design concepts were explored, these concepts are mainly focused on the 'bed' that would hold the chamber. This component was the main focus, as it is considered the most important due to the fact that it holds the chamber and this is the region where the rotation occurs.

Concept One:

The first concept which can be seen in Figure.3-8, shows the 'bed' having a rectangular shape which has a border-like structure going completely around the chamber.

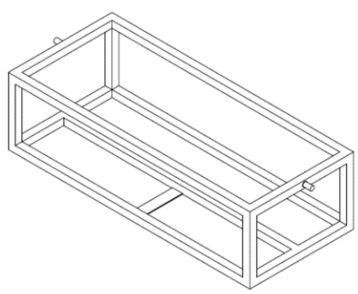


Figure 3-8 Concept one

This concept was thought to be beneficial, as it provides a more secure hold on the chamber. This concept was discarded, because this design added more weight to the entire system, which was a disadvantage as the lighter the system the better, as less force would be required to rotate the chamber.

Concept Two:

The second concept which can be seen in Figure.3-9, shows the ‘bed’ having a more open design with a triangle-like design on the sides where the shafts will be mounted.

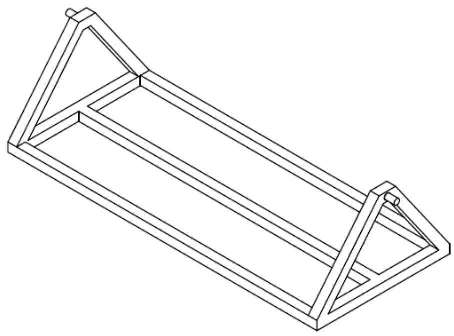


Figure 3-9 Concept two

The shape of the triangle is not a perfect triangle as the centre of mass of the chamber is a more towards the rear end of the chamber, thus, the shape of the triangle is slanted towards the rear end.

This concept was more beneficial when compared to the first concept, because it is much lighter, thus making the entire system lighter. This concept was also structurally strong enough. This concept was perfect to use, as it is light weight and strong enough to support the chamber.

In summary, the new design of the chamber will have the pivot point about the centre of mass point. The side arms will be shortened to make the system less top heavy. Shortening the arms will result in less force being required to rotate the chamber forward and back to the initial position. Concept two was chosen as it was the better option because it is lighter and stronger, thus, preventing the chamber from falling off the ‘bed’. Figure.3-10 shows the final design of the chamber. The dimensions of the final system can be seen in Appendix A.

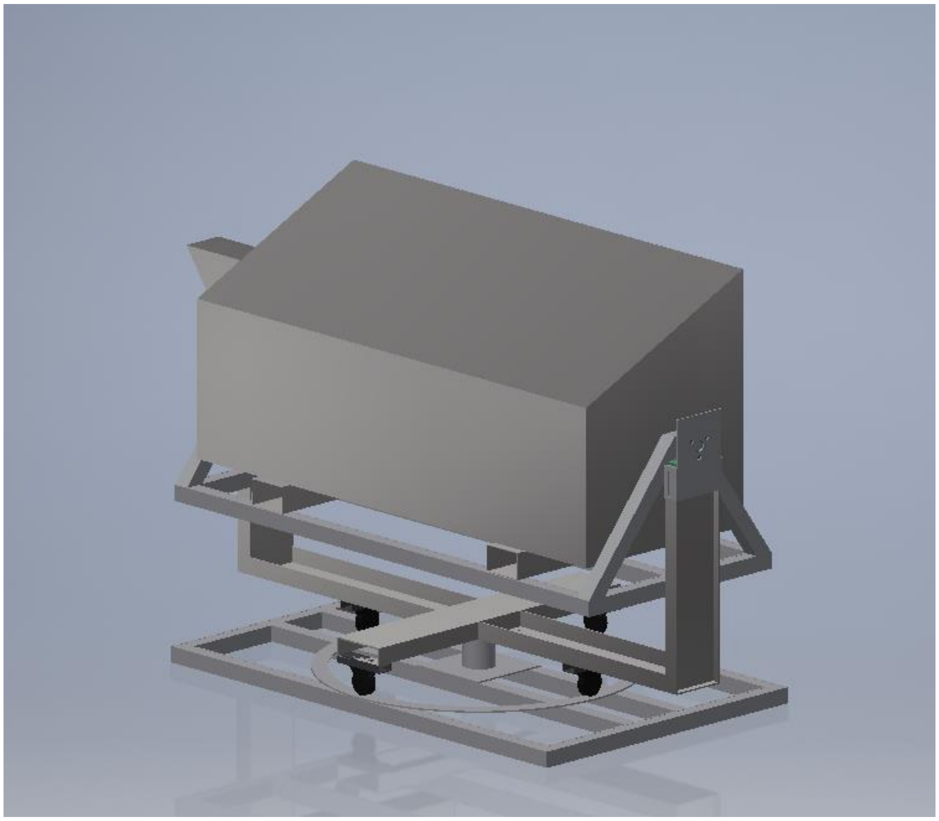


Figure 3-10 Final Design of chamber

3.2 Electrical Design

This section will discuss the electrical plan, including component choice and combination of components. This section will plot the usefulness of every device with reference to the whole climate testing framework. The entire system encapsulates many different sensors and electrical components, each of these sensors will be discussed. The manner in which each of the sensors is integrated into the system is discussed too.

3.2.1 Solar Panel

This project requires the weather testing chamber to be placed anywhere in a remote location and for it to be placed there for at least a year. These requirements mean that there will not be a local power source. To provide power to the system a solar panel is required to charge a battery. The solar panel will be mounted at a 45-degree angle to the back of the chamber. The solar panel will be mounted at this angle is to ensure maximum solar exposure throughout the day. The battery that will be used is a 12V battery, thus, the solar panel must meet those requirements. The specifications of the solar panel are the following:

- Rated Power (Pmax) = 35Wp
- Rated Voltage (Vmp) = 17.10V
- Rated Current (Imp) = 2.05A
- Open Circuit Voltage (Voc) = 21.90V
- Short Circuit Current (Isc) = 2.21A
- Maximum System Voltage = 600V
- Maximum Series Fuse = 10A

The solar panel with these specifications had to be the correct size, as a panel that was too large would make the back of the chamber too heavy, which would require the motor to work harder to rotate the chamber. The battery and Solar Charge Controller were selected based on these specifications.

Figure 3-11 Solar Panel (Source: (Anon., 2018))

3.2.2 Battery

A battery is required to power the system. The battery provides a constant DC voltage to the system but will be used with the solar panel mentioned above, so the battery can be charged. The battery that was already provided with this project was a 12 V, 50Ah Plumb car battery. However, a 12V deep cycle battery would be a better battery to use as the life duration is longer. A car battery provides a very large amount of current for a short period of time and is designed to go through its entire life without ever being drained more than 20 percent of its total capacity, hence it can last a long time used in this manner. A deep cycle battery provides a steady amount of current over a long period of time. It is designed to be deeply discharged over and over again without causing damage to the battery but would cause damage to a car battery (Anon., 2018). Since the application tends more towards the design of the deep cycle battery, it would be better to use it. Due to the fact that this project is a prototype for an automotive company, a car battery is suitable.

Thus, the battery that was used for this project has the following specifications:

- 12 V
- 102 Ah

This battery was used instead of the 50 Ah battery, because it lasts longer, during cloudy days. The total amount of energy coming into the system needed to be compared to the total amount of energy leaving the system to ensure enough power is provided for a sufficient amount of time without depleting the battery until it is charged again. Table 3.1 shows the energy in vs the energy out.

Table 3-1 Energy balance Table

Current In	Current Out	Watts In	Watts Out
102Ah	10	35	40
	5.6	1224	11.928
	0.05		0.6
	0.05		0.6
	6		24
	0.0015		0.00495
	0.067		0.335
	0.0005		0.0025
	0.0001		0.0005
	0.825		19.8
	0.000005		0.000165
	0.8		4
102Ah	23.394105		48
		1259	149.27112

The total current is in Amp hours which means if the system draws 102 amps it will only last for an hour. The system is only using 23.4 amps while the motors are running, when the motors are not running the system is only using 1.8 amps on average. Thus, there is enough energy being provided without completely discharging the battery. The battery can last roughly 35 hours without being charged. This can be calculated by dividing the batteries capacity by the total current draw.

3.2.3 Solar Controller

A solar charge controller is needed to interface the solar panel and battery together. A solar panel can be connected directly to a battery, but it is not wise to do so as you could over charge the battery and damage it, reducing its life. Overcharging occurs because most 12 V panels output around 16 to 20 V and 12 V batteries need around 14 to 14.5 V to get fully charged. 12 V solar panels do not output 12 volts because the weather conditions are not always perfect, thus, the panels would still need to provide some extra voltage when the sun is low or there is cloud cover (Anon., 2018). A solar charge controller is important as it prevents overcharging of the battery and prevents over voltage. The solar charge controller regulates the current and voltage from the solar panel to the battery (Anon., 2018).

There are three types of solar charge controllers, they are:

- Simple 1 or 2 stage controls – They rely on relays or shunt resistors to control the voltage in one or two steps.
- 3-Stage and/or PWM
- Maximum power point tracking (MPPT)

The second type of controller was used as it is the industry standard, cheap and easily available. The controller that was chosen was the Steca Solsum 10.10F, which can be seen in Figure.3-12 as it meets with the solar panel and battery requirements. The data of the controller can be found in Appendix B.

Figure 3-12 Solar Charge Controller (Source: (Anon., 2018))

3.2.4 Accelerometer

The accelerometer for this project plays an important role as it is the key factor in tilting the weather testing chamber. An accelerometer is an electromechanical device which is used to measure acceleration forces (Goodrich, 2013). Accelerometers can measure the angle at which an object has rotated. This is important, because the weather testing chamber needs to rotate forwards and to a maximum of 35 degrees. As the chamber is rotating, the system needs to know how much the chamber has rotated by and needs to know if it needs to rotate forward or backward until the angle of rotation is equal to the elevation angle at which the sun is currently at. In order to do this an accelerometer is needed. Since the main microcontroller is an Arduino Mega, the sensor needs to be compatible, have low power consumption with the Arduino and also needs to be cost effective. There are many different types of accelerometers, some of which range from 9 DOF to 3 DOF. Since this type of application only requires reading the rotation angle, the sensor only needs to be 3 DOF. DOF is the degree of freedom, 3 DOF relates to the x, y and z axis of rotation. This dissertation will focus on three types of accelerometers, they are:

MPU-6050

The InvenSense MPU-6050 sensor contains a MEMS (micro electro mechanical systems) accelerometer and a MEMS gyro in a single chip. It is very accurate, as it contains 16-bit analog to digital conversion hardware for each channel. Therefore, it captures the x, y, and z channel at the same time. The sensor uses the I2C-bus to interface with the Arduino (Goodrich, 2013).

The MPU-6050 is not expensive, especially given the fact that it combines both an accelerometer and a gyro.

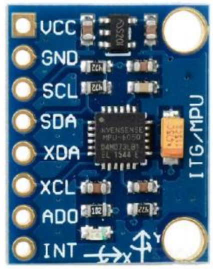


Figure 3-13 MPU-6050 (Source: (Anon., 2018))

ADXL335

The ADXL335 is an accelerometer module part of the ADXL3xx series and it also contains a MEMS sensor. The ADXL335 module is a three-axis accelerometer, which contains six pins, three pins for each axis, one for Vcc, one for ground and the last one for self-test. The self-test is to make sure the accelerometer is working well. The ADXL335 operates with low noise and it has a low power consumption, around 320uA.

The analog-output has a range of +/-3g. That means that at 0g, the output is somewhere in the middle of the voltage. Analog accelerometers are usually easier to use since most microcontrollers have A/D converts built-in.

Figure 3-14 ADXL335 (Source: (Anon., 2018))

LIS3DH

The LIS3DH is also a three-axis MEMS accelerometer module. This module has both I2c and SPI interfaces for communication. This module is popular as it is cheap and has a low power consumption of only 2uA. Compared to the ADXL335 the LIS3DH is a digital accelerometer. Digital accelerometers are more advantageous than analog, because they have more features and are less sensitive to noise (Goodrich, 2013).

The LIS3DH has 4 levels of sensitivities (+-2g/4g/8g/16g) and has a built-in self-test feature. It also has the capability to detect a tap, double tap, orientation, and freefall. Additionally, there are three ADC inputs if required to read over I2C. These features are important, but they will not be needed, since the only requirement for the accelerometer is to measure tilt.

Figure 3-15 LIS3DH (Source: (Anon., 2018))

The accelerometer that was chosen for this project was the MPU-6050. The reason this module was chosen, was because it is readily available, cheap and easy to use with any microcontroller. Also, the electronic community prefer it as it is more stable and accurate than the others.

3.2.5 Magnetometer

The magnetometer is important in this project as it is used for the system to orientate correctly in relation to the azimuth angle. A magnetometer is a device that measures magnetic fields and magnetic flux density B (in units of Tesla or As/ m2) (Jain, 2017).

Since magnetic flux density in air is directly proportional to magnetic field strength, a magnetometer is capable of detecting fluctuations in the Earth's field. Magnetic flux lines are distorted by materials known as magnetic and include materials such as magnetite that possess magnetic fields of their own, as well as very high magnetic conductivity (Jain, 2017). Magnetometers detect the distortions in the Earth’s magnetic flux created from the above-mentioned materials that are flowing around them. A magnetometer measures the magnetic flux density at the point in space there the sensor is located. A magnetic field drops in intensity with the cube of the distance from the object. Magnetometers are classified into two categories:

• **Vector magnetometers** that measure the flux density value in a specific direction in three axes of space. An example is a fluxgate magnetometer that can measure the strength of any component of the Earth's field by orienting the sensor in the direction of the desired component (Jain, 2017).

• **Scalar magnetometers** that measure only the magnitude of the vector passing through the sensor regardless of the direction. Quantum magnetometers are an example of this type of magnetometer (Jain, 2017).

The magnetometer in this project was used as a compass to allow the chamber to orientate its self. Thus, the system does not have to be manually positioned to face north. The system will also know its position in relation to the suns azimuth angel. If these values do not match, the microcontroller will drive the azimuth motor to rotate either clockwise or anti-clockwise depending on how far off the systems angle is compared to the azimuth angle. Once the angles are equal the motor will stop. This will make sure that the system is always tracking the suns azimuth angle throughout the day.

The magnetometer that was used was a vector magnetometer. Specifically, the HMC5883L GY-273. This can be seen in Figure.3-16.

Figure 3-16 HMC5883L GY-273 (Source: (Anon., 2018))

This magnetometer communicates to the microcontroller via I2C. It is very cheap, easily available and has a very low power consumption. This magnetometer is based off the Honeywell HMC5883L chip. The HMC5883L sensor measures the earth's magnetic fields in three axes, namely X, Y and Z. When the XY plane is parallel to the ground, the output of the sensor indicates the compass heading. This is the value that will be compared to the azimuth angle.

3.2.6 GPS

A GPS (Global Positioning System) is a satellite-based navigation system which is made up of at least 24 satellites orbiting the earth. A GPS works 24 hours a day in any weather conditions, anywhere in the world (Sharma, 2017). A GPS module was needed for this project, so the system can know its position and time automatically. The latitude and longitude do not have to be physically inputted into the system. The latitude and longitude values and local time are also needed to calculate the azimuth and elevation angles. These values will be automatically calculated where ever the system is placed.

The most popular GPS module that is used is the NEO-6M, it can be seen in Figure.3-17. This module can be used with most microcontrollers and is easy to interface with them. The GPS module that was used was the NEO-6M. The antenna that came with the GPS module was very short and this would need to be changed, since the GPS module was place inside a metal control box the GPS signal would not be received. A GPS extension antenna had to be used, so that the antenna can be placed outside the control box to receive a signal. The antenna contains a high-performance GPS patch antenna and a high-tech low noise amplifier. It provides excellent signal amplification and out-band-rejection for the receiver with a frequency of 1575MHz. The antenna can be seen in Figure.3-18.

Figure 3-17 NEO-6M GPS (Source: (Anon., 2018))

Figure 3-18 GPS extension antenna (Source: (Anon., 2018))

3.2.7 Temperature and humidity Sensor

Temperature and humidity are two very important aspects that need to be measured and monitored in this project. Sensors were required to measure the temperature and humidity. A sensor that can measure both temperature and humidity was selected, thus fewer sensors were required. The sensors that were used had to withstand high humidity and temperature. Two sensors were explored that are able to achieve these requirements. These sensors were the DHT11 which can be seen in Figure.3-19 and the DHT22 which can be seen in Figure.3-20.

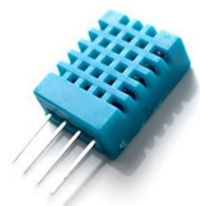


Figure 3-19 DHT11 Temperature and Humidity Sensor (Source: (Anon., 2018))

Figure 3-20 DHT22 Temperature and Humidity Sensor (Source: (Anon., 2018))

The DHT11 detects water vapor by measuring the electrical resistance between two electrodes. The humidity sensing component is a moisture holding substrate with electrodes applied to the surface. When the substrate absorbs water vapor, ions are released by the substrate which then increases the conductivity between the electrodes. The change in resistance between the two electrodes is proportional to the relative humidity. A higher relative humidity decreases the resistance between the electrodes, while a lower relative humidity increases the resistance between the electrodes.

The formula to calculate relative humidity is:

$$RH = \left(\frac{p_w}{p_s}\right) x\ 100\% \quad (3.4)$$

Where:

RH: Relative Humidity
Pw: Density of water vapor
Ps: Density of water vapor at saturation.

The DHT11 measures temperature with a surface mounted NTC temperature sensor (thermistor) built into the unit. The DHT22 works in the same way as the DHT11. The specifications for the DHT11 and DHT22 can be seen in Appendix C. The DHT22 sensor was chosen as it has a better accuracy compared to the DHT11 and the DHT22 has a greater temperature range, thus it can handle higher temperatures than the DHT11. Six of these sensors were placed around the inside of the chamber, one in each corner and two in the center. This was done to get an average temperature and humidity throughout the whole chamber.

3.2.8 DC/DC Boost Converter

A boost converter was needed to boost the 12 volts from the battery to 24 volts. This was required as the cooling fan that was mounted to the original chamber was 24 V DC. The easiest way to solve this issue was to use a DC/DC boost converter. The fan specifications are 24 V, 825 mA and 19.8 W. The boost converter can handle a max current of 6 A, but the current from the fan does not mean that that it is the same current draw from the power source. The following equation calculates how much current the fan will draw from the power source.

$$P_F = 19.8\,W$$

$$C_{PS} = \frac{P_F}{V_S} = \frac{19.8}{12} = 1.65A \quad (3.4)$$

The current draw from the source is 1.65 A which is way below the rated current of 6 A.

The calculation above was done assuming the boost converter has an efficiency of 100%. The booster converter that was used has an efficiency of 93%, which means the current draw is:

$$C_{PS} = 1.65 * 0.93 = 1.53\ A \qquad (3.5)$$

This current draw is still below the rated current, thus the boost converter will handle the fan very well.

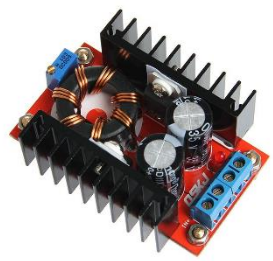


Figure 3-21 DC/DC Boost Converter (Source: (Anon., 2018))

3.2.9 Motor Driver

A motor driver was required for this project so that the microcontroller will be able to control the motor speed and directions. These motors are used to tilt the chamber for elevation and to rotate the chamber for the azimuth. The motor driver that was provided with this project was the Pololu Dual VNH5019 Motor Driver. This motor driver makes it easy to control two bidirectional, high-power 360-watt DC motors with an Arduino microcontroller or compatible board. The motor driver can be seen in Figure.3-22.

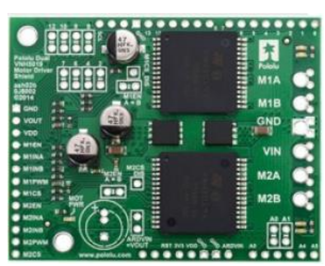


Figure 3-22 Pololu Dual VNH5019 motor driver shield (Source: (Anon., 2018))

The VNH5019 can operate from 5.5 to 24 V and can deliver a continuous 12 A per channel and can handle 30 A peak. The driver uses a pair of VNH5019 driver chips which allows one to control two motors. These driver chips are very robust and can survive input voltages up to 41 V, reverse-voltage protection to -16 V, under voltage and overvoltage shutdown, high-side and low-side thermal shutdown and short-to-ground and short-to-Vcc protection. This motor driver works perfectly for this project as it is easy to use and very robust.

3.2.10 Motors

The motors were used for this project to allow the chamber to tilt for elevation and rotate for the azimuth. The motors that were used were controlled by the motor driver mentioned above. Therefore, the motors had to meet the requirements of the driver and be powerful enough to move the chamber. The two motors that were used were wiper motors which can be seen in Figure.3-23.

Figure 3-23 Wiper Motor (Source: (Anon., 2018))

These wiper motors are bidirectional, 12 V and have a rated current of 10A. These specifications are well met with the driver’s requirements. The wiper motors have a turning torque of 80 Nm. To see if the motors are capable in moving the chamber the following equation is used:

$$T = I * \alpha \tag{3.6}$$

The chamber is required to move at slow speeds, thus the angular acceleration can be small. The required angular acceleration can be the following:

$$80Nm = 39.519kg.m^2 * \alpha$$

$$\frac{80Nm}{39.519kg.m^2} = \alpha$$

$$\alpha = 2.0243\ rads/s^2$$

By ensuring this angular acceleration is met, the motors will be able to tilt and rotate the chamber.

For added protection to the control circuit and motor drivers a cut-off circuit breaker was installed between the motors and motor driver. Since the motor driver can handle a peak current of 30A, anything greater than that will cause the break to cut-off power to the motors.

3.2.11 Internet of Things

A requirement of this project is to implement an IoT aspect. In the literature review above, IoT is discussed. The IoT in this project is used for cloud-based monitoring. All the data that is read from the temperature and humidity sensors is collected and sent to the cloud or server platform. This allows the system to be placed in a remote location and the data can be accessed from another location. The only requirement for this is a Wi-Fi connection, which can be acquired via a Wi-Fi dongle or GSM connection.

The IoT board that was used was the ESP8266 NodeMcu which can be seen in Figure.3-24. This board is similar to an Arduino; however, it is smaller in size and has the ESP8266 Wi-Fi chip built in. This board was used rather than other IoT boards, because of its size, cost and ease of use. The data from the sensors is sent to the NodeMcu via its data pins. The code of the NodeMcu then sends the data to the cloud or a specific server. The server that was used for this project is called Ubidots. Ubidots offers a platform for developers that enables them to easily capture sensor data and turn it into useful information. Ubidots allows data to be sent to the cloud from any Internet-enabled device. There are two versions available, Ubidots education and Ubidots business. Ubidots education is free and can have a maximum of ten devices connected, where Ubidots business can have an unlimited number of devices connected and more. From the Ubidots platform, the data coming in can be stored over time and can be timestamped and downloaded, the data can also be visualized on a dashboard on the Ubidots website.

The protocol in which the data is sent from the NodeMcu to the cloud is MQTT. This type of protocol was discussed earlier in the literature review. The MQTT protocol allows for real time updates of the data being sent.

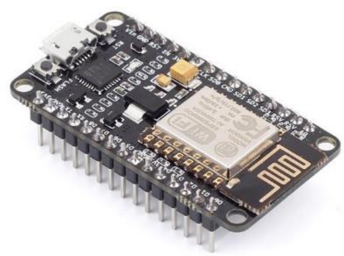


Figure 3-24 NodeMcu ESP8266 IoT Board (Source: (Anon., 2018))

3.2.12 Control Device

The main control of the system is done via two Arduino Mega microcontrollers. These controllers act as the ‘brains’ of the system. Two Arduino Mega’s were used to separate the load of the tasks. The one Arduino controls the temperature and humidity via fuzzy logic this in turn also controls the fan and its speed as well the pump which drives the humidifier misters. The second Arduino controls the solar tracking and movement of the motors. This Arduino has the motor driver that was mentioned above connected to it.

Arduino Mega’s were used instead of Arduino UNO’s because the Mega’s have 52 I/O pins were the UNO only has 13. The clock on the Mega is a lot faster than the UNO, this means that the code running will execute at a faster rate than the UNO. The Arduino Mega can be seen in Figure.3-25.

Figure 3-25 Arduino Mega (Source: (Anon., 2018))

All of the components mentioned above were integrated to produce the final circuit system. This architectural circuit can be seen in Figure.3-26.

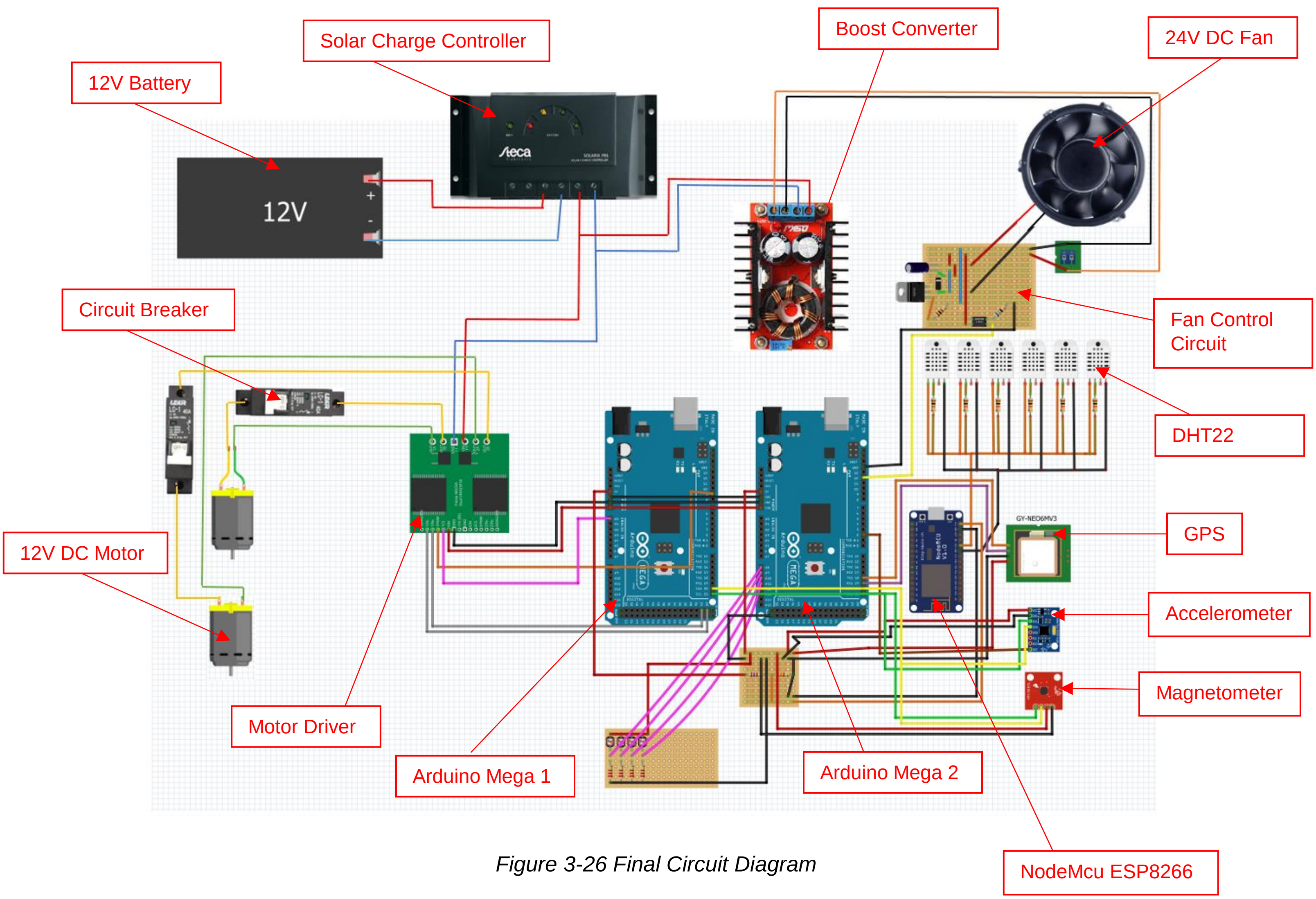


Figure 3-26 Final Circuit Diagram

3.3 IT/Software Design

The Software design section will discuss the various software tools that were implemented throughout the duration of the project. Various software tools were used in the basic structure of the final system and for simulations for the final system.

The various software tools that were used were, Arduino IDE, Matlab and Solidworks. The software that was used the most was Arduino IDE. Arduino IDE is open-source software which allows the interface of all Arduino boards. This software makes it easy to write code and upload it to the board. This software was used to code the two Arduino Mega's to allow them to carry out their specific tasks. This software was also used to code for the NodeMcu IoT board. The data collected by the NodeMcu which is uploaded to the cloud is the basis from which all the results were calculated.

The software such as Solidworks and Matlab were used for simulations. A flow model was designed in Solidworks to simulate the air flow and temperature within the chamber. This can be seen in the section to follow. Matlab was used to simulate the fuzzy logic control and how well it would perform theoretically. Matlab was also used to compare the On/Off logic control.

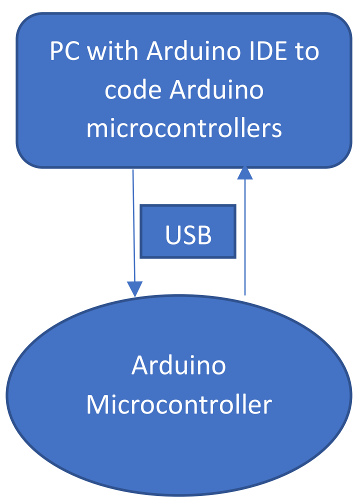


Figure 3-27 Flow diagram of code upload between PC and Arduino

3.3.1 Flow simulation

The flow simulation was done using a software tool called Solidworks. Solidworks is software that is similar to Autodesk Inventor where one can design 3D models and perform simulations on those models. In this case the flow simulation was used, because air is the fluid that is flowing within the chamber, thus, a flow simulation was used to simulate the air flowing within the chamber and the temperature behaviour. This was done to get a better understanding of how the airflow in the chamber behaved and where improvements to the airflow can be made. The chamber was drawn in Solidworks to the correct dimensions of the actual weather testing chamber. The 3D model of the chamber can be seen in Figure.3-27.

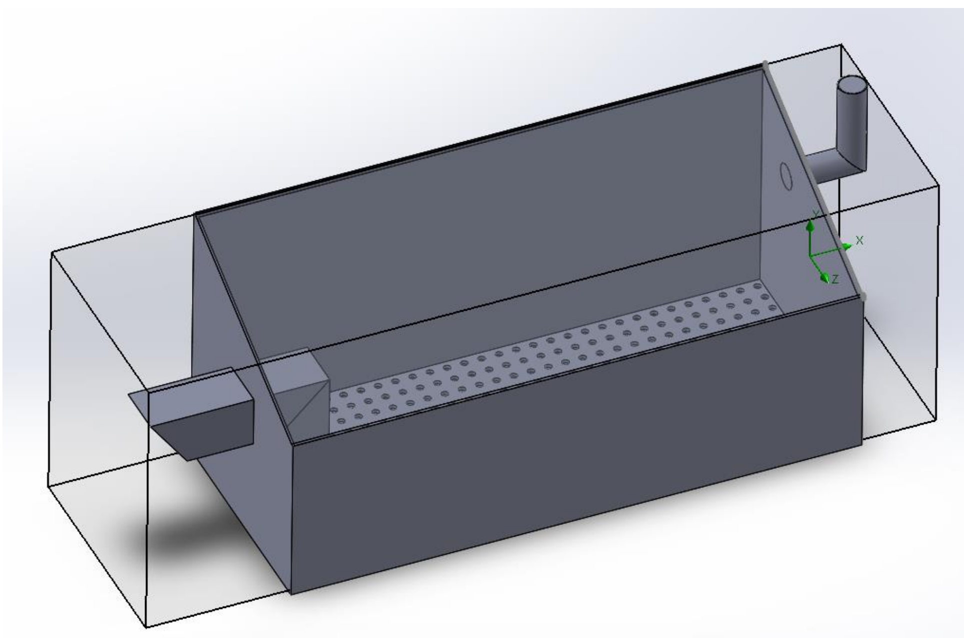


Figure 3-28 3D design of Weather Testing Chamber

The intake vent on the chamber has a fan which sucks in air and pushes the air through the chamber and out the exhaust chimney. In the simulation the intake vent needs a mass flow rate to simulate how the air will move throughout the chamber. The equation below shows how to calculate the mass flow rate of the intake fan.

The size of the fan that was used was 127mm in diameter. The cross-section area was calculated to be 12667.6869mm^2 using the equation below. The equations were taken from (Tumai Zindove, 2015)

$$A = \pi d^2/4 \tag{3.7}$$

The air velocity can be limited to 5m/s to keep pressure drops at reasonable levels. Thus, the volume flow rate was calculated to be:

$$\dot{V} = Av \tag{3.8}$$

$\dot{V} = 5 * 0.0126676869 = 0.063338435\text{m}3. s - 1$. Therefore, mass flow rate can be calculated using Equation 3 where ρ is the density of air:

$$\dot{V} = \dot{m}/\rho \tag{3.9}$$

$\dot{m} = \dot{V}^{*}\rho$ = 0. 063338435*1.225 =0.0775895823 kg. s^{-1}

This value was inputted into the simulation. There were three goals that were measured during the simulation, they include, temperature, temperature of the air and velocity of the air. The ambient outside air was set to a temperature of 25 degrees and a heat source on the glass of the chamber was set to 40 degrees. The results from the simulation can be seen in Figure.3-28 (a), (b) and (c).

Figure.3-28 (a) shows the temperature within the chamber, which reads an average temperature of 29 degrees throughout the chamber. Figure.3-28 (b) shows the temperature of the air within the chamber, which reads an average temperature of 27 degrees throughout the chamber. Figure.3-28 (c) shows the velocity of the air within the chamber, which reads an average of 1.1m/s. These results will then be compared to the real-life results which will be discussed in Chapter 5.

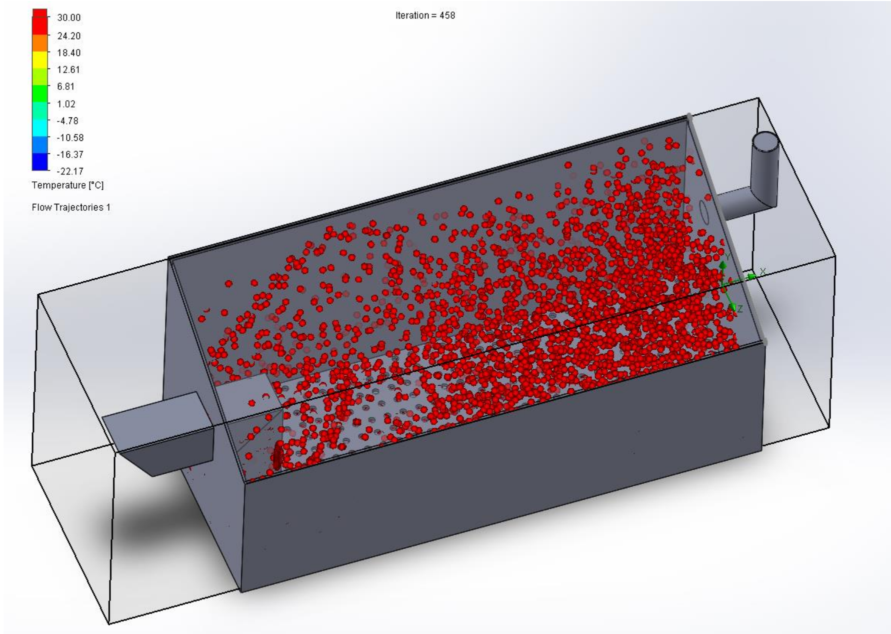
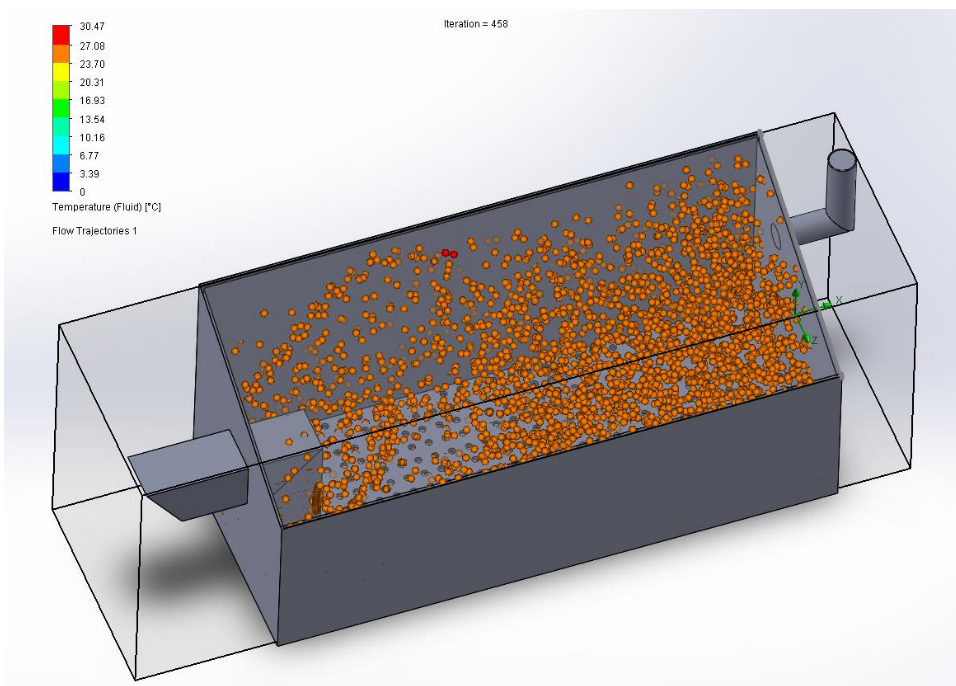
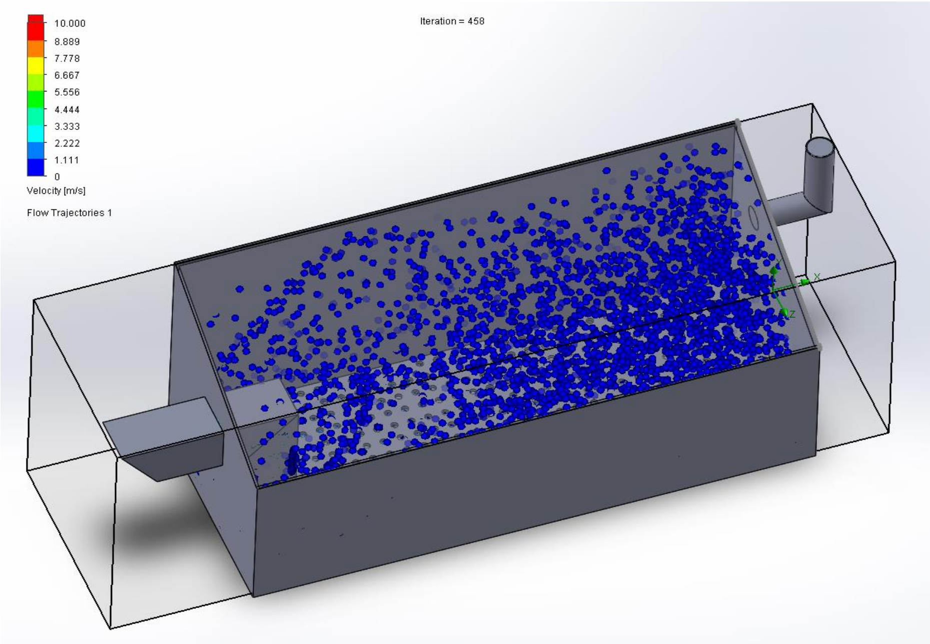


Figure 3-29 Air holes open

(a) Temperature in the Chamber



(b) Temperature of the air



(c) Velocity of the air moving in the chamber

It can also be seen from the above figures that there is less air movement to the left side of the chamber, this could be corrected by closing the floor board holes near to the exhaust chimney. The results of this can be seen in Figure.3-29.

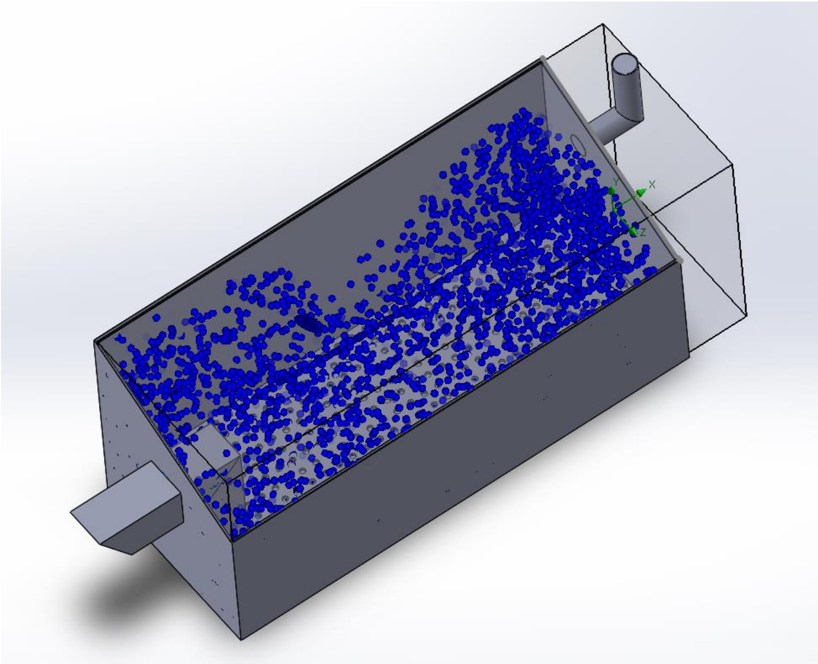


Figure 3-30 Air flow with holes closed

Having the air holes blocked off closer to the exhaust chimney will force more air flow across and over the component being tested.

The Solidworks simulation gave a greater understanding to how the air flow and temperature behaves within the chamber, optimize flow to ensure that temperature and humidity is evenly distributed.

3.3.2 Fuzzy Logic Control

The fuzzy logic control was used to control the temperature and humidity within the weather testing chamber. The fuzzy logic was programmed on one of the Arduino Mega microcontrollers which was used for the temperature and humidity control. To determine how well the fuzzy control works and handles the control of the two variables mentioned above, simulations were run. Matlab was used to simulate the fuzzy logic control as it contains a built-in fuzzy library. The built-in fuzzy library was used to create the input and output membership functions as well as the IF ELSE logic rules used within the fuzzy logic. The rules that were created test the full range of temperature and humidity.

In Matlab a Simulink circuit was designed to test the fuzzy logic rules created, two ramp functions were used to simulate the temperature and humidity. The ramp functions simulate the temperature ranging from 0 degrees to 100 degrees as well as the humidity ranging from 0% relative humidity to 100%. The Simulink circuit can be seen in Figure.3-30.

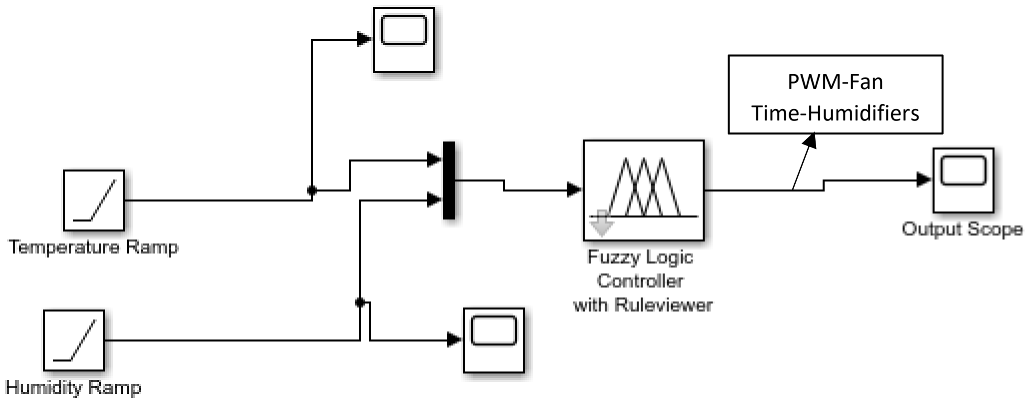


Figure 3-31 Fuzzy Logic Control circuit

After running the simulation, the results were displayed on the output scope. The results from the simulation can be seen in Figure.3-31. The output of the Fuzzy Logic Controller with Ruleviewer outputs the speed of the fan in PWM and the duration for the humidifiers in seconds.

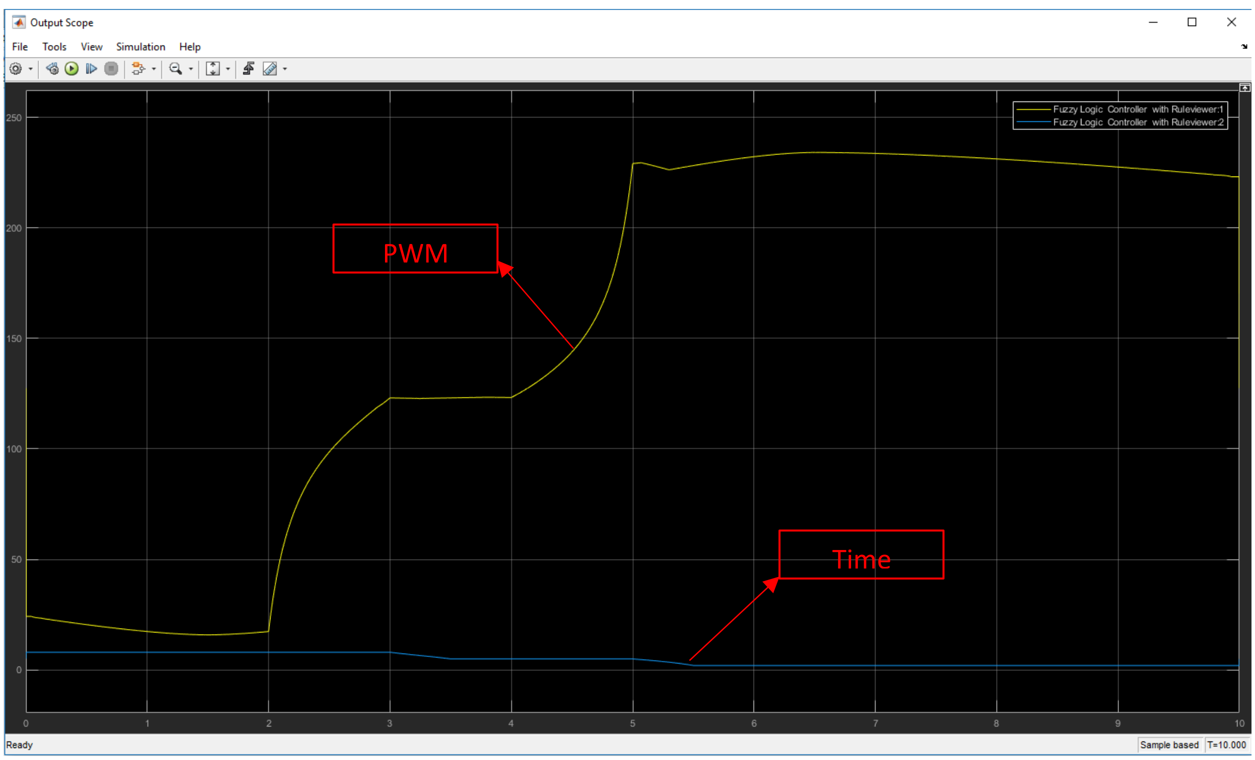


Figure 3-32 Results of Fuzzy Logic Controller

The yellow graph represents the PWM of the fan and the blue graph represents the duration in seconds. It can be seen that the yellow graph has a smooth increase from 20 PWM to 245 PWM as the temperature increases and the blue graph has a smooth decrease from 8 seconds to 0 seconds as the humidity increases. The fuzzy logic control also runs the fan at 245 PWM instead of 255 PWM and maintain the cooling, so less power is needed for the required cooling.

3.3.3 Traditional Logic

Traditional logic is the same as true false or on off logic, either being true/on or false/off. This logic was used to compare it to the fuzzy logic, as the other logic control that would be used to the fan speed would be traditional logic. The traditional logic circuit was designed in Matlab Simulink, like the fuzzy logic controller. The traditional logic circuit uses an IF block library that is built-in the Matlab software. The input into the IF block is a ramp function that represents the temperature increases from 0 degrees to 100 degrees. Only temperature was used and not humidity, as the manner in which the temperature is implemented would be the same as humidity, thus only one is required for the simulation. The traditional logic is only being used to compare to fuzzy logic and to determine which one is better. The IF block uses IF statements, for example, if the temperature is greater than 25 degrees the fan speed must be 150 PWM and if the temperature is greater than 70 degrees the fan speed must be 200 PWM and so on. The Simulink circuit can be seen in Figure.3-32.

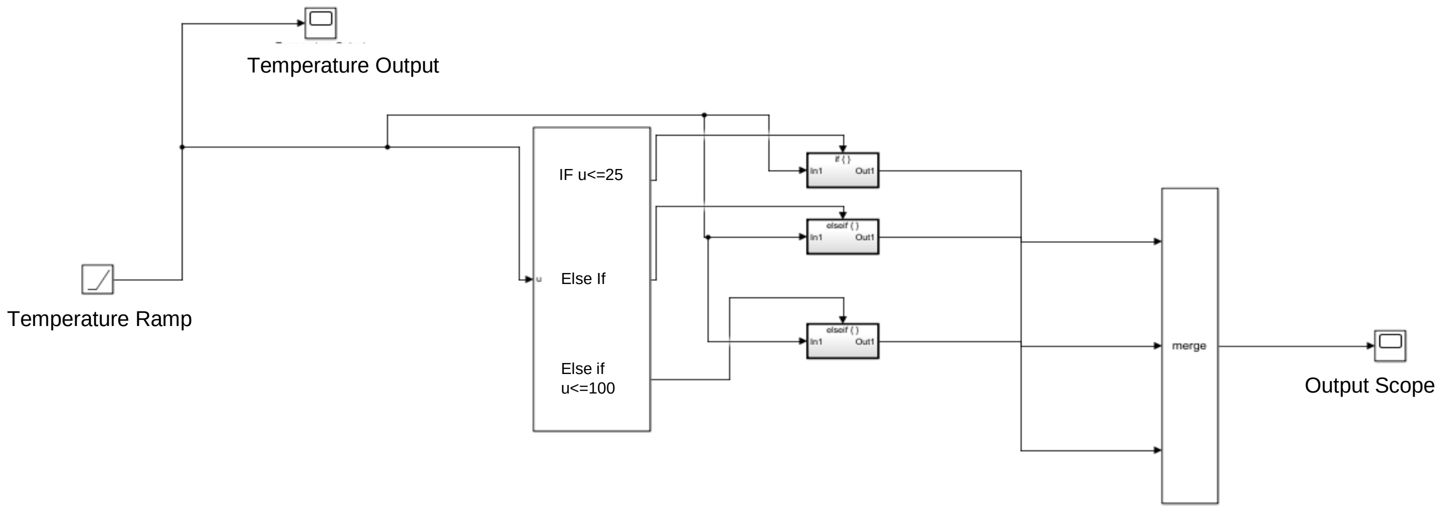


Figure 3-33 Traditional Logic Controller

After running the simulation, the results were displayed on the output scope. The results from the simulation can be seen in Figure.3-33. The output of the traditional Logic Controller outputs the speed of the fan in PWM.

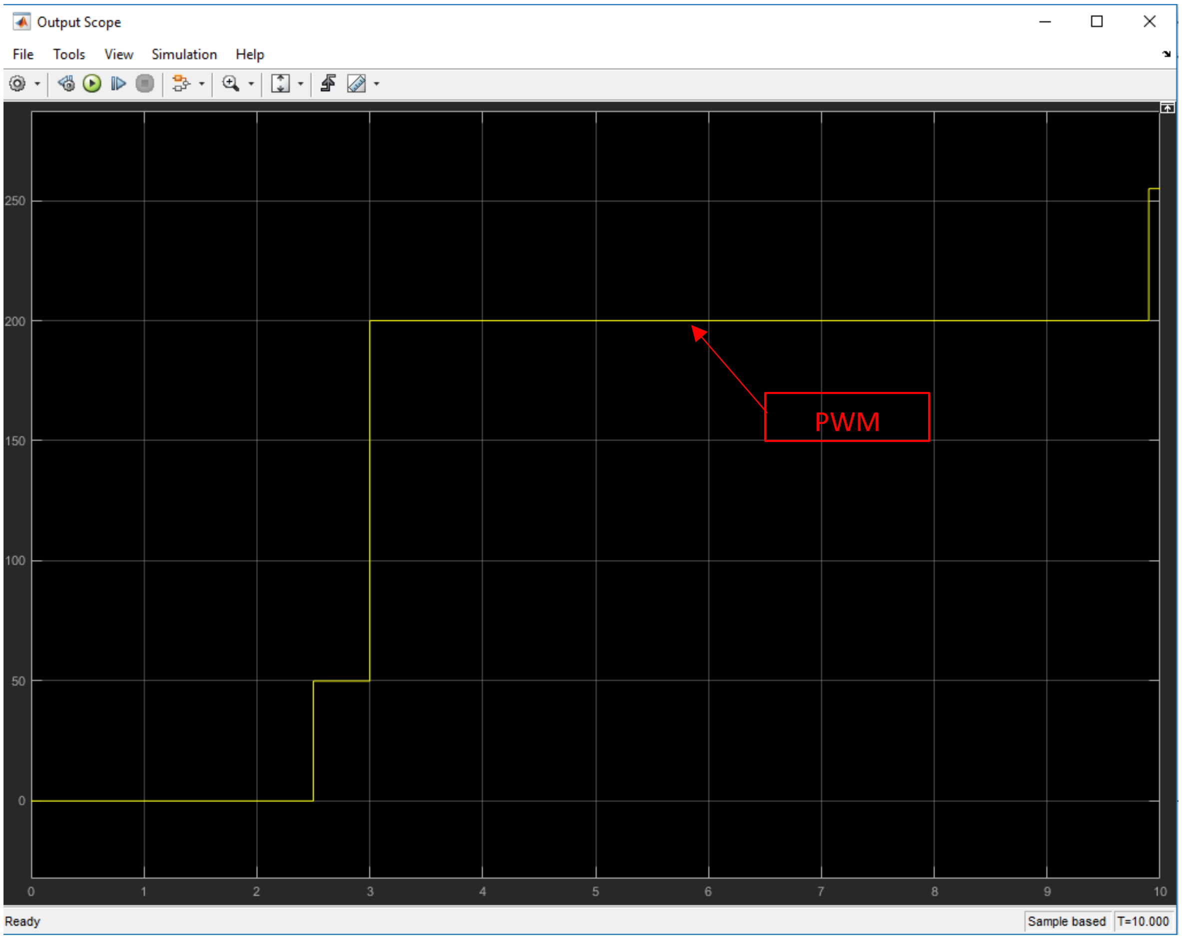


Figure 3-34 Results from traditional logic controller

The yellow graph represents the PWM of the fan. It can be seen that the yellow graph has a sudden square increase from 0 PWM to 255 PWM as the temperature increases. The traditional logic control runs the fan at 255 PWM at the high temperature to maintain the cooling, thus, more power is used for the required cooling. The Fuzzy logic results were combined to the traditional logic results, this can be seen in Figure.3-34.

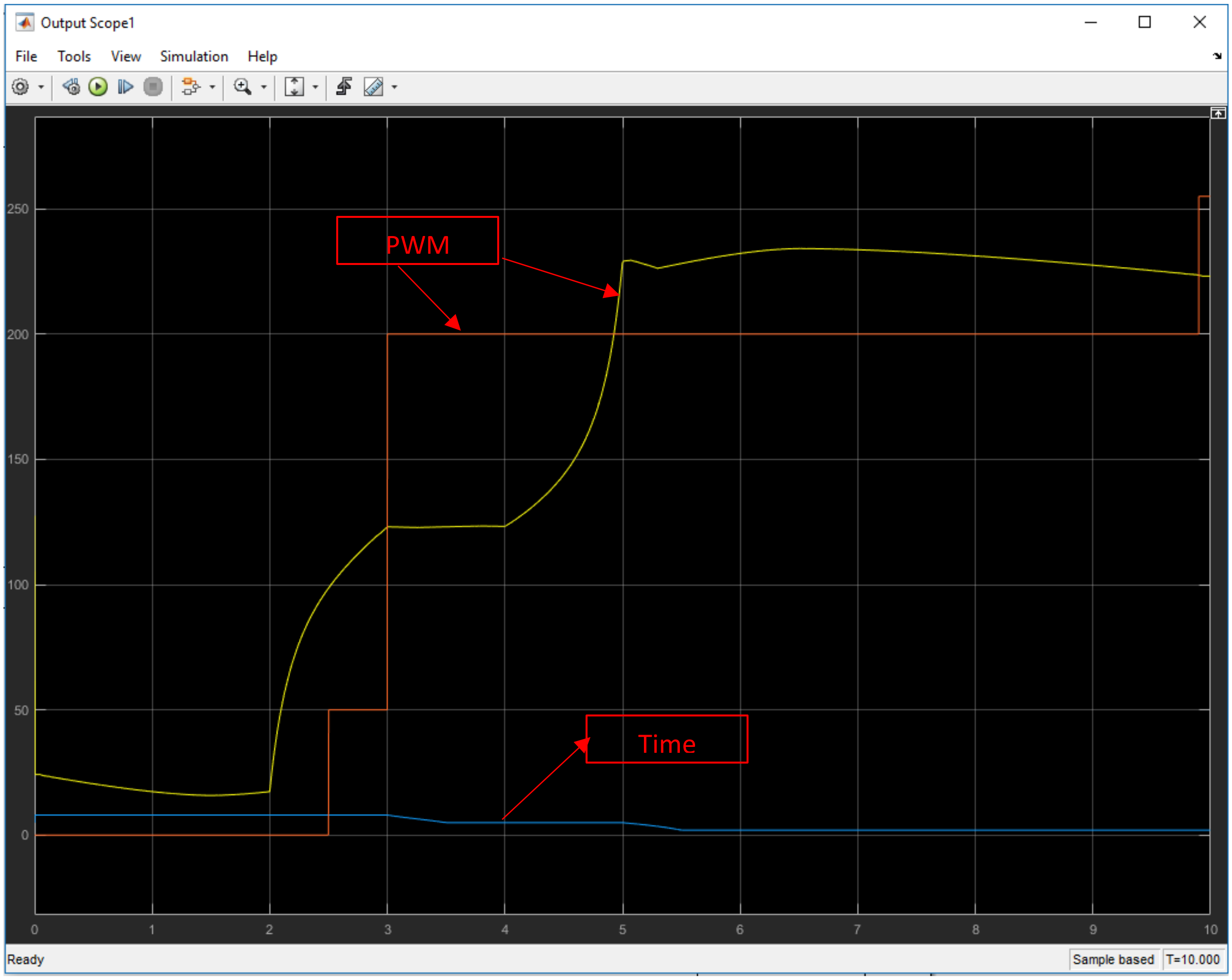


Figure 3-35 Results from Fuzzy logic and Traditional Logic

From Figure 3-35 above it can be seen that the fuzzy logic has a smoother increase of the fan speed compared to the traditional logic. The fuzzy logic also uses less power to maintain the required cooling, which is better in the long run. The fuzzy logic results can be made smoother, this is dependent on how one sets up the membership functions, however, from the two simulations it can be seen that the fuzzy logic controller is the better one to use.

3.4 Process of Code

The process on how the code works with each Arduino microcontroller can be seen in flow diagram in Appendix D. The first part of the diagram shows the solar tracking system and the second part shows the fuzzy logic control system. These two systems are then integrated with each other to give the final control of the weather testing system.

The solar tracking system starts and reads the data values from the Magnetometer, GPS and Accelerometer. The azimuth, elevation, LST, sunset and sunrise times are calculated from the GPS using the equation 2.1 in Chapter 2. If the LST is within the sunset and sunrise time, then the system must run. The system compares the accelerometer readings to that of the elevation value and tells the motor driver to move the motor either forwards, backwards or stop. The system compares the Magnetometer value, which is a reading in degrees, to the azimuth value calculated from the GPS. Depending on which quadrant the azimuth value and magnetometer is, the system tells the motor driver to move the motor either clockwise or anti-clockwise or to stop. The different quadrants can be seen in Figure.3-35.

The fuzzy logic system starts and reads the temperature and humidity values from six DHT22 sensors and gets an average reading for both. If the time of day is also between sunrise and sunset then the system will run, but if not, then the system will not run. The temperature and humidity values are then passed into the fuzzy logic controller method and determines the fan speed and duration of the humidifiers. The change caused by the fan speed and duration of the humidifiers is then fed back into the fuzzy logic controller method.

The system architecture can be seen for both systems in Figure.3-36 and Figure.3-37.

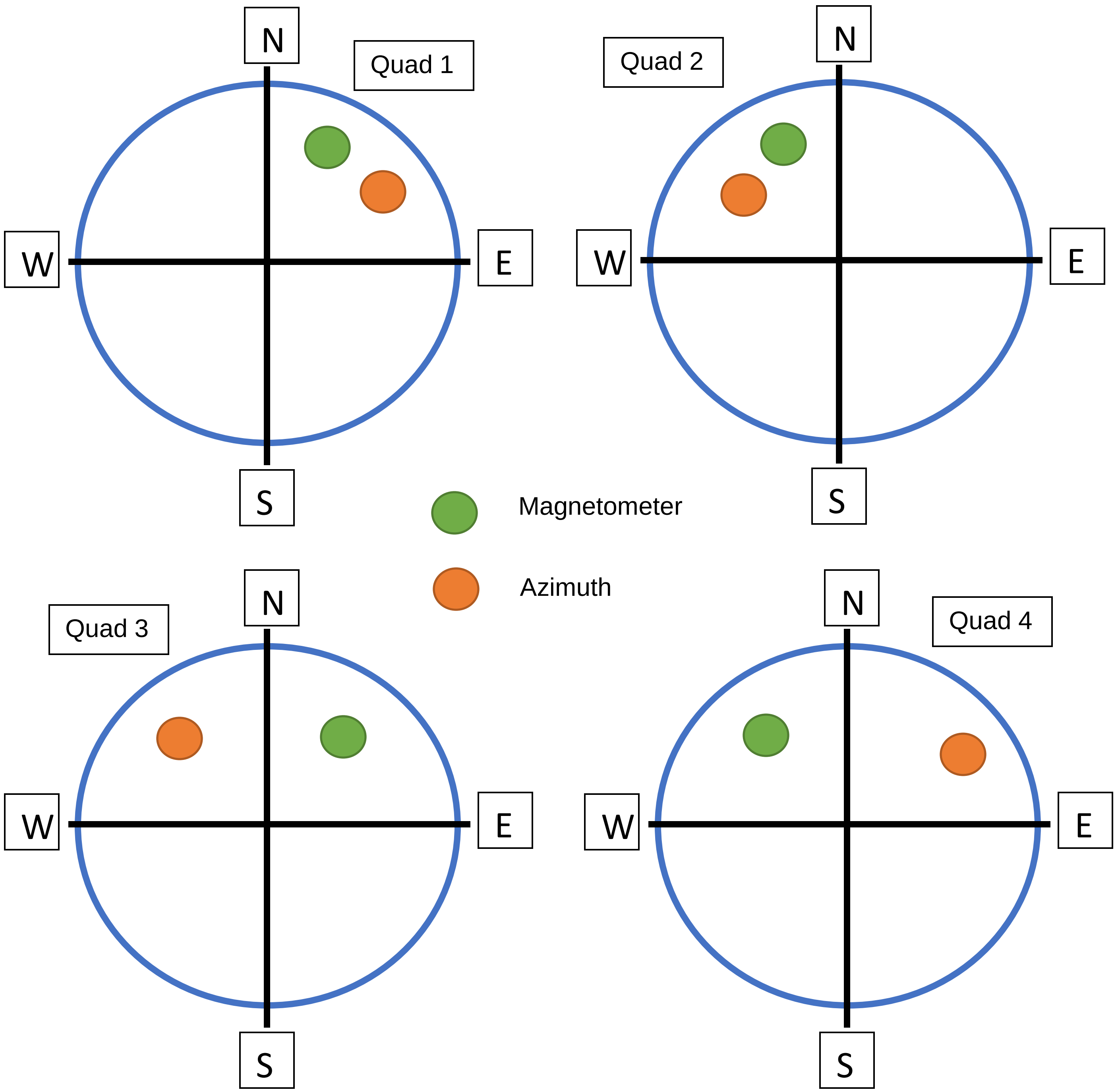


Figure 3-36 the four different quadrants for solar tracking code

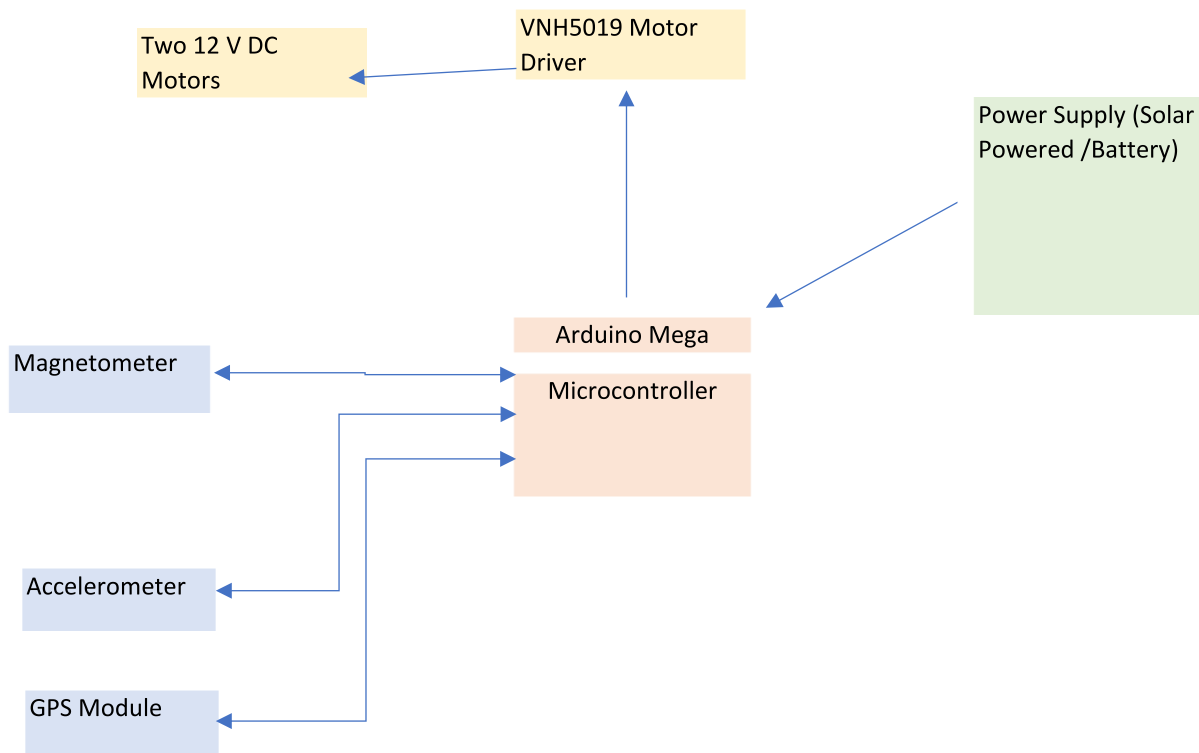


Figure 3-37 System architecture for solar tracking

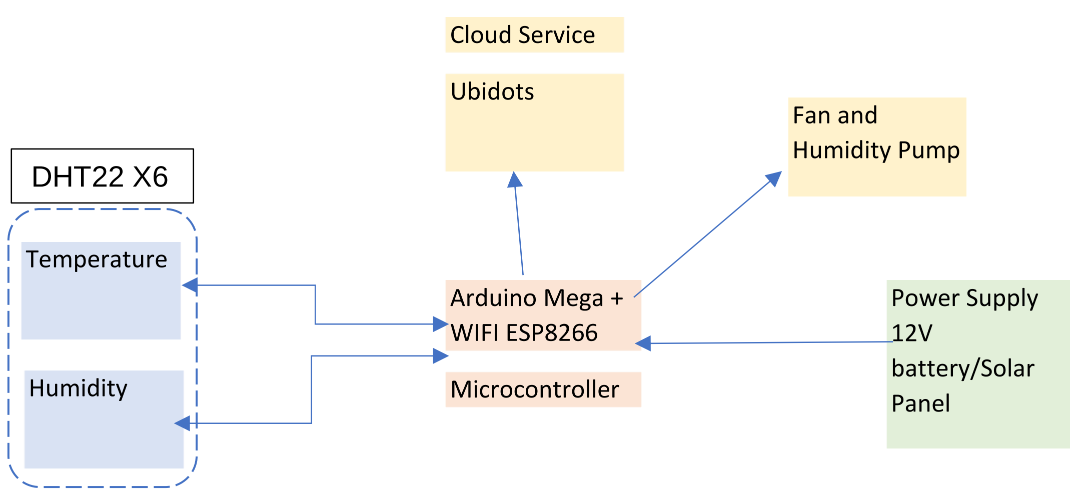


Figure 3-38 System architecture for fuzzy logic circuit

3.5 Chapter Conclusion

In this chapter all the mechanical, various electrical components and software that were used were discussed and researched to make sure that they were sufficient in order for the system to run correctly and for the project to be a success. The mechanical design was thought out thoroughly and many design concepts were discussed in order to make a final decision which would make the system run smoothly and efficiently. All the electrical components that were used were researched and discussed in what the functionality of each component is and how it is integrated into the system. External software was used to help develop the final control system. Simulations were run in order to get a better understanding of how the system would run and what adjustments should be made to make the final system run effectively.

With these components, there could be a change as a result for newer and better components in the future.

4. Testing Method for System

4.1 Introduction

The procedures for testing on the weather testing chamber will be discussed in this section. The purpose of performing these tests was to determine how effective the system is in tracking the sun. The effectiveness of the humidity and temperature control was also explored. Three tests will be conducted on the system. The tests conducted are as follows:

- The first test completed was to determine how effectively the system tracked the sun. The method used to track the sun will be compared to another solar tracking method as well as to solar tracking data which can be found on the internet. The movement of the system tracking the sun was monitored. This was done to ensure that the movement was smooth, and no excessive force was exerted on the motors, which could ultimately cause an unnecessary amount of energy being consumed and increased motor wear and tear.

- The second test was to determine the overall effectiveness of the fuzzy logic control by providing a predetermined set of rules to be followed. The rules relate to the fuzzy logic rules that were previously discussed under the literature review section. The conditions in which this test was carried out was for a duration of two days. The data logging was completed by making use of the IoT system.
- The third test completed was similar to that of the second test. However, a set point was provided for the temperature and humidity. The fuzzy logic was required to control the temperature and humidity at the given set point.

The results obtained, as discussed in the following sections, prove that the system worked sufficiently.

4.2 Test 1: Solar Tracking Test

Two systems were created for the purpose of this project. The first system that will be discussed was used for this project. The second system was created to compare the results.

The first system created consisted of a GPS module. The GPS module provides a location and time to the system. The system uses the time and location to calculate the azimuth and elevation angle of the sun relative to the system. The calculations used were discussed in Chapter 2 equations 2.1 and onwards.

The second system consisted of a four LDRs, in a square formation divided by a cross section. This can be seen in the Figure.4-1:

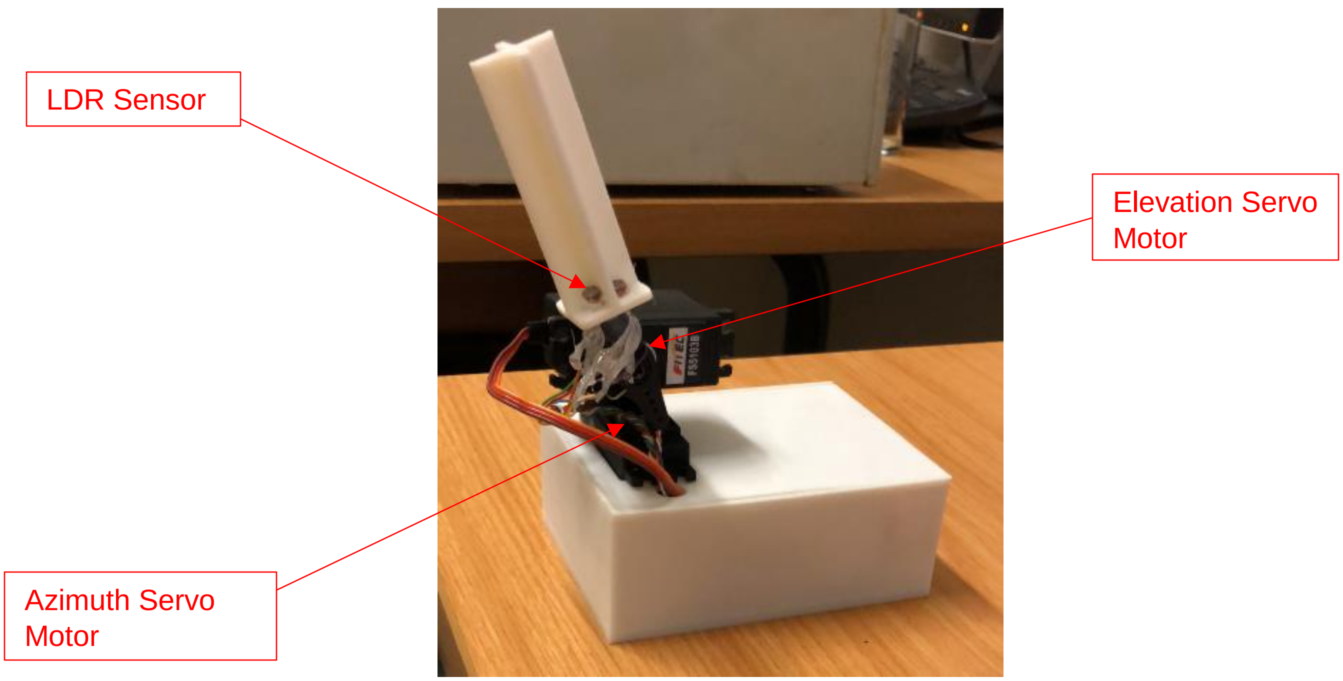


Figure 4-1 LDR Solar Tracker

This system works by tracking the light produced from the sun.

Both systems were placed outdoors throughout the day to track the sun. The conditions on the day were clear skies. Readings of the azimuth and elevation angles produced by the two systems were recorded every hour. This procedure was followed for one day. The results obtained were compared to each other as well as to values from the internet. The results can be seen in the following chapter.

4.3 Test 2: Fuzzy Logic Control

For this test, the general fuzzy logic control was tested to determine its effectiveness in controlling temperature and humidity. The weather testing chamber was placed outdoors, thus exposing all components to the natural elements. The test was conducted from the morning to the afternoon for the duration of two days, one day with the system tracking the sun and the other day without the system tracking the sun. This was done to compare how well the fuzzy logic handles while tracking and without tracking. A predetermined set of rules was provided to the fuzzy logic controller. The rules provide were as follows:

1. If (Temperature is Cold) and (Humidity is Dry) then (FanSpeed is slow)(Duration is long) (1)
2. If (Temperature is Cold) and (Humidity is normal) then (FanSpeed is slow)(Duration is meduim) (1)
3. If (Temperature is Cold) and (Humidity is moist) then (FanSpeed is slow)(Duration is short) (1)
4. If (Temperature is Warm) and (Humidity is Dry) then (FanSpeed is medium)(Duration is long) (1)
5. If (Temperature is Warm) and (Humidity is normal) then (FanSpeed is medium)(Duration is meduim) (1)
6. If (Temperature is Warm) and (Humidity is moist) then (FanSpeed is medium)(Duration is short) (1)
7. If (Temperature is Hot) and (Humidity is Dry) then (FanSpeed is fast)(Duration is long) (1)
8. If (Temperature is Hot) and (Humidity is normal) then (FanSpeed is fast)(Duration is meduim) (1)
9. If (Temperature is Hot) and (Humidity is moist) then (FanSpeed is fast)(Duration is short) (1)

Figure 4-2 Fuzzy Logic Rules

These rules could be changed to various sets depending on what type of setpoint control the user would want. These rules controlled the systems temperature and humidity. All the data obtained from within the chamber was sent to the cloud service, Ubidots. At the end of each day, the data collected was downloaded and examined to determine how effectively the fuzzy logic controlled the temperature and humidity with the given rules. The temperature and humidity outside of the weather testing chamber were also recorded each day. This was done to compare the external conditions to the internal conditions. The results captured were compared to the simulations that were run using MATLAB. These simulations can be seen in chapter 3. This test assessed how well the IoT system functioned when data was uploaded.

4.4 Test 3: Fuzzy Logic Control with setpoint

The purpose of this test was to determine how well the set rules behaved with various setpoints and to determine if the setpoints were met i.e. if the fuzzy logic controlled the temperature and humidity so that it met the desired values for temperature and humidity. The setpoints used for this test were as follows:

Table 4-1 Fuzzy Setpoints

Humidity setpoint	Temperature setpoint
60%	50°C

The setup for this test was the same as test 2. However, as previously mentioned, a setpoint was included.

4.5 Chapter Conclusion

This chapter explains how the system was tested and what methods were set in place for the tests as well as how the data acquisition was done. This test setup was conducted to compare the results for tracking and non-tracking, but at the same time test how effective the fuzzy logic runs and handles any changes. The simulation models were run in a similar manner in order to get a sense of how well the system would be tested.

This test method ensures that every aspect of the system will be tested and on a quantitative level. The results from the various tests will be presented in the following chapter.

5. Results

5.1 Introduction

The following section presents and discusses the results of the tests done with the weathering system.

Firstly, the results for the GPS tracking system are compared with the LDR solar tracking results and then together compared with the results found on the website called NOAA.

Secondly, the fuzzy logic control results will be discussed. This will look at how well the system handled general conditions. It will look at how well the system uses fuzzy logic and how well the system is tracking the sun and when it is not tracking.

Thirdly, the fuzzy logic control with setpoint results will be discussed. This will look at how well the fuzzy logic handles and controls the temperature and humidity around the given setpoint, this is done with tracking and without tracking and the two results will be compared.

5.2 Solar Tracking Results

The solar tracking results were captured every hour from 8:30 in the morning to 16:30 in the afternoon. The web tracking values for the azimuth and elevation were found and taken from a website called NOAA and the website is www.esrl.noaa.gov/gmd/grad/solcalc/. These values were compared to those received from the GPS model in the system and a small LDR solar tracker that was built separately.

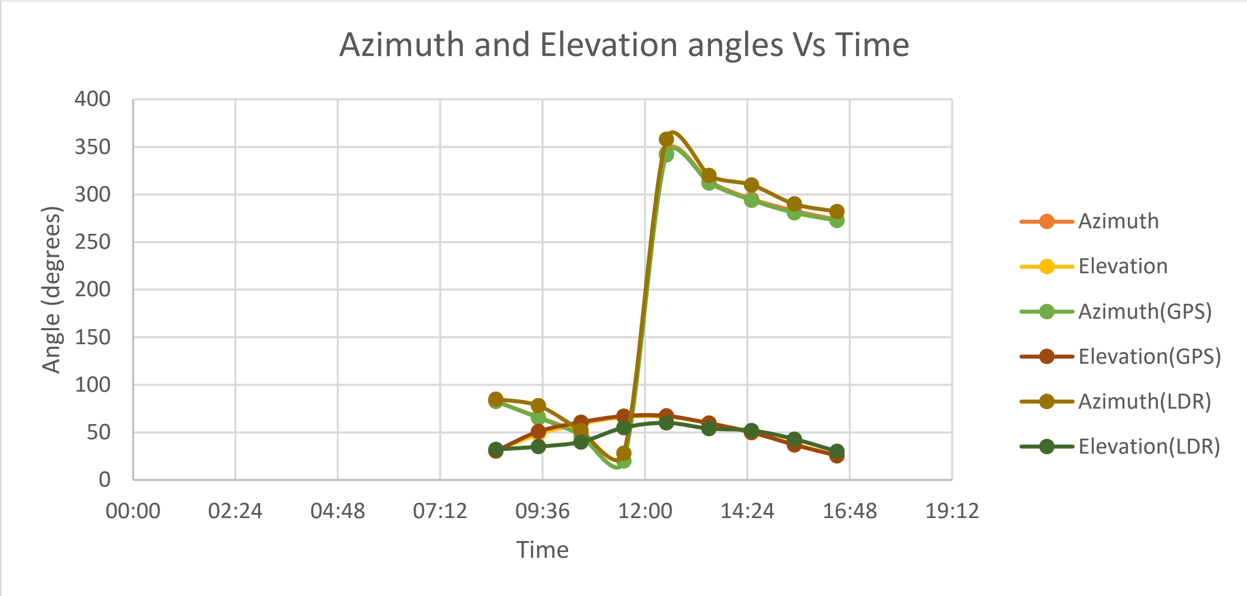


Figure 5-1 Graph showing the Azimuth and Elevation values compared to GPS and LDR solar tracking

From the graph above it can be seen that the GPS tracking values are almost identical to those form the internet. The LDR values are close, but there is a variance between the GPS and internet values.

The table below shows the actual values that were recorded. It is clear that the GPS values are much closer to the internet values compared to the LDR tracking values.

Table 5-1 Recorded values for the Azimuth and Elevation Angles

Time	LDR Tracking		GPS Tracking		Web Tracking	
_	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation
8:30	85	32	82.62	30.41	82.82	30.39
9:30	78	35	65.3	50.83	66.08	48.1
10:30	52	40	47.38	60.71	48.53	58.93
11:30	28	55	20.14	67.16	20.23	66.1
12:30	358	60	341.59	67.36	343.09	66.49
13:30	320	54	311.92	59.59	313.55	59.84
14:30	310	52	293.94	50.04	295.19	49.52
15:30	290	43	280.82	36.95	282.91	37.75
16:30	282	30	272.52	25.52	273.43	25.43

From the table above the error between the azimuth from GPS and the azimuth from the internet is 0.74% and for the Elevation it is 1.17%. The error between the azimuth from the LDR tracking and the azimuth from the internet is 9.25% and for the elevation it is 5.94%.

The above results show that the GPS tracking is much better compared to the LDR tracking. This is important as the GPS tracking is more accurate. The reason why LDR tracking performs worse than the GPS could be that it uses four LDR sensors in a four-quadrant formation and if the one quadrant is darker than the others it will move the motors so that there is equal amount of light in all four quadrants, hence the system would be pointing directly at the light source. Since the outside light is quite bright from all sides, the system does not really position itself correctly and this could be the reason for the high error. The LDR tracking system does work well, because the values obtained were close to the actual values, but it is just not as accurate as the GPS tracking.

This concludes that the GPS tracking was the best tracking system to use for solar tracking.

5.3 Fuzzy Logic Control Results

The following results are from the general use of the fuzzy logic throughout the day. This test shows how well the system handles with general natural conditions. The temperature reading is the temperature of the air in the chamber.

The first set of graphs show the results of the system tracking the sun and the second set of graphs show the results of the system not tracking the sun and only facing north. These results were then compared to each other.

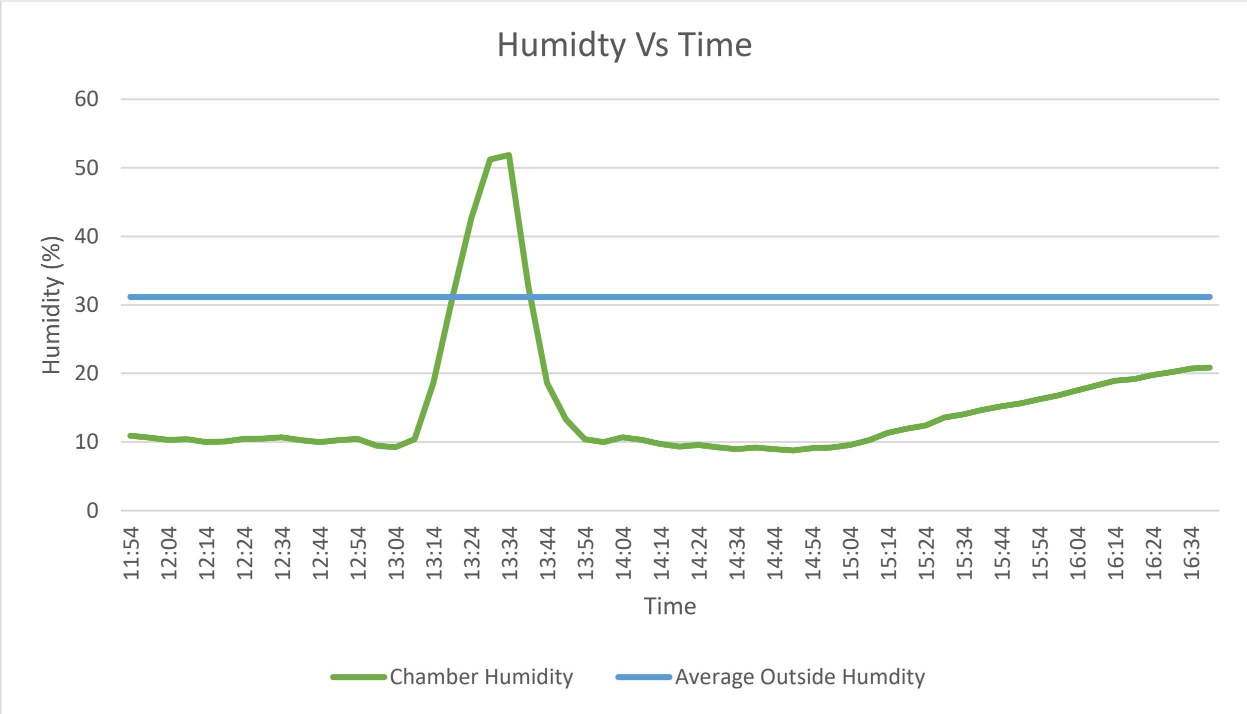


Figure 5-2 Humidity during tracking throughout the day

From the graph above it can be seen that the outside humidity on average throughout the day was 33%. It can be seen that from the start the humidity in the chamber was quite low and decreased a bit and remained fairly constant. The humidifiers of the system came on every day between 13:00 and 14:00 every day. It was required that only the humidity come on for an hour a day to see what the effects would be on the component when it is at a high temperature and then there is a humidity increase. Between 13:00 and 14:00 it can be seen that the humidity increases to a maximum humidity of 53% and then decreases down back to 8% once the humidifiers turn off. Later in the day the humidity starts to increase as the temperature decreases as the sun goes down. The fuzzy logic handled the humidity control very well as it maintained the humidity at about 10% for the majority of the day and increased when required, as this will strain the component from a very low humidity to a quick increase in humidity and then back to low again.

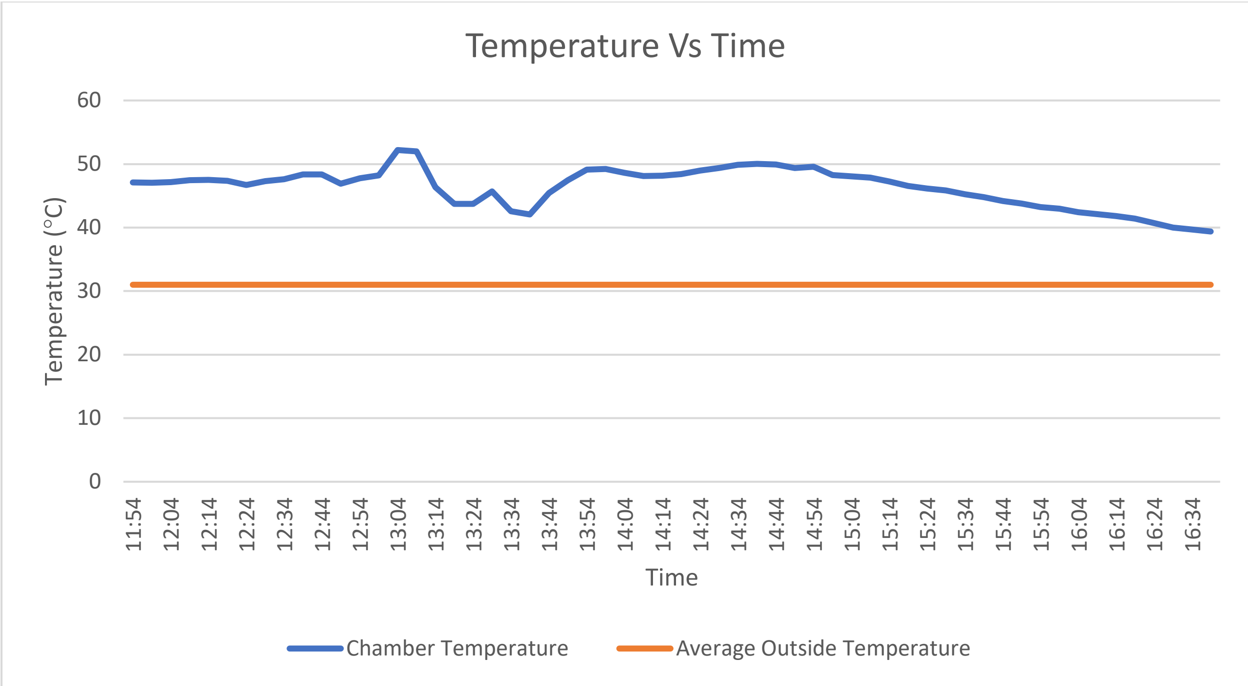


Figure 5-3 Temperature during tracking throughout the day

From the graph above the temperature started at 47 °C and increased to 53 °C. The temperature decreased to 42 °C during the period that the humidifiers were on. The humidifiers cooled the chamber down by 11 °C, but the fuzzy logic increased it again within 10 minutes to a temperature of 50 °C. From about 15:00 to 16:30 the temperature started decreasing, this could be due to the sun moving below the horizon, thus, the radiation is less and hence the temperature decreases. The fuzzy logic handled well with the temperature as it increased as required after the humidifiers were switched off. The average outside temperature throughout the day was 32 °C, thus, the chamber was 1.6 times hotter while tracking the sun. Since this is only the air temperature and the max temperature was 53 °C, the temperature on the surface of the component would be approximately double that temperature and should behave in the same manner as the air temperature.

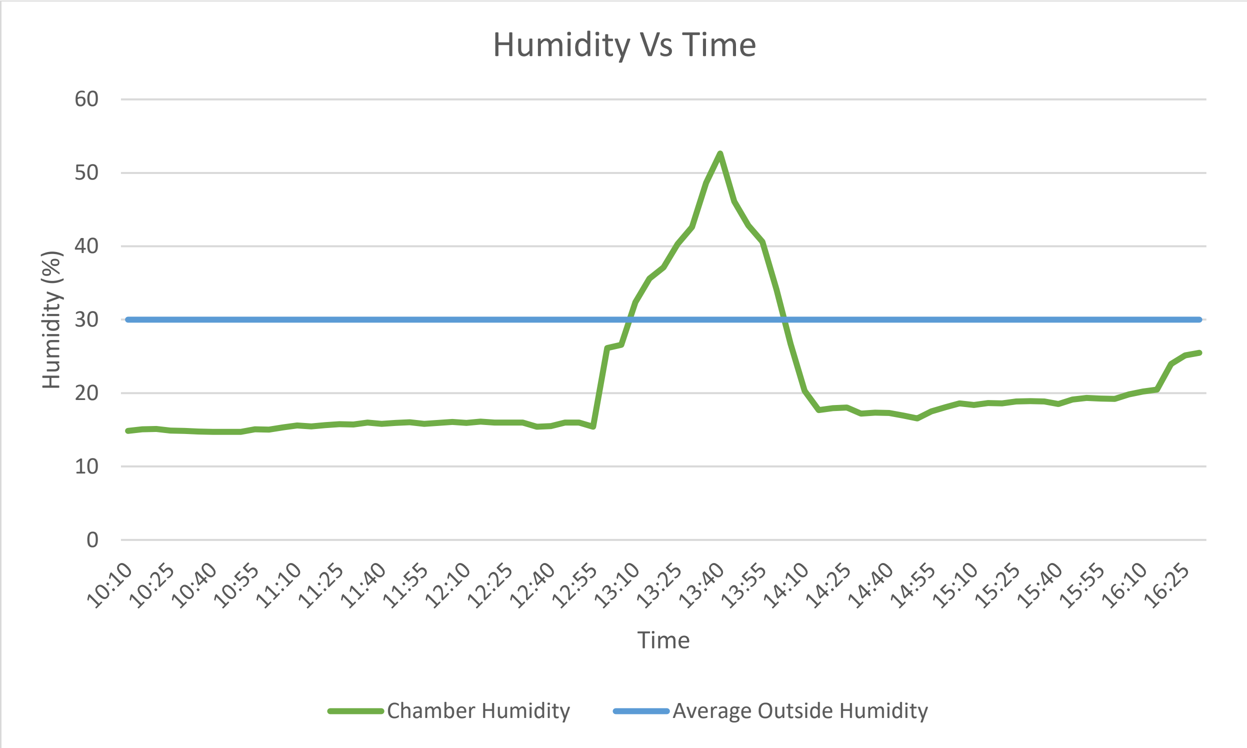


Figure 5-4 Humidity during non-tracking throughout the day

From the graph above it can be seen that the outside humidity on average throughout the day was 30%. It can be seen that from the start the humidity in the chamber was quite low and remained fairly constant in the morning. The humidity is a bit higher than the solar tracking and this could be because the chamber wasn't tacking the sun and not in direct sunlight. Between 13:00 and 14:00 it can be seen that the humidity increases to a maximum humidity of 54% and then decreases down back to 18% once the humidifiers turn off. Later in the day the humidity starts to increase as the temperature decreases as the sun goes down. The fuzzy logic handled very well with the humidity as it maintained the humidity at about 14% for the majority of the morning and increased when required, this will strain the component from a very low humidity to a quick increase in humidity and then back to low again. The humidity in the non-tracking test was generally higher than the tracking test, but both increased in humidity when required. The tracking test gives a greater range of humidity throughout the day, which would be better in testing the component.

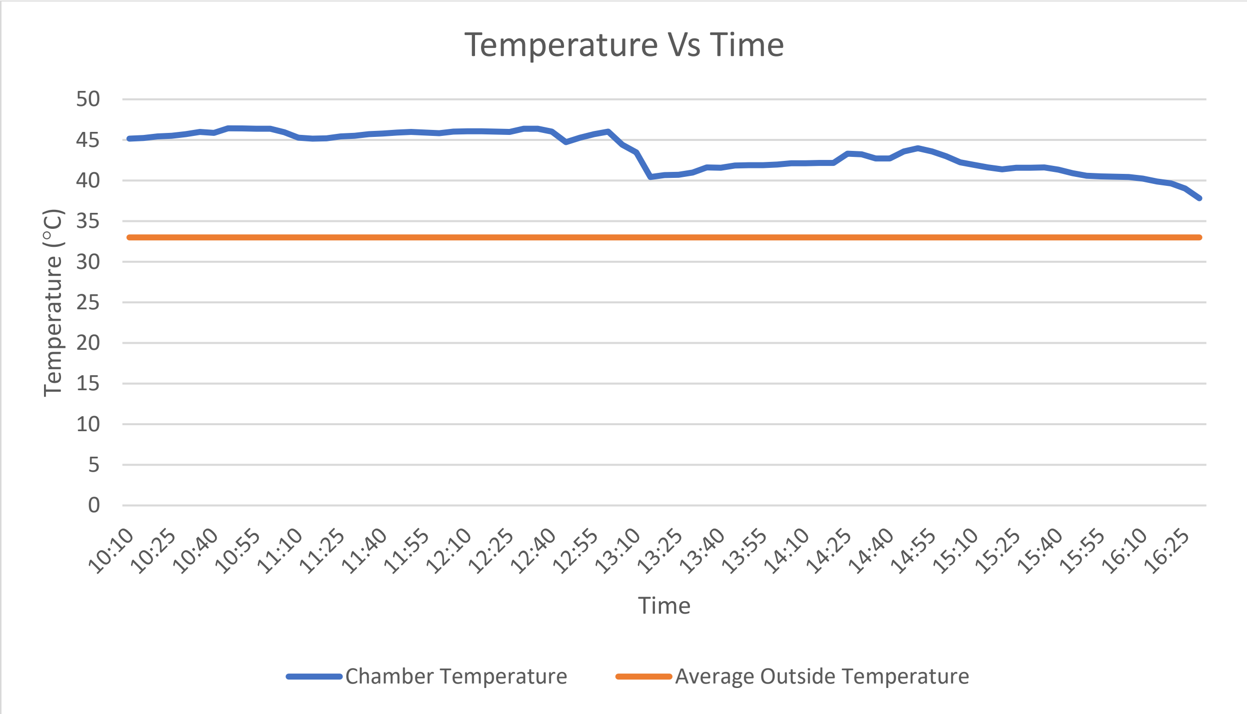


Figure 5-5 Temperature during non-tracking throughout the day

From the graph above the temperature started at 45 °C and remained constant throughout the day. The temperature decreased to 40 °C when the humidifiers were on. The humidifiers cooled the chamber down by 5 °C, but the fuzzy logic increased it again within 65 minutes to a temperature of 44 °C. From about 15:00 to 16:30 the temperature started decreasing, this could be due to the sun moving below the horizon, thus, the radiation is less and hence the temperature decreases. The fuzzy logic handled well with the temperature as it increased when required after the humidifiers were switched off. The average outside temperature throughout the day was 35 °C, thus, the chamber was 1.3 times hotter while not tracking the sun. Since this is only the air temperature and the max temperature was 47 °C, the temperature on the surface of the component would be approximately double that temperature and should behave in the same manner as the air temperature. It can be seen from the two temperature graphs the temperature did not really increase and remained in a 5 °C range while not tracking the sun, where the tracking of the sun test increased more and remained in a range of 10 °C. The tracking test gives a greater range of temperature throughout the day, which would be better in testing the component as it is more accurate.

5.4 Fuzzy Logic Control with Setpoint Results

The following results are from the Fuzzy Logic control with setpoints throughout the day. This test shows how well the system handles in controlling the humidity and temperature around a given setpoint, both for tracking and non-tracking. The temperature reading is the temperature of the air in the chamber.

The first set of graphs show the results of the system tracking the sun. The second set of graphs show the results of the system not tracking the sun and only facing north. These results were then compared with each other.

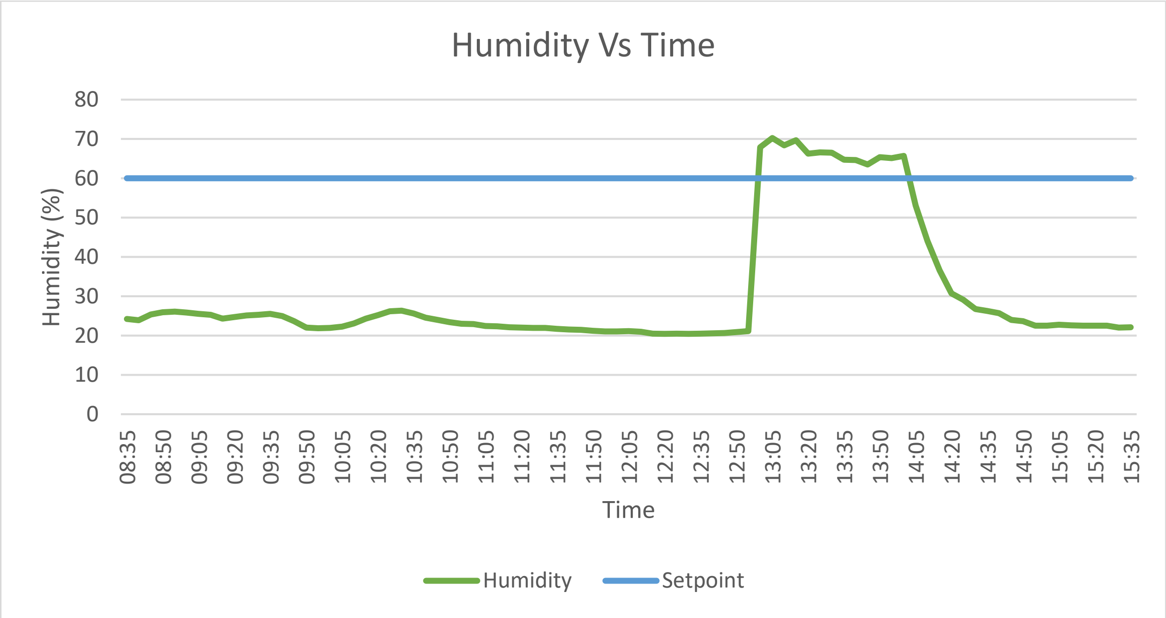


Figure 5-6 Humidity during tracking throughout the day with setpoint

From the graph above the setpoint that was given was 60%. It can be seen that from the start the humidity remained constant between 20 % and 30%. The humidifiers of the system were turned on every day between 13:00 and 14:00. It was required that the humidity come on for an hour a day to see what the effects would be on the component when it is at high temperature and then a sudden humidity increase. Between 13:00 and 14:00 the fuzzy setpoint control takes place and it can be seen that the humidity increases to a maximum humidity of 71% and then decreases to 63%. Within that hour the humidity is maintained just above 60%, thus, the fuzzy setpoint control worked very well as it kept the humidity close to that point. After 14:00 the humidity decreases back down to 20%.

The fuzzy setpoint control handled very well with the humidity as it maintained the humidity at about 60% for the majority of the hour. Comparing Figure.5-2 to the graph above, it can be seen that while tracking, the humidity in the chamber can become very low, thus, for the fuzzy setpoint control to increase the humidity and maintain it at a certain level is very beneficial. If a certain humidity is required for a specific time, the system will be able to keep it at the required humidity while tracking.

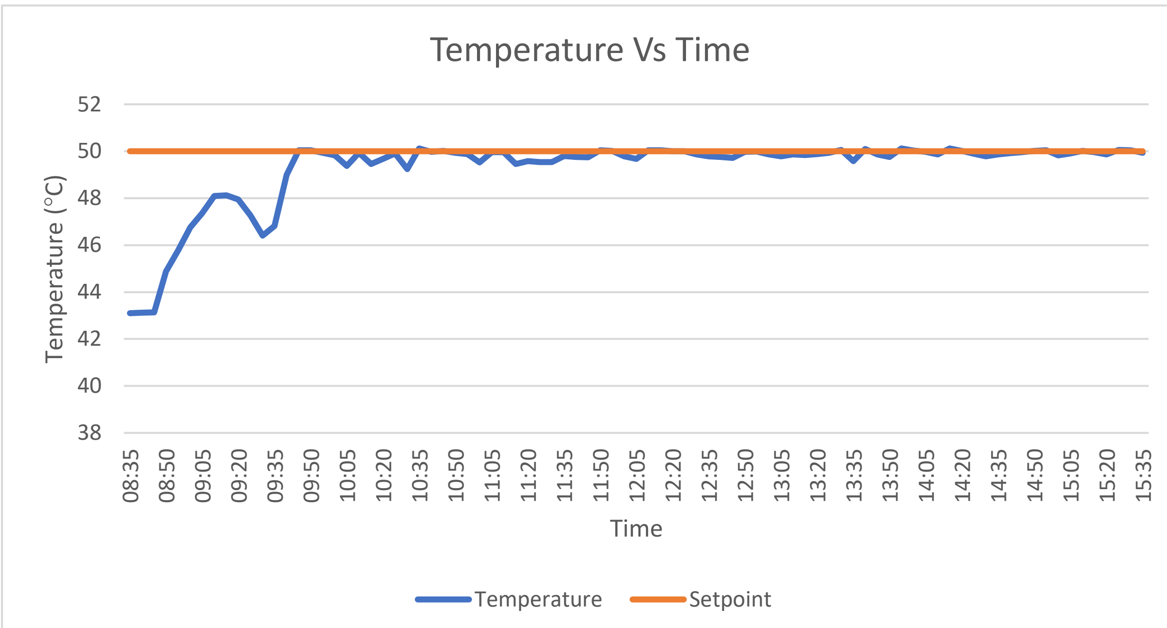


Figure 5-7 Temperature during tracking throughout the day with setpoint

From the graph above the temperature started at 43 °C and increased up to 50 °C, which was the given setpoint for this test. The temperature was controlled and maintained around 50 °C for the remainder of the day. The temperature stayed at 50 °C even when the humidifiers came on. In Figure.5-3, when the humidifiers came on, the temperature decreased as the humidity cooled the chamber down. The fuzzy setpoint control worked very well as it did what was required and controlled the air temperature within the chamber at 50 °C. During this test, the temperature and humidity were maintained at 50 °C and 60% respectively. This is advantageous as the component would be tested both at a high temperature and high humidity, whereas in the previous test the temperature decreased when the humidity increased. Since this is only the air temperature and the max temperature was 52 °C, the temperature on the surface of the component would be just over double that temperature and should behave in the same manner as the air temperature.

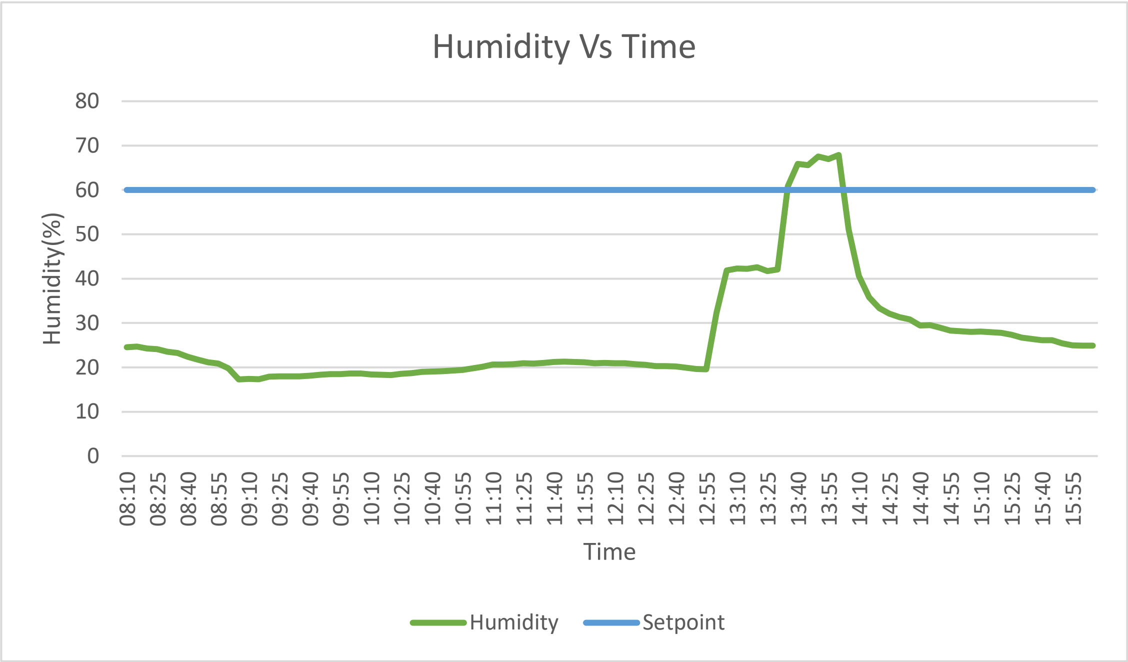


Figure 5-8 Humidity during non- tracking throughout the day with setpoint

From the graph above the setpoint that was given was 60%. It can be seen that from the start the humidity remained constant at 20 % in the morning which is a bit less from Figure.5-6. Between 13:00 and 14:00 the fuzzy setpoint control takes place and it can be seen that the humidity increases to a maximum humidity of 69% and then remains at 67%. Within that hour the humidity is maintained above 60% for the majority of the hour, thus, the fuzzy setpoint control worked well as it kept the humidity close to that point. After 14:00, the humidity decreases back down to 26%.

The tracking graph Figure.5-6 seemed to have controlled the humidity at 60% better than the non-tracking. From all the humidity graphs above, it can be said that the tracking in both tests worked the best as it tests a wider range of humidity and controlled the humidity at a given setpoint very well. This is very important with testing, because it allows for a greater testing scope to be covered. This does not mean that non-tracking does not work, because as seen above it still clearly works, however, tracking works better.

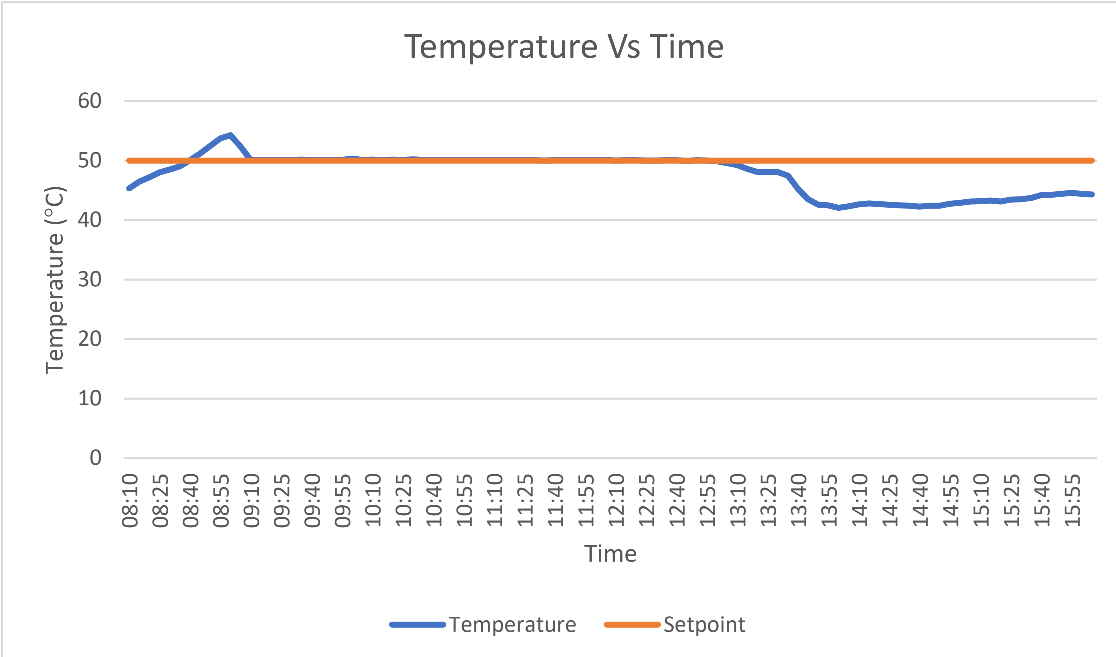


Figure 5-9 Temperature during non-tracking throughout the day with setpoint

From the graph above the temperature started at 44 °C and increased up to 53 °C. This could be a small data outlier from the sensors. The temperature then decreased to 50 °C, which was the given setpoint for this test. The temperature was controlled and maintained around 50 °C for the remainder of the day. The temperature started to decrease at the same time the humidifiers came on. After the humidifiers were turned off, the temperature started to increase again, but at a slow rate. It is possible that later in the afternoon the chamber was not facing the sun, thus, the temperature was much less and took a while to increase. When compared to the tracking graph on Figure.5-7, the temperature did not decrease when the humidifiers came. This could be due to the fact that the chamber is tracking the sun so the temperature in the chamber is much hotter than the non-tracking. This compensated for the humidifiers coming on.

The fuzzy setpoint control worked very well as it did what is was required to control the air temperature within the chamber at 50 °C. During this test the temperature and humidity were maintained at 50 °C and 60% respectively. From all the temperature graphs above it can be said that the tracking in both tests worked the best as it tests a wider range of temperature and controlled the temperature at a given setpoint very well. This is very important with testing, because it allows for a greater testing scope to be covered. This does not mean that non-tracking does not work, because as seen above it still clearly works, however, tracking works better.

During the tests the fuzzy logic control was running the fan in the chamber at 236 PWM when the temperature in the chamber was 50 °C. Looking at Figure.3-34 the PWM at 50 °C was around 236 PWM. This shows that the simulation results for the fuzzy logic control prove to be similar to the actual results collected. These results show a similar flow to the results obtained from the flow simulations. The results from the simulation show that the temperature inside the chamber decreases, but is then maintained at a fairly constant value. The results obtained from the real-life test 2 behave similar. For test 2, the temperature is high at 50 °C initially and slowly decreases until it is maintained at a constant value of 45°C.

All the data that was collected from the tests was collected via the IoT cloud server. The data that was sent to the cloud was collected successfully. Figure 5-10 shows the real time data being collected.

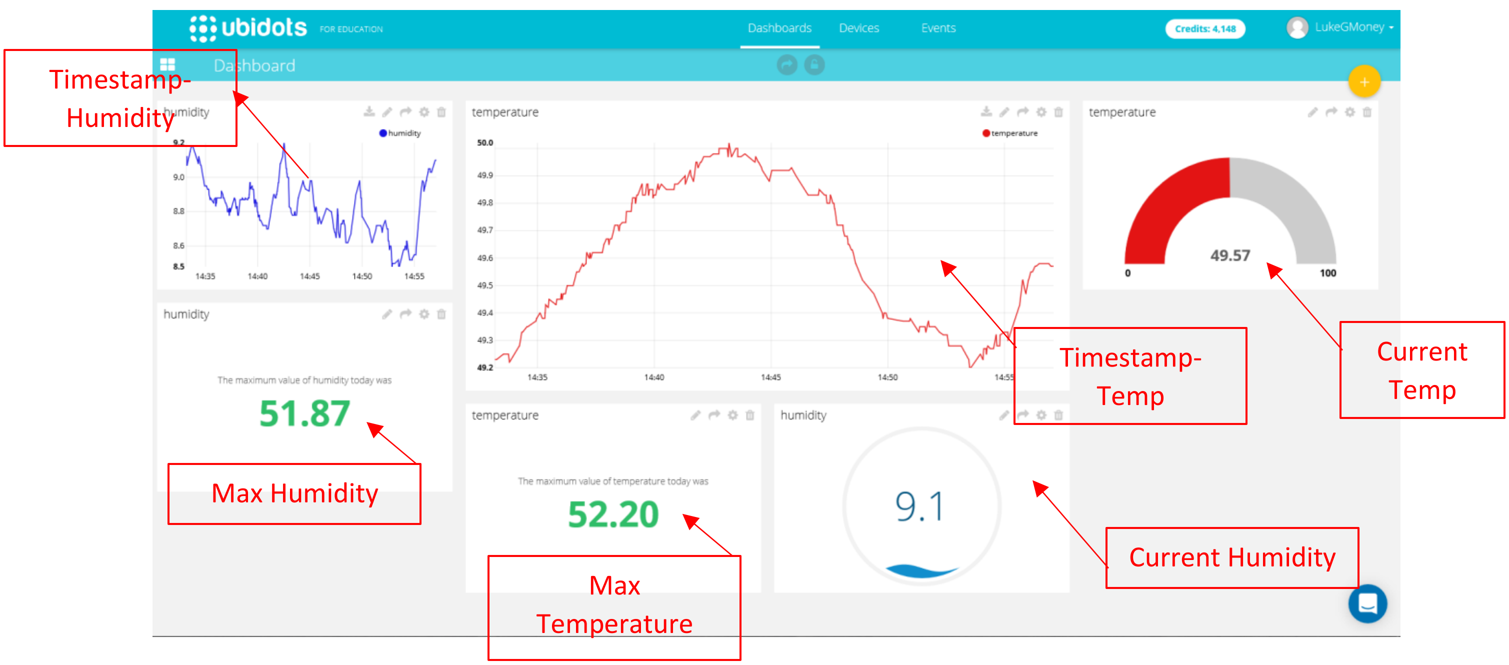


Figure 5-10 Ubidots Dashboard of Data from the Weather Test Chamber

5.5 Chapter Conclusion

It is possible to see that the weather testing chamber system has been fully tested. It can also be seen that the data collection to the cloud was successful and can be monitored throughout testing. The results above show that the fuzzy logic system performed very well and could maintain a given temperature or humidity setpoint. This control showed to be better when the system was tracking the sun as opposed to the system not tracking the sun. An important aspect to note was that during the fuzzy logic setpoint control during solar tracking, the temperature was maintained at a high temperature even when the humidifiers came on, this gives a more strenuous test on the component.

6. Conclusion

6.1 Discussion of Results

Weathering of components especially in the automotive industry has been a critical subject for many years. These tests show the behaviour of materials under adverse conditions-be-it high solar radiation, high humidity and high temperature. Many of these tests are simulated in chambers to mimic real life cycles. Although these accelerated tests provide somewhat accurate results in much shorter periods, natural weathering is still essential as it is uncontrolled and unpredictable. Currently automotive manufacturers use static temperature-controlled test boxes to expose components to solar radiation.

Research was done on designing a solution to a have a non-static weather test chamber and with humidity and temperature control. This proved to be somewhat challenging as the system was required to track the sun, control the temperature and humidity via fuzzy logic control and have an IoT monitory control. With these requirements the system also had to be cost effective and use renewable energy.

Once the research was complete and the system was designed, the goals had to be determined and the best method to achieve these goals such that the above-mentioned requirements were met was explored. The design and construction of the frame that would hold the chamber as well as rotate and tilt it had to be redesigned. This was a successful task as it proved to be a better solution to the existing method.

The design and implementation of the entire control system was a challenge in its self. Part of the control system was the solar tracking as well as the fuzzy logic control.

The solar tracking system was tested to see how well the system tracked the sun and how efficient the movement of the system was during tracking. The tests for the solar tracking proved to be very successful, as it showed that the tracking method used, which was the GPS tracking, proved to be accurate. The movement of the system also proved to be a success as the movements throughout the day were smooth and controlled. The only issue with this, was the ring that was on the base frame on which the wheels rotated started to warp. This could be an issue in the future as it would prevent the rotation of the chamber to be smooth. Reinforcements should be added to prevent this warping from occurring.

The fuzzy logic control tests also show that testing the system while tracking the sun with and without the setpoint control proved to be better than a system that is not tracking the sun. These results show that a component that would be tested, would be provided with more solar radiation and higher temperatures with high humidity conditions and would thus strain the component and accelerate the testing of the component.

The IoT system showed to be very successful, as all the data that was collected during the tests was done so via the Ubidots server. The data that was collected came in as real-time data, this proves that the MQTT protocol worked very well. This also proves that any non-intelligent, normal system can be integrated with IoT and used for monitoring and collecting data.

The above-mentioned hypothesis is confirmed and met as the weather testing chamber could control and maintain a given variable temperature and humidity value at the same time. The system has used standard components which are integrated together and allow the system to track the sun and does so effectively. The weather testing chamber was placed outdoors and is water and dust proof. The results obtained prove that the system can simulate the natural weather conditions on automotive components. The data collection and monitoring of the data was successfully done so via the cloud.

The research that was conducted in this dissertation increased the general understanding in solar tracking, solar energy and weathering of components. The work done in this dissertation provides a strong theoretical and application-based solution for an accelerated weather testing chamber. This dissertation also provides the process in converting static weather testing chambers in accelerated solar tracking weather testing chamber.

6.2 Future Development

The future development ideas for this project will be discussed in this section. This future development will be looked at improving the system as a whole.

The first idea would be to add plug points on the control panel, which would connect all the motors, power and sensors to the control box. This would improve the ease of access for the box, so that if there is any work or replacements of the sensors the box can be removed worked on off the chamber. This will also give a standard connection for each weather testing chamber, so that if a control box needs replacing or needs to be tested it can just be removed off one weather testing chamber and then be placed on another, in other words it would be a plug and play method. The type of plug connector can be seen in Figure.6-1 as it is robust and can have multiple wires connected to it.

Figure 6-1 16 Pole connector for Control box (Source: (Anon., 2018))

The second idea would be to add a Bluetooth receiver to each Arduino Mega. Adding a Bluetooth receiver to each Arduino would make it easier and faster to update the code on the Arduinos. Currently the control box has to be removed by removing four screws on each corner and then plugging in a USB cable to each Arduino and then uploading the updated code. With a Bluetooth receiver added, the removing of the control box cover and plugging into each Arduino would not be needed, as the user can just connect their laptop or desktop to the Arduinos via Bluetooth and then upload the changes in the code that way, making it easier and faster for any changes that need to me made. The Bluetooth receiver module can be seen in Figure.6-2. This module is cheap and is compatible with Arduino, making the change an easy task.

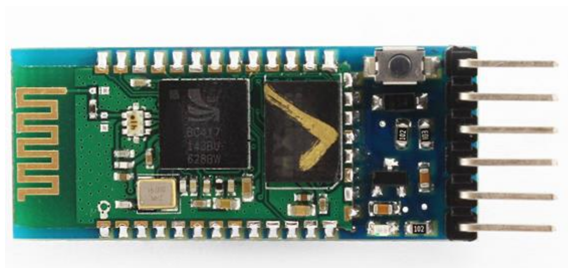


Figure 6-2 Bluetooth Module (Source: (Anon., 2018))

The third and final idea would be to change to method on how the weather testing chamber is tilted. The first idea on making this change would be to use the concept that was mentioned in chapter 3 with regard to the linear actuator. Using a linear actuator instead of a wiper motor on the side, would make the tilting movement of the weather testing chamber more controlled, stable and accurate. The reason for this is that the wiper motor on the side is not energized when it has moved the chamber in the correct position and when this is the case and the wind blows, the wind then moves the weather testing chamber out of position. The system would then always have to correct this issue, which would cause more wear on the motor and more power to be used. The linear actuator would move the weather testing chamber into the correct position and hold it there, as the linear actuator locks until it is energized again, thus preventing the weather testing chamber from moving in the wind. This idea is quite expensive, since the linear actuator would have to be custom made. A cheaper solution to the problem, would be to use the wiper motor on the side and to attach it to the bottom of the frame and to have a universal joint connected to the shaft of the motor and then to have a threaded rod connected to the universal joint. When the motor turns it will rotate the threaded rod. On the other end of the threaded rod there would be a nut which would be fixed to the front end of the 'bed' that holds the weather testing chamber. This nut would be able to rotate up and down, so that when the motor turns it would rotate the threaded rod and in turn pull the weather testing chamber down or up depending on which way the motor is turning. This concept works similar to the linear actuator as it is more controlled, stable and accurate in tilting the chamber. This idea can be seen in Figure.6-3.

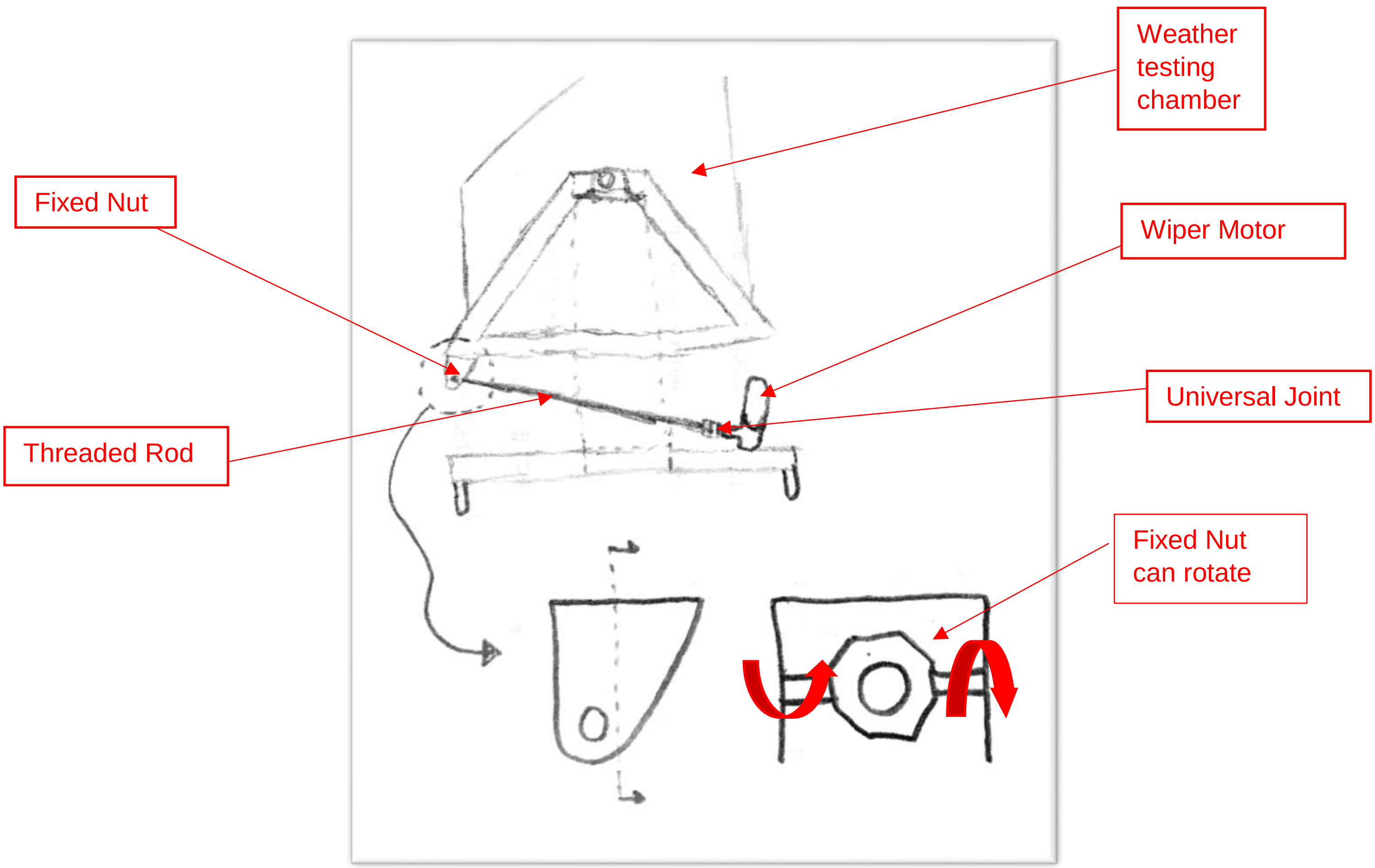


Figure 6-3 Threaded Rod Concept

With these future developments put in place, the newer system would be easier to operate and would be smoother and more controlled while running, thus making it a more efficient and accurate system.

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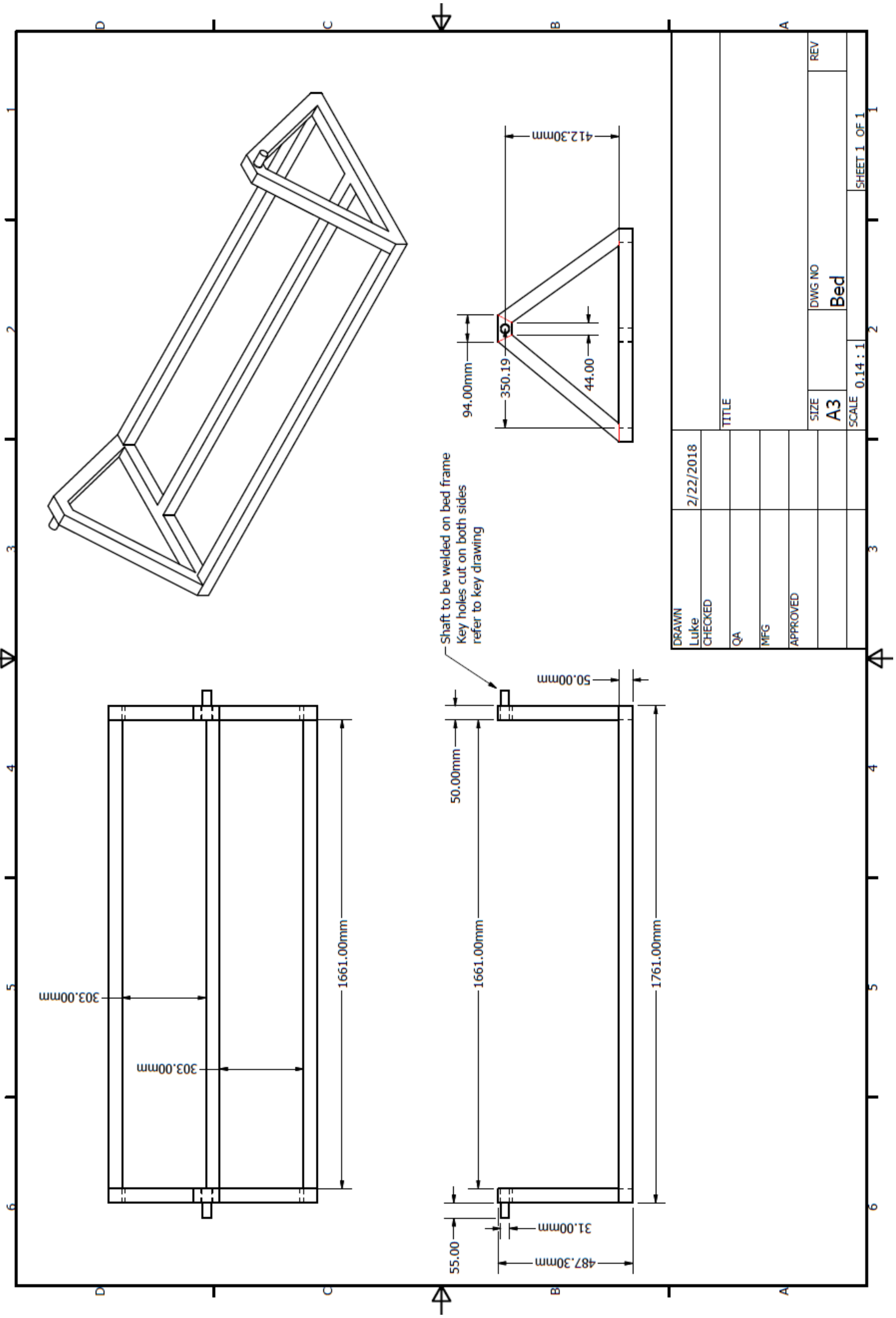
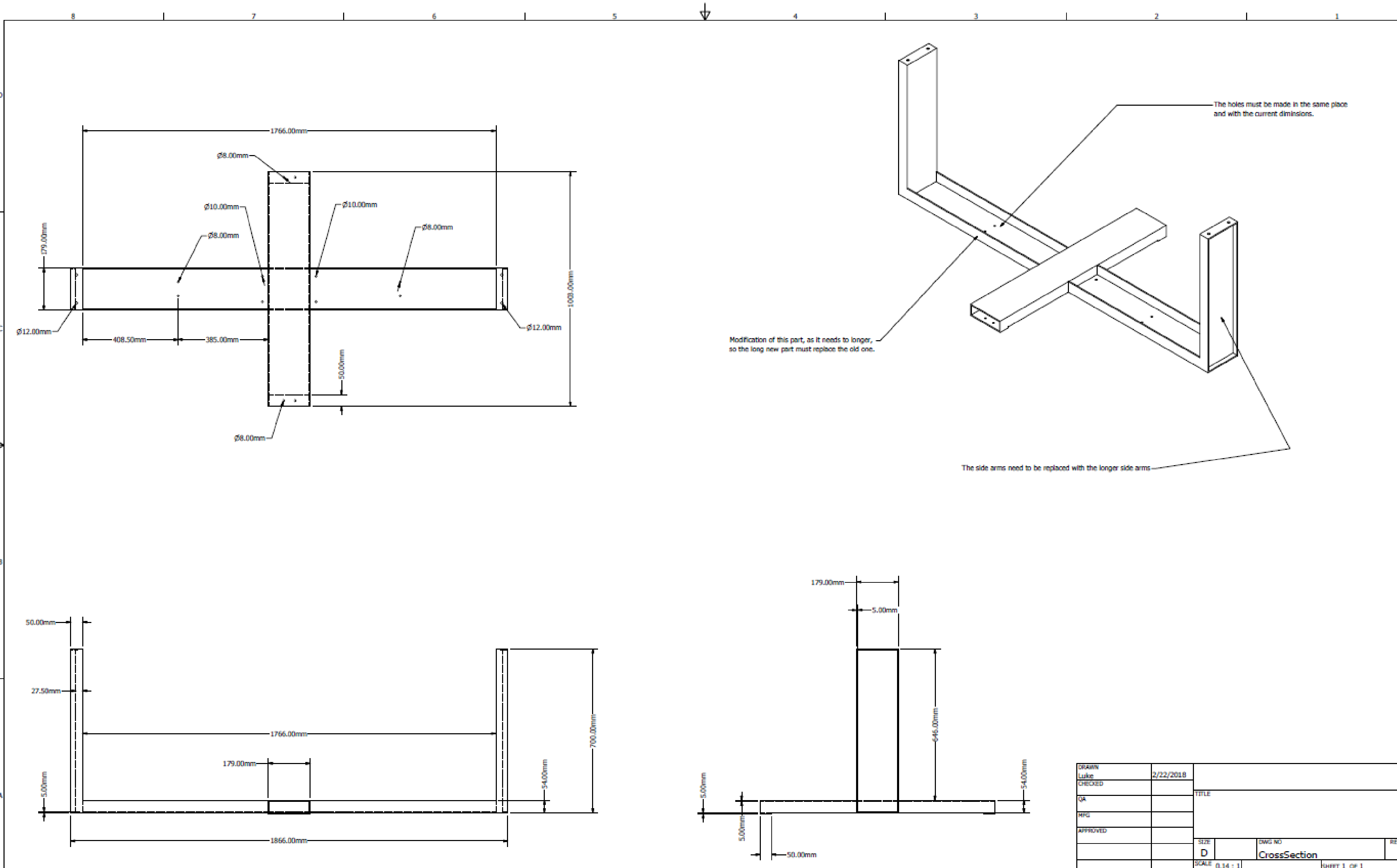
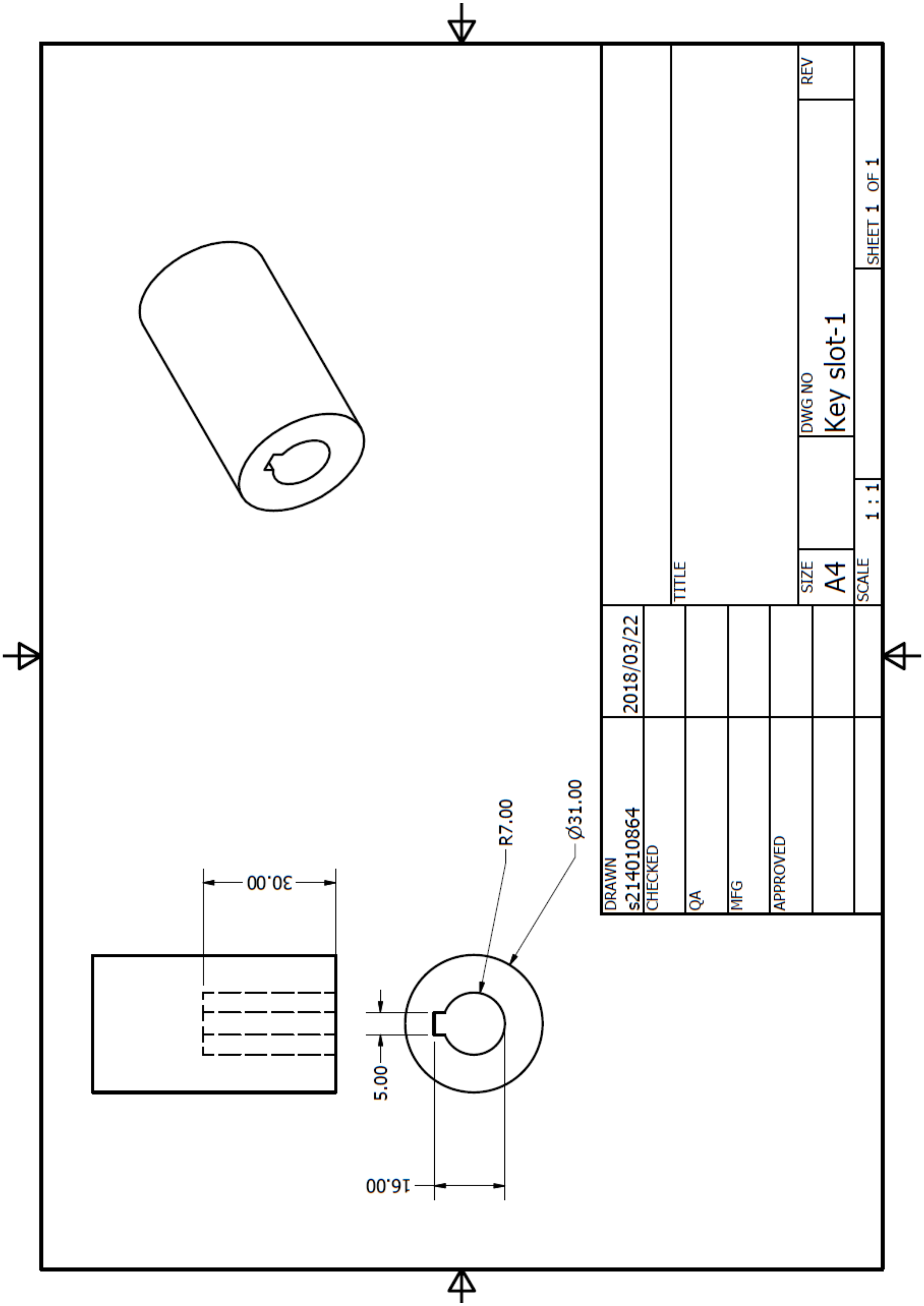
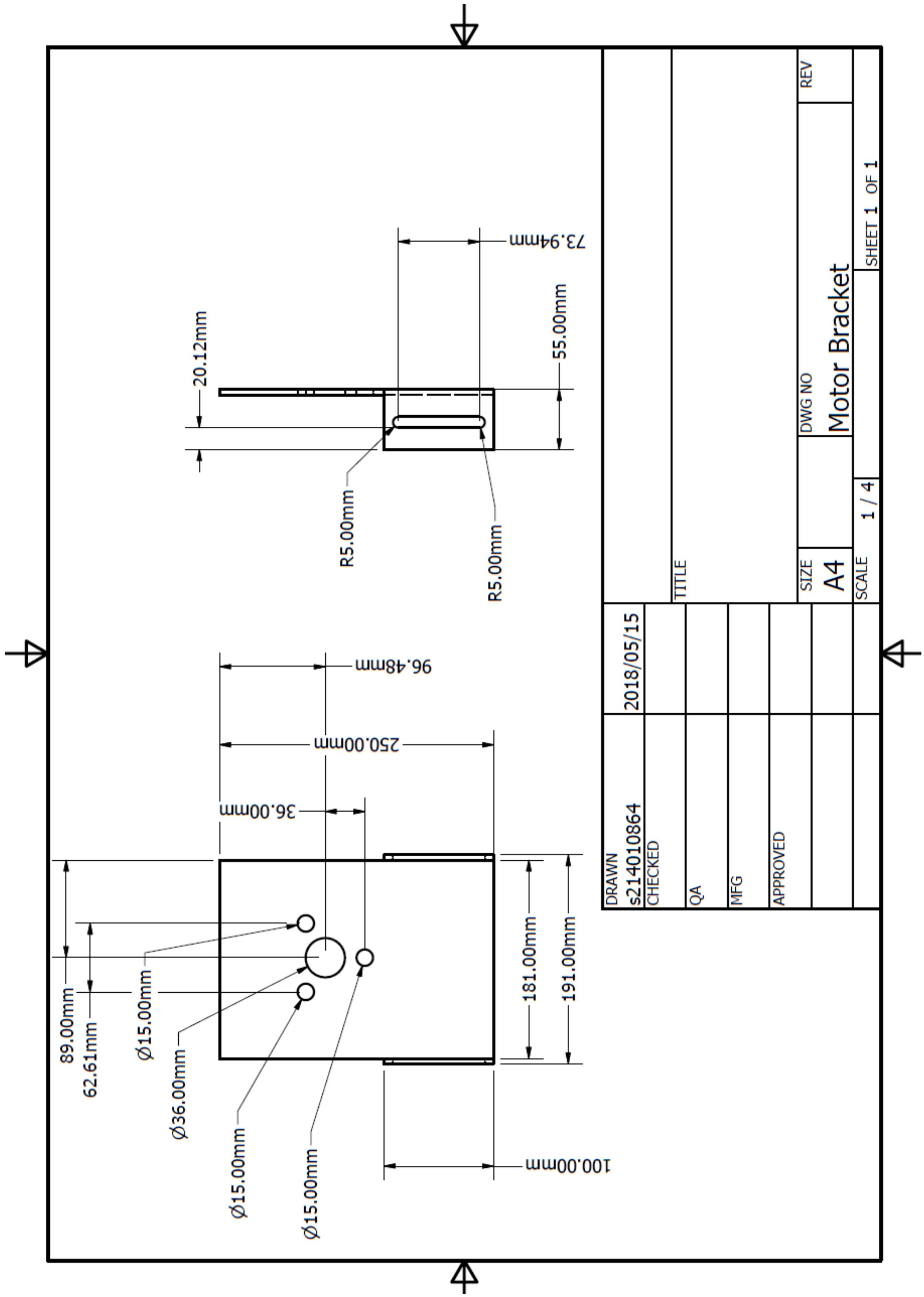
8. Appendices

8.1 Appendix A (Dimensions)




The holes must be made in the same place and with the current dimensions.
Modification of this part, as it needs to longer, so the long new part must replace the old one.
The side arms need to be replaced with the longer side arms
1766.00mm
1008.00mm
179.00mm
408.50mm
385.00mm
50.00mm
Ø8.00mm
Ø10.00mm
Ø12.00mm
27.50mm
5.00mm
54.00mm
700.00mm
1866.00mm
646.00mm
DRAWN
Luke
2/22/2018
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
D
DWG NO
CrossSection
REV
SCALE 0.14 : 1
SHEET 1 OF 1


30.00
16.00
5.00
R7.00
Ø31.00
DRAWN
s214010864
2018/03/22
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
A4
DWG NO
Key slot-1
REV
SCALE
1 : 1
SHEET 1 OF 1


89.00mm
62.61mm
Ø15.00mm
Ø36.00mm
Ø15.00mm
Ø15.00mm
36.00mm
250.00mm
96.48mm
181.00mm
191.00mm
100.00mm
20.12mm
R5.00mm
R5.00mm
55.00mm
73.94mm
DRAWN
s214010864
2018/05/15
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
A4
DWG NO
Motor Bracket
REV
SCALE
1 / 4
SHEET 1 OF 1

8.2 Appendix B (Charge controller)

SOLAR CHARGE CONTROLLERS

Steca Solsum F

6.6F, 8.8F, 10.10F

The Steca Solsum F-Line continues the huge success of one of the most used SHS controllers. With a power range of up to 10 A at automatically recognized 12 V or 24 V it fits to a system sizes of maximum 240 W.

Full circuit board protection with LED display for simple recognition of battery status. Various connections make it possible to connect easily to solar panels, battery and load. The Steca Solsum F works on PWM as a low loss series controller.

Product features

- Serial topology with MOSFETs
- Automatic detection of voltage
- Voltage regulation
- PWM control
- Multistage charging technology
- Current compensated load disconnection
- Automatic load reconnection
- Temperature compensation
- Negative earthing of one or positive earthing of several terminals possible
- Monthly equalisation charge

Electronic protection functions

- Overcharge protection
- Deep discharge protection
- Reverse polarity protection of module (≤36 V),load and battery
- Automatic electronic fuse
- Short circuit protection of load and module
- Overvoltage protection at module input
- Open circuit protection without battery
- Reverse current protection at night
- Overtemperature and overload protection
- Load disconnection on battery overvoltage

Displays

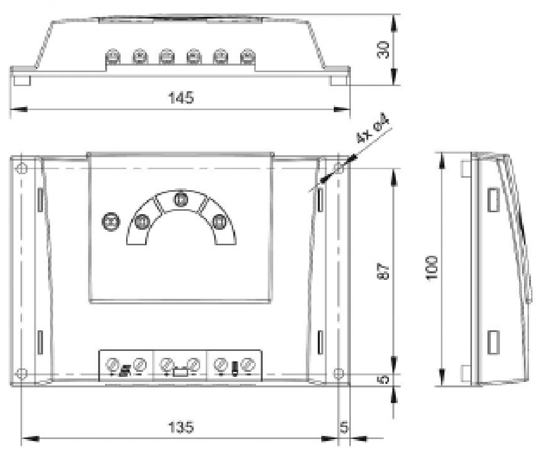
- Multifunction LED display
- Multi-coloured LED
- 4 LEDs show operating states
- for operation, state of charge, fault messages

Options

- Evening or night light function pre-set in the factory or adjustable via Steca PA RC 100
- Parameterisation of function values via Steca PA RC 100

Certificates

- Compliant with European Standards (CE)
- RoHS compliant
- Made in EU
- Manufactured according to ISO 9001 and ISO 14001



	6.6F	8.8F	10.10F
Characterisation of the operating performance			
System voltage	12 V (24 V)		
Own consumption	< 4 mA		
DC input side			
Open circuit voltage solar module (at minimum operating temperature)	< 47 V		
Module current	6 A	8 A	10 A
DC output side			
Load current	6 A	8 A	10 A
Reconnection voltage (LVR)	12.4 V … 12.7 V (24.8 V … 25.4 V)		

Accessories
- Steca PA RC100

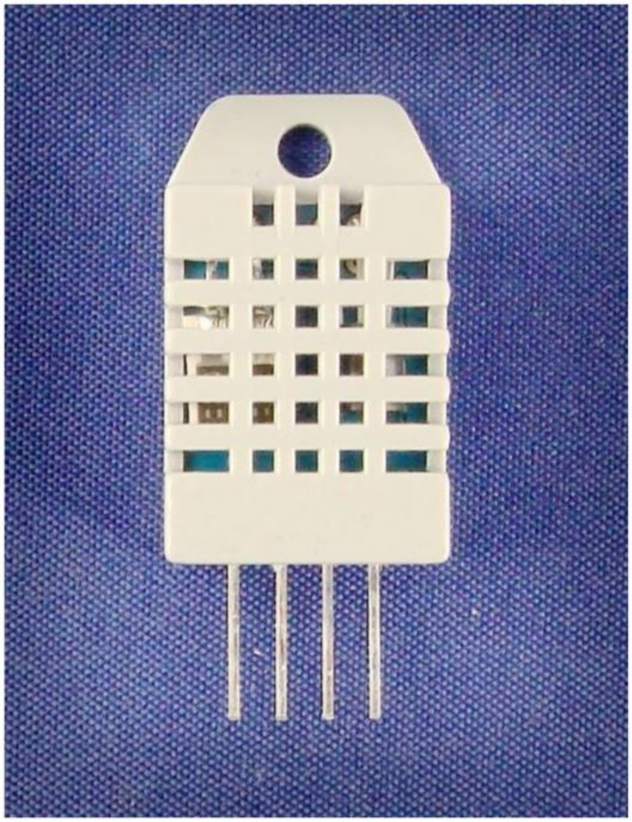
Deep discharge protection (LVD)	11.2 V ... 11.6 V (22.4 V ... 23.2 V)
Battery side	
End-of-charge voltage	13.9 V (27.8 V)
Boost charge voltage	14.4 V (28.8 V)
Set battery type	gel
Operating conditions	
Ambient temperature	-25 °C ... +50 °C
Fitting and construction	
Terminal (fine / single wire)	4 mm² / 6 mm² - AWG 12 / 9
Degree of protection	IP 31
Dimensions (X x Y x Z)	145 x 100 x 30 mm
Weight	ca. 150 g

- Technical data at 25 °C / 77 °F
- adjustable via Steca PA RC100: reconnection voltage, deep discharge protection, end of charge voltage, boost charge voltage, battery type
- Inverters must not be connected to the load output.

8.3 Appendix C (DHT22)

Digital-output relative humidity & temperature sensor/module

DHT22 (DHT22 also named as AM2302)



Capacitive-type humidity and temperature module/sensor

1. Feature & Application:

* Full range temperature compensated * Relative humidity and temperature measurement
* Calibrated digital signal *Outstanding long-term stability *Extra components not needed
* Long transmission distance * Low power consumption *4 pins packaged and fully interchangeable

2. Description:

DHT22 output calibrated digital signal. It utilizes exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability.Its sensing elements is connected with 8-bit single-chip computer.

Every sensor of this model is temperature compensated and calibrated in accurate calibration chamber and the calibration-coefficient is saved in type of programme in OTP memory, when the sensor is detecting, it will cite coefficient from memory.

Small size & low consumption & long transmission distance(20m) enable DHT22 to be suited in all kinds of harsh application occasions.

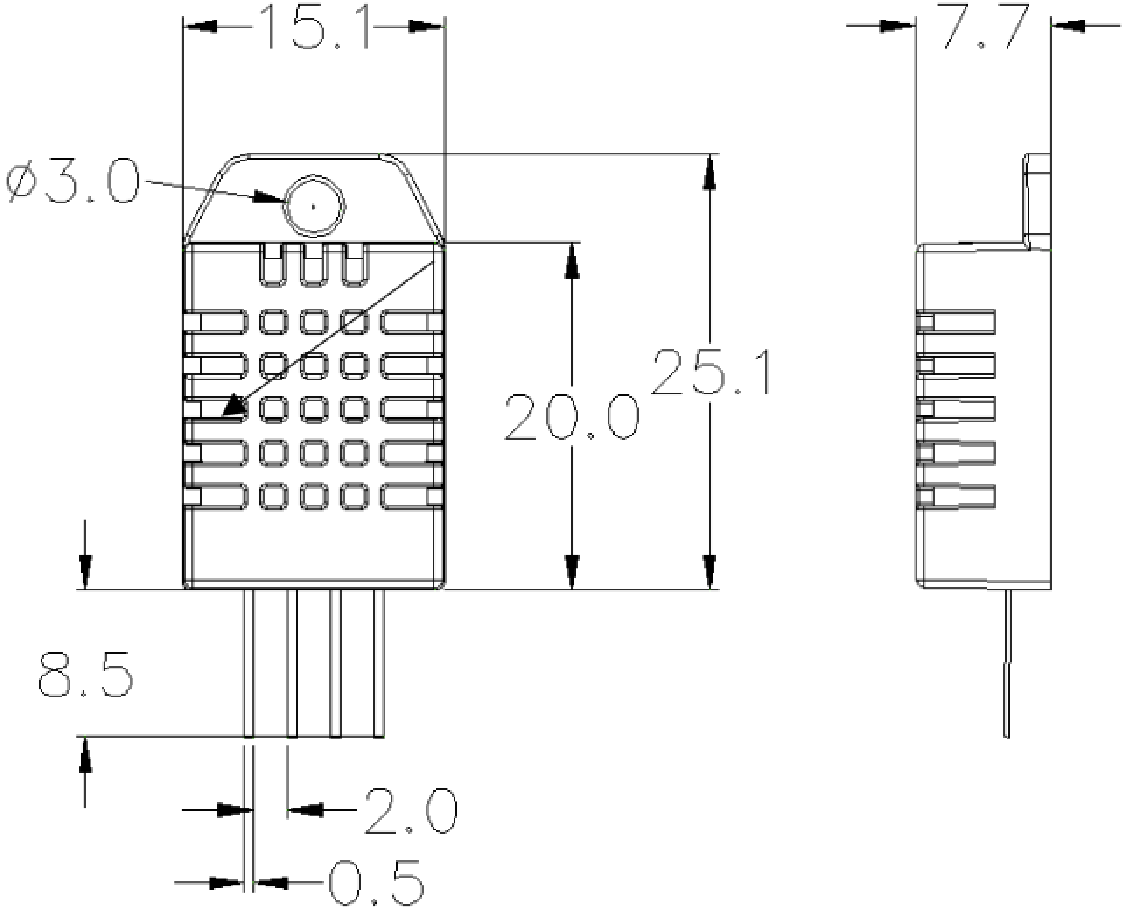
Single-row packaged with four pins, making the connection very convenient.

3. Technical Specification:

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

4. Dimensions: (unit----mm)

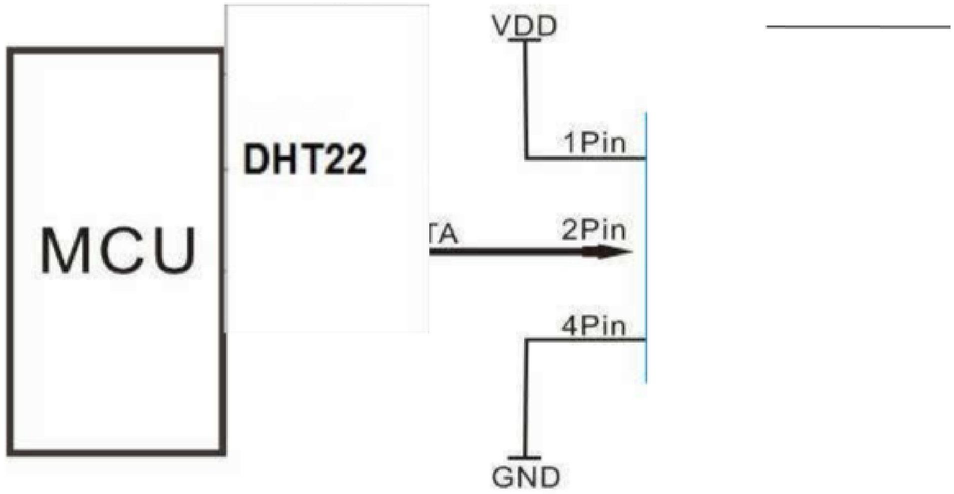
1) Small size dimensions: (unit----mm)



Pin sequence number: 1 2 3 4 (from left to right direction).

Pin	Function
1	VDD----power supply
2	DATA--signal
3	NULL
4	GND

5. Electrical connection diagram:



3Pin---NC, AM2302 is another name for DHT22

6. Operating specifications:

(1) Power and Pins

Power's voltage should be 3.3-6V DC. When power is supplied to sensor, don't send any instruction to the sensor within one second to pass unstable status. One capacitor valued 100nF can be added between VDD and GND for wave filtering.

(2) Communication and signal

Single-bus data is used for communication between MCU and DHT22, it costs 5mS for single time communication.

Data is comprised of integral and decimal part, the following is the formula for data.

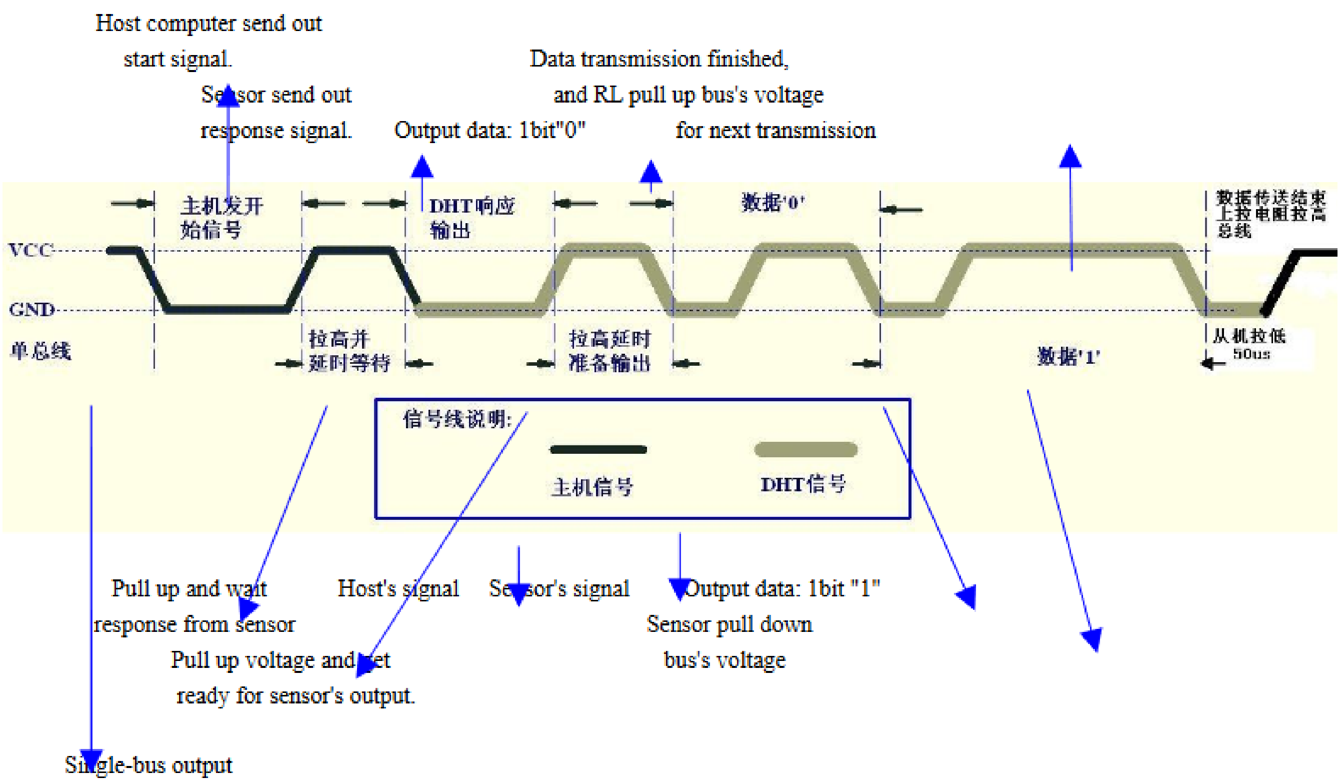
DHT22 send out higher data bit firstly!
DATA=8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data+8 bit check-sum
If the data transmission is right, check-sum should be the last 8 bit of "8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data".

When MCU send start signal, DHT22 change from low-power-consumption-mode to running-mode. When MCU finishs sending the start signal, DHT22 will send response signal of 40-bit data that reflect the relative humidity

5

and temperature information to MCU. Without start signal from MCU, DHT22 will not give response signal to MCU. One start signal for one time's response data that reflect the relative humidity and temperature information from DHT22. DHT22 will change to low-power-consumption-mode when data collecting finish if it don't receive start signal from MCU again.

1) Check bellow picture for overall communication process:



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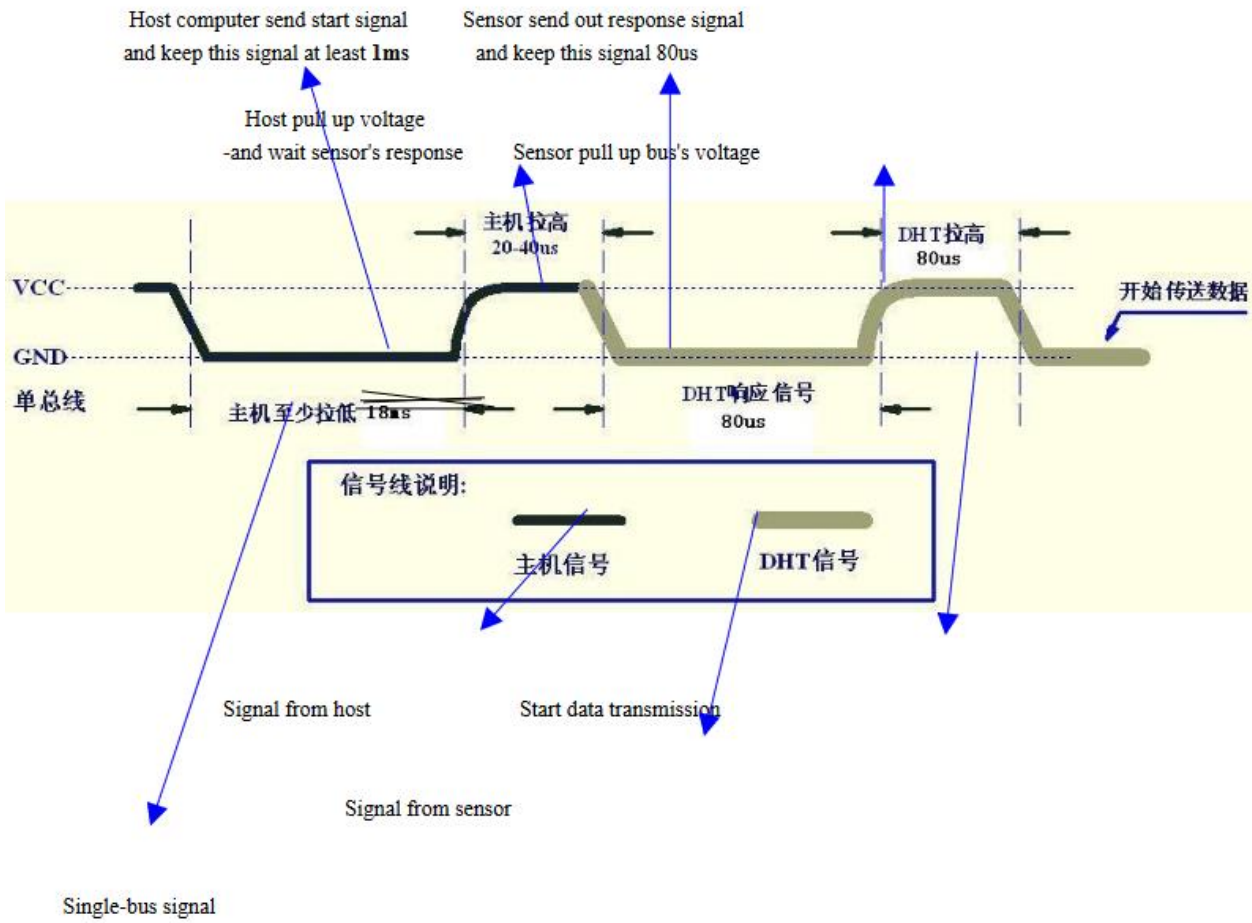
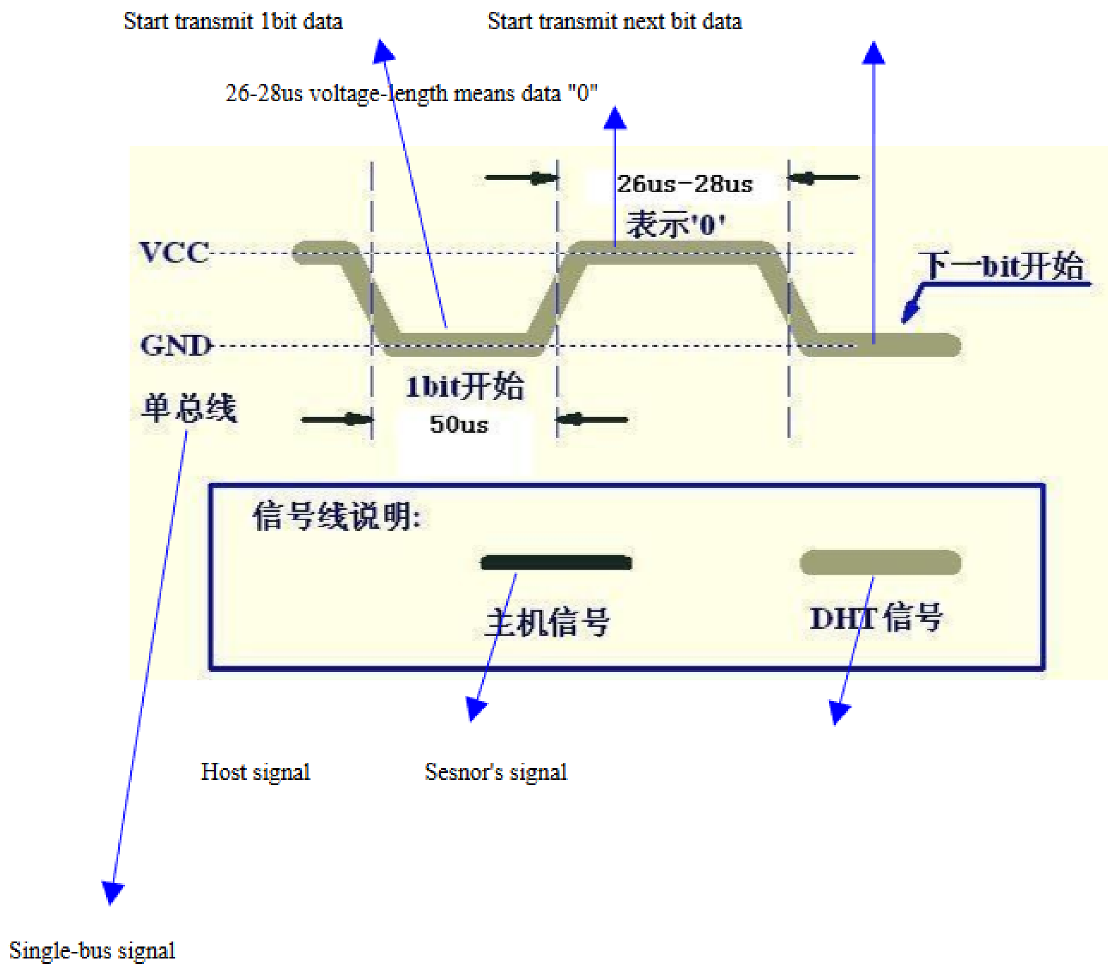
2) Step 1: MCU send out start signal to DHT22

Data-bus's free status is high voltage level. When communication between MCU and DHT22 begin, program of MCU will transform data-bus's voltage level from high to low level and this process must beyond at least 1ms to ensure DHT22 could detect MCU's signal, then MCU will wait 20-40us for DHT22's response.



Step 2: DHT22 send response signal to MCU

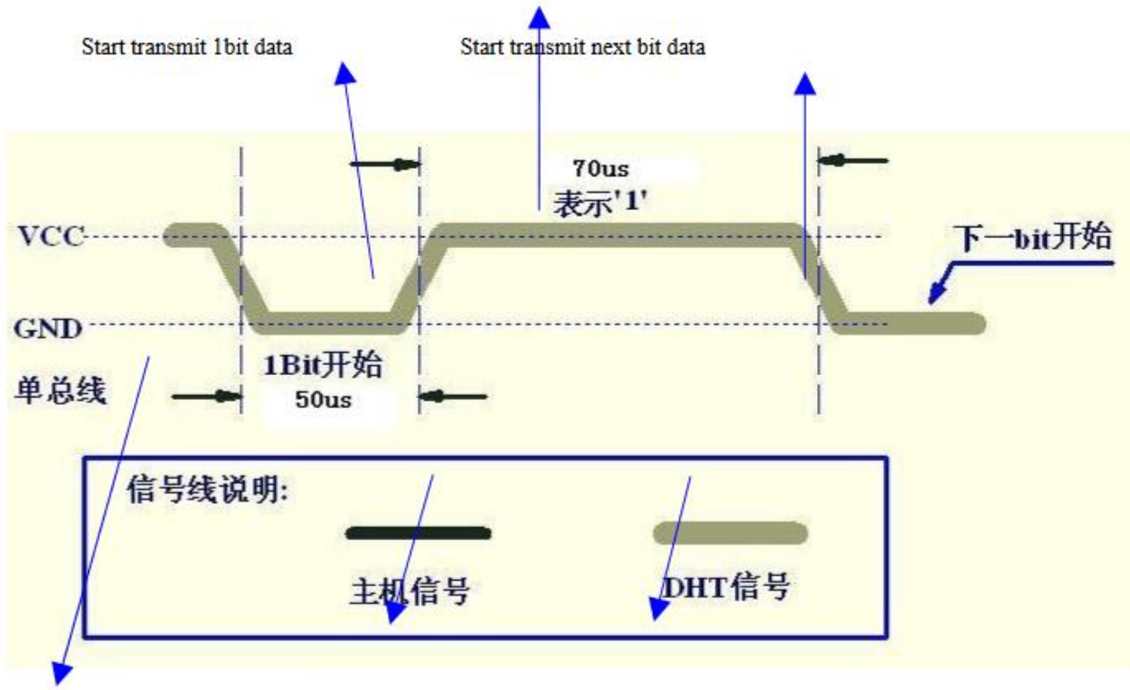
When DHT22 detect the start signal, DHT22 will send out low-voltage-level signal and this signal last 80us as response signal, then program of DHT22 transform data-bus's voltage level from low to high level and last 80us for DHT22's preparation to send data.



Step 3: DHT22 send data to MCU

When DHT22 is sending data to MCU, every bit's transmission begin with low-voltage-level that last 50us, the following high-voltage-level signal's length decide the bit is "1" or "0".

Start transmit 1bit data Start transmit next bit data



Host signal Sesnor's signal

Single-bus signal

If signal from DHT22 is always high-voltage-level, it means DHT22 is not working properly, please check the electrical connection status.

7. Electrical Characteristics:

Item	Condition	Min	Typical	Max	Unit
Power supply	DC	3.3	5	6	V
Current supply	Measuring	1		1.5	mA
	Stand-by	40	Null	50	uA
Collecting period	Second		2		Second

*Collecting period should be : >2 second.

8. Attentions of application:

(1) Operating and storage conditions

We don't recommend the applying RH-range beyond the range stated in this specification. The DHT22 sensor can recover after working in non-normal operating condition to calibrated status, but will accelerate sensors' aging.

(2) Attentions to chemical materials

Vapor from chemical materials may interfere DHT22's sensitive-elements and debase DHT22's sensitivity.

(3) Disposal when (1) & (2) happens

Step one: Keep the DHT22 sensor at condition of Temperature 50~60Celsius, humidity <10%RH for 2 hours;

Step two: After step one, keep the DHT22 sensor at condition of Temperature 20~30Celsius, humidity >70%RH for 5 hours.

(4) Attention to temperature's affection

Relative humidity strongly depend on temperature, that is why we use temperature compensation technology to ensure accurate measurement of RH. But it's still be much better to keep the sensor at same temperature when sensing.

DHT22 should be mounted at the place as far as possible from parts that may cause change to temperature.

(5) Attentions to light

Long time exposure to strong light and ultraviolet may debase DHT22's performance.

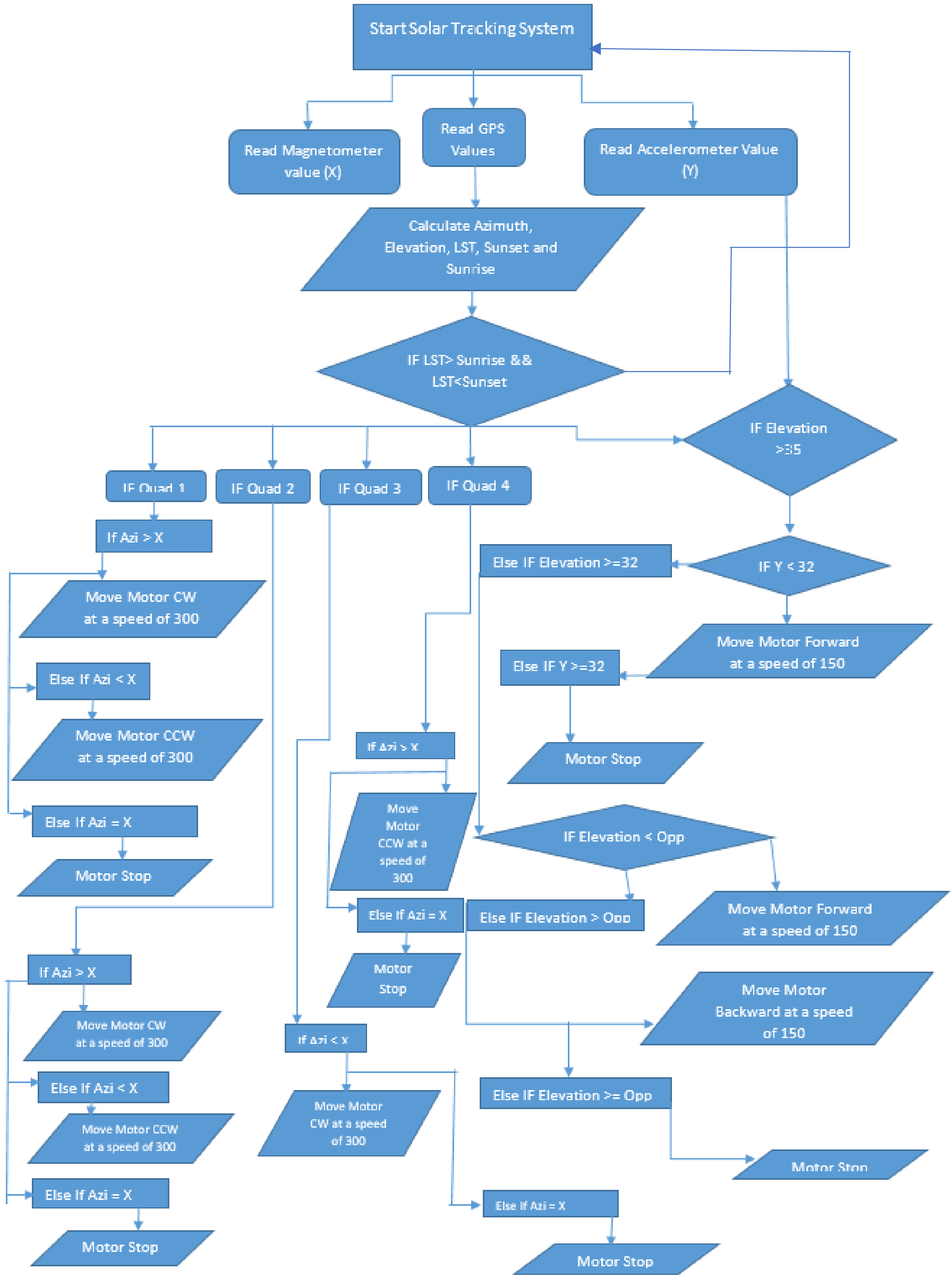
(6) Attentions to connection wires

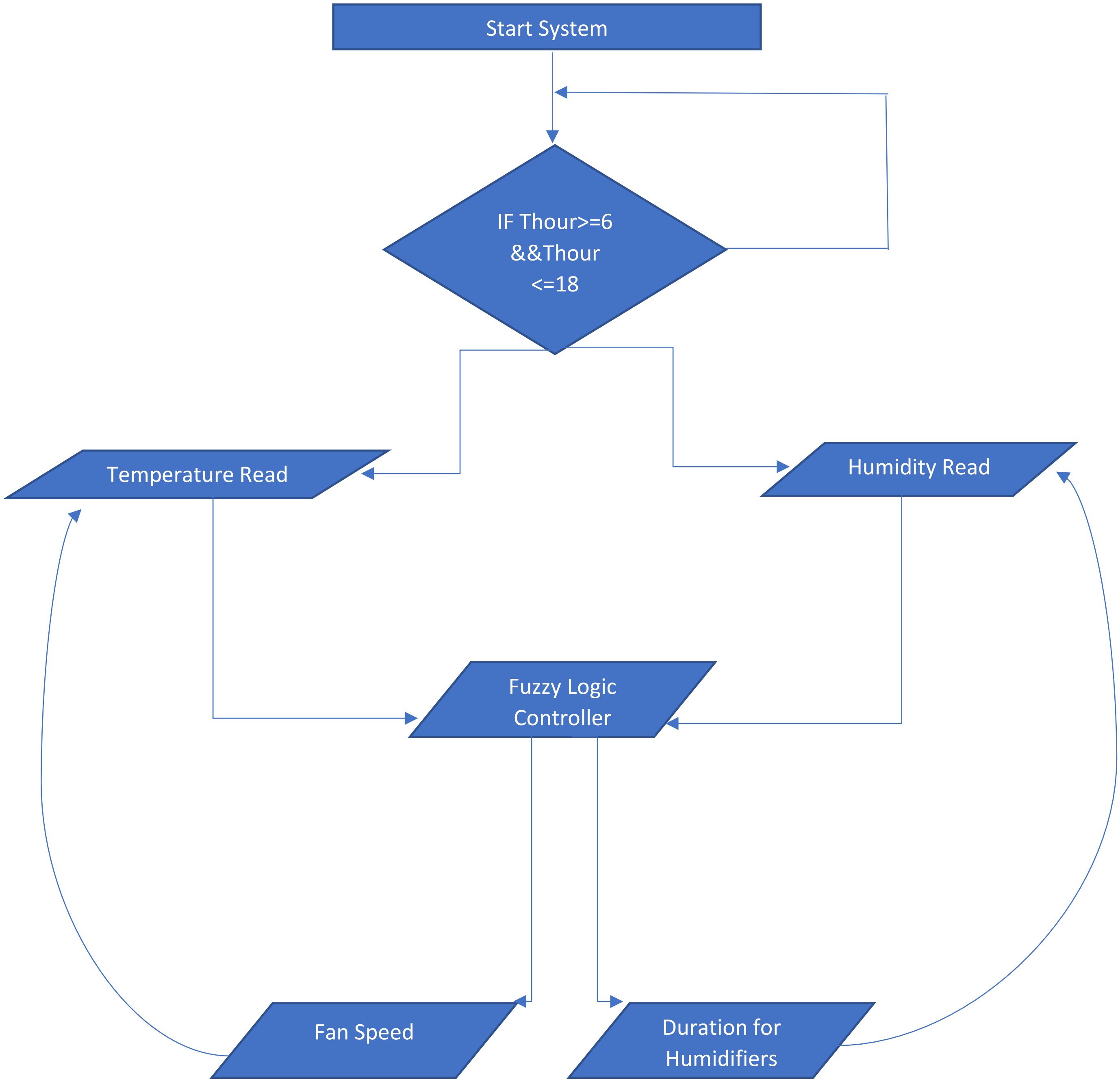
The connection wires' quality will effect communication's quality and distance, high quality shielding-wire is recommended.

(7) Other attentions

* Welding temperature should be bellow 260Celsius.
* Avoid using the sensor under dew condition.
* Don't use this product in safety or emergency stop devices or any other occasion that failure of DHT22 may cause personal injury.

8.4 Appendix D (Flow Diagram)




Start System
IF Thour>=6
&&Thour
<=18
Temperature Read
Humidity Read
Fuzzy Logic
Controller
Fan Speed
Duration for
Humidifiers