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NANYANG TECHNOLOGICAL UNIVERSITY

# Build A Better Whole Sky Imager

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# Abstract

The Whole Sky Imager (WSI) is an automated ground-based system used to assess and document cloud fields and cloud fields dynamics. A basic WSI consists of an optical clear dome, camera body with fish eye lens and a single-board computer to control the camera.

The WSI will be operated in harsh environment. Special care has to be taken when designing the new WSI to ensure the system is kept cool and dry to protect the components. The size of the new WSI is an important factor to consider as the WSI will be deployed in other sites other than in the university.

The images captured by the camera through the optical clear dome must be sharp so that the images can be used for cloud monitoring to study how clouds can attenuate signals.

# Acknowledgements

I would like express my deepest gratitude and great thanks to Professor Lee Yee Hui and Dr. Stefan Winkler (ADSC) for their invaluable guidance and patience during the course of the Final Year Project. More as a mentor, Professor Lee Yee Hui and Dr. Stefan Winkler has always empowered me in exploration of new ideas and accepting failures as part of a learning process.

I would also like to take this opportunity to thank all the laboratory technicians in the Autonomous Robotics Research Laboratory (S2-B6A-01) for their guidance and help during the manufacturing process of the project. Special mention must be made to Florian, Jun Xiang and Soumya for their invaluable advices and the support given despite their busy schedule. Special thanks to Final Year Project student, Jun Yi, for assisting me with the sensors which helps me in the process of designing my project.

Lastly, I would like to thank my family and my fiancée for their unwavering support and understanding. I am forever grateful for their presence in my life as it has been the biggest encouragement in times of difficult periods and celebrating with me when there is success.

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# Chapter 1

# Introduction

## 1.1 Background

Satellite is an object that moves around a big object and they can be categorised into natural and man-made. The natural satellites would include the Earth and moon while the man-made are machines made by people that are launched into the space. Satellites are important as they can see large areas of the Earth. Some of the important applications include Global Positioning System (GPS), long distance communication, weather and reconnaissance.

Satellite signal could be affected by various atmospheric factors such as rain, snow and cloud. Water is known to attenuate signals and clouds are a visible aggregate of minute droplets of water or particles of ice or a mixture of both floating in the free air.

A Whole Sky Imager (WSI) is used to assess and document cloud fields and cloud fields dynamics.[1] To study the effect of clouds on satellite communication links, the university has built two versions of WSI and called it Wide Angle High Resolution Sky Imager System (WAHRSIS) I and WAHRSIS II. However, only WAHRSIS I is operational.

For the purpose of 3D reconstruction using image-based method, two WSI is required. As shown in figure 1, the height of a 3D point could be calculated using triangulation method. The type of clouds varies in the different atmospheric levels and as the height increases, the water content in the cloud reduces. Thus, by calculating the height of the clouds using 3D reconstruction, it allows us to identify the types of clouds.

This project mainly focuses on building an improved version of WSI without the sun blocker and be able to withstand the hot weather that it will be operating in. In the previous WSI designs, there is a sun blocker built to reduce the sun glare as well as to protect the sensor onboard the camera from burning. However, as shown in figure 2, when the sun blocker is in position, it covers a portion of the image. Although there is an algorithm developed to inpaint the captured image, the inpainted area may not be true to the ground truth.

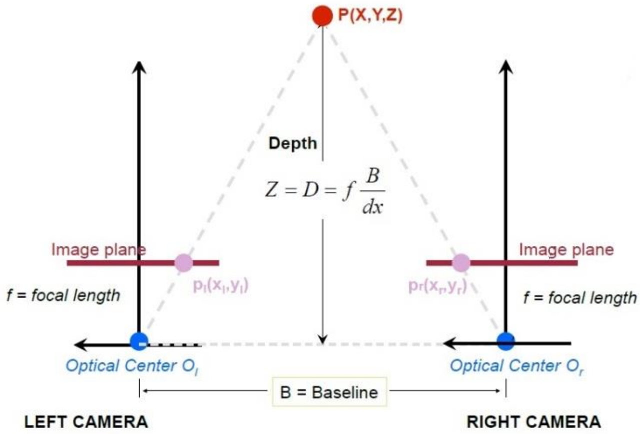


**Figure 1: 3D Reconstruction – Height Calculation**


**Figure 2: Sun Blocker in Position**

## 1.2 Purpose

The purpose of this project is to design and develop an improved version of WSI. Some of the main considerations include wireless connection, internet connectivity (mobile) and compact design for mobility.

## 1.3 Objectives

The main objectives of this project are:

1. Understand the operation of a WSI.
2. Study and design a weatherproof WSI suitable for operating under hot weather.
3. Build an improved version of WSI.

# Chapter 2

# Literature Review

## 2.1 Clouds

Clouds are visible accumulations of water droplets or ice crystals that float in the Earth's troposphere that moves with the wind.[2] Clouds are formed when water vapour rises into the atmosphere and condenses on the atmosphere particles.[3]

Clouds are categorised according to the altitude:

- Low-Level Clouds - < 6,5000 ft
- Middle-Level Clouds – 6,5000 to 23,000 ft
- High-Level Clouds – 16,5000 to 45,000 ft

The types of clouds are further categorised in their respective level:

Low-Level Clouds

(a) Stratus Clouds (Liquid Water)
(b) Stratocumulus Clouds (Liquid Water)

Middle-Level Clouds

(a) Altocumulus Clouds (Mostly Liquid Water but may contain Ice Crystals)
(b) Altostratus Clouds (Both Liquid Water and Ice Crystals)

High-Level Clouds

(a) Cirrus Clouds (Ice Crystals)
(b) Cirrocumulus Clouds (Ice Crystals)
(c) Cirrostratus Clouds (Ice Crystals)

Clouds with large vertical extending at heights of 0 to 45,000 ft

(a) Cumulus Clouds (Liquid Water)
(b) Cumulonimbus Clouds (Liquid water throughout, ice crystals at the top)
(c) Nimbostratus Clouds (Liquid water, raindrops, snowflakes and ice crystals)

Stratus Clouds

Stratocumulus Clouds

**Figure 3: Low-Level Clouds**

Altocumulus Clouds

Altostratus Clouds

**Figure 4: Middle-Level Clouds**

Cirrus Clouds

Cirrocumulus Clouds

Cirrostratus Clouds

**Figure 5: High-Level Clouds**

Cumulus Clouds

Cumulonimbus Clouds

Nimbostratus Clouds

**Figure 6: Clouds with Vertical Extending at Heights of 0 to 40,000 ft**

## 2.2 Clouds Attenuation

Satellites orbiting the Earth communicate with stations using Radio Waves. The satellite receives an uplink signal from a transmitter on the ground and the satellite would broadcast the same information on a different frequency (downlink) to a second station (receiver) on the ground that is located thousands of miles away from the transmitter.[4]

Satellite communication usually operates in the higher frequency band in the range of Ku-band (12 – 18GHz) or Ka-band (26-40GHz).[5] Higher frequency may provide wider bandwidth but these frequencies are also more susceptible to signal attenuation due to Tropospheric degradation.[6]

Water droplets are known to absorb and scatter radiowave energy (as shown in figure 7).[7] Therefore, the attenuation of electromagnetic radiation by water droplets in the cloud is due to both absorption and scattering.[8]

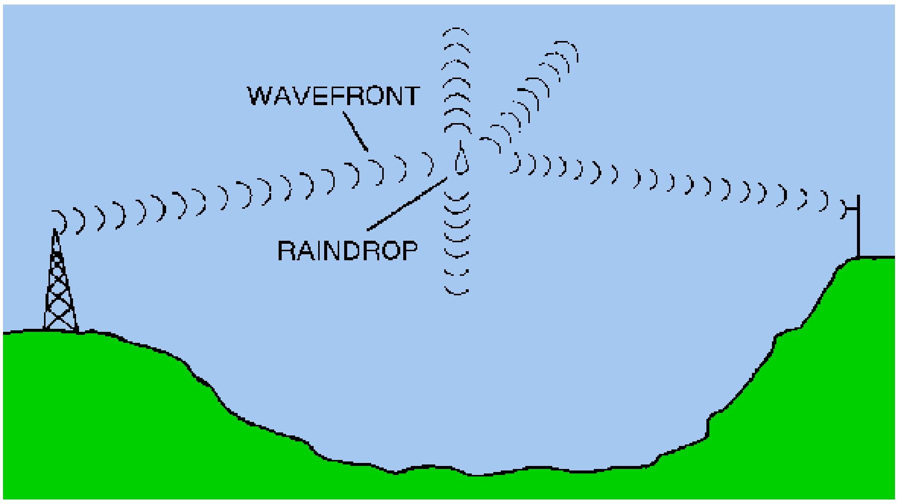


**Figure 7: RF Signal Scattering**

The scattering of a RF signal happens when it strikes an uneven surface causing it to be scattered. This results in a weaker signal received by the receiver than the original signal that was transmitted by the transmitter. The absorption of RF signals is due to the conversion of the RF signal energy into heat. This happens when the molecules in the medium it is passing through are unable move fast enough to keep up with the RF waves.[9]

As mentioned earlier in Section 2.1, clouds are visible accumulation of water droplets or ice crystals. Each types of cloud have different water droplet concentration. Clouds containing ice crystals and non-precipitating clouds causes less attenuation as the liquid content are too low to absorb much of the energy and the droplets are too small to scatter the signal.[10] As compared to the mid-level and high-level clouds, the low-level clouds causes more signal attenuation due to its higher water content.

# Chapter 3
# Design of Whole Sky Imager

## 3.1 Main Concept

A Whole Sky Imager (WSI) is an outdoor equipment that is placed on the rooftop to have a clear view of the sky without any infrastructure obscuring the imager's view. Because of its placement on the rooftop, the WSI will be exposed to harsh environment such as rain and hot weather. Therefore, the design of the WSI must take into consideration of the environment that it will be operating in. A Canon 600D body with 4.5mm F2.8 EX DC HSM Circular Fisheye Lens will be used as the imager of the WSI. The camera will be connected to a single-board computer which controls the camera. The captured images will then be uploaded to the server through LAN or WLAN.

## 3.2 Mechanical Design

Before the start of the design process, it is important to understand the operating principle of a WSI as well as the pros and cons of the previous versions of WSI that the university has built. There are two WSI currently set up on the rooftop of S2.1 but only one is operational. As shown in figure 8, WAHRSIS I being the only operational WSI, is not rainproof because of the stepper motor being exposed to the environment and a RJ45 cable is connected to the Raspberry Pi through the opening of the enclosure. While WAHRSIS II was designed to overcome the problems that WAHRSIS I faced, the design itself creates another problem of overheating. As shown in figure 9, the WAHRSIS II was designed to be large enough to contain all the components including the sun blocker and the two stepper motors within the enclosure and is rain proofed. However, because of the large enclosure and transparent dome, the large volume of air in the enclosure gets heated up easily and there is no way for the heated air to be ventilated out due to a tightly sealed enclosure. Subsequently, a Peltier Cooler was installed on the WAHRSIS II to solve the problem of overheating but it is not sufficient enough to cool the temperature down within the operating temperature of the camera (0°C ~ 40°C). The installation of the Peltier Cooler also resulted in the enclosure losing its tightly sealed properties. Coupled with the hot air and a not tightly sealed enclosure, condensation starts to form on the transparent dome as shown in figure 10.

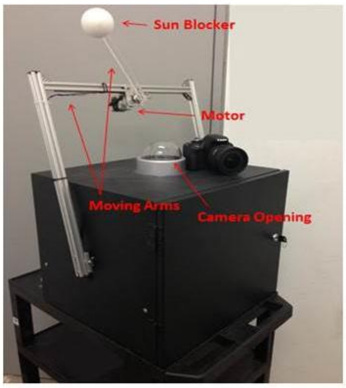



**Figure 8: WAHRSIS I**

**Figure 9: WAHRSIS II**

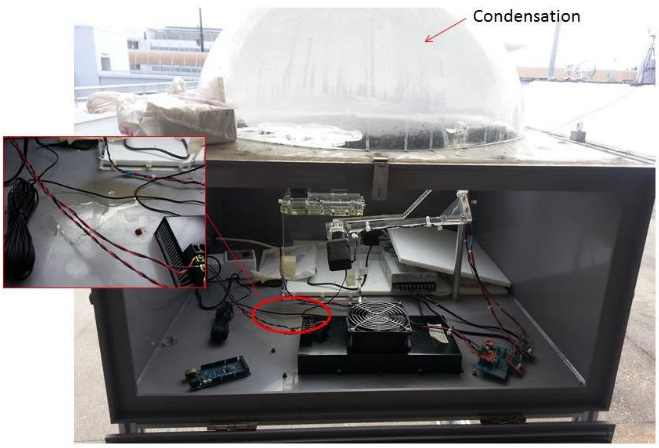


**Figure 10: Condensation Forming on WAHRSIS II**

### 3.2.1 Enclosure

The most important factor when designing the WSI is the type of enclosures to be used because of the problems faced by the previous versions of WSI. To aid in deciding whether a fully enclosed box or ventilated box to be used, a study has been carried out on mock up boxes to ensure the new WSI is able to operate under the harsh weather condition in Singapore. As shown in figure 11 and figure 12, a fully enclosed box and a ventilated box was constructed for the purpose of measuring the internal temperature and relative humidity.

**Figure 11: Fully Enclosed Box**

**Figure 12: Ventilated Box**

Both of the boxes has a dimension of 300mm x 300mm x 300mm (L x W x H) and a piece of 80mm x 800mm (L x W) acrylic is glued to the cover of the box for the purpose of simulating sun ray entering the box through the dome.

As shown in figure 13, the sensors used to measure the internal temperature and relative humidity is Sensirion SHT 15 that was borrowed from a Final Year Project (FYP) student.

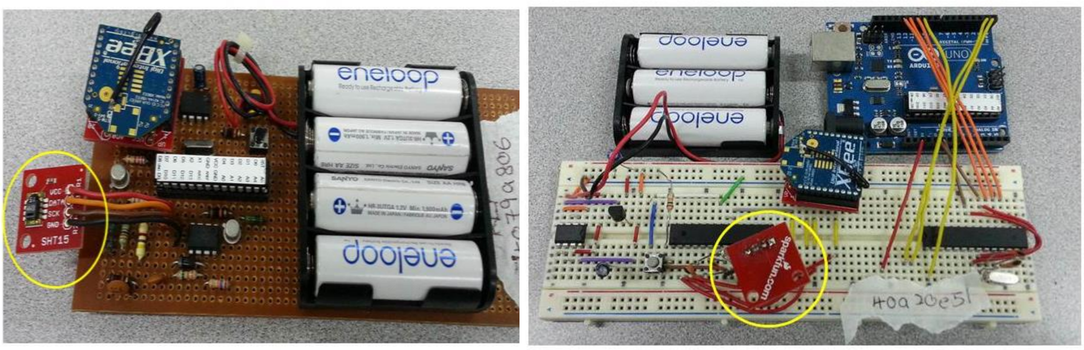



**Figure 13: Sensirion SHT 15**

The sensors specification is as of following:

- Factory calibrated sensors for relative humidity and temperature
- Measurement range for relative humidity: 0 – 100%
- Relative humidity accuracy: +/- 2.0% @ 10 – 90% and +/- 4.0% @ 100%
- Measurement range for temperature: -40 to 100°C
- Temperature accuracy: +/- 0.3°C @ 25°C

The sensors were first calibrated under a controlled air conditioned (approximately 23°C) environment in the Communication Laboratory III (S2-B3c-26). As shown in table 1, there is a difference of average 0.55°C between the two sensors with for the measured temperature. As relative humidity is dependent on temperature, it is not a factor consider if a calibration of the sensors is required.

| **Temperature (°C)** | | |
|---|---|---|
| **Sensors** | | **Difference** |
| 40a20e51 | 4079a806 (Ref) | |
| 22.77 | 23.34 | -0.57 |
| 22.8 | 23.32 | -0.52 |
| 22.77 | 23.37 | -0.6 |
| 22.81 | 23.36 | -0.55 |
| 22.78 | 23.36 | -0.58 |
| 22.81 | 23.26 | -0.45 |
| 22.81 | 23.33 | -0.52 |
| 22.77 | 23.34 | -0.57 |
| 22.76 | 23.31 | -0.55 |
| 22.8 | 23.37 | -0.57 |
| Average | | -0.55 |

| **Relative Humidity (%)** | | |
|---|---|---|
| **Sensors** | | **Difference** |
| 40a20e51 | 4079a806 (Ref) | |
| 77.07 | 75.19 | 1.88 |
| 77 | 75.21 | 1.79 |
| 77 | 75.11 | 1.89 |
| 76.84 | 75.11 | 1.73 |
| 76.91 | 75.11 | 1.8 |
| 77 | 75.19 | 1.81 |
| 77.03 | 75.24 | 1.79 |
| 77.24 | 75.46 | 1.78 |
| 77.15 | 75.34 | 1.81 |
| 77.03 | 75.19 | 1.84 |
| Average | | 1.81 |

**Table 1: Calibration of Sensors**

The difference in the measured temperature of both sensors is acceptable as the accuracy of the sensors is specified as +/- 0.5°C @ 25°C. Thus, there is no requirement to make any adjustment to the data collected in the subsequent experiment. As shown in figure 14, an experiment was set up to measure the internal temperature and relative humidity of the boxes.

**Figure 14: Experiment Setup**

One of the challenges faced during the experiment is the intermittent connection in between the sensors and the Raspberry Pi (circled in yellow). The sensors are unable to transmit the data to the Raspberry Pi at times and this resulted in readings at certain time is not obtainable. This is shown in figure 15 where some of the readings are zero.

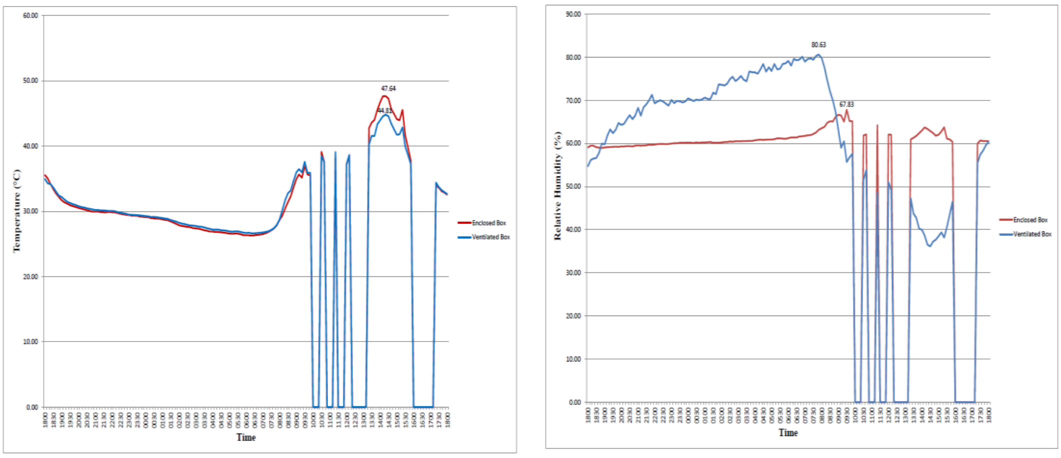


**Figure 15: Example of Obtained Reading**

The experiment has to be closely monitored round the clock so that timely measures can be taken to reconnect the sensors with the Raspberry Pi when connection is lost to ensure continuity in the data collected. As shown in figure 16, the best data collected is from 28 October 2014 to 29 October 2014.

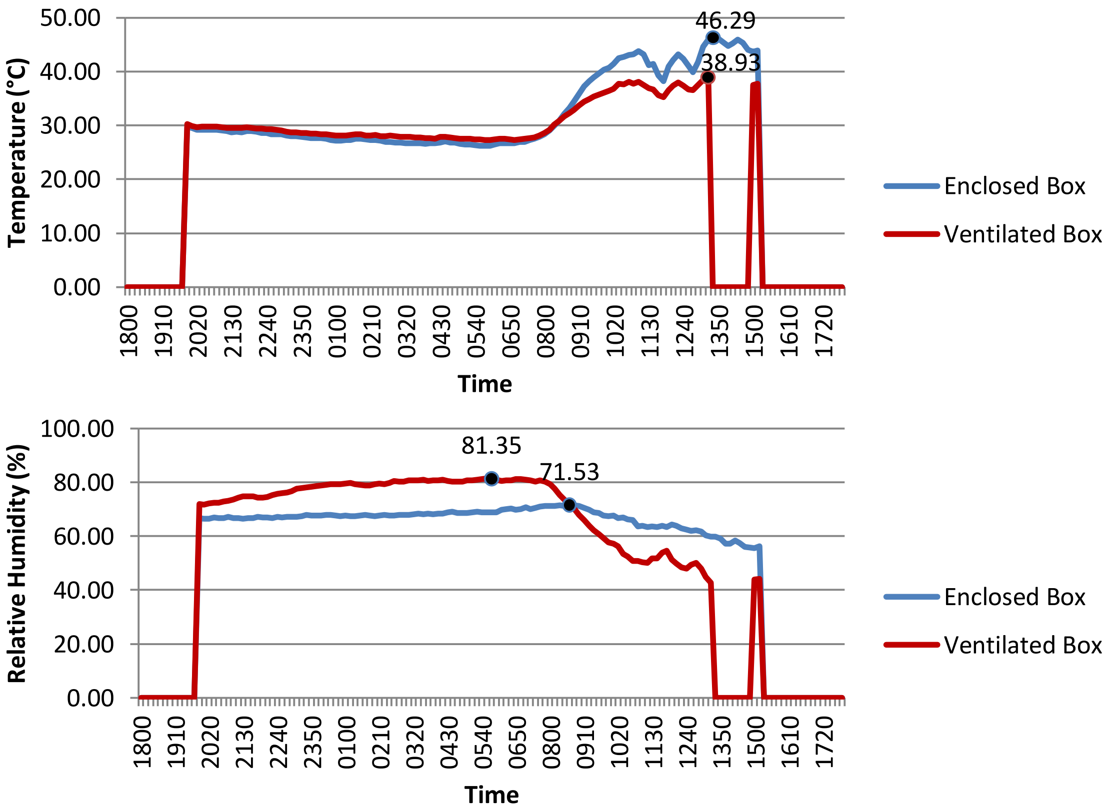


**Figure 16: Data Recorded**

As shown in the above figure, the measured temperature in a ventilated box is lower than of a fully enclosed box during the day. However, the downside of a ventilated box is that its relative humidity is higher compared to a fully enclosed box although both boxes have about the same measured temperature.

The ventilated box is a solution to the overheating problem faced by the previous versions of WSI but the high measured relative humidity is a concern as condensation might form on the dome should the relative humidity reaches 100%. However, according to National Environment Agency (NEA)[11], the mean daily maximum for relative humidity is about 95% to 97% for the past 80 years.

With these factors taken into consideration, I have decided to proceed with a ventilated box design as it has a lower internal temperature during the day. Though the measured relative humidity is on the high side, records has shown that occurrence of relative humidity reaching 100% is very low.

### 3.2.2 Material

The choice of material for the enclosure is important as each material has its own properties, advantages and disadvantages. Two of the important factors that have to be taken into consideration are the strength and the cost of the chosen material. As the WSI will be operated under harsh environment, the material chosen has to be able to withstand long duration of heat from the sun and any impact it may sustained during the process of transportation to other sites. A summary of some properties of the three materials is shown in table 2.

| Material | Weatherproof | Wireless Connection | Strength | Cost |
|---|---|---|---|---|
| Metal | Yes | No | High | High |
| Plastic | Yes | Yes | Middle | High |
| Wood | No | Yes | Low | Low |

**Table 2: Summary of Materials**

Wood without any treatment is not weatherproof. Lacquer and paint may be applied to make it water resistant but it is not a long term solution as the wood has to be coated with new lacquer or paint after a period of time.

Plastic may be an ideal material as it is weatherproof and is wireless friendly. However, plastic cracks easily upon impact. The strength of a plastic can be increased with thickness but this will result in an increased in cost and weight.

Metal, on the other hand, is weatherproof and strong even as a thin sheet. Long exposure to the sun over a long period of time will not cause the metal to crack. It may not be wireless friendly but this issue can be easily solved if the antenna is mounted on the outside of the enclosure. Therefore, metal has been chosen as the material to be used for the enclosure.

### 3.2.3 Dome

The dome is the most important part of a WSI as it is used to house the camera lens protecting it from dust, rain and dirt. The dome has to be optically clear so that it does not cause any distortion to the captured images. In the previous versions of WSI, acrylic was chosen as the material for the fabrication of the dome. However, acrylic is prone to scratches and this is not ideal as it will affect the images used for cloud monitoring. Also, transparent acrylic turns yellow over time due to a chemical reaction when exposed to light. Glass dome is an alternative to an acrylic dome. Glass is resistant to scratches and it does not turn yellow even after long periods of exposure to the sun. However, the cost of a glass dome is expensive and it is costly to replace the glass dome should it crack upon impact. After much consideration, glass dome is chosen as the preferred material as it allows the camera to produce better images which is important for the purpose of cloud monitoring.

### 3.2.4 Cooling Technique

Although a ventilated enclosure has been proven to be a better design because of a lower internal temperature, measures still has to be taken to further lower the internal temperature of the enclosure. Two cooling techniques namely thermoelectric cooling and double roof design were considered.

**Thermoelectric Cooling**

Thermoelectric cooling uses Peltier effect to create a heat flux between the junctions of two different types of materials.[12] As shown in figure 17, the device has two sides, when a DC current flows through the device; it brings the heat from one side to the other resulting in a cool side and a hot side. A heat sink is mounted on the “hot” side of the device to dissipate off the heat maintaining it at ambient temperature while the “cool” side will go below room temperature.

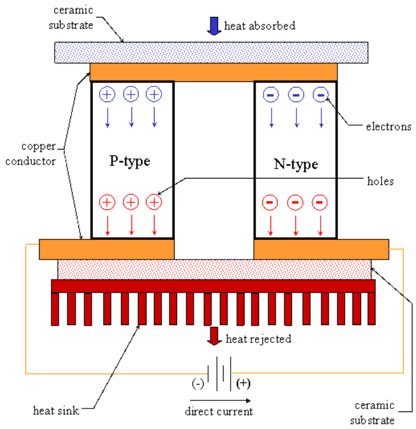


**Figure 17: Thermoelectric Cooling using Peltier Effect**

As shown in figure 18, the Peltier element on its own is a small piece of device measuring 40mm x 40mm (L x H). However, when mounted with the heat sink, fan and a DC power supply, the whole Peltier Cooler becomes bulky as shown in figure 19.

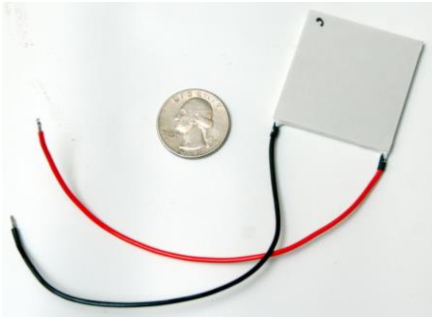

**Figure 18: Peltier Element**

**Figure 19: Peltier Cooler**

**Double Roof**

Heat transfer is the exchange of thermal energy between physical systems and it always occur from a region of high temperature to another region of lower temperature. There are four fundamental modes of heat transfer namely advection, conduction, convection and radiation. In this section, the method of conduction will be discussed.

Conduction is the transfer of energy between objects that are in physical contact and it is the most significant means of heat transfer between objects in thermal contacts. Gases including air have low thermal conductivities and so the atmosphere is a poor conductor of heat.[13] As shown in figure 20, the double roof design is a passive cooling technique that makes use of the above mentioned method to minimise the heat being transferred into the home. The transfer of heat from the sun through the first layer of roof is through conduction. As air is a poor conductor of heat, the amount of heat being transferred into the home has reduced significantly. The gap between the first and second layer of roofs also means that cool air could mix in with the hot air thus further reducing the overall heat.

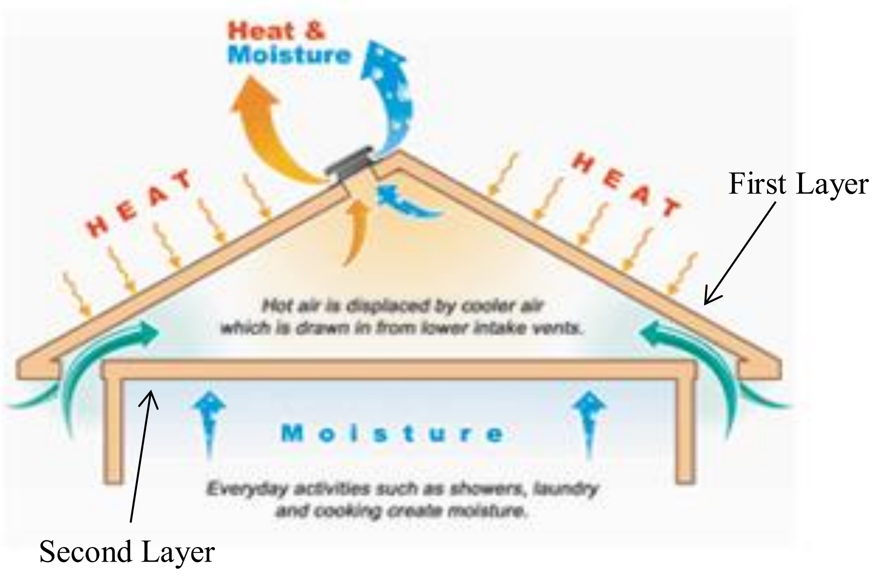


**Figure 20: Double Roof Design**

Considering the two cooling techniques, the double roof design has been chosen because it is easy to implement, no additional cost and no maintenance is required.

# Chapter 4

# Manufacturing & Application

## 4.1 Initial Design

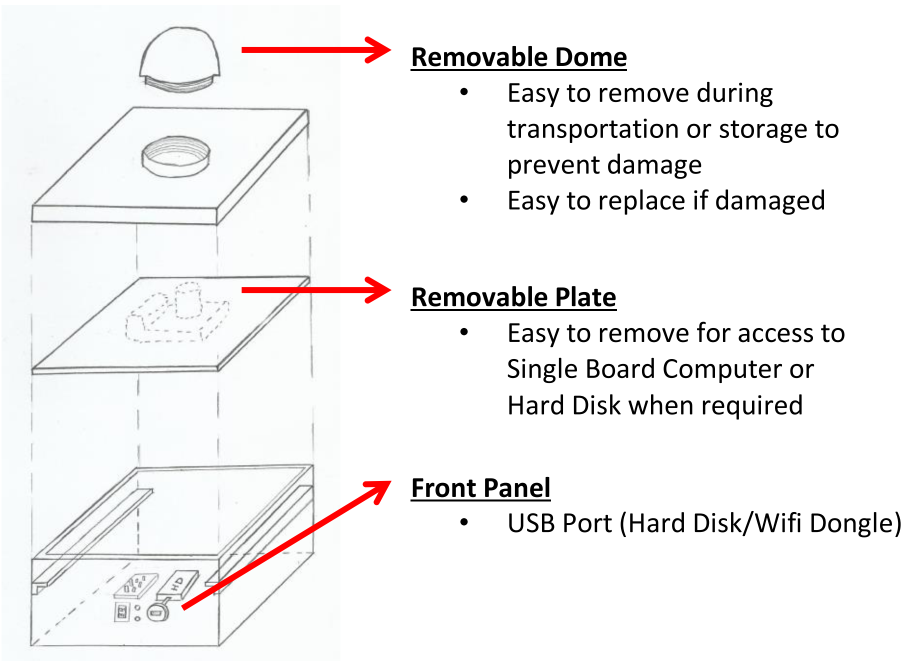


**Figure 21: Initial Design**

Figure 21 shows the initial design on the new WSI. The motivation behind the initial design is as follow:

- Two Level Storage – With the two level storage, components can be stacked above one another resulting in a smaller and compact WSI.
- Smaller and Compact – For better mobility as the WSI will eventually be deployed on sites other than the rooftop of S2.1.
- Simplicity – The design is kept simple for easy production and to keep the manufacturing cost low.

## 4.2 Final Design

**Enclosure**

As discussed in Section 3.2, there were many factors taken into consideration when deciding on the final design of the new WSI.

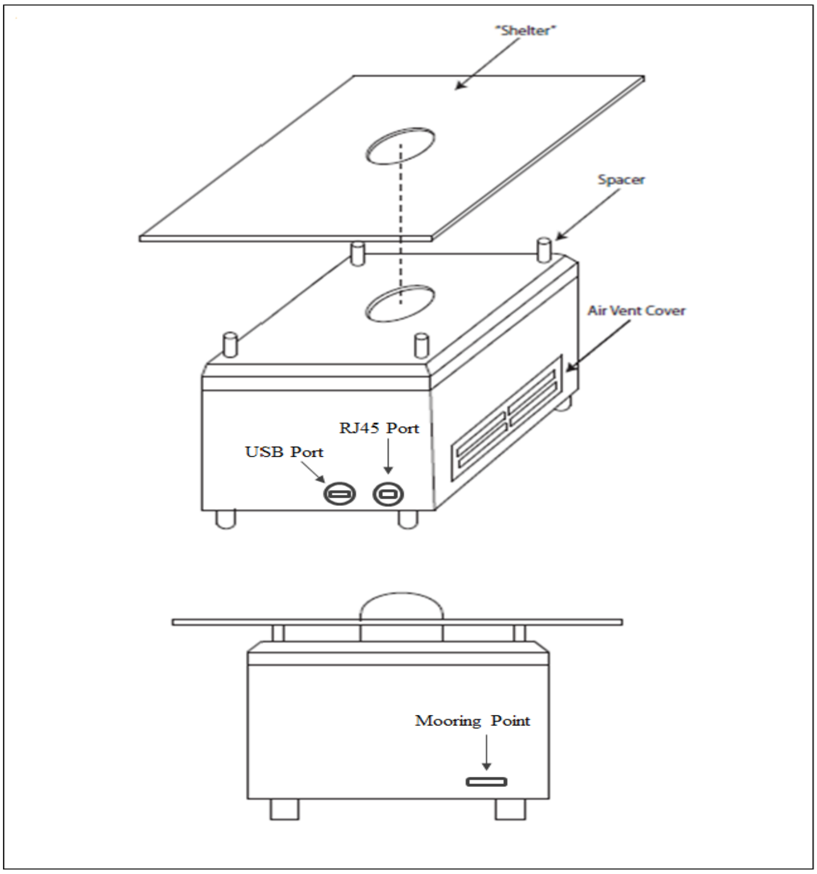


**Figure 22: Final Design**

Figure 22 shows the final design of the new WSI. The motivation behind the final design is as of follow:

- Shelter – The shelter is used as the first layer of "roof" for the WSI as part of the double roof design.
- Spacer – The spacer is used to create an air gap between the shelter and the enclosure.
- Air Vent Cover – For ventilation purposes and the cover have grills which prevents water from entering the enclosure.

- Mooring Point – The WSI will be deployed on sites outside of the university, the mooring point is provided for security purposes.
- USB Port – The USB port is IP54 certified which means it is dust protected and able to withstand splashing of water. It provides a means of easy access to the hard disk and for plugging the Wi-Fi dongle on the exterior as the material of the enclosure is metal.
- RJ45 Port – The RJ45 port is IP67 certified which means it is dust tight and can be immersed up to 1m of water. The port allows the plugging in of Wi-Fi dongle on the exterior of the enclosure where it is not possible to do so on the inside due to the material of the enclosure.
- Handles – For easy carriage.

The interior of the enclosure has the same design as the initial drawing. The new WSI design does not include the sun blocker because it is understood that the sensor onboard the camera is covered by the shutter until it opens to take a photo. Therefore, even without the sun blocker, the sensor does not get burned as it will not be constantly being exposed to the sun for prolong period.

**Glass Dome**

The glass dome was fabricated by a India based manufacturer using the hand blown technique.

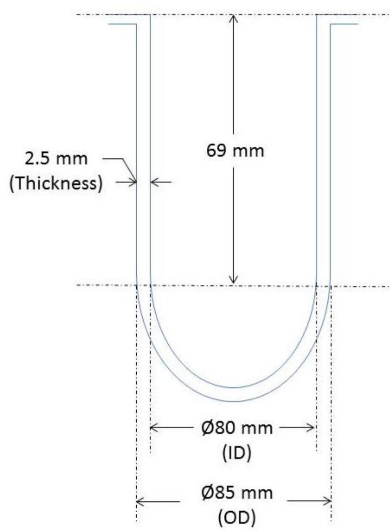


**Figure 23: Schematic Drawing of Glass Dome**

# 4.3 Manufacturing Process

The enclosure made of galvanised steel was bought off the shelf thus reducing a great amount of manufacturing time. However, modifications have to be made as the enclosure was made to be an accessories storage box as shown in figure 24.

**Figure 24: Original Enclosure**

### 4.3.1 Phase I

The manufacturing process was broken into two phases. Phase one is the general modification which includes the installation of handles, mooring point, air vent covers, cutting of spacers and shelter.

**Figure 25: Installation of Handles and Mooring Point**

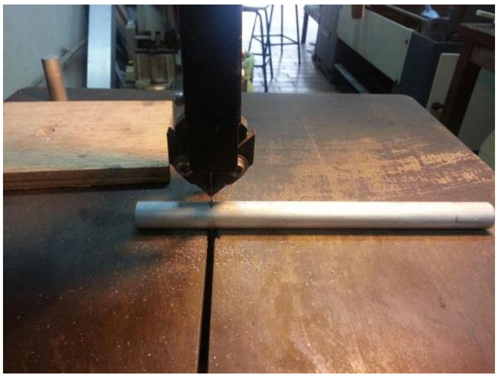

**Figure 26: Cutting of Spacer**

**Figure 27: Completion of Phase I**

### 4.3.2 Phase II

The phase two of the manufacturing process involved a more precise engineering work which includes the cutting of hole on the main cover and first layer of roof for the camera lens and installing the rack on the inside of the enclosure. Precision in cutting the hole on the main cover for the camera lens is very important so that the dimension of the hole is large enough just to fit the camera lens. This is because the small gap of 2 mm between the hole and the camera lens will limit the amount of sun light from entering the enclosure as shown in figure 28. As shown in figure 29, the milling machine was used because of the precision involved.

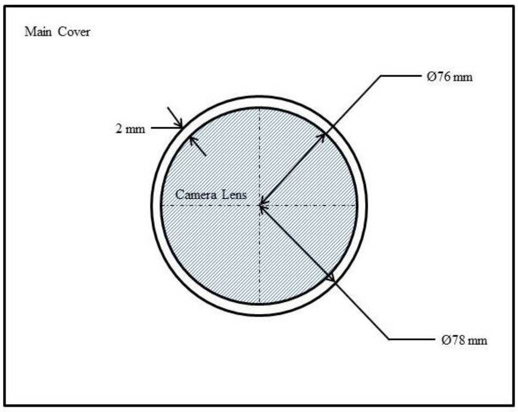




**Figure 28: Dimension of Hole on Main Cover for Camera Lens**

**Figure 29: Cutting of Hole with Milling Machine**

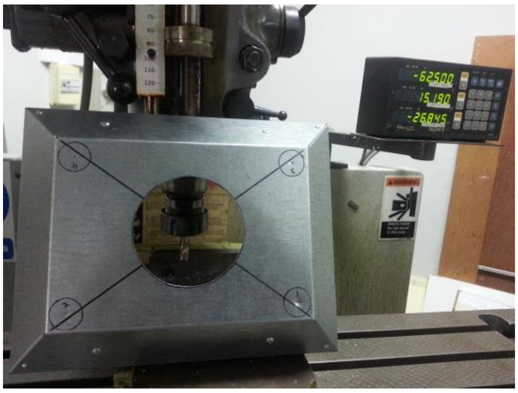

**Figure 30: Completion of Cutting**

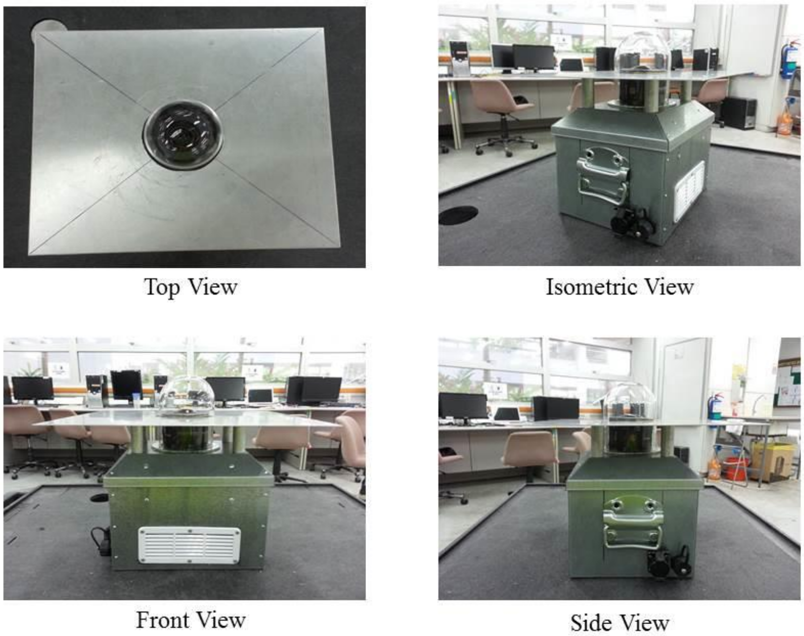


**Figure 31: Completion of New WSI**

Figure 31 shows the completion of the manufacturing process for the new WSI. After the completion, the next step is to measure the internal temperature and relative humidity of the new WSI.

## 4.4 Cost of Manufacturing

| S/N | Items | Qty | Price |
|---|---|---|---|
| 1 | Galvanised Steel Box | 1 | $49.90 |
| 2 | Hardware Accessories | NA | $24.50 |
| 3 | Mini Air Vent Cover | 2 | $15.82 |
| 4 | USB Port | 1 | $39.84 |
| 5 | RJ45 Port with Cover | 1 | $21.73 |
| 6 | Glass Dome | 1 | $140 |
| | | **Total** | **$291.79** |

**Table 3: Total Cost of Manufacturing**

# Chapter 5
# Component Specification

## 5.1 Single Board Computer

In the previous versions of WSI, a Raspberry Pi was used as the single board computer for the control of the camera and the sun blocker. The Raspberry Pi was chosen because of its low price and there is a large community using the Raspberry Pi for various projects. Having a large community using the same single board computer is important as there are many technical forums on the internet. However, the Raspberry Pi specifications are not good enough for a new image processing algorithm to be computed onboard the computer. Therefore, a better performing single board computer is required.

Three important factors have to be taken into consideration when looking for the new single board computer and they are good performance, reasonable price and support from other users. Based on the three factors, the Odroid-U3 has been chosen as replacement for the Raspberry Pi. Below table shows the comparison between the Raspberry Pi B+ and the Odroid-U3.

| **Type** | **Raspberry Pi B+** | **Odroid-U3** |
|---|---|---|
| Price (USD) | 39.95 | 65 |
| Size (mm) | 85 x 56 | 83 x 48 |
| **Specifications** | | |
| Cores | 1 | 4 |
| Frequency (MHz) | 700 | 1700 |
| RAM (MB) | 512 | 2048 |
| On-Board Storage | | |
| **Interface** | | |
| USB 2.0 | 2 | 3 |
| Ethernet 10/100 Mbps | Yes | Yes |
| I2C | Yes | Yes |
| IO Pins | 26 | 12 |

**Table 4: Comparison of Raspberry Pi B+ and Odroid-U3**

# Chapter 6
# Evaluation of New WSI

The new WSI would be commissioned as WAHRSIS IV or also known as WSI 4.

## 6.1 Operation in Harsh Environment

### 6.1.1 Temperature and Relative Humidity

As mentioned in Section 3.2, one of the major problems faced by WAHRSIS II is overheating. Therefore, it is important put WSI 4 to test under the harsh weather condition to ensure that the problem of overheating does not surface. As shown in figure 32, two improved version of sensors were borrowed from the same FYP student. With the improved version, there is a continuity of data recorded.

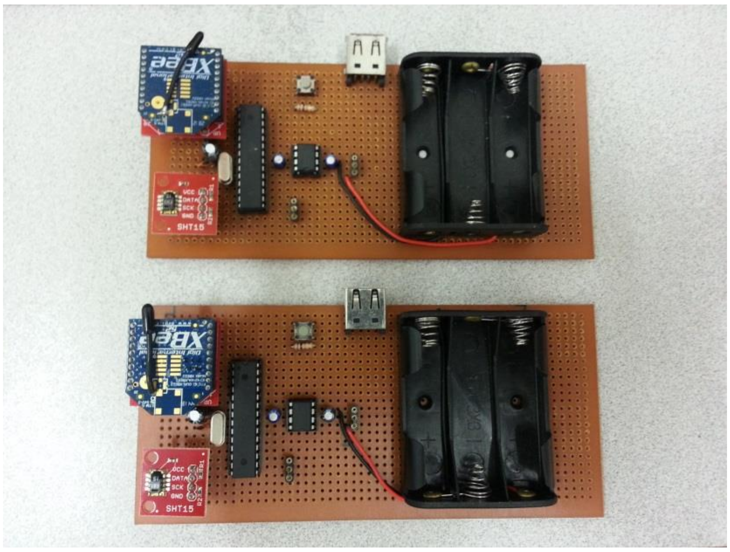

**Figure 32: Improved Version of Sensors**

The following experiment shown in figure 33 was set up at the rooftop of S2.1 on the 20 March 2015 to measure the internal temperature and relative humidity of the WAHRSIS II and WSI 4 for the period of 20 March 2015 to 23 March 2015.


**Figure 33: Experiment Setup**

The experiment was ended on the 23 March 2015 after collecting a continuous 48 hours of data. The data collected was compared with the measurements taken by the Weather Station 3 (as shown in figure 34) located about 5 meters above the rooftop of S2.1.


**Figure 34: Weather Station 3**

As shown in the following figures, WSI 4 records a much lower internal temperature than WAHRSIS II which has Peltier Cooler in operation during the period of test. This results have shown that the ventilated enclosure and double roof design is sufficient to cool the enclosure without the need of a Peltier Cooler. On top of the ventilation and double roof design, the amount of sunlight entering the enclosure is limited by the small gap between the hole on the main cover and the camera lens thus further reducing the internal temperature.

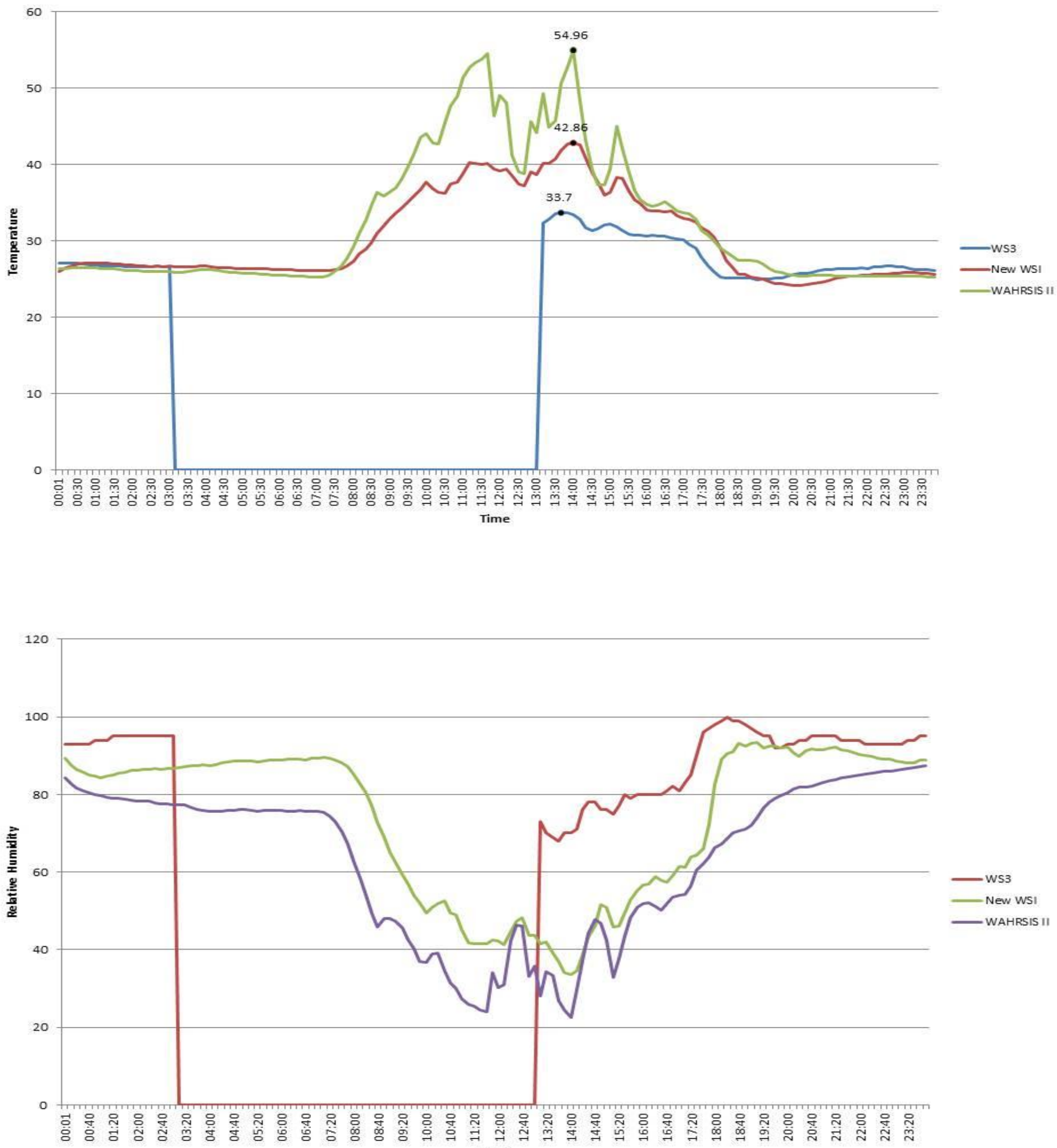


**Figure 35: Data Recorded on 21 March 2015**

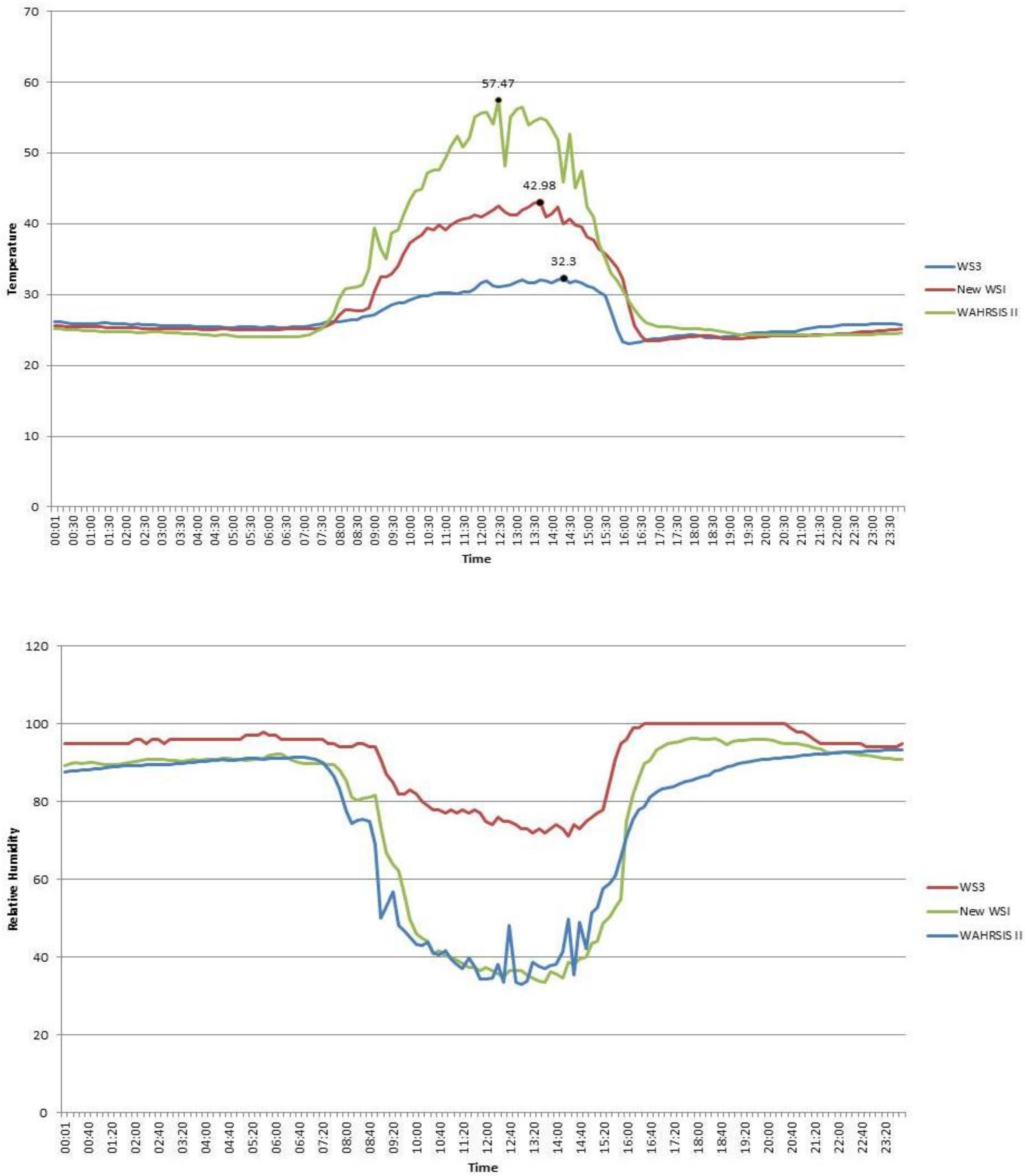


**Figure 36: Data Recorded for 22 March 2015**

As mentioned earlier in Section 3.2.1, the main problem with ventilated enclosure is the high relative humidity which may cause condensation to form should the level reaches 100%. However, it was also mentioned that the occurrence of 100% relative humidity is very remote. On the 21 March and 22 March 2015, there was heavy downpour in the late afternoon on both days. Although the weather station recorded relative humidity of 100% during this period of time, the relative humidity of WSI 4 has never reach 100%.

Another experiment was set up to measure the internal temperature and relative humidity of WAHRSIS I, WAHRSIS III and WAHRSIS IV. WAHRSIS III was designed by an intern student from Switzerland. The WAHRSIS III also known as WSI 3 uses the Peltier Cooler as its cooling technique. The Peltier Cooler is programmed to switch on if the measured reading sensed by the onboard sensor is out of the pre-determined threshold. To ensure consistency, a comparison test between the onboard sensor and the sensor used in previous experiment was carried out. The sensor was placed together with the onboard sensor in WSI 3. As shown in figure 37, the two sensors give about the same reading with a difference of average 0.9°C which is acceptable.

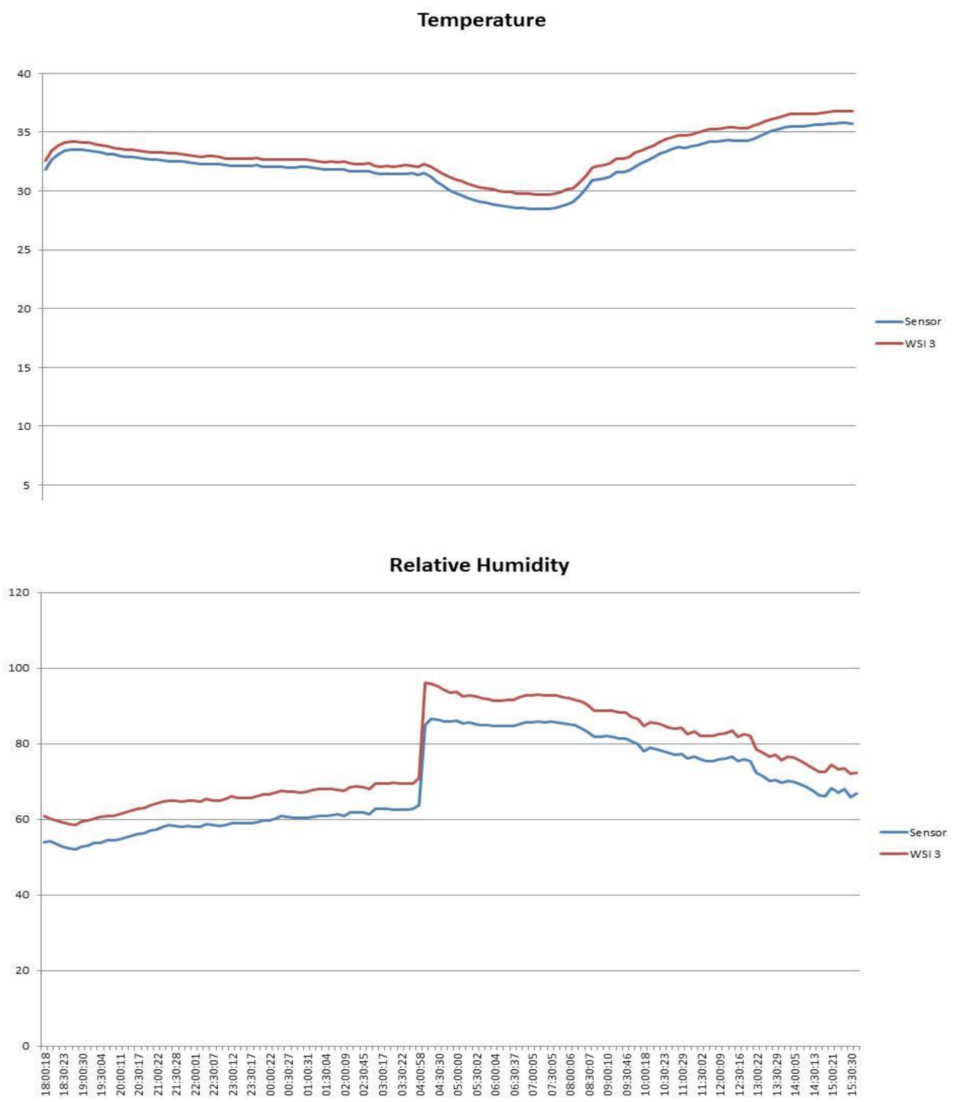




**Figure 37: Comparison Test**

The experiment was carried out from 28 March to 29 March 2015 and the setup is as shown in figure 38.


**Figure 38: Experiment Setup**

As shown in the following figures, WSI 3 and WSI 4 record a much lower internal temperature as compared to WSI 1. Both the design of WSI 3 and WSI 4 are able to maintain the internal temperature within the operating temperature of a camera. However, as shown in the figures, the onboard sensor of WSI 3 gives erroneous reading (above 100%) for the measured relative humidity. Such errors could happen to the measured temperature as well. As mentioned earlier, the operation of the Peltier Cooler is based on the readings given by the onboard sensor. If the onboard sensor did not work as intended, there is a possibility that the Peltier Cooler will not be switched on when required to. The double roof design is not dependent on other system; therefore it has a better reliability compared to the Peltier Cooler.

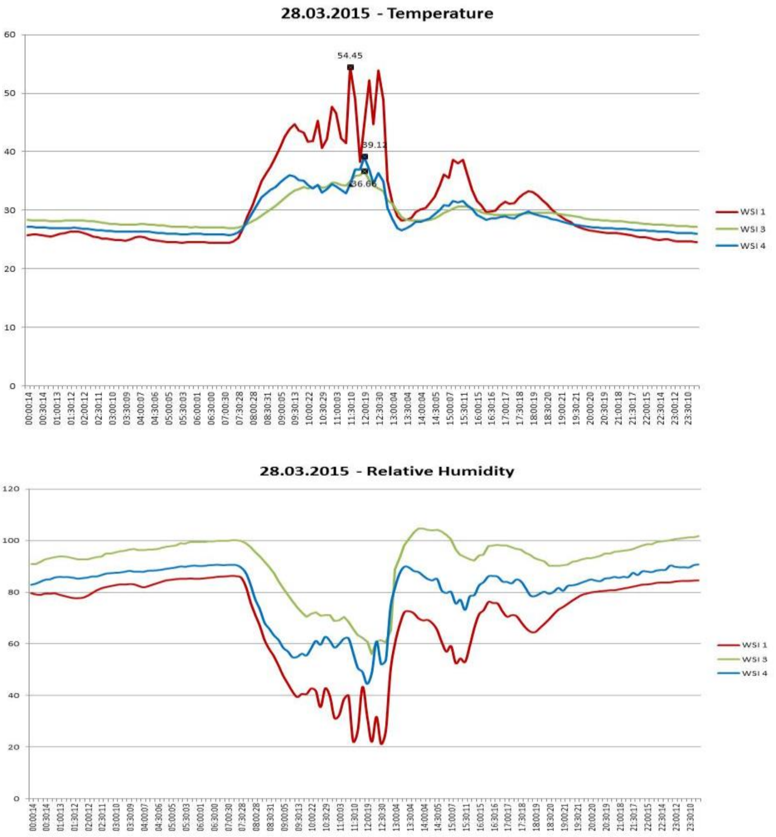


**Figure 39: Data Recorded for 28 March 2015**

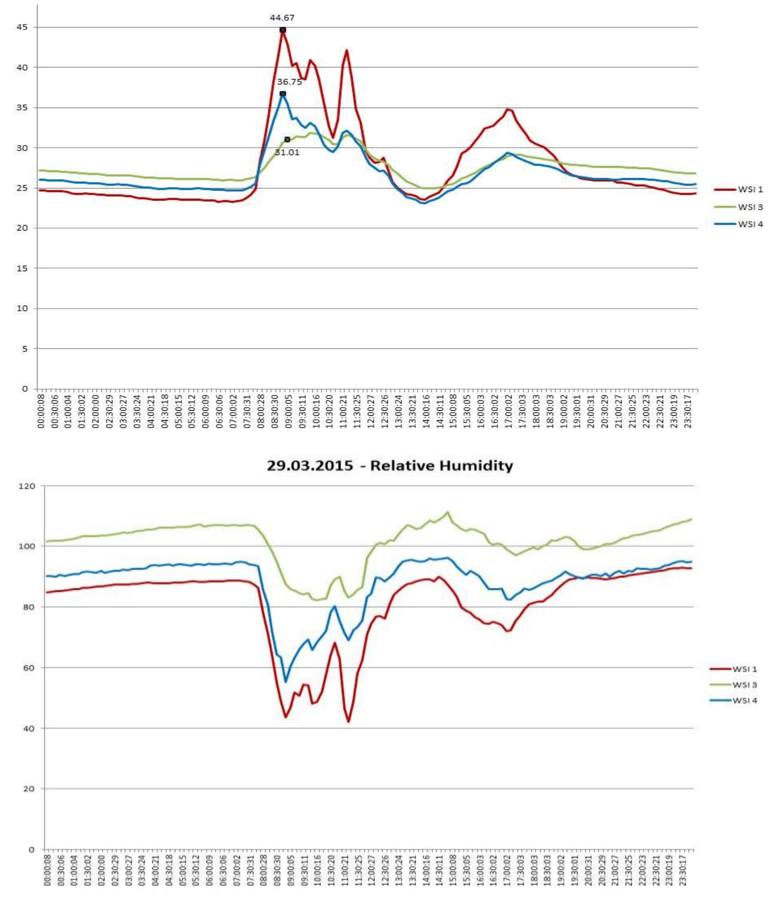


**Figure 40: Data Recorded for 29 March 2015**

To study the effectiveness of the double roof design, the first layer of roof was removed for a period of 30 minutes. As shown in figure 41, the internal temperature of WSI 4 increased by 5°C when the first layer of roof was removed. Subsequently, the roof was replaced back and the temperature decreased thereafter.

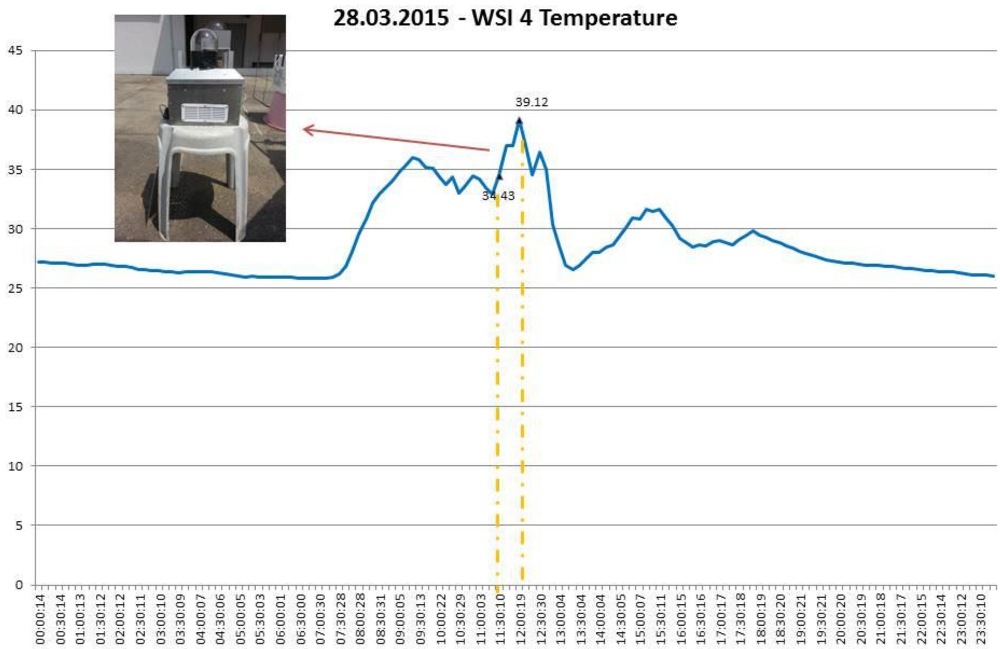


**Figure 41: First Layer of Roof Removed**

### 6.1.2 Withstanding Harsh Weather Condition

Weatherproof is the main problem faced by WAHRSIS I. With the heavy downpour and windy condition over the period of experiments, WSI 4 has proven to be able to withstand such condition as shown in the following figures.

**Figure 42: State of Setup**

**Figure 43: Interior of WSI 4 Remaining Dry**

Figure 42 shows that WSI 4 is able to withstand the windy condition without toppling over and figure 43 shows that despite the heavy downpour, the interior of WSI 4 remains dry without water getting in through the air vent covers.

Through the experiments, it can be concluded that the design of WSI 4 is successful in overcoming the problems faced by the previous versions of WSI. The differences in size are also clearly shown in figure 38 where WSI 4 is a lot smaller compared to WAHRSIS I and WAHRSIS II. This large reduction in size gives WSI 4 the mobility and flexibility to be deployed on any sites.

# Chapter 7
# Other Works

While the work on the new WSI is underway, continual operation of WAHRSIS I and WAHRSIS II is still required for cloud monitoring. However, some modifications have to be made to both WAHRSIS I and WAHRSIS II so that it can continue to operate under rain and hot weather condition.

## 7.1 WAHRSIS I

To shut down the Raspberry Pi on WAHRSIS I, the operator has to do it through the Terminal Emulator. For the convenience of the operator, a Pi Supply Switch Kit (as shown in figure 44) that is available off the shelf was put together and programming was done. With the supply switch, the operator can shut down the Raspberry Pi on WAHRSIS I itself without having the need to do it through the Terminator Emulator.

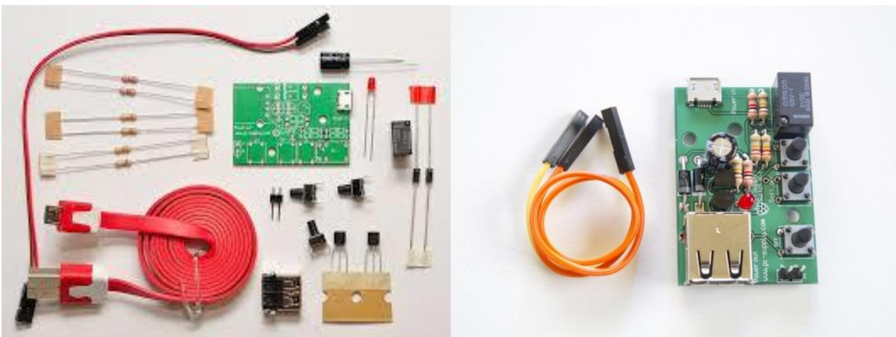

**Figure 44: Pi Supply Switch**

For WAHRSIS I to continue operation even under rain condition, weather seals were glued onto the door frame to prevent water from seeping in. The stepper motor was also wrapped with plastic wraps so that water will only remain on the surface on the plastic wrap without getting onto the stepper motor. As shown in figure 45, a IP67 RJ45 plug was also installed onto the WAHRSIS I so that the LAN cable can be connected to the Raspberry Pi without opening the door.

**Figure 45: Weather Seals and IP67 RJ45 Plug Installed on WAHRSIS I**

As shown in figure 46, the interior of WAHRSIS I remain dry even with the heavy downpour during the experiment conducted from 28 March to 29 March 2015.

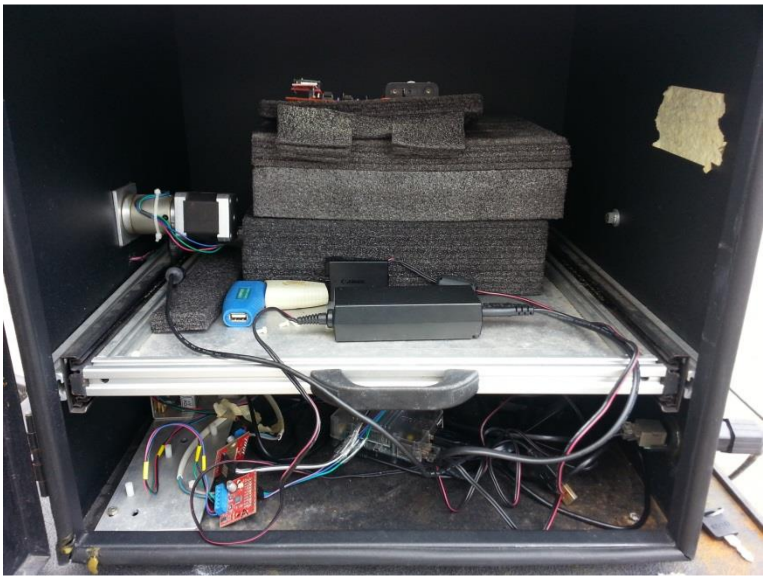

**Figure 46: Interior of WAHRSIS I Remaining Dry**

# 7.2 WAHRSIS II

A continuation to the previous FYP student's work, a Peltier Cooler has to be installed onto the WAHRSIS II to solve the problem of overheating due to the large enclosure space.

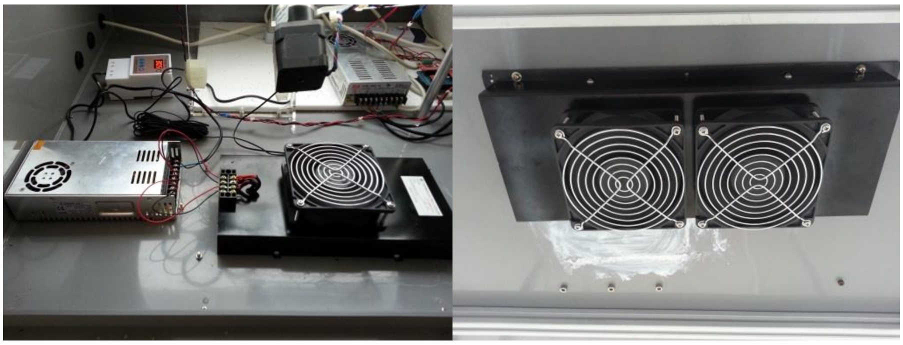

**Figure 47: Peltier Cooler Installed on WAHRSIS II**

# 7.3 WAHRSIS III

This WSI was not operational as there were some issues with the MOSFET switch that he designed to control the Peltier Cooler. The MOSFET switch circuit was unable to switch on the Peltier Cooler and the Odriod-U3 during testing. Troubleshooting on the MOSFET switch circuit was carried out and eventually found that the intern student has used the wrong resistor value. Other than the wrong resistor value, there was a short circuit connection found on the circuit. After some rectification, the MOSFET switch circuit is now able to switch on the Peltier Cooler.

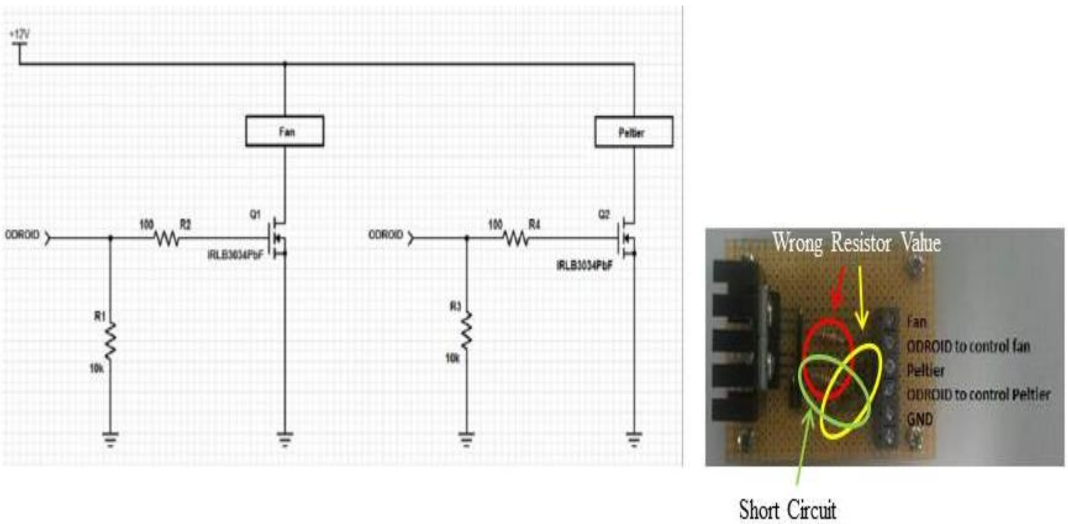


**Figure 48: MOSFET Switch Circuit**

# Chapter 8
# Conclusion and Future Work

## 8.1 Conclusion

The objective of a Whole Sky Imager (WSI) is for clouds monitoring to study how clouds can attenuate signals. This project focuses mainly on the process of building a new WSI. While a WSI is available commercially off the shelf, it is too expensive to procure one let alone procuring a few sets for the purpose of 3D reconstruction. Furthermore, building our own WSI allows us to customise the design and specifications according to our needs.

The first semester were focused on studying the design of the previous versions of WSI and exploring new ideas for the new WSI. Concurrently, modifications have to be made on the two WAHRSIS so that it can continue to operate for the time being. This process of modification gave me an insight of the WSI operating principle as well as pointers to note when designing the new WSI. Sourcing for components both locally and worldwide taught me to consider various factors when deciding which vendor makes the best offer. Special attention to specifications and details is crucial to avoid making the wrong purchase.

Most of the time spent in the second semester was on the manufacturing process of the new WSI. A lot of time was spent looking for materials outside of the university. Fortunately, most of the materials can be found in the university's workshop which helps to reduce the overall manufacturing cost significantly. I remembered a research engineer once told me that commercial projects are unlike school projects. It is not about beautifying it with the best components but to complete it at the lowest cost possible with the best optimal result. I am glad that I applied his teaching in my project by keeping it simple yet able to serve its intended function well.

Given the dynamics in the team, I really appreciated the fact that all of us work very well together, learning from one another and the willingness of the senior members to share their experience and knowledge with me. In general, Asians like me are afraid of failing which is the reason why we do not dare to explore new ideas. The assurance that I have from my team members that failure is part and parcel of the learning process has encouraged me to dare to think and explore new ideas. Overall, this has been a great learning journey for me and the memories forged with the team will always remain with me.

## 8.2 Future Work

Whilst every care has been taken to ensure that WSI 4 was developed to the best of my ability, there will still be rooms for improvement.

One major issue faced with the design of WSI 4 is the glass dome. As discussed in Section 3.2.3, the glass dome presents an important advantage of optical clearness as compared to a plastic dome but it is expensive to fabricate. I managed to find a manufacturer who could fabricate the glass dome at a lower price using hand blown technique. However, the quality of a hand blown glass dome is dependent on the skills of the glass blower. As shown in figure 49, a hand blown glass dome is almost impossible to achieve an even finishing at the curvature area which results in distortion in the image. This defeats the purpose of using a glass dome for its optical clearness.

**Figure 49: Distortion in Image**

An even finishing of the curvature area could only be achieved using machine blown technique. However, it is very expensive for the manufacturer to produce a mould for the dome and it would cost a few thousand dollars for a piece of machine blown glass dome. Another problem that was discussed in the earlier section is that the glass dome cracks easily. As shown in figure 50, the WAHRSIS III uses a glass dome and it cracked when it was placed on the rooftop of S2.1 overnight. It was postulated that the glass dome cracks because of the expansion in the day and contraction in the night.

**Figure 50: Cracked Dome on WAHRSIS III**

I found a China based manufacturer who fabricates plastic dome (as shown in figure 51) for CCTVs using injection moulding. The cost of a plastic dome is SGD 24.00 which is just 17% of the price of a hand blown glass dome. If a routine change of the plastic dome is carried out annually due to scratches or yellowing, it takes seven years to break even with the cost of a glass dome. These seven years does not include the possibility of the glass dome cracking prematurely. Therefore, in the long run, it is concluded that it makes more economical sense to use a plastic dome instead.

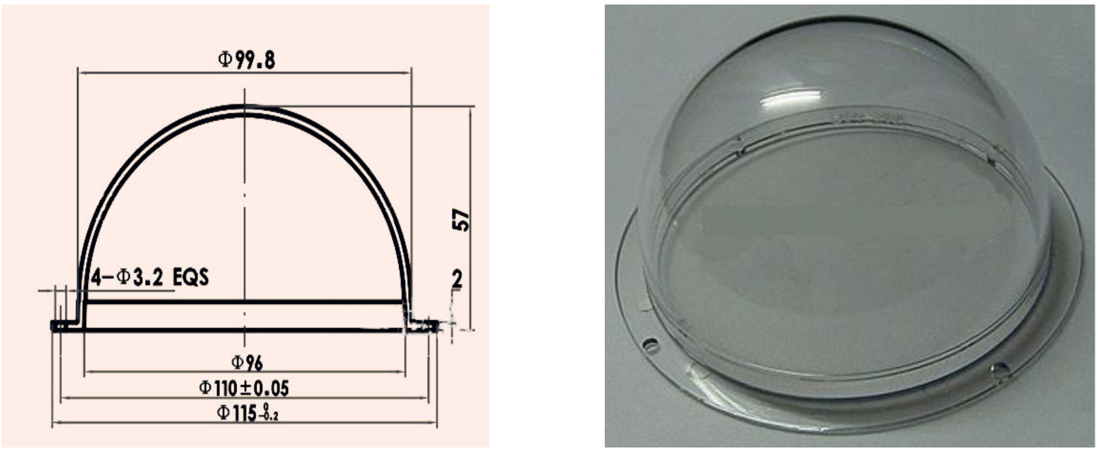


**Figure 51: Plastic Dome**

Another improvement that could be made is the power supply for the entire WSI. Currently, the WSI can only be deployed on sites where there is available power outlet to power the WSI. We could explore the idea of using the battery as a power source since the Single-Board Computer and the camera does not consume a lot of power. With the battery, the WSI will be able to deploy in any part of Singapore without the worrying about the availability of a power outlet.

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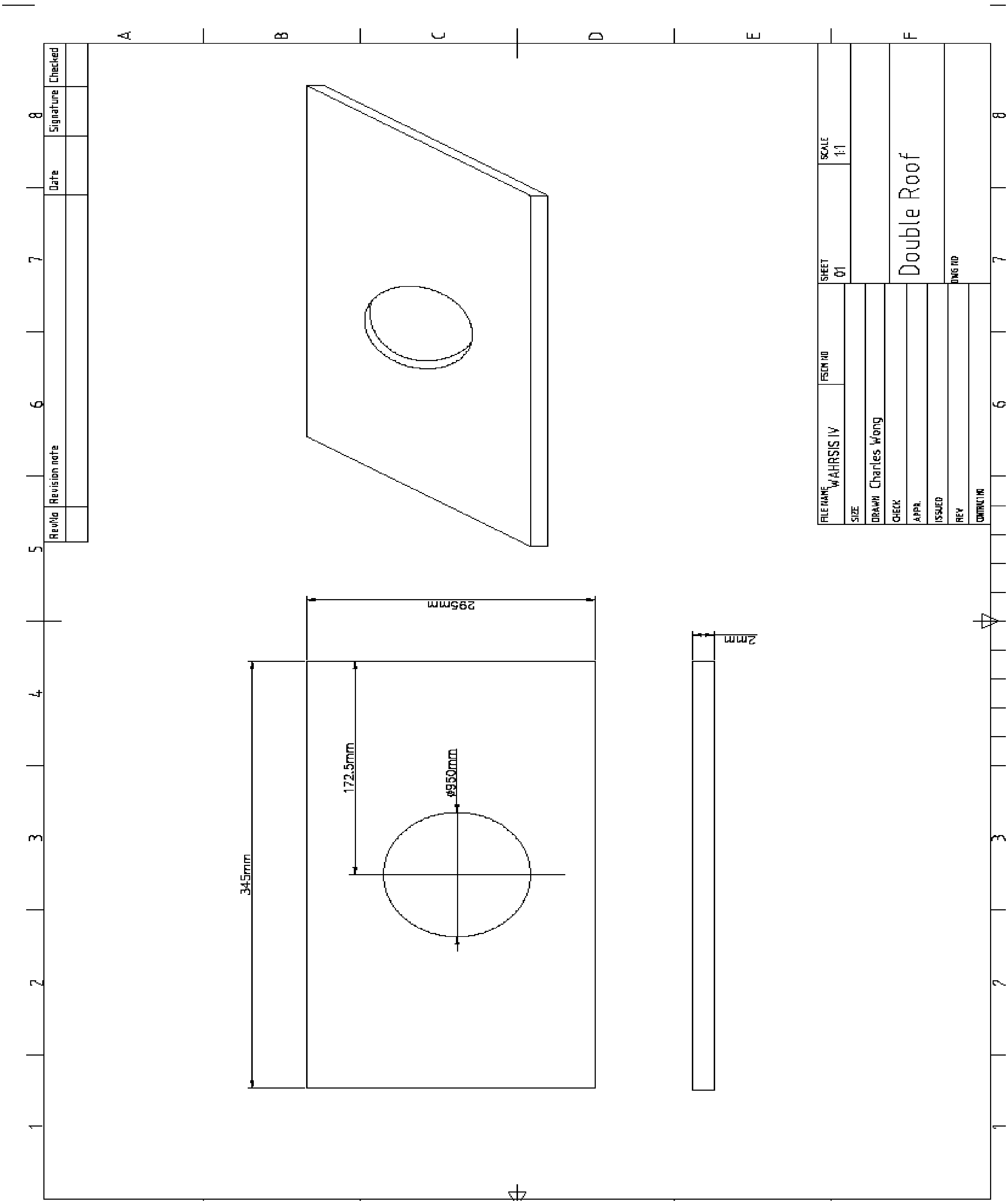
# Appendix A



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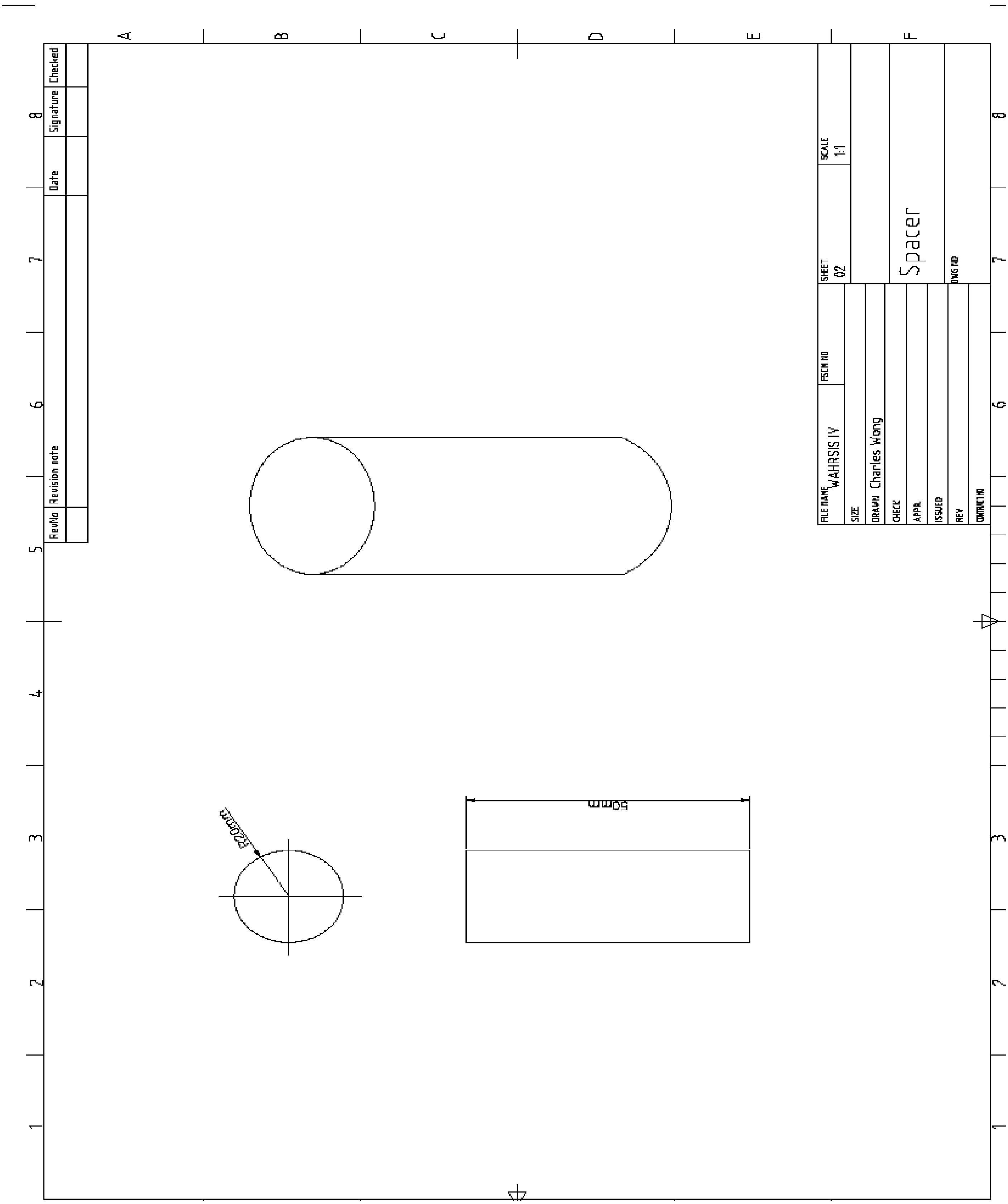

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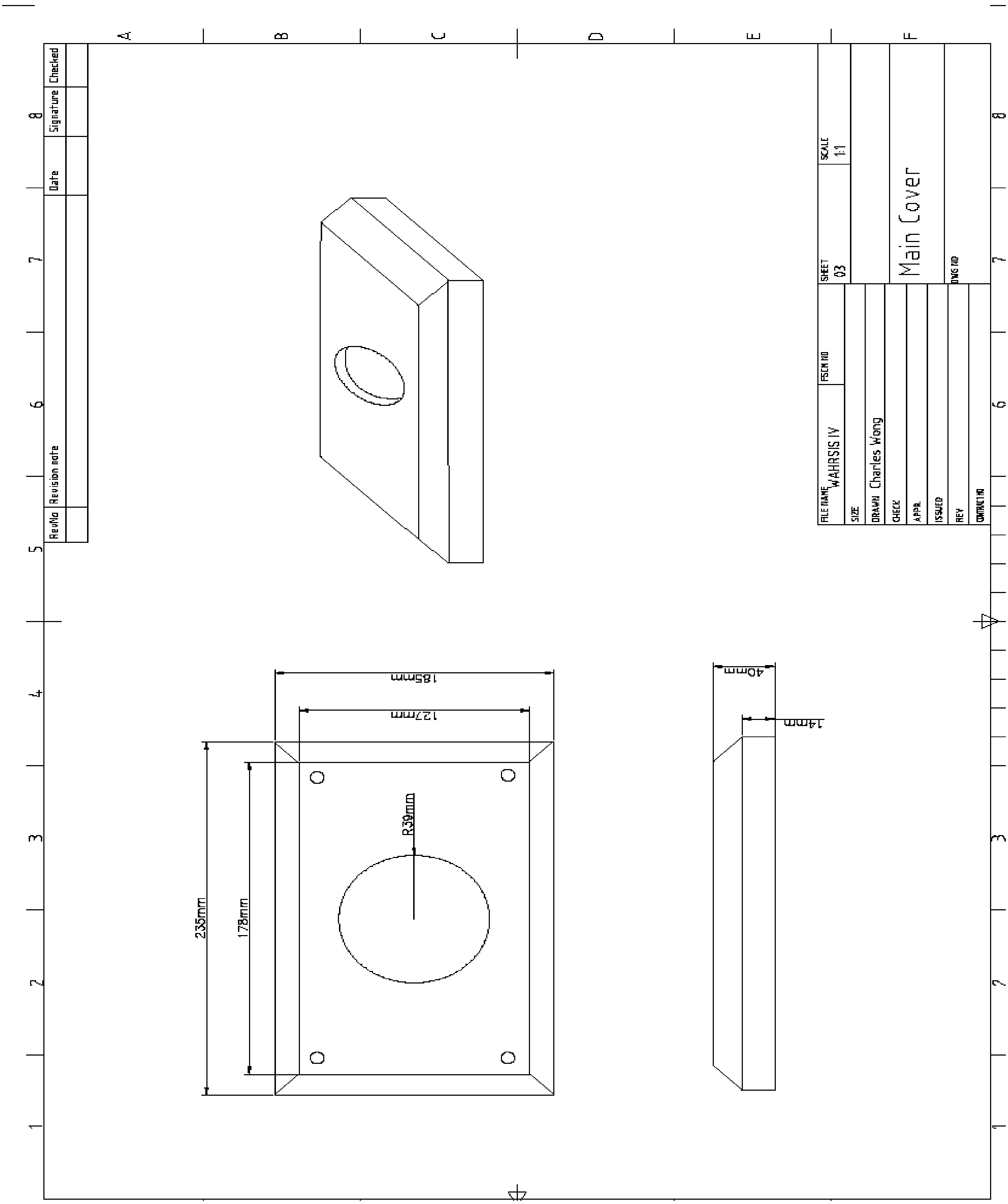
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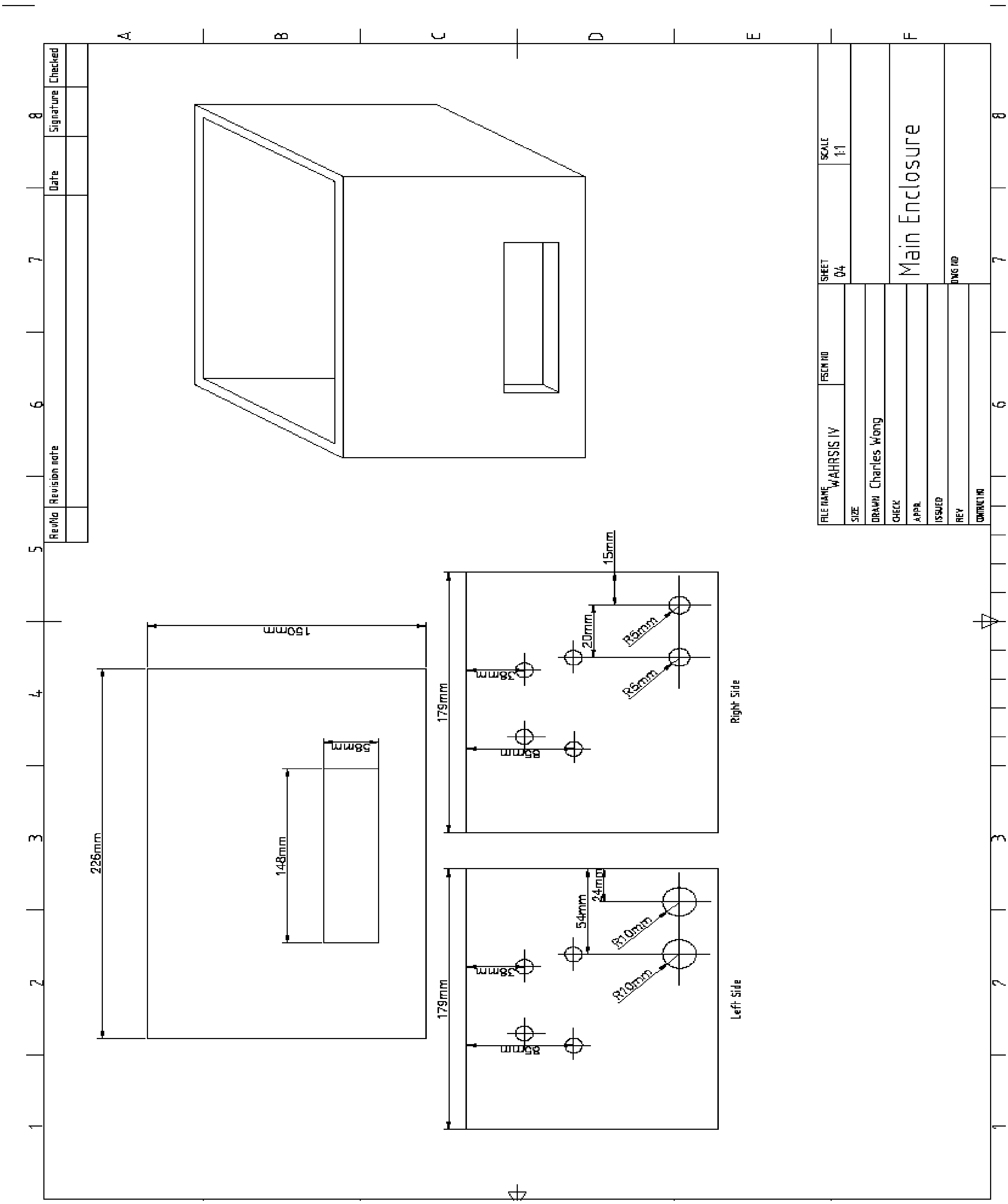
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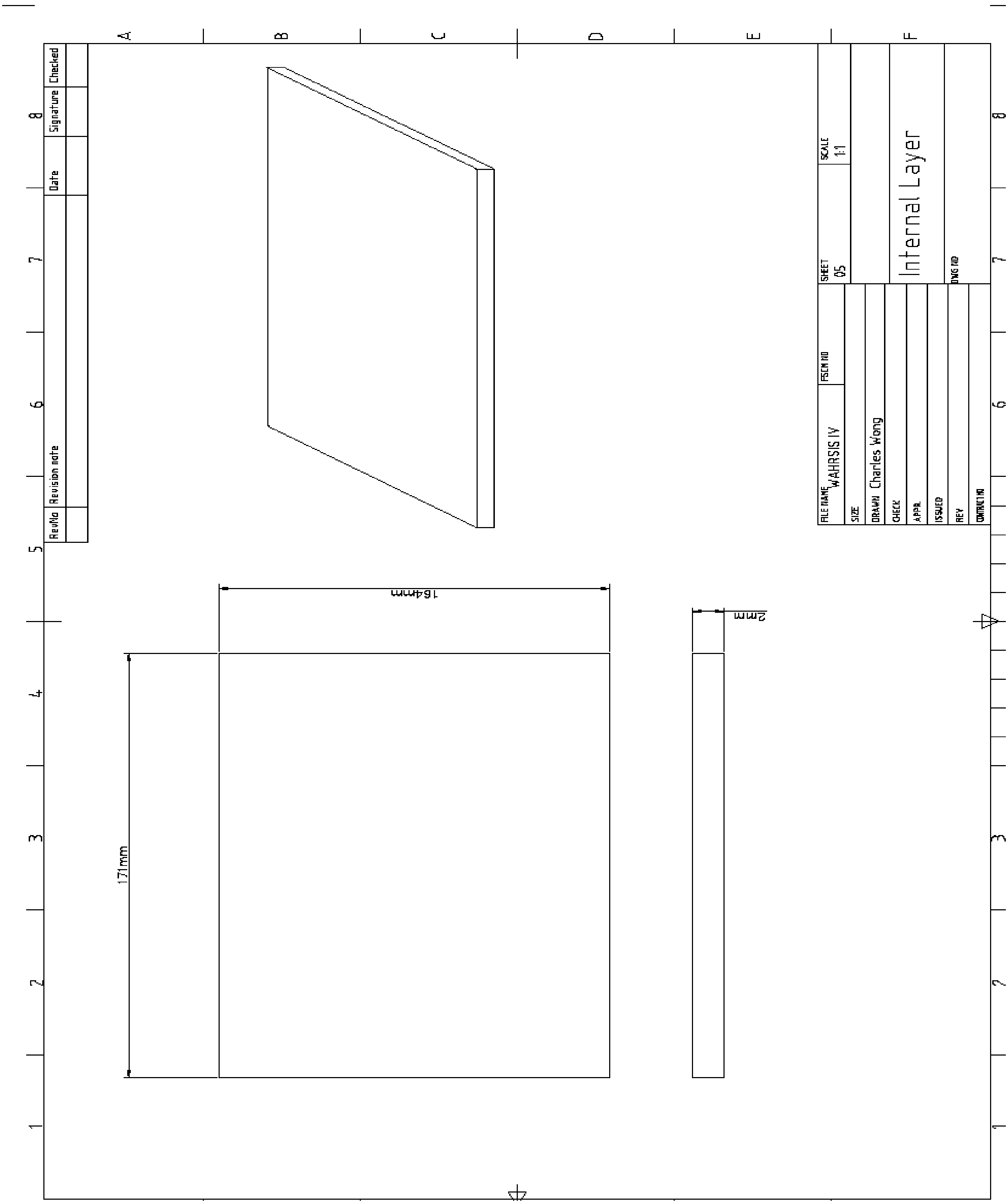
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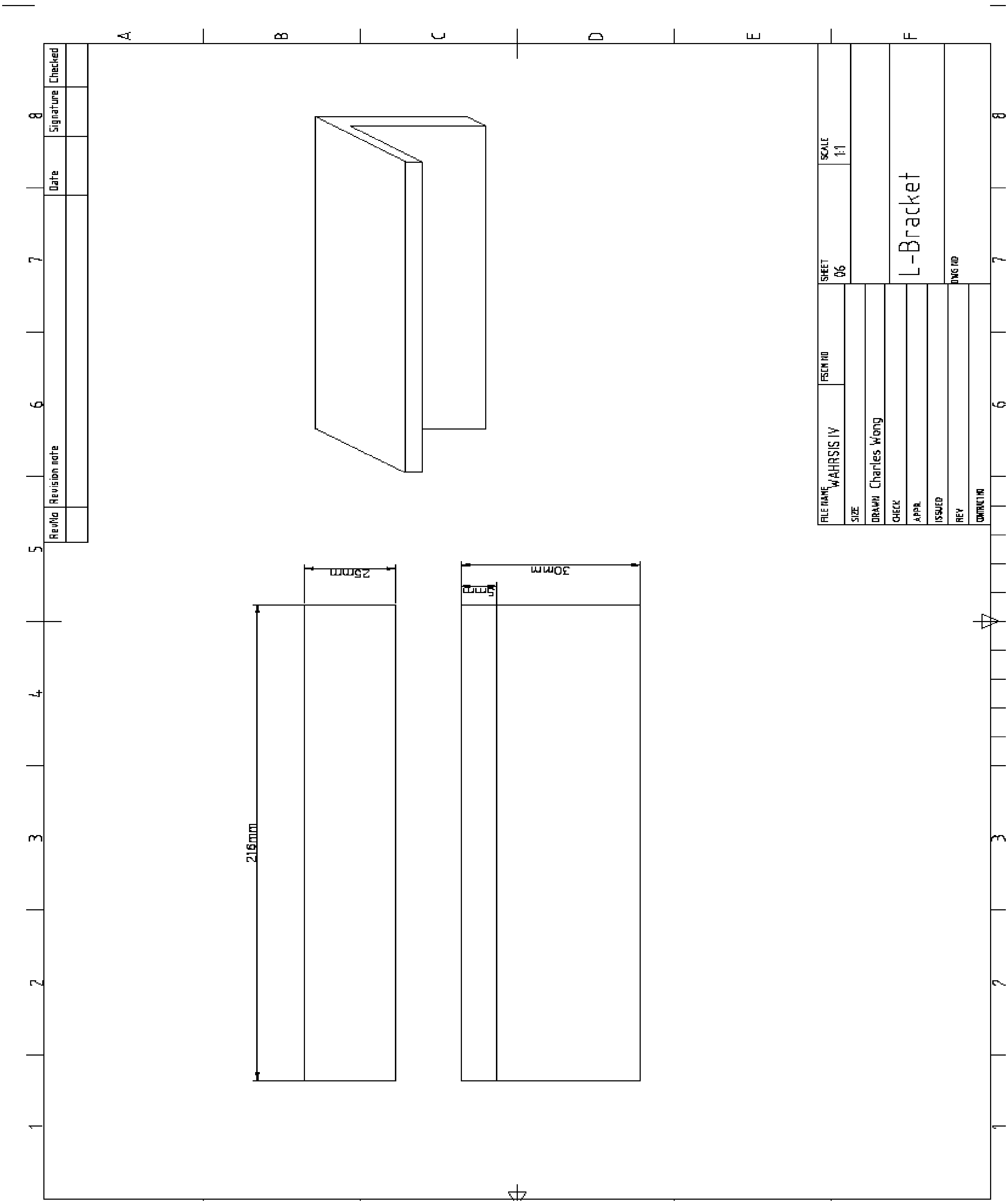
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# Appendix B

## FYP Schedule