HASP Student Payload Application for 2019

Payload Title: Sheffield University Nova Balloon Lifted Telescope	
Institution: The University of Sheffield	
Payload Class (Enter SMALL, or LARGE): Large	Submit Date: 14/12/2018

Project Abstract:
Space weather has recently been classified by the UK's Met Office as one of the highest priority natural hazards in the UK National Risk Register [1]. The USA's National Oceanic and Atmospheric Administration (NOAA) also has an entire department dedicated to space weather prediction (SWPC). As the functioning of human society and scientific research has become more dependent on satellites in space, understanding and predicting space weather has become increasingly important. There are many ground-based and satellite-based experiments dedicated to observing the Sun in multiple wavelengths and modalities, such as NASA's Solar Dynamics Observatory, however these are expensive to develop and maintain and therefore not accessible to most students and research institutions.

SunbYte III is the third iteration of the Sheffield University Nova Balloon Lifted Telescope. The previous versions were flown on BEXUS 25 in 2017, and on HASP in 2018. The general aim of the SunbYte project is to develop a low cost telescope system capable of being lifted by a weather balloon out of the thick, distorting atmosphere of the troposphere to take high quality full disk images of the Sun. The successful flights of the previous iterations have proven the robustness of the structural, Sun tracking, and ACDS systems, therefore SunbYte III aims to build on this and take high resolution images of the Sun in two wavelengths - the Hydrogen-alpha line (656.28 nm) and the near ultraviolet (UV) Calcium II K (CaK) line (393.4 nm). The ability to study these lines simultaneously will provide scientifically valuable data on the layered chromosphere structure of the Sun, and the ability to link the processes visible in each.

Team Name: SunbYte III		Team or Project Website: Sunbyte.group.shef.ac.uk
Student Leader Contact Information:		Faculty Advisor Contact Information:
Name:	Sagar Shah	Dr Viktor Fedun
Department:	Aerospace Engineering	Automatic Control System Engineering
Mailing Address:	Department of Automatic Control and Systems Engineering University of Sheffield	Department of Automatic Control and Systems Engineering University of Sheffield
City, State, Zip code:	Sheffield, S1 3JD	Sheffield, S1 3JD
e-mail:	svshah2@sheffield.ac.uk	v.fedun@sheffield.ac.uk
Office Telephone:	+447712154062	+44 114 2225197
Mobile Telephone:	+447712154062	+44 114 2225197

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Acronyms / Abbreviations

3D	Three Dimensional
ADC	Analogue to Digital Converter
ADCS	Attitude Determination and Control System
AU	Astronomical Unit
BEXUS	Balloon EXperiments for University Students
CAD	Computer Aided Design
CME	Coronal Mass Ejection
CMOS	Complementary metal–oxide–semiconductor
Cntl	Control
COMM	Communications
CRC	Cyclic Redundancy Check
CWL	Centre Wavelength
DAC	Digital-to-Analog Converter
DC	Direct Current
DOF	Degrees Of Freedom
EDAC	Error Detection And Correction
ERF	Energy Rejection Filter
FCS	Frame Check Sequence
FEA	Finite Element Analysis
FOV	Field Of View
FPS	Frames Per Second
FWHM	Full Width at Half Maximum
GB	Gigabyte
GND	Ground
GPS	Global Positioning System
GUI	Graphical User Interface
HASP	High Altitude Student Payload
HSV	Hue, Saturation, Value Color Space
IMU	Inertial Measurement Unit
I^2C	Inter-Integrated Circuit
keV	Kilo Electron Volt
LED	Light Emitting Diode
LEO	Low Earth Orbit

MCU	Microcontroller Unit
MeV	Mega Electron Volt
MPU	Microprocessor Unit
MS	Micro Stepping
NASA	National Aeronautics and Space Administration
NEMA	National Electrical Manufacturing Association
NOAA	National Oceanic and Atmospheric Administration
PCB	Printed Circuit Board
PE	Polyethylene
PWM	Pulse Width Modulation
RGB	Red, Green, Blue Color Space
RPi	Raspberry Pi
RST	Reset
Rx	Receiver
SCL	Serial Clock Line
SDA	Serial Data Line
DIR	Direction
SSD	Solid State Drive
STEM	Science, Technology, Engineering and Maths
SWPC	Space Weather Prediction Center
Teensy LC	Teensy Low-Cost
TLD	Thermoluminescent Dosimeter
Tx	Transmitter
UART	Universal Asynchronous Receiver-Transmitter
UK	United Kingdom
UML	Unified Modelling Language
URL	Uniform Resource Locator
USA	The United States of America
USB	Universal Serial Bus
UV	Ultra Violet
Vcc	Voltage common collector
VDC	Volts Direct Current
Vin	Voltage in
WDT	Watchdog Timer
YUV	Luminance and Color information color space

1 Introduction

1.1 Scientific / Technical Background

Space weather has the potential to seriously disrupt normal life on Earth. Solar flares and coronal mass ejections (CMEs) can send huge amounts (on average 1.6×10^{12} kg) [2] of charged particles and high energy photons towards Earth. Each different component of solar radiation can cause different problems, for instance charged particles can add energy to the atmosphere and cause it to increase in size, thereby increasing drag on satellites. According to the National Oceanic and Atmospheric Administration's Space Weather Prediction Centre (NOAA SWPC), during solar minimum satellites in LEO - defined as up to 2000 km - may only need to be boosted 3 or 4 times a year, whereas during the maximum point of the Sun's 11 year cycle satellites may need to be boosted every 2-3 weeks to maintain their orbit [3].

Charged particles can also disturb the sparse plasma in the ionosphere, which is essential to GPS and satellite communications systems, as it bends and reflects the radio frequency signals used to communicate between GPS satellites and devices on the ground. During a solar storm the accuracy of GPS information may decrease by a factor of 10 [4].

As well as producing beautiful arorae at the poles, charged particles moving through Earth's magnetic field can also induce electric currents in power grids. Normally these disturbances produce electric field differences on the order of volts/km however during severe solar storms the induced changes can overwhelm the grid and cause large scale blackouts, as was the case in Quebec, Canada in 1989 [5]. Solar storms can also increase the radiation dose delivered to astronauts and airline passengers in polar flights [6], as well as damage solar cells and electronic components onboard satellites and spacecraft [7].

By imaging the Sun in two wavelengths, Hydrogen-alpha (656.28 nm) and the near-UV Calcium II K line (CaK) (393.4 nm) simultaneously, SunbYte III will be able to view solar processes such as filaments/prominences, spicules, and solar flares at temperatures between 4400K and 6000K, and at different depths. The H-alpha line allows the viewing of layers 1250 - 1700 km above the photosphere, whereas the CaK filtered image will show a region 600 - 1500 km above the photosphere. The temperature of the chromosphere increases with height above the photosphere, therefore the CaK filtered images will show a slightly cooler layer [8].

Solar filaments and prominences (filaments at the outer limbs of the Sun viewed against the blackness of space behind it) are clouds of plasma that follow the magnetic field lines of the Sun. By imaging these features, the magnetic field lines of the Sun may be observed. Both wavelengths allow the viewer to look into the chromosphere, the layer just above the bright photosphere which radiates white light, and obscures many of the Sun's interesting surface features [9].

The main benefit of taking astronomical images from high altitudes is the reduction of atmospheric extinction and turbulence ('seeing'). Extinction occurs when dust molecules in the atmosphere scatter and absorb light, causing a dimming and reddening effect when viewing objects in space, due to the shorter wavelength and blue light being absorbed more strongly. In addition, turbulence due to slight atmospheric temperature differences degrades the resolution of an image recorded by a telescope and blurs it, as the brightness and refractive index of the light coming from the observed object constantly varies - an effect known as scintillation. Both of these complications are mostly negated with space-based telescopes, due to the lack of a thick atmosphere between the celestial objects and telescopes themselves. Thus, the seeing and therefore image quality will be much improved when compared to small Earth-based solar telescopes and imaging systems. In the UK, the seeing is approximately 3 - 4 arcseconds, and can be further worsened by increased air humidity and warm air currents. It is hoped that the seeing from HASP's float altitude will be below 0.5 arcseconds, much closer to the telescope's resolution limit. In addition, Earth's atmosphere blocks almost 100% of the UV and near-UV range, therefore by lifting the telescopes out of the atmosphere, SunbYte shall be able to take clear images of the Sun's UV light [10].

Space-based and ground-based solar telescopes are expensive and can take many years to build and become operational. For example, NASA's Solar Dynamics Observatory mission cost $850 million to develop and launch [11].

Figure 1.1.a: Distortion due to Atmosphere

Ground-based telescopes must also compensate for the distorting effects of the atmosphere as seen in Figure 1.1.a using adaptive optics, which adds further cost and complexity. This kind of project is not financially feasible for smaller countries and research groups. SunbYte III will demonstrate that a small balloon lifted telescope system can produce simultaneous images of solar processes and features in two different wavelengths, and show scientific value.

1.2 Mission Statement

The purpose of the SunbYte projects is to develop a low cost solar imaging system that can be lifted by a high altitude balloon to take high quality images of the Sun. SunbYte III will build on the success of the previous two projects, namely the robust structure, Sun tracking systems, and take high resolution images of the Sun in the H-alpha and the CaK wavelengths, rather than continuum as with previous iterations. The ability to image these lines simultaneously will provide scientifically valuable data on the structure of different layers of the chromosphere of the Sun, and the ability to link the visible processes. SunbYte III will also carry small radiation dosimeters to quantify the amount of radiation received by high altitude balloon experiments, and the performance of the insulating materials used on SunbYte III.

Throughout the proposal SunbYte III will be compared to SunbYte II to demonstrate how the new system will improve upon previous versions of SunbYte.

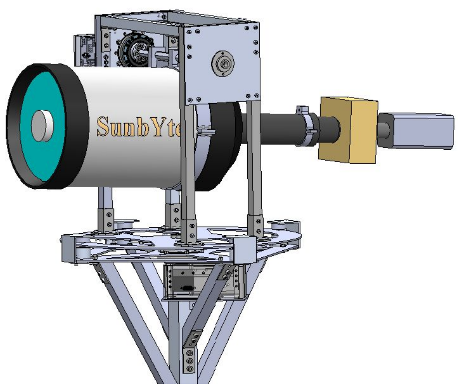


Figure 1.2.a: Sunbyte I

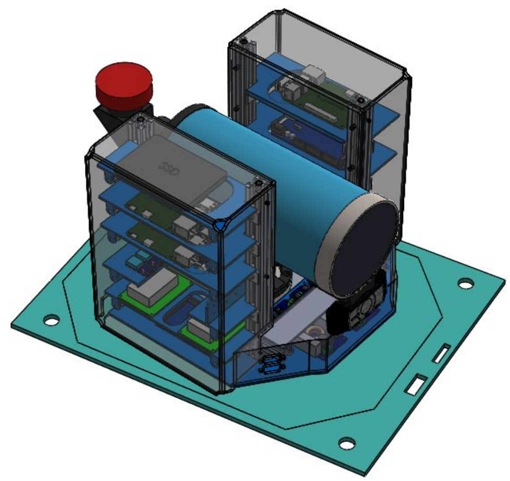


Figure 1.2.b: Sunbyte II

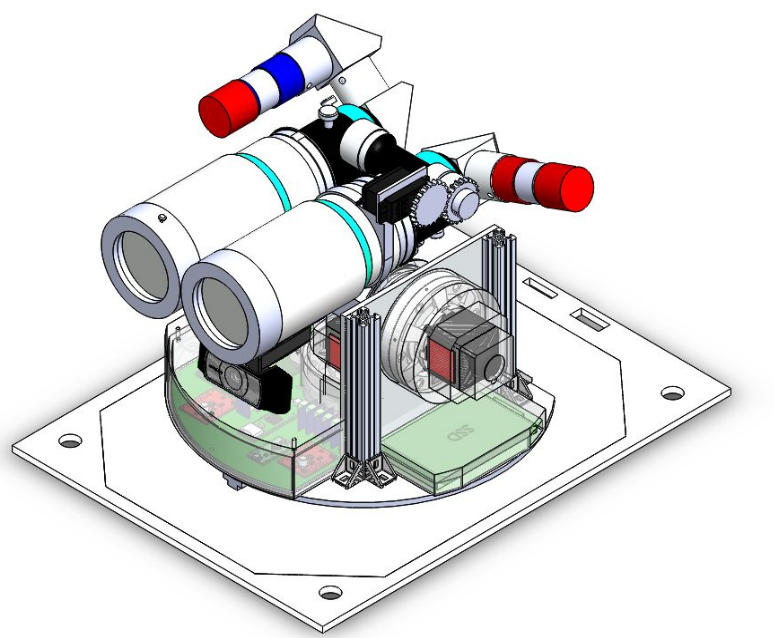


Figure 1.2.c Sunbyte III

1.3 Experiment Objectives

1. Capture in focussed images of the Sun through the telescope
2. Capture images in two different wavelengths, CaK and H-alpha
3. Promote and increase space engineering studies in courses across the country
4. Measure the radiation dose received by the structure, and the efficacy of the insulation

1.4 Team Details

1.4.1 External Support

Table 1.4.1.a: External Support

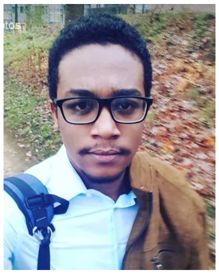
	**Dr. Viktor Fedun** Department of Automatic Control and Systems Engineering PhD University of Sheffield (UK) **Role:** Academic Lead **Responsibilities:** Scientific and organisational support for funding and outreach purposes. Engages internal stakeholders and other departments.
	**Dr. Gary Verth** Department of Automatic Control and Systems Engineering PhD University of Sheffield (UK) **Role:** Scientific and organisational support **Responsibilities:** Scientific and organisational support for funding and outreach purposes. Engages internal stakeholders and other departments
	**Dr. Istvan Bali** School of Mathematics and Statistics PhD University of Sheffield (UK) **Role:** Scientific and organisational support **Responsibilities:** Scientific and organisational support for funding and outreach purposes. Engages internal stakeholders and other departments

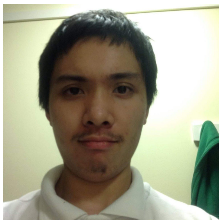
	**Yun-Hang Cho** Department of Civil Engineering,3rd Year PhD University of Sheffield (UK) **Role:** Mentor **Responsibilities:** Systems Engineering support and mentorship. Yun was leader of SunbYte I and lead the team to launch with the European Space Agency as part of REXUS/BEXUS program.

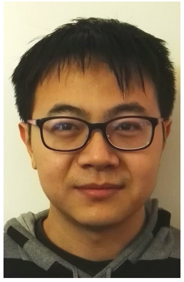
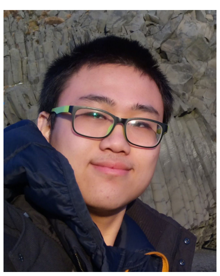
1.4.2 Team Members

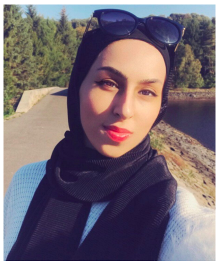
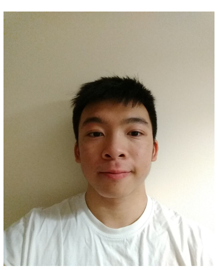
Table 1.4.2.a Team Members

	**Sagar Shah** 2nd Year Aerospace Engineering MEng University of Sheffield (UK) **Role:** Project Leader **Responsibilities:** Overall project management and coordination of all sub-teams, assisting in the structure team.
	**Joshua Brownlow** 4th Year Mechatronic & Robotic Engineering MEng University of Sheffield (UK) **Role:** Systems Integration, Electronics and Structure Engineer **Responsibilities:** System Integration, Electronics, Sensors, Motor Control and Structure Design
	**Roisin Clear** MSc(Eng) Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Optics & Focusing Subsystem Team Leader **Responsibilities:** Procurement and design of optical system, design and implementation of focusing system, image quality and storage.
	**Stefan Stoian** 3rd Year MEng Aerospace Engineering, Avionics systems University of Sheffield (UK) **Role:** Power and Actuation Subsystem Team Leader, Design & Structure **Responsibilities:** Oversee the design, testing and manufacture of the optimized electrical system. CAD Design (SolidWorks)

	**Wayel Abdelgaleel** MSc(Eng) Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Attitude Determination & Control Systems Subsystem Team Leader **Responsibilities:** Implement image processing algorithm to detect and track the Sun, design and implement motor control algorithm for attitude of the payload.
	**Emilie Brannan** BEng Aerospace Engineering University of Sheffield (UK) **Role:** Thermal System Team Leader **Responsibilities:** Designing an active and passive heating system.
	**Abdel Alomari** MEng Mechatronics and Robotics engineering University of sheffield (UK) **Role:** Communications Subsystem Team leader, System Integration, mechanical, electronic, and thermal engineer **Responsibilities:** Developing the algorithms for the communication with the ground station and the GUI associated. managing the integration between the teams.
	**Prathamesh Khatavkar** MSc(Eng) Automatic Control and Systems Engineering (with Industry) University of Sheffield (UK) **Role:** Design & Structure Co Team Leader, Optics & Focusing Subsystem **Responsibilities:** Materials selection and CAD Design using SolidWorks.
	**Daniel James Pickering** MEng Aerospace Engineering University of Sheffield (UK) **Role:** Design and Structure Co Team Leader and Thermal Systems Team Member **Responsibilities:** Creation of the base structure of the payload and the integration of heaters and insulation for thermal systems.

	**Jack Cheng Ding Han** MComp Computer Computer Science University of Sheffield (UK) **Role:** Optics & Focusing Subsystem Team **Responsibilities:** Produce software for the focusing subsystem.
	**Vaiva Zokaite** MEng Aerospace Engineering University of Sheffield (UK) **Role:** Optics & Focusing Subsystem Team **Responsibilities:** Optical and focusing system design and implementation
	**Gabriel Mason** MPhys Physics and Astrophysics University of Sheffield (UK) **Role:** Optics & Focusing Subsystem Team **Responsibilities:** Procurement and design of optical system, design and implementation of focusing system, image quality and storage, optical physics input.
	**Abdullah Alsulami** MSc(Eng) Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Electronics Engineer **Responsibilities:** Design of the electronic system and PCB design.
	**Jahid Ahmed** MSc Electronic and Electrical Engineering University of Sheffield (UK) **Role:** Power Electronics Team Member **Responsibilities:** Electronic System Design

	**Xia Chengping** MEng Mechatronics Engineering University of Sheffield (UK) **Role:** Electronics & Electrical Power Systems Team Member **Responsibilities:** Embedded software development using the Teensy LC and the Raspberry Pi v3.
	**Omar Mohamed** BEng Automatic Controls and Systems Engineering University of Sheffield (UK) **Role:** Attitude Determination & Control Systems Subsystem **Responsibilities:** Implement image processing algorithm to detect and track the Sun, design and implement motor control algorithm for attitude of the payload.
	**Khalid Tubeileh** BEng Automatic Controls and Systems Engineering, University of Sheffield (UK). **Role:** Attitude Determination & Control Systems Subsystem Team. **Responsibilities:** Image processing algorithm to detect and track the Sun, implement motor control algorithm for attitude of the payload.
	**Chun Iao Tai** MSc(Eng) Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Attitude Determination & Control Systems Subsystem **Responsibilities:** Implement image processing algorithm to detect and track the Sun, design and implement motor control algorithm for attitude of the payload.
	**Chamode De Silva** BEng Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Attitude Determination & Control Systems Subsystem **Responsibilities:** Assist in implementing an image processing algorithm to detect and track the Sun, design and implement motor control algorithm for attitude of the payload.

	**Grigorios Michos** MSc(Eng) Automatic Control and Systems Engineering University of Sheffield (UK) **Role:** Attitude Determination & Control Systems Subsystem Team **Responsibilities:** Assist in implementing image processing algorithm to detect and track the Sun, design and implement motor control algorithm for attitude of the payload.
	**Dana Arabiyat** MEng Aerospace Engineering 1st Year University of sheffield (UK) **Role**: Thermal System Team **Responsibilities**: Designing an active heating system, including insulation using Kapton tapes.
	**Bobby Brailsford** BEng Aerospace Engineering 1st Year University of Sheffield (UK) **Role:** Thermals Team member **Responsibilities:** Insulation Research and Design
	**Oscar Downing** BEng Mechanical Engineering 1st Year University of Sheffield (UK) **Role:** Thermals Team member **Responsibilities:** Insulation Research and Design
	**David Chung** MEng Digital Engineering University of Sheffield (UK) **Role:** Communications Team **Responsibilities:** Developing a Python algorithm that will control the data flow to Uplink and Downlink.
	**Abdulla Omaruddin** MEng Systems & Controls Engineering University of Sheffield (UK) **Role:** Communications Team Member **Responsibilities:** Telemetry System

	**Gan Jiang** BSc Artificial Intelligence & Computer science University of Sheffield (UK) **Role:** Business & Outreach **Responsibilities:** Publicize the project by making videos and posts about the project on Facebook and LinkedIn.
	**Ali Kavoosi** BEng Electronic and Electrical Engineering University of Sheffield (UK) **Role:** Financing **Responsibilities:** Applying for funding and grants, completing applications and publicity.

1.4.3 Team Structure

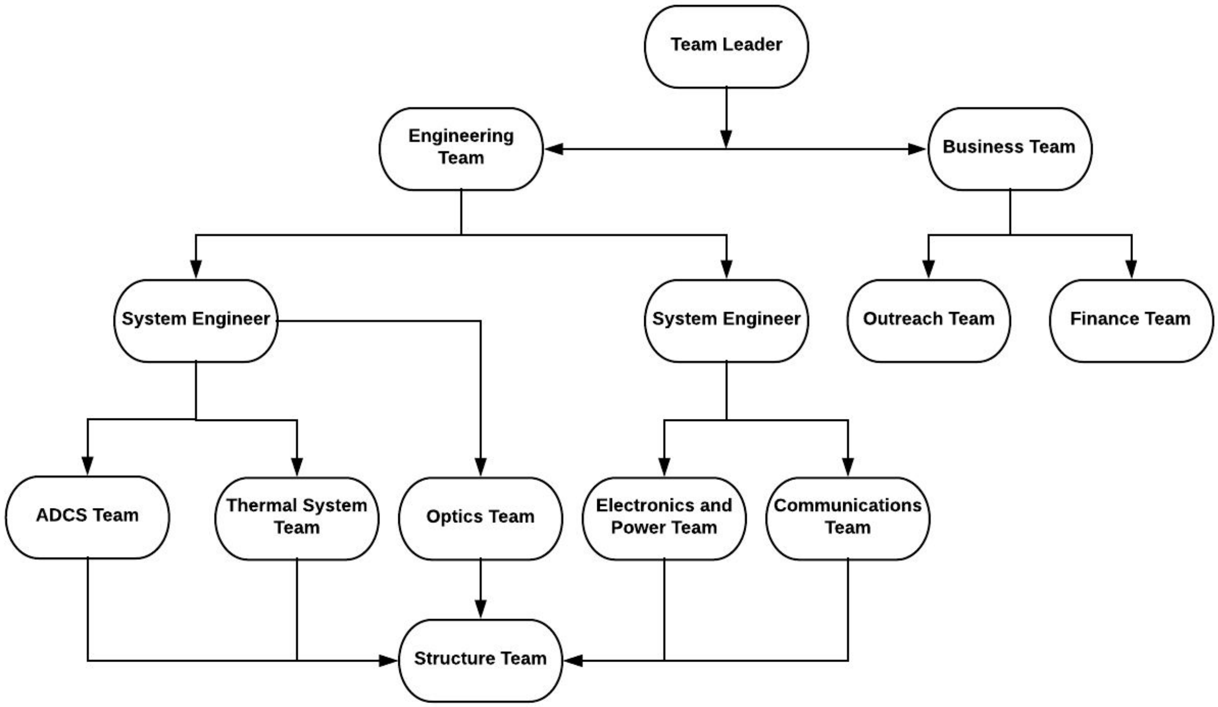


Figure 1.4.3.a: Team Structure

The team leader is responsible for the successful initiation and delivery of the following tasks:

1. Meeting the contractual obligations of the project (financial, administrative, and scientific).
2. Monitoring the progress of the project and ensuring deliverables are met.
3. Organising, chairing and reporting on project meetings.
4. Ensuring good, timely communication between team members and stakeholders.

The team is split into two main teams which are engineering and business. The engineering team will be responsible for ensuring that the payload is fully functional for flight. The business team will conduct outreach and project promotion activities, in addition to applying for funding and sponsorships to ensure that the engineering team has enough money to buy the parts and tools necessary to construct the payload.

Within the engineering team each person will be assigned to one of the following subsystems teams: ADCS, Thermal, Optics, Electronics and Electrical Power, or Communications. Each subsystem will have a leader who will ensure that the subsystem deadlines and requirements are met, and that their team is working well together. Furthermore, as all subsystems will be affected by the structure of the payload, each subsystem team will have a designated member who will work on the structure, therefore the structural team consists of engineers from all subsystems. To ensure the subsystems will work together, nominated system engineers will work across multiple subsystems to aid communications between the teams.

2 Experiment Requirements and Constraints

2.1 Functional Requirements

F1. The telescopes shall track the Sun.

F2. The telescopes shall automatically focus during flight.

F3. The experiment shall image the Sun in the Hydrogen-alpha (656.28 nm) and Calcium K (393.4 nm) spectral lines.

F4. The experiment shall store data locally and transmit live data that can be manipulated and analysed by the ground station.

F5. The experiment shall autonomously maintain the functional temperature of the components during the flight.

F6. The experiment shall monitor the status of the microprocessor(s) and microcontroller(s) periodically and reboot if any errors are detected.

2.2 Performance Requirements

P1. The gimbal system shall direct the telescope towards the Sun with an accuracy of at least 1 arc minute.

P2. The diffraction limited resolution of the telescopes shall be within a value of 1.5 arcsecs.

P3. The Sun shall be photographed at a maximum rate of 60 FPS.

P4. The experiment shall produce images with a resolution of 0.5 arcsec at the vacuum wavelengths of the Hydrogen-alpha and Calcium K lines.

P5. The maximum current draw shall not exceed 2.5A.

P6. The maximum transient current draw shall not exceed 6A for more than 1 second.

P7. The supporting structure shall withstand a maximum compressive load of 200N.

P8. The tracking camera shall have a video resolution of no less than 640 by 480 pixels and 30 FPS

P9. The maximum downlink speed is 4800 baud.

P10. The Watchdog Timer shall receive pulses at a minimum frequency of 1Hz, to monitor the functionality of the Teensy MCU and the Raspberry Pi.

2.3 Design Requirements

D1. The experiment shall operate in the temperature profile of the HASP vehicle flight.

D2. The experiment shall operate in the vibration profile of the HASP vehicle flight.

D3. The experiment shall operate in the pressure profile of the HASP vehicle flight.

D4. The experiment shall not disturb or harm the launch vehicle or other payloads.

D5. The experiment shall not broadcast at a frequency prohibited in the USA.

D6. The length of the telescope shall not exceed 380 mm.

D7. The mass of the experiment shall not exceed 20 kg.

D8. The maximum tolerance of any gearing shall be within 0.2 arc minutes.

D9. The supporting structure shall not twist by more than 0.1 degrees.

D10. The supporting structure shall not buckle under a safety factor of 2.

D11. The experiment shall be able to run for up to 20 hours.

D12. The data logger shall be able to receive signal and store it.

D13. The main computer shall be able to communicate with the ground station.

D14. The external focuser shall be able to adjust focus up to 8 mm.

2.4 Operational Requirements

O1. The experiment shall accept a manual commands for actuating components if such a command is sent.

O2. The experiment shall enter the searching pattern if the location of the Sun is not found.

O3. The experiment shall transmit a compressed image to the ground at a minimum of every 5 minutes.

O4. The experiment shall transmit telemetry data to ground at a minimum of every 5 minutes.

O5. The experiment shall cease to rotate on landing.

O6. The experiment shall be able to read data from a GPS device.

3 Project Planning

3.1 Schedule

3.1.1 Main Phases

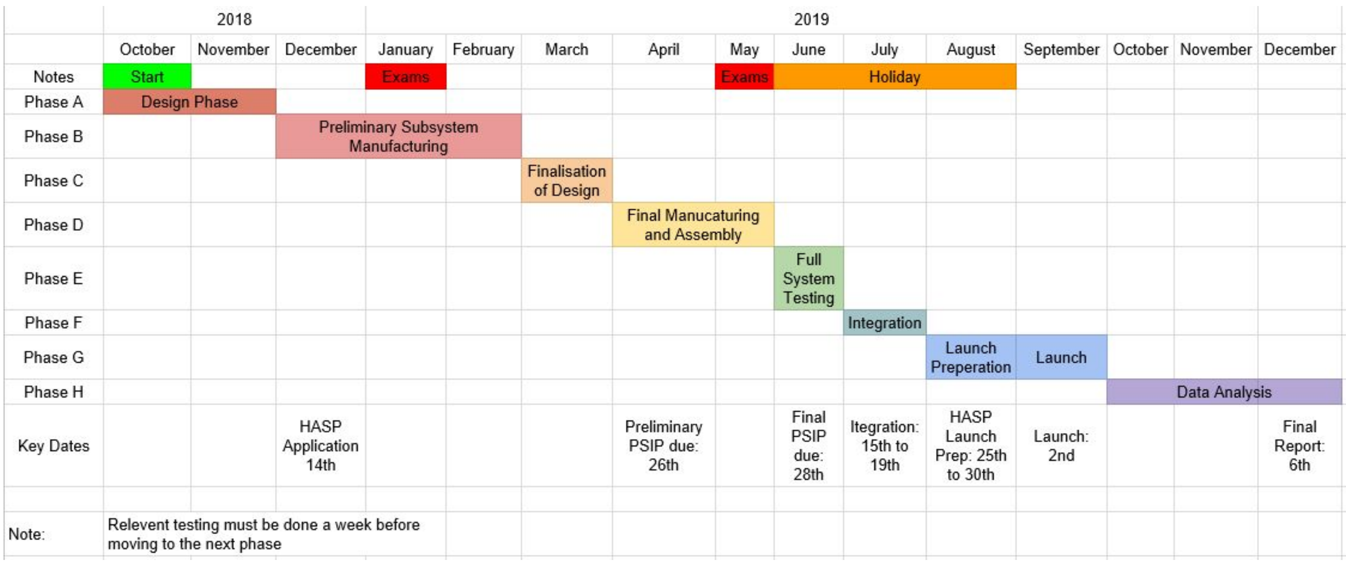


Figure 3.1.1.a: Schedule of SunbYte III Project

The project can be divided into 8 major phases: design, preliminary subsystem manufacturing, finalisation of design, final assembly, system testing, integration, launch sequence, and data analysis. Before any of the phases from 1 to 6 have concluded, tests will be conducted to ensure the project can move to the next phase. These tests will be simulations in the early phases and then physical testing in the latter ones.

3.1.1.1 Phase A

The design phase is when the primary planning decisions are made. These decisions include the first designs of the structure and all of the designs of the subsystems.

3.1.1.2 Phase B

During the preliminary subsystem manufacturing phase, the subsystems designed in phase 1 are manufactured, tested and validated. During this phase the designs will be refined and tuned in order to get an idea of what works and what does not.

3.1.1.3 Phase C

Following the preliminary subsystem manufacturing the designs will be finalised. After this stage no further changes can be made unless they are needed to ensure the primary objectives are met. This prevents discrepancies between the subsystems, and the teams' understanding of the systems.

3.1.1.4 Phase D

During the final manufacturing phase all subsystems will be assembled and integrated. At this point all the materials and components used will be the ones that will fly providing they all survive all subsequent testing.

3.1.1.5 Phase E

Rigorous full system testing will be done before integration at NASA. This month-long period is to check whether the whole system is working cohesively and is ready to pass integration after the first vacuum test at CSBF.

3.1.1.6 Phase F

Integration is when the payload will be when the payload is demonstrated to be certifiable for launch by NASA standards.

3.1.1.7 Phase G

Launch preparation is when the payload is configured ready for flight and ensure that all systems are go and so will ensure that the mission goals are achieved. Launch is when the beautiful images of the Sun will start to appear on the computer screen.

3.1.1.8 Phase H

During this phase of data analysis the evaluation of the data received will be conducted to formulate a scientific report to show what was successful and what can be improved upon.

3.1.2 Optics Schedule

Following the definition of the optical performance requirements in October/December 2018, the components will be ordered and acquired by February 2019. Following bench testing in March 2019 the optical components will be integrated with the ADCS and Electronic and Power subsystems. In May all the optics systems will tested on the ground to provide images for comparison with images taken during the HASP flight. Full tests lasting the approximate duration of a HASP flight will be conducted to ensure the robustness and stability of the image storage, focusing, and imaging systems. At this point a manual checklist and operational procedure will be written to ensure that all optical components and systems will be fully functional for the launch. The HASP integration will be in July/August 2019. Final testing and preparation of the filters and and image storage system will take place in August. Launch will take place in September 2019. From October 2019 the image processing can begin, as well as the analysis of the performance of the filters, cameras, focusing systems, and image storage, for the initial and interim post flight reports.

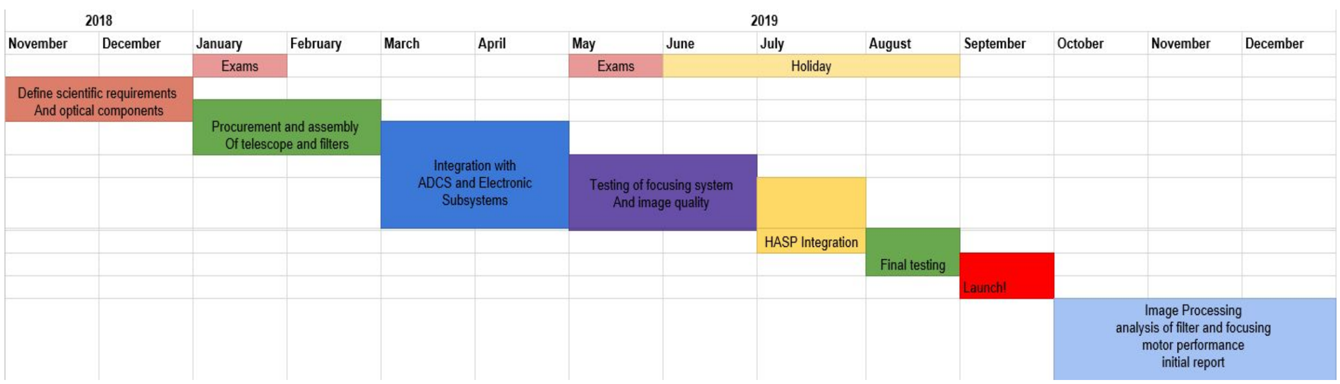


Figure 3.1.2.a: Optics Team Schedule

3.1.3 Electronics and Electrical Power System Schedule

The preliminary components shall be acquired by January 2019 to develop an initial prototype on breadboard early in 2019. This prototype circuit shall be tested and validated, design iterations will take place, with the target to have finalised the circuit and PCB design before March 2019. Multiple PCBs will be produced by a third party company for testing. The PCB shall be tested and will help in the integration of the full electronic circuit. The circuit shall then be tested with the full SunbYte III system and verified. The electrical system will be fully integrated and operationally ready by July 2019. August will be used to correct any issues, run full system tests and prepare for launch.

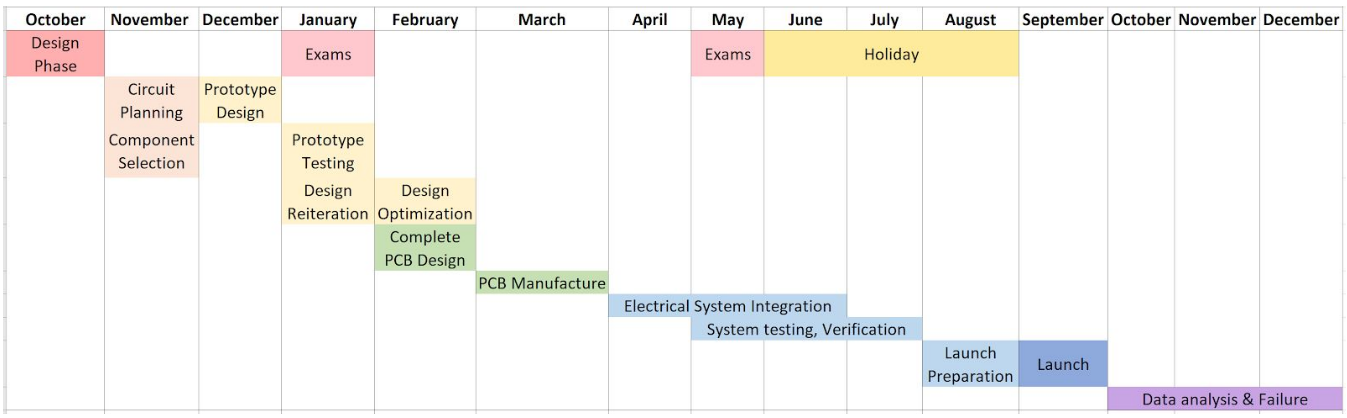


Figure 3.1.3.a: Electronics and Electrical Power System Schedule

3.1.4 ADCS Schedule

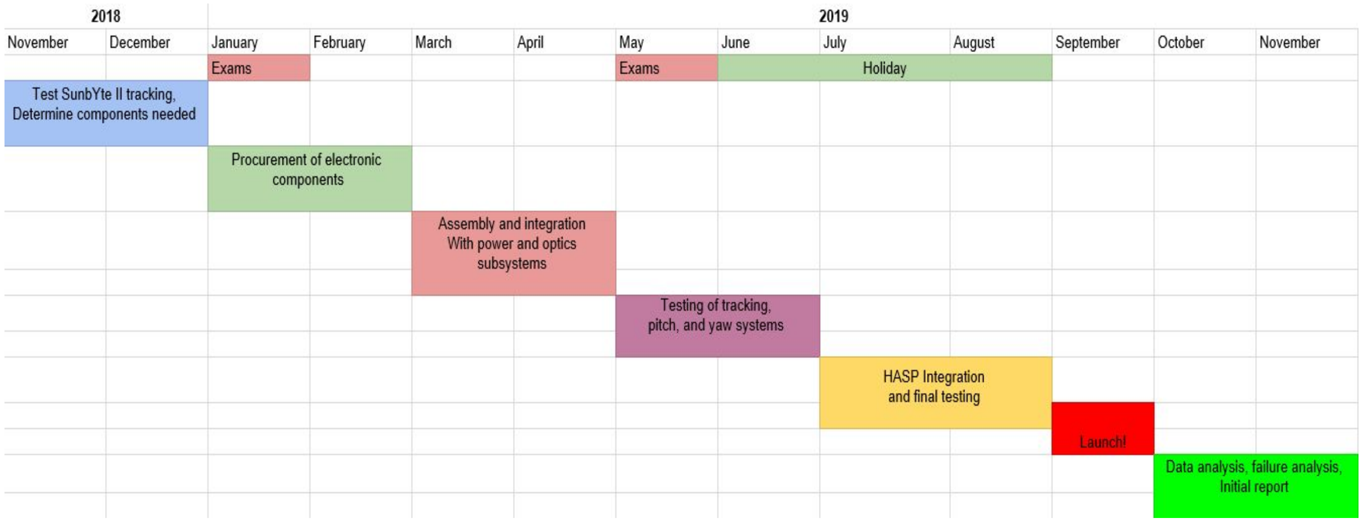


Figure 3.1.4.a: ADCS Team Schedule

3.1.5 Thermal Schedule

Heaters and insulation will need to be bought by February of 2019. Active and passive heating needs will have to be set up and assembled to the whole structure by June 2019. Once the parts have been received, the heating system needs to be tested before flight, by bench testing and computer simulation (FEA). Re-check the heaters are working using thermal vacuum chamber and no insulations sheets have come off before flight. During flight collect temperature data of the internal and external temperature. After flight, the temperature sensors will provide some clear results, and a data analysis of the heating system will be made for future generations of SunbYte.

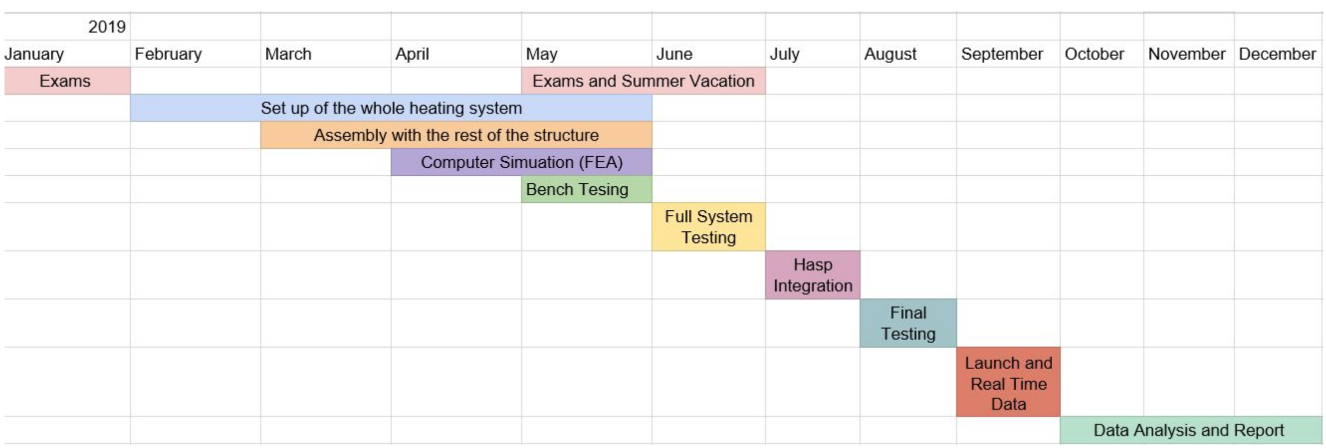


Figure 3.1.5.a: Thermal Team Schedule

3.1.6 Communications Schedule

	2018			2019											
	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
Notes			Exam & Christmas Break					Exam & Summer Vacation							
Phase 0	Concept														
Phase A		Define requirements.													
Phase B				Procurement of Raspberry Pi & development of software											
Phase C						Testing of software by creating simulations. Integrate the software with the overall software for the system.									
Phase D										Payload Integration with HASP					
Phase E												Launch			
Phase F														Post processing of data	

Figure 3.1.6.a: Communications Team Schedule

3.1.7 Structure Schedule

2018			2019											
October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
Start			Exams				Exams	Holiday						
Designing Structure														
		CAD Structure												
			Material Selection											
				Prototype Structure										
					Finalise Parts									
						Manufacture and Assemble Final Design								
								Test Structure with all other components on						
									Integration					
										Launch Sequence				
												Structural Analysis		

Figure 3.1.7.a: Structure Team Schedule

3.2 Risk Assessment

3.2.1 Risks

Table 3.2.1.a: Risk Assessment Matrix

High /\ Severity \/ Low	D. Solar flare during flight	B. Fatigued Team Members	A. Major Software Failure
	G. Payload gets damaged during transit to the USA	E. Being Behind Schedule	C. Run Out of Funds
	J. Thermal system failure L. Components are not delivered on time	H. Team Members Leave	F. Over Complicate System - results in being difficult to debug
	M. MPU or MCU software malfunction	K. Images are out of focus	I. Incorrectly Manufacturing Parts
	Low < Probability > High		

3.2.2 Prevention

A. Rigorous pre-launch testing will be performed to rule out as many causes of failure as possible. Additionally, parallel coding will be used, so that a failure in one system will not result in total system failure.

B. The team will be managed to ensure work is always spread between members and the workload does not get pushed onto one person.

C. Having a dedicated business team will mean that some people will have a sole purpose from sourcing funds which means they are more likely to succeed. Moreover the finance sub team will track the expenditures and ensure the budget will be kept.

D. Space weather forecasts will be checked days before flight. The insulation will protect against moderate radiation levels

E. The team will have regular meetings and reviews by the project leader and sub team leaders to ensure that everything is progressing as expected. The gantt chart will be used to check whether the project is on schedule.

F. The system will be well documented so that it can be understood by anyone. From a programming point of view any pieces of code will be well commented and written in an understandable manner. Mechanically the structure will have manuals to show how it should be assembled to ensure any ambiguity is mitigated.

G. When transporting the payload, it will be securely packaged in a suitable sized box and the airline or courier that the package is fragile. In addition to that the payload will be made to withstand transportation and so will be able to survive the journey.

H. Team members will be allowed to provide feedback about the project to ensure they are happy, however as stated previously work will be documented and so if there is a loss of team member then their knowledge is not lost.
I. Parts will be properly CAD to ensure that there are proper schematics to work from when manufacturing. Also prototypes with cheap materials will be made first to ensure that all parts fit cohesively before manufacturing the final structure with the top quality material.
J. The active heating system will be thoroughly tested before flight, with the estimated environmental conditions being simulated in a controlled environment.
   The passive system will still provide insulation even if the active one fails.
K. The focusing system will have to be tested before flight to ensure operational status. With the Sun being the only target which can be considered infinitely far away, the focusing system is not expected to be required during flight. If it is deemed unfit for flight, the telescopes can both be focused on the Sun before launched and then locked shut in the position.
L. Different approved vendors are available from the University. Alternative versions of the selected components have been selected as backup strategy in the event of unsatisfactory delivery.
M. A Watchdog will monitor both the MPU and the MCU with the given power to reset them both by flipping a relay to their power supply.

3.3 Business

3.3.1 Finance

Table 3.3.1.a: Budget

Expenses	**Budget (£)**	**Budget ($) (Rate: 1.27)**
Mechanical Parts	2 000.00	2 540.00
Electronic Parts	1 000.00	1 270.00
Tools	400.00	508.00
Optics Equipment	5 000.00	6 350.00
Travel to Integration & Launch (six people)	8 100.00	10 287.00
Total	**16 500.00**	**20 955.00**

Table 3.3.1.b Finance Secured

Supporter	**Amount (£)**	**Amount ($) (Rate:1.27)**
Student Led Activities, Faculty of Engineering University of Sheffield	8 100.00	10 293.00
The Alumni Foundation, University of Sheffield	1 000.00	1 272.00
Automatic Control Systems Engineering Department, University of Sheffield	1 500.00	1 906.00
Total	**10 600.00**	**13 471.00**

The project will aim to gather funds from engineering institutions, university departments and companies which sponsor us. In addition we may be able to receive components from companies and or use of their equipment, therefore money would not be required for those things. The designated business team will be responsible for this part so will have designated members to solely focus on this.

The structure of financing the project is to balance the budget based on those and the information provided by technical team leaders regarding if there is a need for any extra components compared to previous projects.

Furthermore, there will be more authorities which the business team plans to apply to in terms of funding, such as the Institute of Mechanical Engineers team project award. The funding process is repeatedly being done until the minimum budget for the project has been reached.

To gain even more support, we have posted about the project on multiple platforms to use them as a means of outreach and publicity to attract attention for those willing to donate or fund the project.

3.3.2 Outreach

Project SunbYte's tertiary objective is to inspire student engineers about the space industry. The project will have many ways to promote what is being done to showcase the challenges related to space exploration engineering. Since 2016 the project has a very active Facebook page and a website, more recently a LinkedIn page has been created to start promoting all progress to industry representatives. Moreover, the University's Department of Automatic Control and Systems Engineering have published articles about the project and its developments. In addition to having an online presence, the team will publicly display all the work done either by hosting talks or manning a stall on university open days. At the moment plans are being formed to participate in an event called Get up to Speed with STEM [25], this event is projected to have 4000 students attending from all across the United Kingdom.

Figure 3.3.2.a: SunbYte II Team Leader Presenting to IMechE Members

Figure 3.3.2.b: SunbYte at the University Open Day

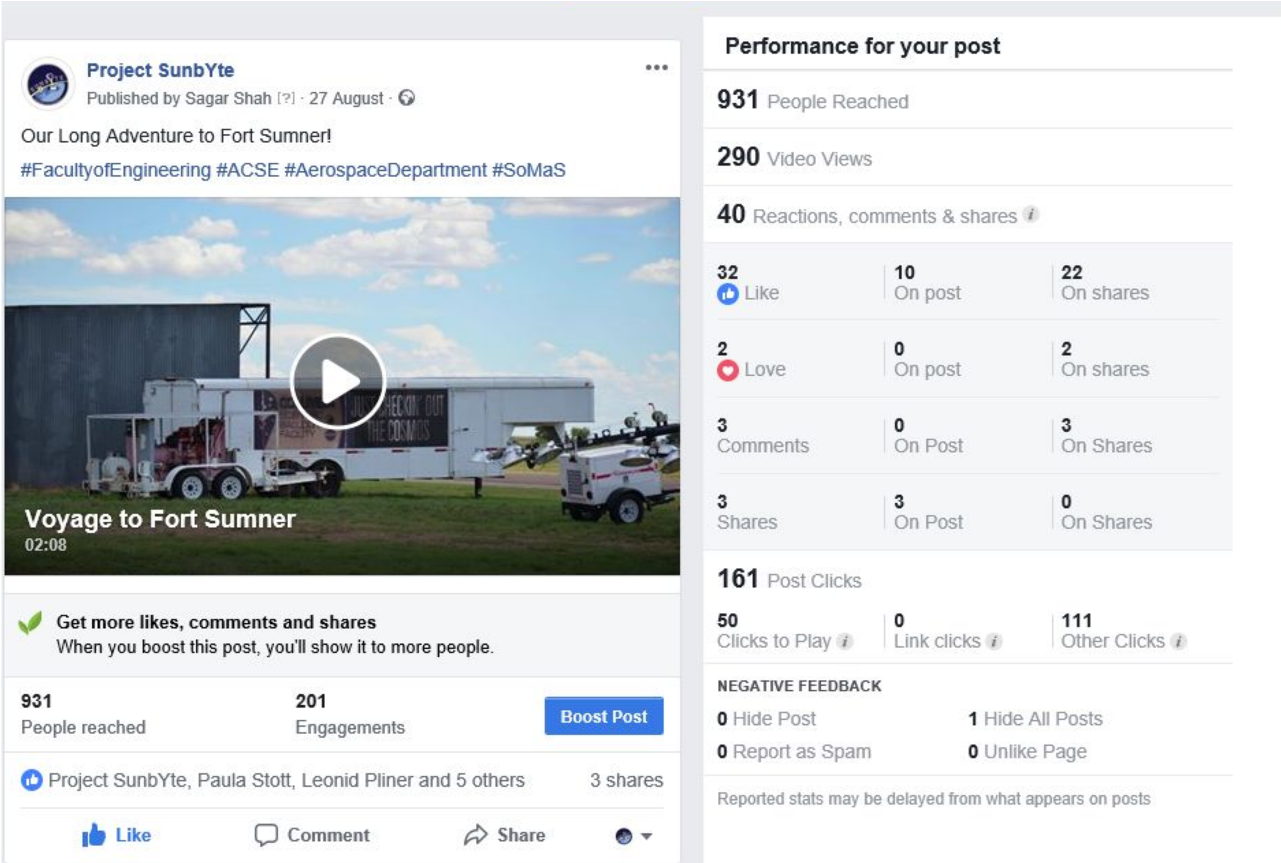


Figure 3.3.2.c: Facebook Insight of Most Popular Post

Figure 3.3.2.d: SunbYte Facebook Page Likes 22/1/2017 - 13/12/2018

Using Facebook Insight the most popular post of the project is a video of the journey to Fort Sumner for the launch of 2018. It reached 931 people as shown in Figure 3.3.2.c. Figure 3.3.2.d shows that the Facebook page is becoming increasingly popular and interest in the project is increasing steadily. As a consequence, the reach of the Facebook pages is increasing.

4 Experiment Description

4.1 Optics

4.1.1 Telescope

This experiment will use two Williams Optics Zenithstar 61 telescopes (shown in Figure 4.1.1.a), one for H-alpha imaging, and one for CaK imaging. The telescopes are both apochromatic refractors with an aperture of 61 mm and focal length of 360 mm. The objective lenses are doublet apochromatic lenses, which will show fewer optical aberrations than a single lens. These telescopes are light at 1.45 kg, and their robustness has been proven, as the same telescope was successfully flown and recovered on SunbYte II. These telescopes are ideal for imaging as they contain a field-flattener which will flatten and focus the curved image produced by the objective lens on to the flat camera sensors.

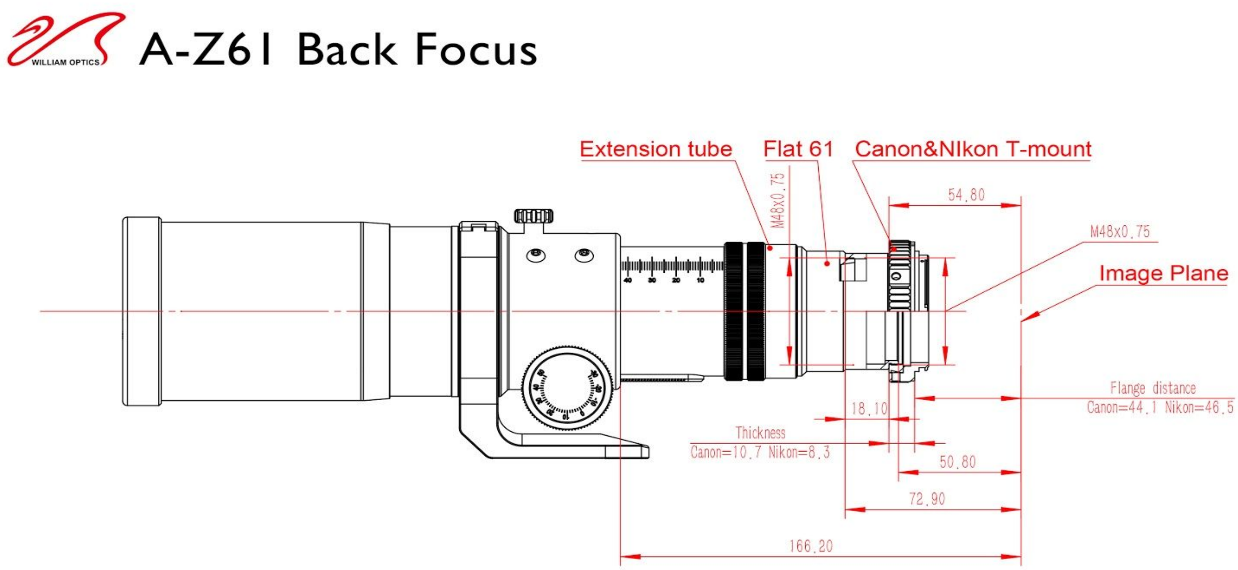


Figure 4.1.1.a: Technical Drawing of the Telescope.

4.1.2 Filter Selection

Each telescope will have a rear-mounted Daystar Quark camera filter, one H-alpha and one CaK. Both filters are heated and tunable, and will have a FWHM band pass of 0.25 - 0.5 nm. These filters contain etalons, which consist of a transparent plate with highly reflective parallel surfaces. They act as optical resonators, with the reflections from the two surfaces cancelling each other via destructive interference during resonance. These effects occur even with a very small tilt between the surfaces, meaning the tilt angle can be changed to control the resonant frequencies. An etalon can therefore be used as an adjustable optical filter; in this case for selecting a single atomic transition for imaging (H-alpha and CaK) [12]. The tuning of these filters will be optimized for the desired Centre Wavelength (CWL) for the temperature conditions during the float phase. Both telescopes will also have front mounted energy rejection filters, which will block incident Infrared light in the case of the CaK telescope, and UV light in the case of the H-alpha telescope, thus preventing the internal components from overheating. By collecting images in two wavelengths SunbYte III hopes to improve the scientific data yield compared to the previous SunbYte projects.

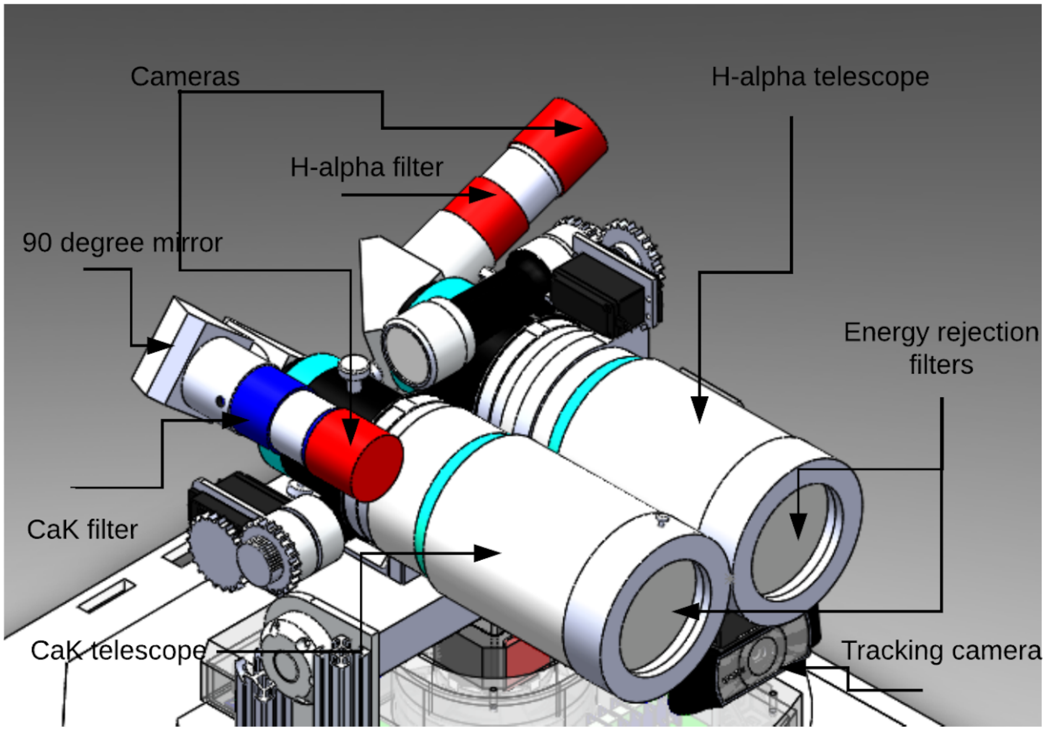


Figure 4.1.2.a: Diagram of Layout of Optical Components

4.1.3 Camera Selection

The cameras will both be monochrome ZWO ASI 120MM Mini USB 3.0 CMOS (Complementary metal–oxide–semiconductor) camera, with a maximum resolution of 1280 × 960 (the resolution of Solar Dynamics Observatory images is 1024 × 1024). This CMOS chip has a quantum efficiency of ~ 54% at the H-alpha wavelength and ~ 45% at the CaK. The monochrome camera will give a higher dynamic range than that of a colour camera, with a 12 bit ADC. Colour may be added during post flight image processing. The robustness of this particular camera was also proven during the SunbYte II flight. The camera did not save any images during the SunbYte II flight as the file which the images were to be saved to was accidentally deleted before the flight. This will be avoided during the 2019 flight by writing a detailed pre-flight checklist which will ensure the correct functioning of the camera and imaging systems, and ensuring that the system will create a new image storage file if one is not detected.

4.1.4 Image Storage

As the purpose of this mission is to prove that a student built, balloon-lifted telescope is capable of taking images of scientific value, it is important that this system has the capability to image a solar flare developing. Solar flares can cause a noticeable increase in irradiance within seconds, and can last for several minutes, therefore the cadence needs to be less than 60 seconds. Based on the last 3 HASP launches, the float time of HASP experiments is ~36,000 seconds (10 hours). To get a high-contrast, low-noise image, a high number of images should be taken, and the best 20% should be stacked in the post flight image processing.

The cameras will produce images with a resolution of 1280 × 960 pixels, which is estimated at 150 kB. The maximum frame rate of the camera is 60 FPS. If both cameras take images successfully for 36,000 seconds, it is expected that 4,320,000 images in total will be taken. These images need 648 GB of storage, therefore a 750GB SSD will be required. The SSD will also store flight data, and data from the final tests conducted before launch. The SSD has been proven to be capable of surviving the large temperature ranges during the ascent and flight phases.

4.1.5 Focusing

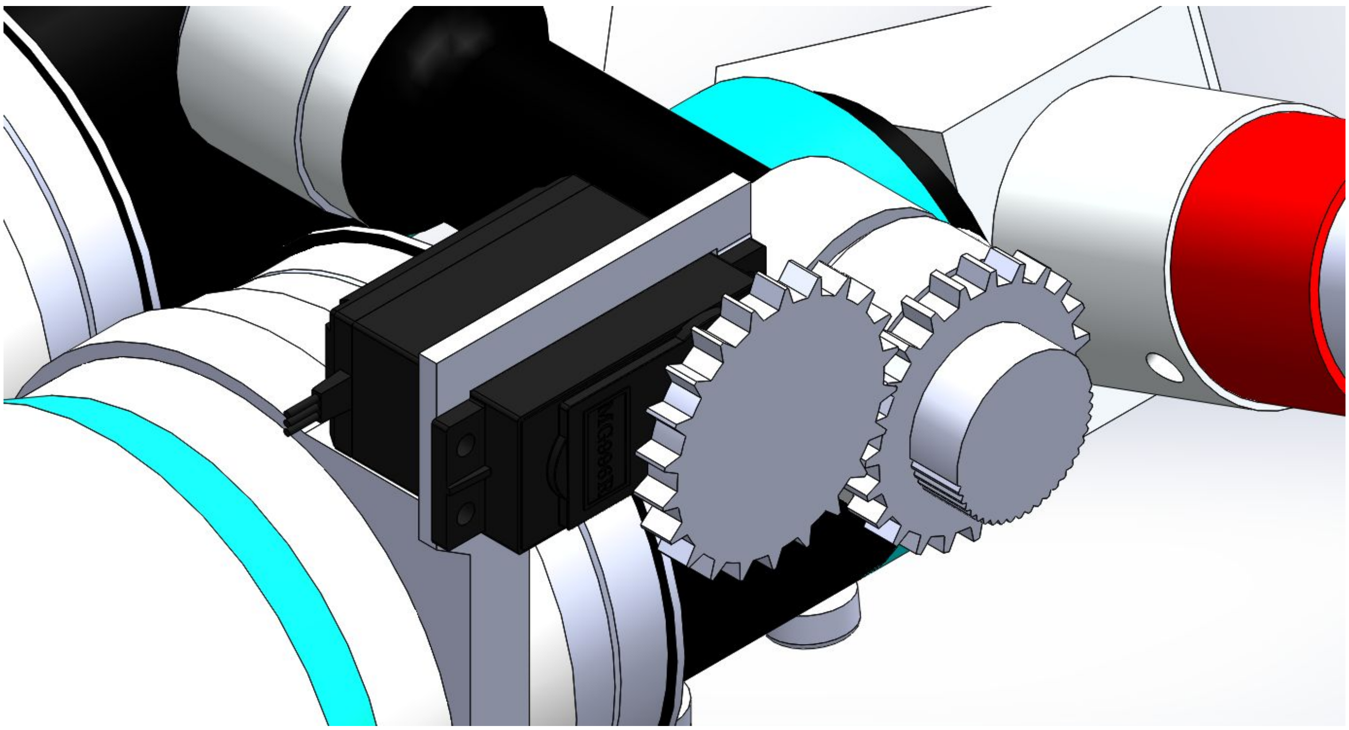


Figure 4.1.5.a: Focusing Mechanism

The focusing system will be implemented in Python and will run on the RPi. The focusing of each telescope is set using MG996R servo motors. The gears connecting the servo motors to the focusing knobs will be 3D printed. The focusing will be tested and adjusted on the ground before integration and launch. Once the focus has been set, it is anticipated that the focusing algorithm will do two tasks: move the focusing and compute the contrast of the image. The image contrast is obtained by converting the image from the science camera into grayscale, taking a histogram, and subtracting the maximum grayscale value from the minimum. The algorithm computes the image contrast of images taken at 2 different neighboring focusing points, and moves the focusing knob to whichever has the highest contrast. This process is repeated until the position with the highest contrast is found. To actuate the servos, commands are sent to the MCU to update the servo target position, the MCU then handles the movement of the servos.

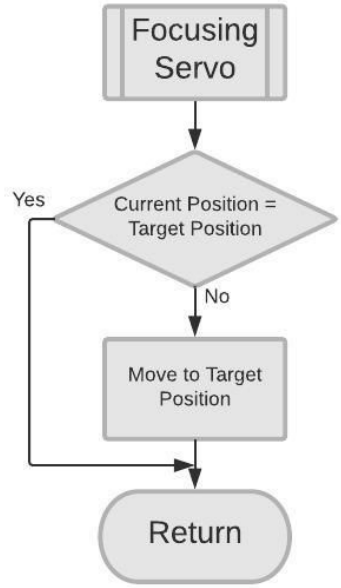


Figure 4.1.5.b: Servo Flow Control Diagram

4.1.6 Image Quality Considerations

According to the Rayleigh Criterion, the diffraction limited resolution due to the telescope aperture for each wavelength is:

$$\theta_{HA} = 1.220 \frac{\lambda}{D} = 2.7 \textit{ arcseconds}$$
$$\theta_{Ca} = 1.220 \frac{\lambda}{D} = 1.6 \textit{ arcseconds}$$

Where 1 radian = 206,265 arcseconds. An arcseconds roughly equals 727.5 km on the surface of the Sun in August, therefore the smallest resolvable distance on the Sun in the H-alpha wavelength will be 1964.3 km, and 1164 km in the CaK wavelength (for comparison the diameter of the Sun is 1.39 billion km) [13]. This should be sufficient to image solar filaments in detail as their length is typically between 60,000 km and 600,000 km long [14]. The solar prominence shown in Figure 4.1.5.a is approximately 70,000 km across [29].

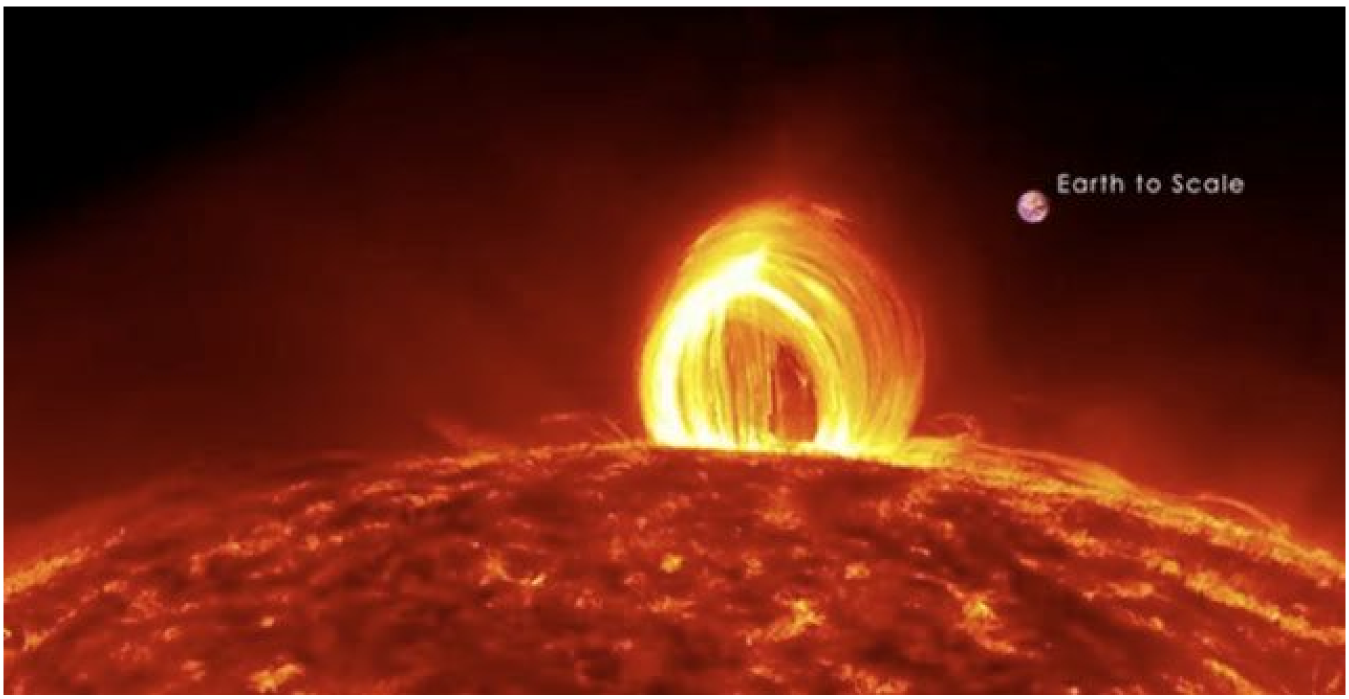


Figure 4.1.6.a: Solar Prominence Size Comparison

The camera's gain is automatic and is therefore not adjustable. The image sharpness and flat field correction will be optimized during image processing after the flight. The best 20% of images will be taken from each exposure and combined to give the maximum image quality. To avoid the interference phenomenon known as Newton's Rings, the cameras (specifically the CMOS chips) will be placed at a slight angle with respect to the plane of the H-alpha and CaK filters.

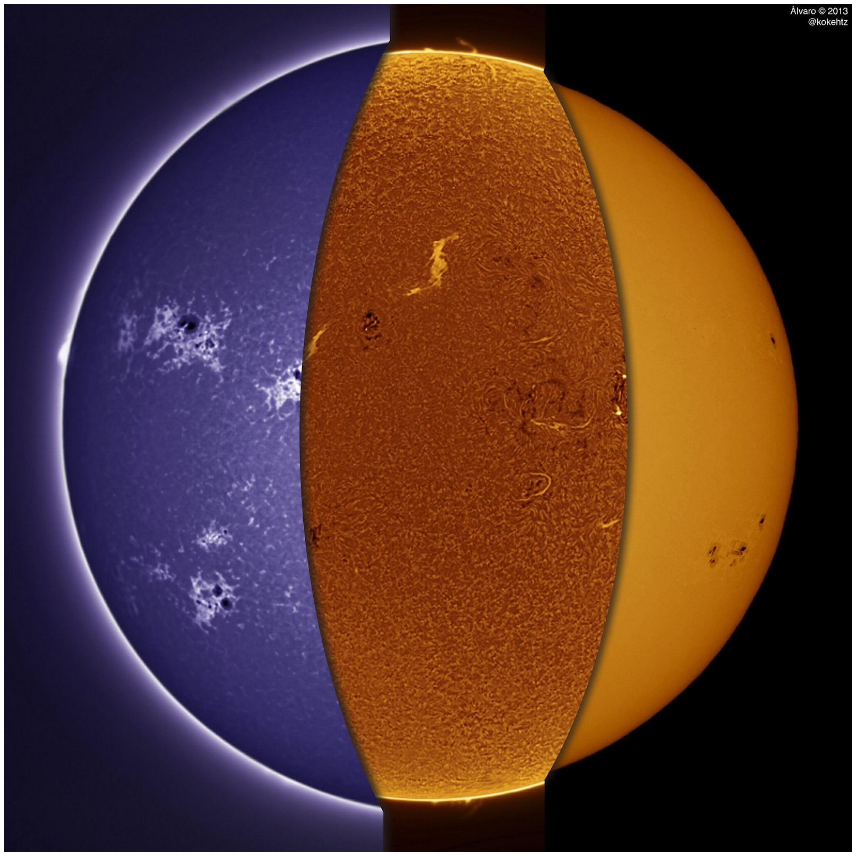


Figure 4.1.6.b: The Sun Imaged in CaK, H-alpha, and Continuum Wavelengths

4.1.7 Improvements on SunbYte II

SunbYte III will take images in two wavelengths, Hydrogen-alpha (656.28 nm) and Calcium K (393.4 nm). A manual checklist for pre-launch activities and testing will be made and strictly adhered to. To avoid the human error encountered in SunbYte II which led to the folder which was meant to receive the images from the camera being deleted, redundancy code will be created so that if the system doesn't find the image storage folder, a new folder will be created.

4.2 Electronics and Electrical Power System

The objective of this project is to design a low-cost telescope to study the Sun, hence the circuit has been designed to use inexpensive yet reliable off-the-shelf components. The electronic circuit is responsible for integrating the processors, input, and output devices, and must therefore be reliable. A custom Printed Circuit Board (PCB) shall be used to do this. Additionally, a Watchdog Timer safety system is included to monitor the electronics. Figure 4.2.a shows the high level circuit and flow of data between components.

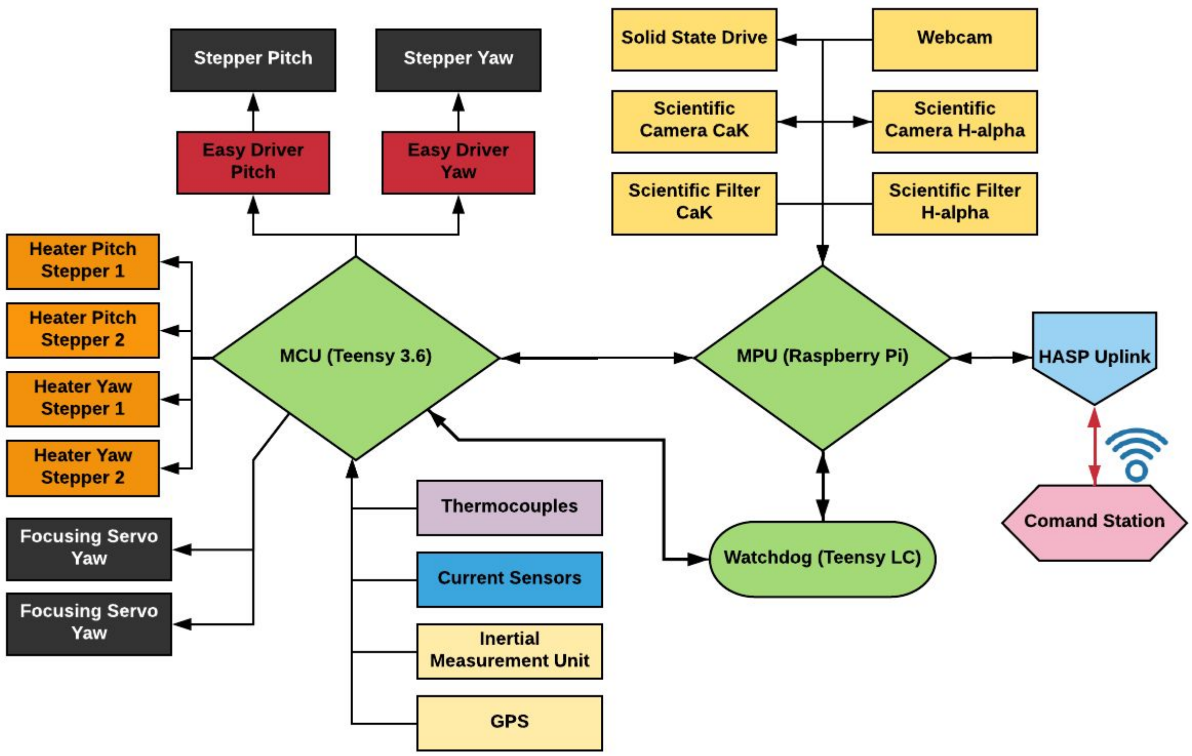


Figure 4.2.a: Electronics Block Diagram

4.2.1 Component Overview

Each component was selected to be more than sufficient for its task. The following table lists the selected components, their purpose within the electrical system and justification for selection over alternative components.

Table 4.2.1.a: Component List

Component	Purpose	Justification
MCU - Teensy 3.6	Microcontroller unit (MCU), Stepper/Servo Control, read sensors, control heaters, communicate with RPi.	Small, powerful MCU capable of many tasks, with many pins available and SD card slot.
MPU - Raspberry Pi 3 Model B+	Microprocessor unit (MPU), used to communicate with ground station and process and store images.	High computational power and variety of input/output pins.
Watchdog - Teensy LC	Monitor electronics, detect problems and reboot MCU/MPU.	Small, inexpensive MCU for a simple task.
Stepper Motor - Bipolar NEMA 17	2 motors for pitch and yaw control respectively to angle telescope towards the Sun.	Sufficient torque for task, compact, high holding torque.
Stepper Motor Driver - Big Easy Driver	Control stepper motor coil switching.	Simple, affordable driver with sleep mode and adjustable coil current.
Encoder - HKT22	Closed loop position feedback for pitch and yaw control. Allows for calibration of stepper motor positions and position feedback.	HKT22 is designed to fit on the selected stepper motor to combine into a single unit.
Servo Motor - MG996R	2 motors, one for each science camera to automatically focus telescopes	Inexpensive, lightweight actuator with sufficient torque for the task.
DC-DC Converter (to 12V)	Provide power to Stepper Motors and heaters.	High efficiency to step down 30 VDC input voltage from HASP to 12 VDC.
DC-DC Converter (to 5V)	Provide power to MCUs, MPUs, Webcam, Science cameras, Servo Motors and sensors.	High efficiency to step down 30 VDC input voltage from HASP to 5 VDC.
Relay	Control heaters, manage power consumption, force reboot MCUs and MPUs.	Simple, easy to control relays requiring only a single digital line.
Real-time Clock	Reference for timestamping data, especially from sensors.	Timestamps are necessary, this method of generating timestamps is most reliable.

Table 4.2.1.b: Sensor List

Sensors	Purpose	Justification
GPS	Measure altitude with onboard sensor to avoid relying on uplink signal for HASP GPS position.	Sensor to measure altitude up to 40 km above sea level.
Thermocouple - Adafruit MAX31850	K-type thermocouple, used to measure temperature in a suitable range based on the expected thermal environment of SunbYte III.	Monitor heaters, gather data about the environment. Allows for multiple sensors on a single digital line.
Current Sensor	Measure current of high power components, such as heaters and stepper motors.	Used to control and monitor use of high power components.
Adafruit 9-DOF IMU Breakout - L3GD20H + LSM303	Measures the orientation of the system.	Used to gather data about the flight profile.

4.2.2 Electronics Communication

The Figure 4.2.2.a details the communication methods between components. Inter-Integrated Circuit (I^2C) communication is used between the MPU, MCU and certain sensors, because many sensors can be connected to a single pair of I^2C lines freeing up digital lines for alternative uses. For I^2C communication the MCU shall be a master to sensors using the microcontroller's first set of I^2C lines, a second set will be used for communication with the Raspberry Pi, in this case the MCU shall be the slave. The thermocouples use one-wire communication, which is an efficient method of connecting many temperature sensors to a single digital line, without requiring a power line.

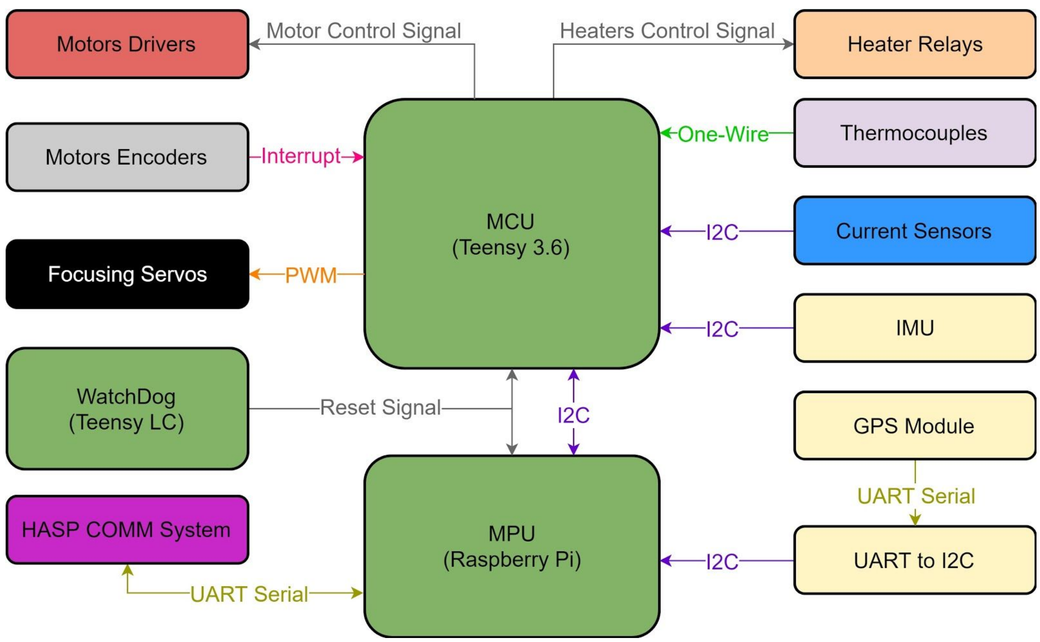


Figure 4.2.2.a: Electronic Component Communication Methods

4.2.3 Printed Circuit Board

From experience, large strip board circuits can be unreliable and problematic, given the increased possibility for incorrect wiring and poor connections. Additionally, large quantities of solder connections can lead to outgassing in the upper atmosphere, causing problems in the circuit. To mitigate these issues and reduce the overall size that the electronics require, a printed circuit board (PCB) shall be used. The PCB shall be based on the above schematic and developed after circuit prototyping is complete and a software simulation of the system has been completed using hardware-in-the-loop techniques. Utilising a PCB has many advantages, including robust integration of electronic components and reliable connections. This PCB will save space and provide immunity to repeatability and wiring issues, particularly on launch day. In addition, PICOBLADE 51021 MOLEX connections will be used to connect from the PCB to off-board components. Sensor modules will be connected to the PCB using male right angle pin headers and female headers. This allows for components to be replaced and provides a stronger connection to the board than solder joints. The PCB will be tested rigorously and reviewed by professionals before manufacture to mitigate design errors and reduce re-printing costs. A robust PCB circuit will save time in many stages of development alongside the significant reliability improvements. Spare PCBs will be assembled as backups. The pin assignments for the PCB design is laid out in figure 4.2.2.b, wires are coloured depending on their purpose.

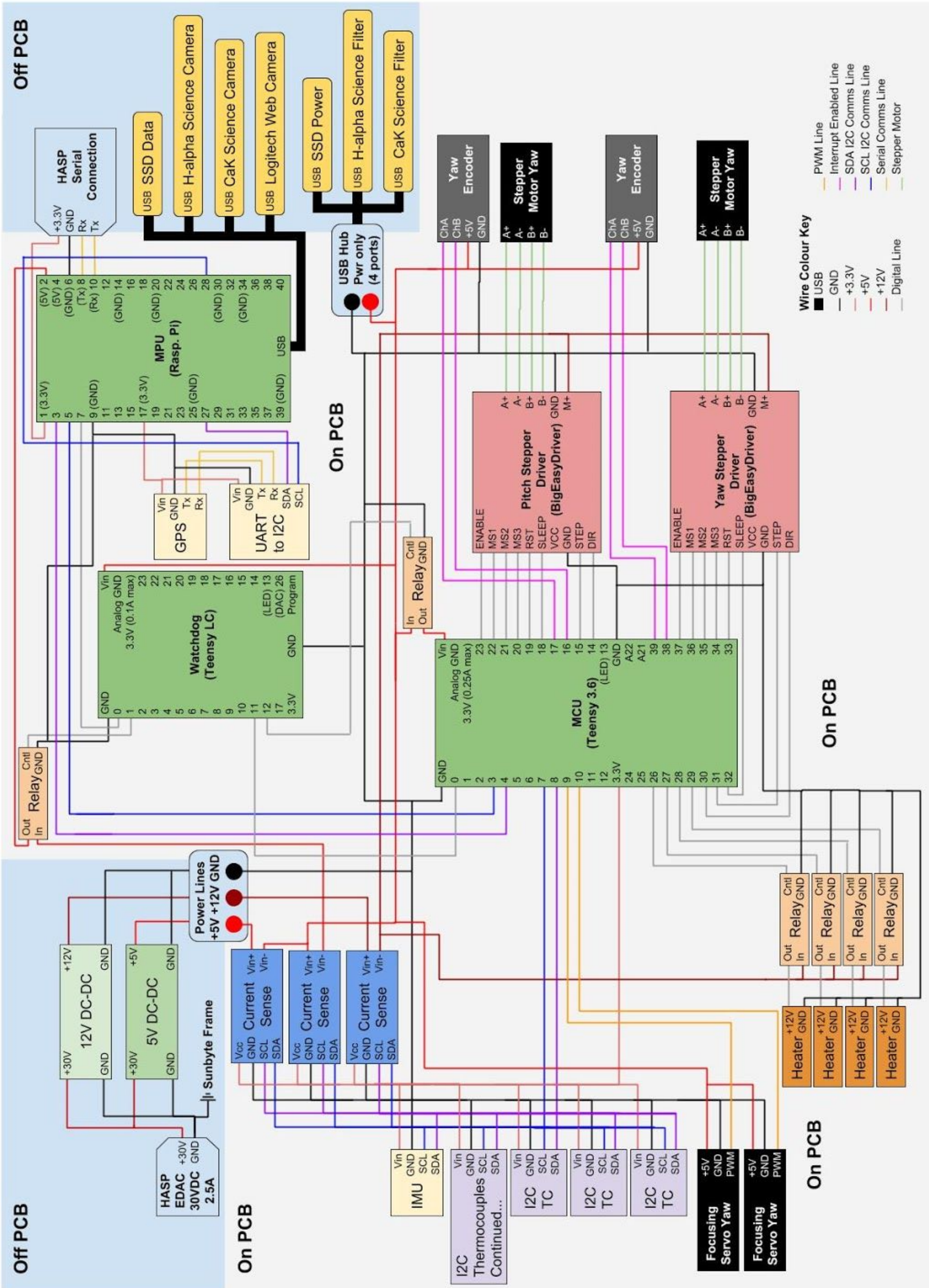


Figure 4.2.3.a: Electronics Pin Assignments

Figure 4.2.3.b shows the layout of the electronic components on the base plate of SunbYte III. All electronic parts will be insulated as protection from the cold temperatures and physical damage, which are represented by translucent grey boxes in Figure 4.2.3.b. Figure 4.2.3.c highlights the proposed shape of the PCB and is represented in light green, while Figure 4.2.3.d details the PCB measurements.

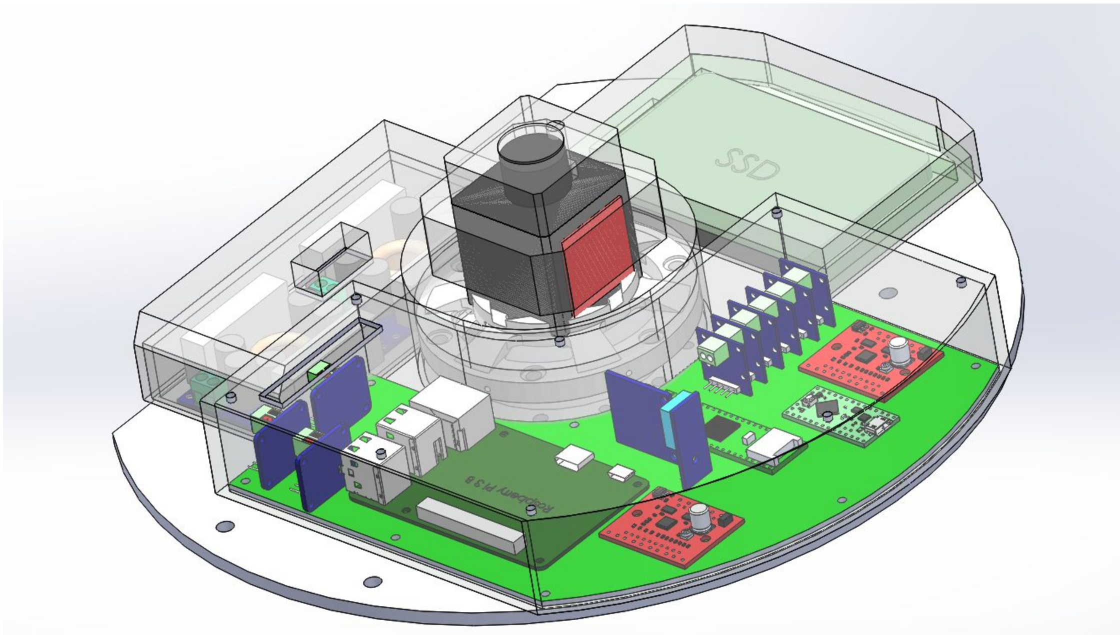


Figure 4.2.3.b: PCB Layout on Base Plate

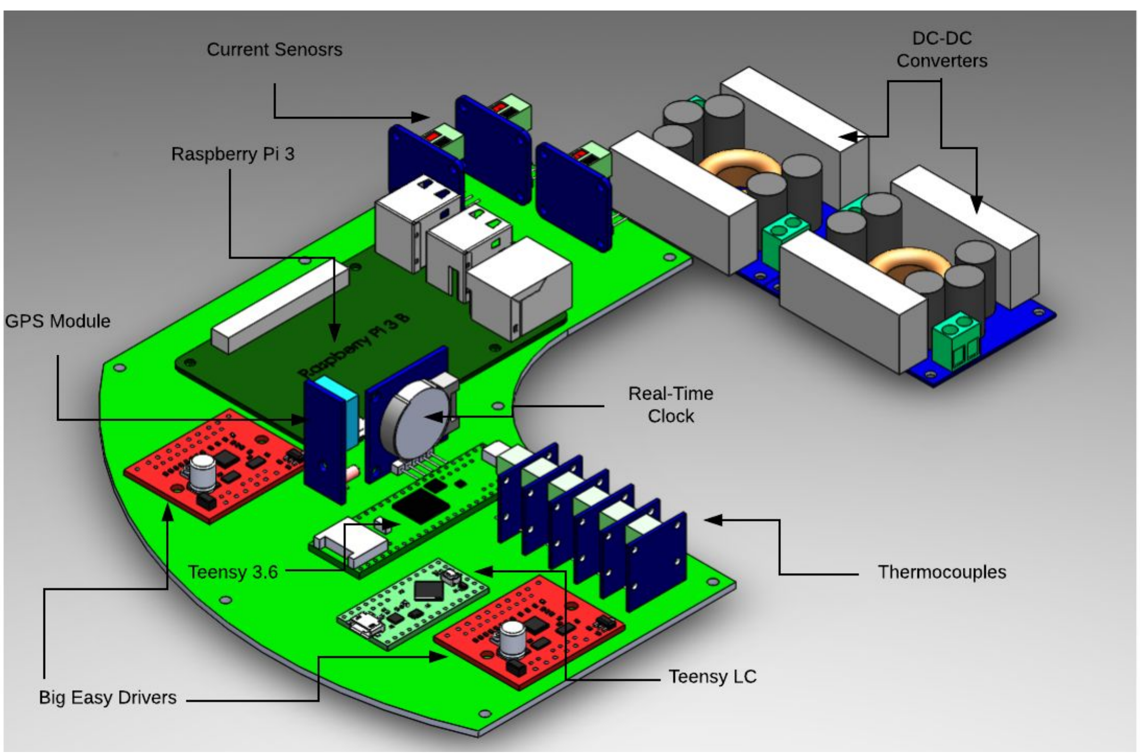


Figure 4.2.3.c: PCB and Components

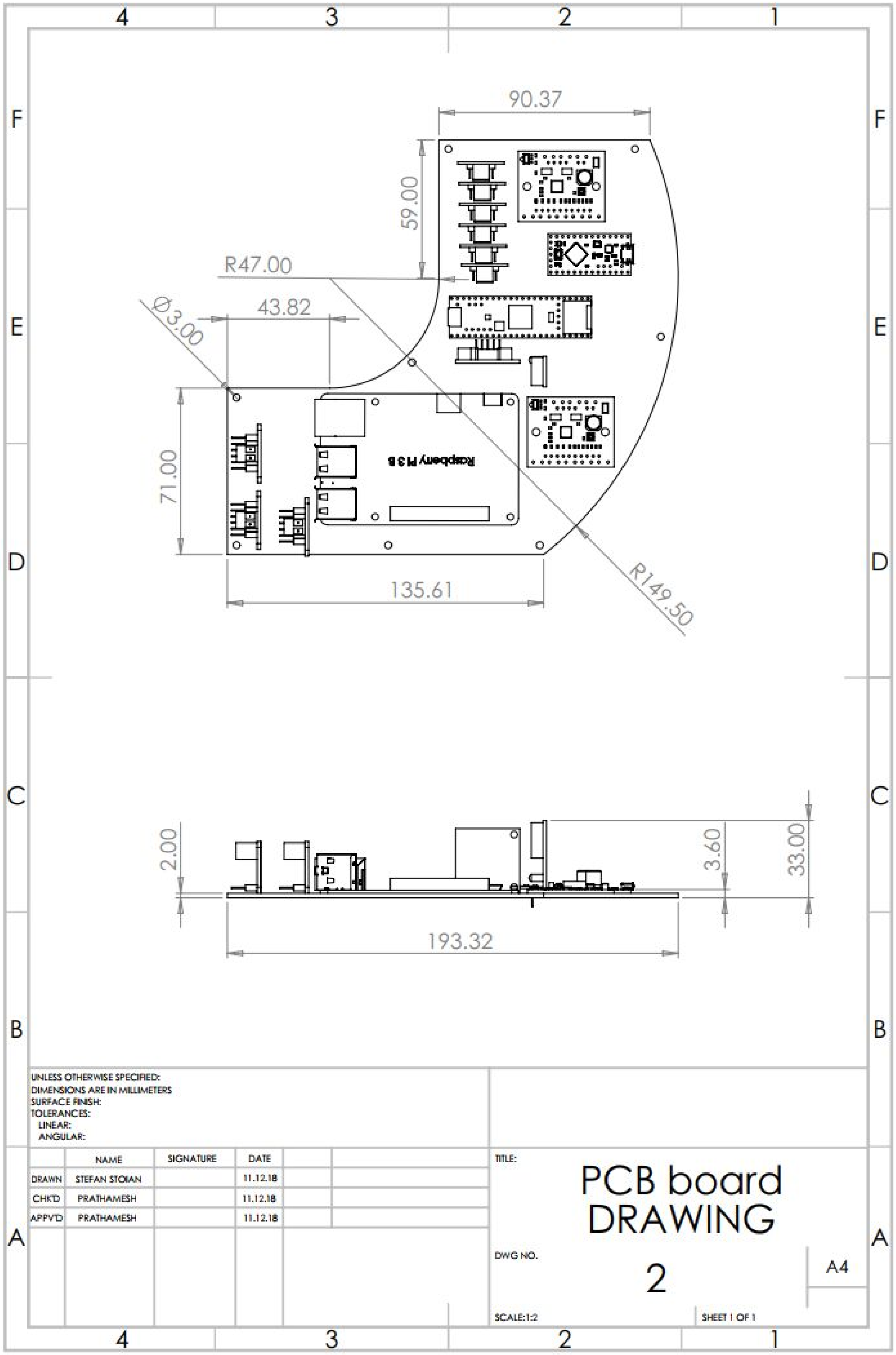


Figure 4.2.3.d: Technical Drawing of PCB

4.2.4 Power Management

The circuit operates mostly on 12V or 5V rails to reduce the number of power stages while maintaining high power efficiency. Some sensors can operate at 3.3V, which will be supplied by MPU or MCU 3.3V outputs to save power, since many sensors draw similar current at both voltage levels. The MCU uses a 3.3V digital line voltage range, which will match the sensors when powered at 3.3V. For the purpose of power estimation in sections 4.2.4.1-4.2.4.3 the sensor current values are listed for use at 5V. The power management of the system shall be software based with current sensors as a means of input. The system's output shall be control of the motor drivers and relays for the heaters. The power management system is divided into 3 power modes: ascending, tracking, and descending. Each mode behaves in a manner that is optimal for the environment of SunbYte III at that time, the power mode is determined from altitude and cumulative flight time. A total flight time of 20 hours is assumed, the power management system will adapt in real-time changing power modes when considered necessary and adapting to the flight by monitoring altitude.
The electronic circuit operates at 3 power levels, 12V, 5V and 3.3V after initially converting from the 30VDC HASP input. Figure 4.2.4.a shows a how each component shall be powered.

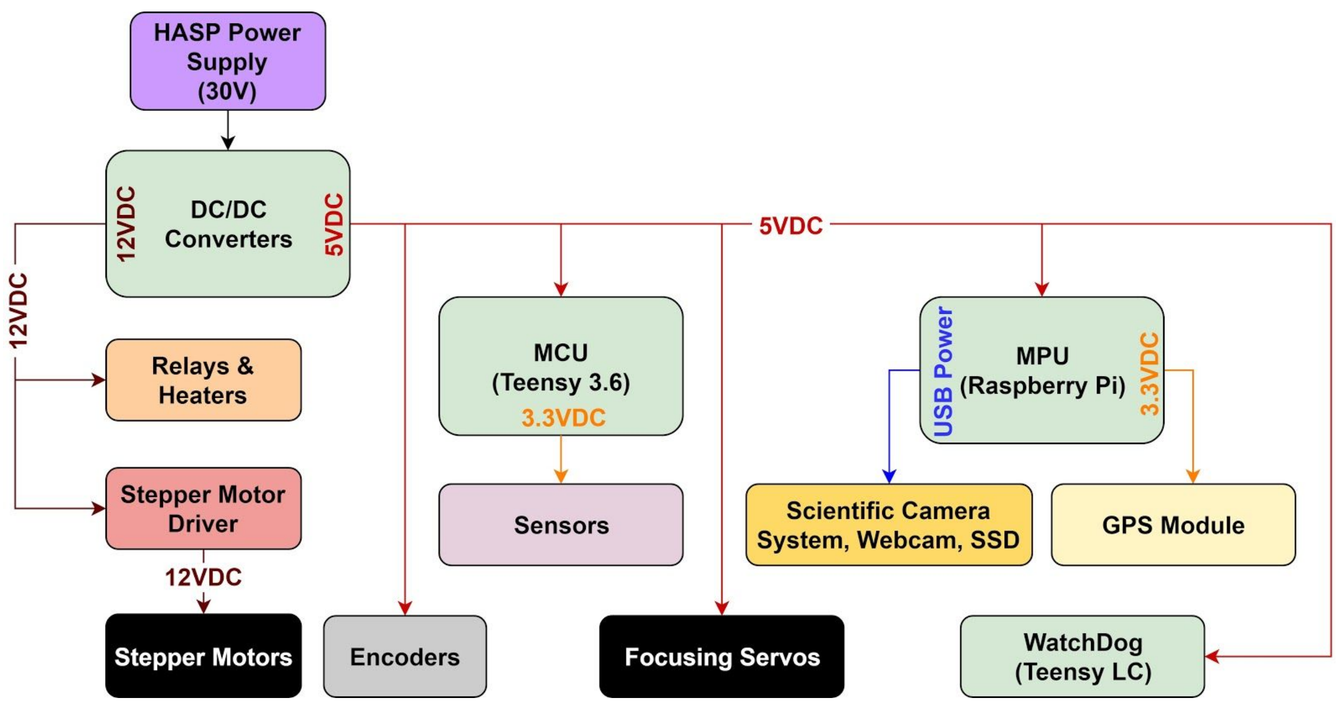


Figure 4.2.4.a: Electronic Component Power Levels

4.2.4.1 Ascending Power Mode (Ground to Tropopause)

During the ascending mode all subsystems will be running, with the exception of the photography, focusing servos and positioning stepper motors. The heaters are prioritised during this power mode due to the low temperature, but when power is available the Sun can be tracked. The power consumption during the ascending power mode is shown in the following table:

Table 4.2.4.1.a: Ascending Power Mode Distribution

12V Components							
Component	Voltage (V)	Current (A)	Units	Running Time (hours)	Total Current (A)	Power (W)	Consumption (Wh)
Heaters	12	0.4	4	2	1.6	19.2	38.4
Stepper Motor	12	1.2	2	0	0	0	0
Motor Driver	12	0.015	2	2	0.03	0.36	0.72
Total					1.63	19.56	39.12
5V Components							
Component	**Voltage (V)**	**Current (A)**	**Units**	**Running Time (hours)**	**Total Current (A)**	**Power (W)**	**Consumption (Wh)**
Teensy 3.6	5	0.115	1	2	0.115	0.575	1.15
Teensy LC	5	0.05	1	2	0.05	0.25	0.5
Raspberry Pi	5	1.5	1	2	1.5	7.5	15
Sci-Cam	5	0.15	2	2	0.3	1.5	3
Web-Cam	5	0.15	1	2	0.15	0.75	1.5
Sci-Filters	5	1.5	2	2	3	15	30
Thermocouple	5	0.05	6	2	0.3	1.5	3
IMU	5	0.028	1	2	0.028	0.14	0.28
Current Sensor	5	0.01	3	2	0.03	0.15	0.3
GPS	5	0.025	1	2	0.025	0.125	0.25
SSD	5	0.6	1	2	0.6	3	6
Servo Motor	5	0.5	2	2	1	5	10
Encoder	5	0.01	2	2	0.02	0.1	0.2
Total					7.118	35.59	71.18
DC-DC Converters							
Conversion Efficiency	**Input Volts (V)**	**Input Current (A)**	**Output Volts (V)**	**Output Current (A)**			**Consumption (Wh)**
0.95	30	0.686	12	1.63			39.12
	30	1.249	5	7.118			71.18
Total		**1.935**					**110.3**
Maximum		2.5					150

4.2.4.2 Tracking Power Mode (Stratosphere)

Due to the warmer environment, the heaters are a lower priority and shall be turned off unless the temperature of vital components approaches the minimum temperature threshold. All other systems will be running during this power mode as there should be a clear line of sight to the Sun. For this mode the power consumption will be as follows:

Table 4.2.4.2.a - Tracking Power Mode Distribution

12V Components							
Component	**Voltage (V)**	**Current (A)**	**Units**	**Running Time (hours)**	**Total Current (A)**	**Power (W)**	**Consumption (Wh)**
Heaters	12	0.4	4	0	0	0	0
Stepper Motor	12	1.2	2	17	2.4	28.8	489.6
Motor Driver	12	0.015	2	17	0.03	0.36	6.12
Total					2.43	29.16	495.72
5V Components							
Component	**Voltage (V)**	**Current (A)**	**Units**	**Running Time (hours)**	**Total Current (A)**	**Power (W)**	**Consumption (Wh)**
Teensy 3.6	5	0.115	1	17	0.115	0.575	9.775
Teensy LC	5	0.05	1	17	0.05	0.25	4.25
Raspberry Pi	5	1.5	1	17	1.5	7.5	127.5
Sci-Cam	5	0.15	2	17	0.3	1.5	25.5
Web-Cam	5	0.15	1	17	0.15	0.75	12.75
Sci-Filters	5	1.5	2	17	3	15	255
Thermocouple	5	0.05	6	17	0.3	1.5	25.5
IMU	5	0.028	1	17	0.028	0.14	2.38
Current Sensor	5	0.01	3	17	0.03	0.15	2.55
GPS	5	0.025	1	17	0.025	0.125	2.125
SSD	5	0.6	1	17	0.6	3	51
Servo Motor	5	0.5	2	17	1	5	85
Encoder	5	0.01	2	17	0.02	0.1	1.7
Total					7.118	35.59	605.03
DC-DC Converters							
Conversion Efficiency	**Input Volts (V)**	**Input Current (A)**	**Output Volts (V)**	**Output Current (A)**			**Consumption (Wh)**
0.95	30	1.023	12	2.43			495.72
	30	1.249	5	7.118			605.03
Total		**2.272**					**1100.75**
Maximum		2.5					1275

4.2.4.3 Descending Power Mode (Stratosphere to Ground)

During the descending power mode heaters or motors will be put in to idle mode, all the systems will be running. The power consumption will be:

Table 4.2.4.3.a: Descending Power Mode Distribution

12V Components							
Component	Voltage (V)	Current (A)	Units	Running Time (hours)	Total Current (A)	Power (W)	Consumption (Wh)
Heaters	12	0.4	4	0	0	0	0
Stepper Motor	12	1.2	2	0	0	0	0
Motor Driver	12	0.015	2	1	0.03	0.36	0.36
Total					0.03	0.36	0.36
5V Components							
Component	**Voltage (V)**	**Current (A)**	**Units**	**Running Time (hours)**	**Total Current (A)**	**Power (W)**	**Consumption (Wh)**
Teensy 3.6	5	0.115	1	1	0.115	0.575	0.575
Teensy LC	5	0.05	1	1	0.05	0.25	0.25
Raspberry Pi	5	1.5	1	1	1.5	7.5	7.5
Sci-Cam	5	0.15	2	1	0.3	1.5	1.5
Web-Cam	5	0.15	1	1	0.15	0.75	0.75
Sci-Filters	5	1.5	2	1	3	15	15
Thermocouple	5	0.05	6	1	0.3	1.5	1.5
IMU	5	0.028	1	1	0.028	0.14	0.14
Current Sensor	5	0.01	3	1	0.03	0.15	0.15
GPS	5	0.025	1	1	0.025	0.125	0.125
SSD	5	0.6	1	1	0.6	3	3
Servo Motor	5	0.5	2	1	1	5	5
Encoder	5	0.01	2	1	0.02	0.1	0.1
Total					7.118	35.59	35.59
DC-DC Converters							
Conversion Efficiency	**Input Volts (V)**	**Input Current (A)**	**Output Volts (V)**	**Output Current (A)**			**Consumption (Wh)**
0.95	30	0.013	12	0.03			0.36
	30	1.249	5	7.118			35.59
Total		**1.262**					**35.95**
Maximum		2.5					75

4.2.4.4 Power Consumption Summary

Table 4.2.4.4.a: Power Distribution Summary

	SunbYte III			HASP
	Ascending	Tracking	Descending	
Current (A)	1.935	2.272	1.262	2.5
Power (W)	55.15	64.75	35.95	75
Energy (Wh)	110.3	1100.75	35.95	1500

4.2.4.5 Power Monitoring Algorithm

The software algorithm to monitor and control power usage is shown in Figure 4.2.4.5. Components are controlled using relays through digital lines on the MCU with the exception of stepper motors which can be turned on or off through the Big Easy Driver. Figure 4.2.4.5.a shows the management process at a high level, which is designed to optimise power usage with the available resources. The algorithm ensures the highest priority components are powered. Priorities are assigned based on the power mode. Software to prevent components being turned on and off repetitively will be included in the turning on process, additionally the current readings shall be averaged over multiple readings. Any time the power usage gets close to the safety power limit (power available), the low priority components shall be immediately turned off.

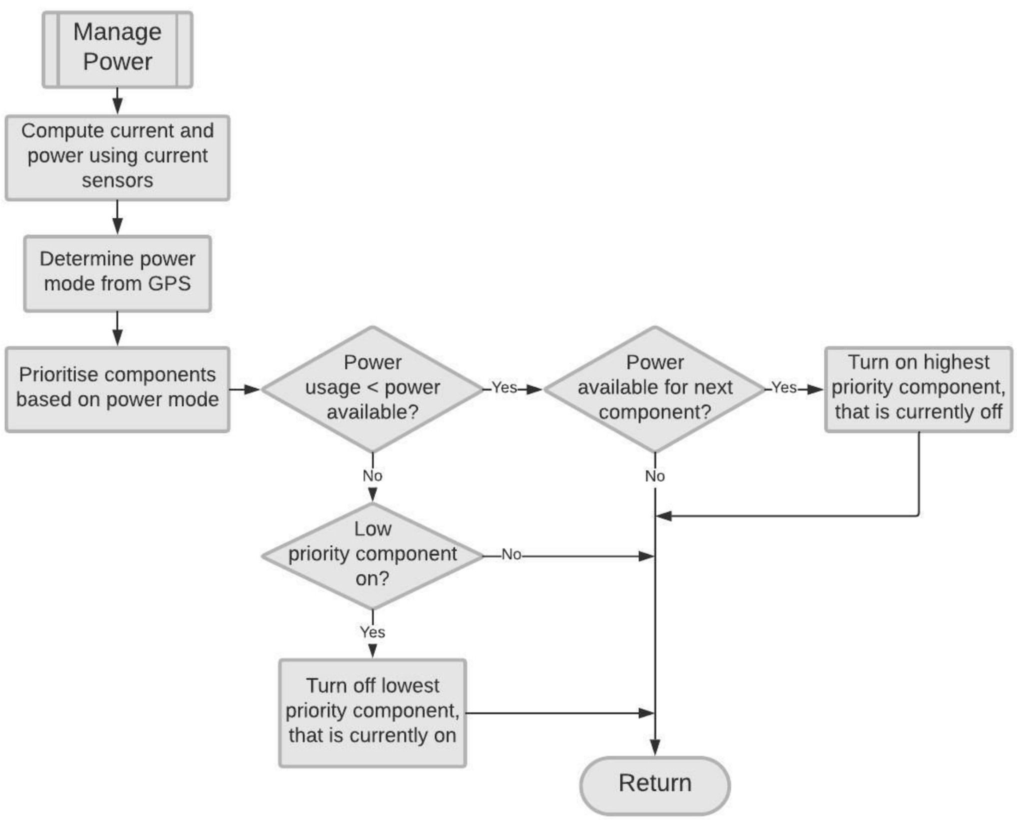


Figure 4.2.4.5.a: Power Management Control Algorithm

4.2.5 Radiation Protection of Electronics

The SunbYte III team will also investigate the impact of radiation on the electronic components, and assess whether radiation damage or 'bit-flipping' is a serious concern for future SunbYte flights. Thermoluminescent Dosimeters (TLDs) are small, low-cost dosimeters which exploit the phenomenon of thermoluminescence - thermally activated phosphorescence. Following radiation exposure, the TLDs are processed and emit light when heated in a process known as annealing. The amount of light emitted during annealing is proportional to the degree of radiation exposure seen by the TLDs [15]. Each TLD is 3.2 mm x 3.2 mm x 0.9 mm, therefore they are lightweight and easy to place in multiple areas of the structure. The dose range of these dosimeters is 10 micro Gray - to 1 Gray (1 mrad to 100 rad). TLDs can detect radiation from photons above 5 keV, neutrons from thermal to 100 MeV, and electrons/beta radiation above 70 keV. These ranges are appropriate for this project's purposes as solar wind electron energies are 1-2 keV, and a large eruption from the Sun such as a CME or solar flare could produce solar particles with energies of 10 MeV [16]. Another benefit of using TLDs is that they do not need to be annealed immediately, and will experience a dose 'fade' of $< 20\%$ over 3 months, which allows the SunbYte III team time to recover the TLDs and transport them back to the UK for processing without major time constraints [17]. TLDs can also survive the wide temperature range that the experiment will encounter. A TLD will be placed in the following areas: PCB, Sun-facing side outside of the insulation, Sun-facing side inside the insulation, shadow side inside the insulation, and shadow side outside of the insulation.

4.2.6 Electronics and Power System Integration with HASP

Power is supplied from the 20 pin EDAC 516-020-000-301 connector (Figures 4.2.8a-c) [26],[27]. Two of the four 30 V connections from ports A-D will be transformed to 12 V and 5 V using DC-DC converters. A ground wire is connected to the converters and SunbYte III's structural metal frame.

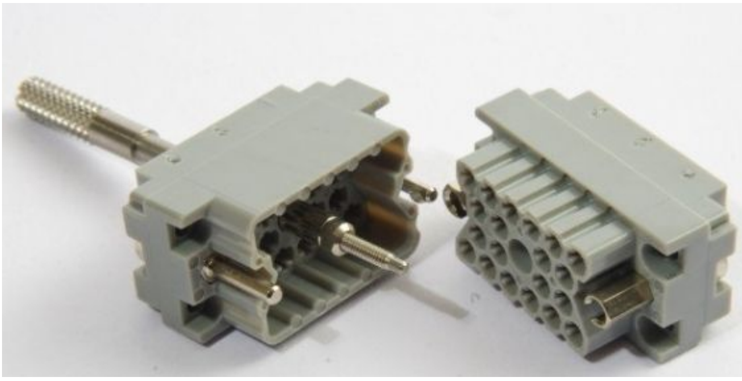


Figure 4.2.6.a: EDAC 516 Series Connector

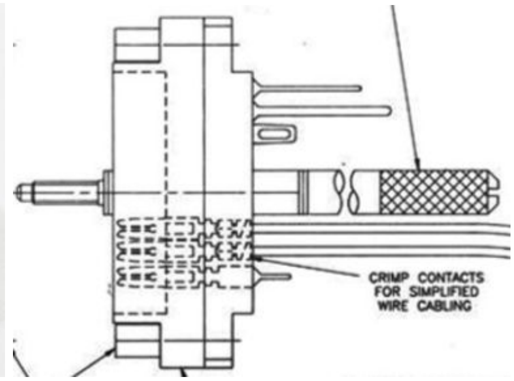


Figure 4.2.6.b: EDAC Connector Section

Function	EDAC Pins	Wire Color
+30 VDC	A,B,C,D	White with red stripe
Power Ground	W,T,U,X	White with black stripe
Analog 1	K	Blue
Analog 2	M	Red
Signal Return	L, R	Black
Discrete 1	F	Brown
Discrete 2	N	Green
Discrete 3	H	Red with white stripe
Discrete 4	P	Black with white stripe

Table 4.2.6.a: EDAC Pins Layout

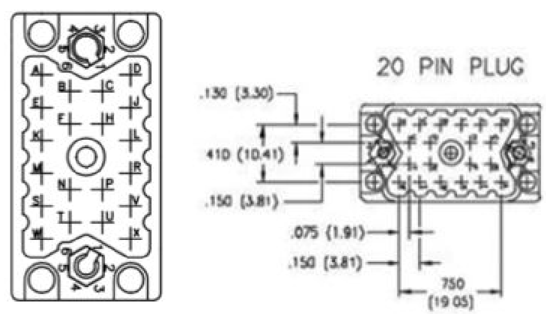


Figure 4.2.6.c: EDAC Receptacle Pins

The electronic connection between SunbYte III and HASP is made by a slack flexible cable from the HASP base plate to the revolving plate.

4.2.7 Improvements on SunbYte II

Following the flight of the SunbYte II, the team has found ways to make the electronics system more robust, compact, and efficient. Considering the many electronic issues that were faced in the previous system, the team has decided to design a printed circuit board (PCB) that will house all the components of the system including the sensors, motor drivers, and microcontrollers. This will ensure that no electrical faults occur such as a short-circuit or out-gassing of solder. As described above, a watchdog backup system will be created to ensure the main processing units are functioning correctly. The SunbYte III system will also attempt to quantify the amount of radiation received by the system to better understand the effect of high energy particles during HASP flights.

A significant problem encountered in SunbYte II was loss of control of the yaw stepper motor, causing the tracking algorithm to be unable to actuate the telescope. The reasons for this are not fully known, hence SunbYte III addresses the problem from multiple angles to mitigate future problems:

1. To avoid low temperature malfunction of components, the new system accommodates heaters, insulation and thermal feedback loops controlled by multiple thermocouples and the MCU.
2. Not using stepper motor acceleration may have caused problems for the yaw stepper motor when rotating the entire SunbYte II payload, potentially causing the motor to miss steps or fall out of synchronisation with the magnetic coils. The new motor drive algorithm suitably accelerates the motors, instead of abruptly increasing from zero to maximum speed.

4.3 Attitude Determination and Control System

4.3.1 Overview

The Attitude Determination and Control System mainly uses image processing to localize the position of the Sun. Images are constantly obtained using a simple webcam interfaced with a RPi microprocessor. Figure 4.3.1.a below represents the ADCS general performance:

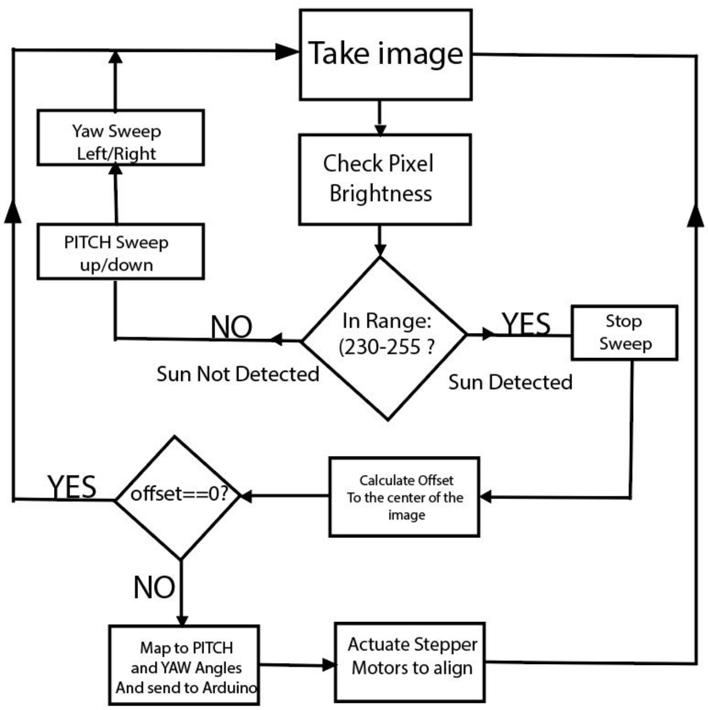


Figure 4.3.1.a: General Algorithm for Attitude Determination

In order to obtain high-quality images of the Sun, it will be necessary to track the location of the Sun. Tracking the Sun is carried out in two steps. Firstly, an algorithm will look for the brightest object in the space and ignore dimmer reflections, provided that the approximate Sun brightness is pre-set. This algorithm is repeated till the Sun is detected. Following verification of step one, the Raspberry Pi will then calculate the offset in orientation of the bright spot (the Sun) from the center of the image, translate the difference into corrections for the yaw and pitch angles, and send them to the Teensy 3.6. The Teensy 3.6 will convert the angles into a number of steps to be executed by the stepper motors, to center the Sun in the image scope.

4.3.2 Detection Process

In terms of detecting the Sun, the main goals are to manipulate the image of the Sun so it becomes a perfect light source without distortion. Once this is achieved, a detection algorithm which runs image processing will detect the brightest source of light. When there is no Sun detected within the scope of the image, a search command will be sent to the MCU, which will sweep the webcam's field of view to look for the Sun.

4.3.2.1 Solar Filter

The tracking process uses the webcam to locate the Sun as it has a wider field of view than the telescopes. The position of the webcam on SunbYte III is shown in the CAD model in Figure 4.3.2.1.a.

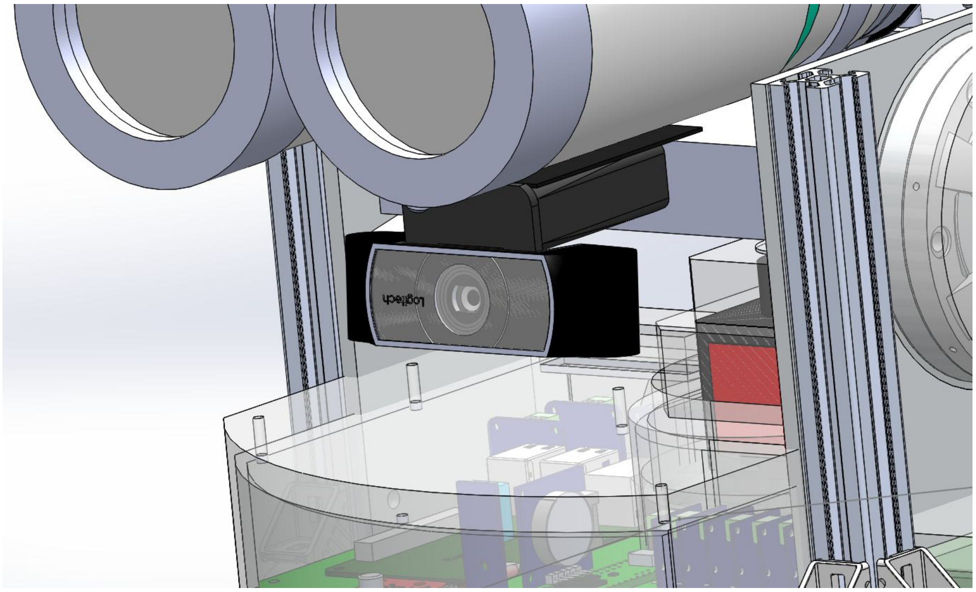


Figure 4.3.3.a: Tracking Camera

The first step in detection is hardware based, where a solar filter is used to eliminate the side reflection beams around the Sun. This is primarily done by a black-film solar filter attached to the webcam as shown in Figure 4.3.2.1.a, greatly simplifying the detection during the process of searching for the brightest object. The black-film solar filter from SunbYte II, shown in figure 4.3.2.1.a will be reused.

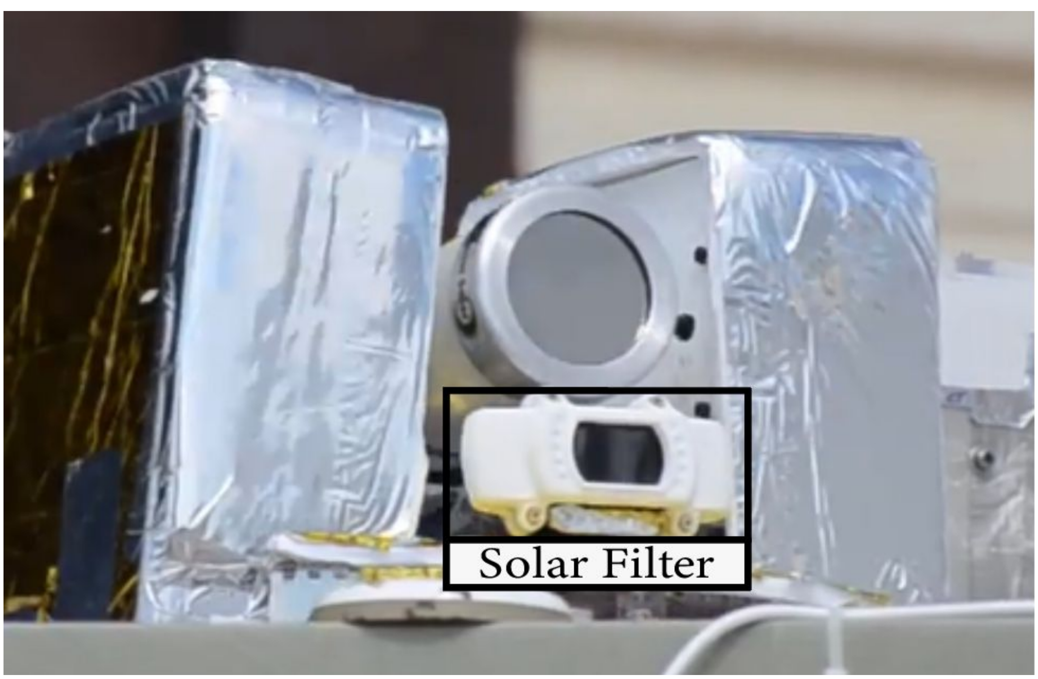


Figure 4.3.2.1.a: On-board Solar Filter for the USB Webcam, shown on SunbYte II

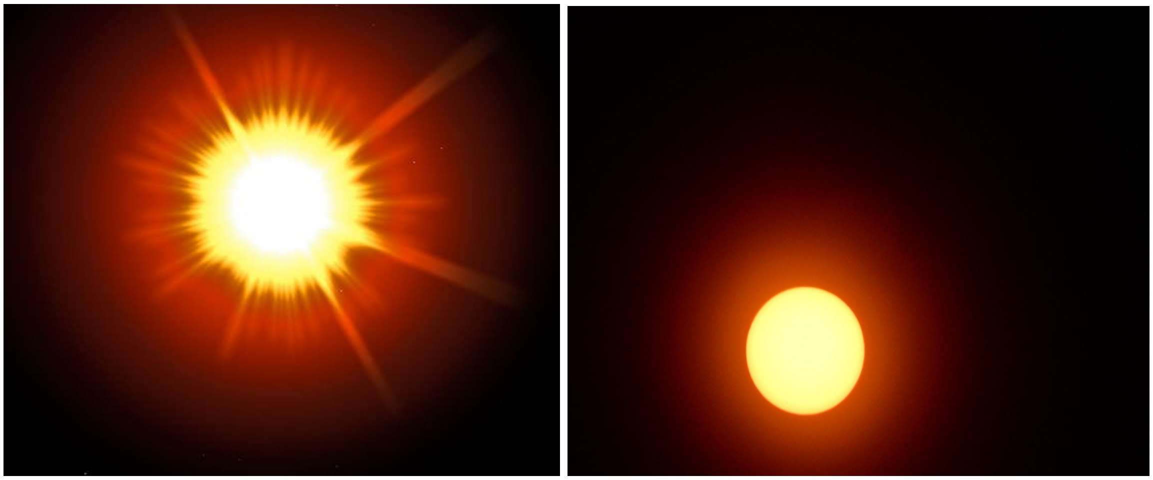


Figure 4.3.2.1.b: The Effect of the Solar Filter

Figure 4.3.2.1.b shows the effects of applying the solar filter to an image of the sun.
The following processes are software based successive steps for Sun detection using image processing:

4.3.2.2 Grayscale

In image processing, colour spaces refer to a certain way of organising colours. There are several colour spaces; RGB, YUV, HSV etc. They are a fusion of two elements, a colour model and a mapping function. RGB is the default colour space that is given from the image captured by the camera. This has to be converted to gray scale, to reduce the complexity of the perception exhibited by an RGB image. In many image processing applications, it is difficult to identify important edges or other features using three ranges of colour, which is the case with an RGB colour space, therefore using gray scale images lowers the difficulty of visualising results and features as well as decreasing the required processing time.

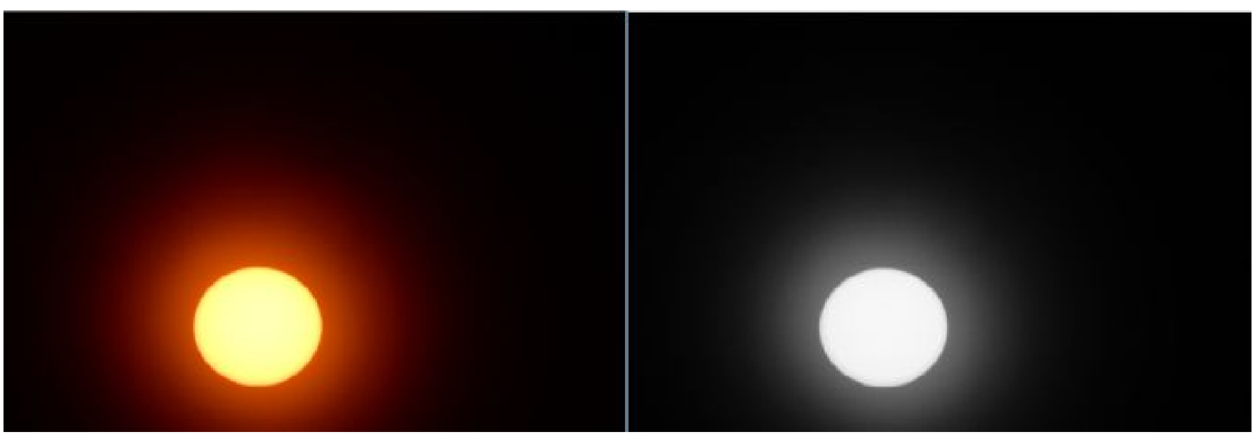


Figure 4.3.2.2.a: Converting to Grayscale

4.3.2.3 Gaussian Blur

The next step is to blur the image using a Gaussian blur filter. In essence, a Gaussian blur filter is a low pass filter that rejects a high difference in image contrast. It creates a blur effect and smoothes the image by removing small darker regions of the Sun, contributing to the main objective to turn the Sun into a pure light source.

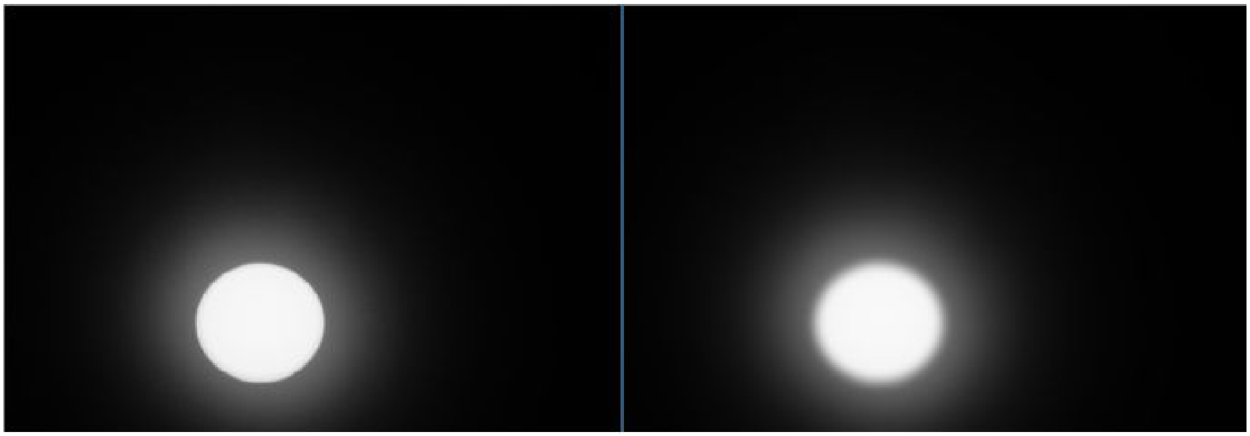


Figure 4.3.2.3.a: Blurring using Gaussian Filter

4.3.2.4 Thresholding

The intensity of a pixel is a 3D argument (RGB), but since this image was converted to grayscale, the dimension of the pixel representing the color space is reduced to one argument representing the intensity of that pixel, which is a value between 0 (black) to 255 (white). A mask is created by thresholding the image. As the most common background is the black space, a threshold is used in a way such that any pixel in the frame with an intensity less than 230 becomes 0.

As can be seen from Figure 4.3.2.4.a, the thresholding turned the distorted image of the Sun to a perfect circular light source with intensity between 230 and 255. This process is the core idea for the detection algorithm.

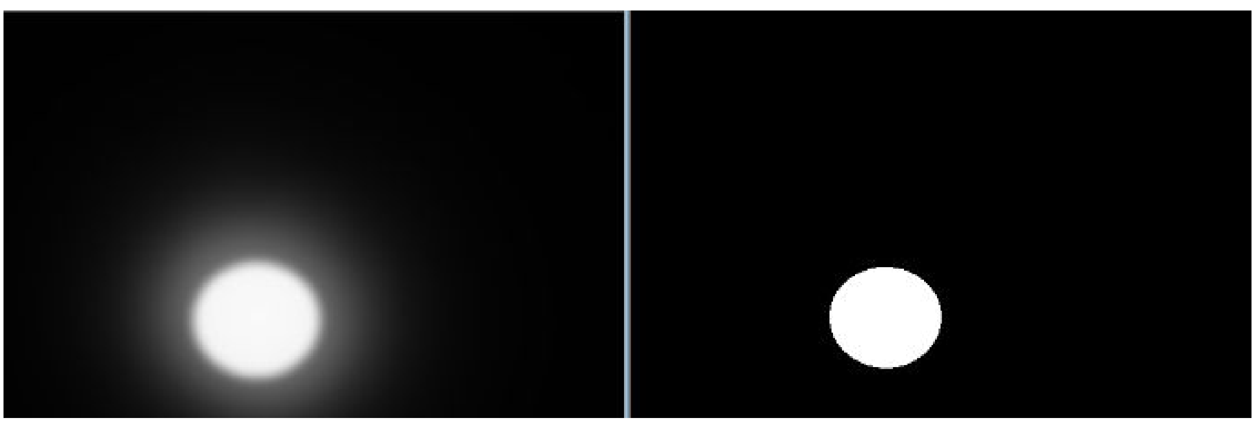


Figure 4.3.2.4.a: Thresholding: Kill off pixels with intensity of less than 230

4.3.2.5 Erosion and Dilation

Erosion and dilation are image processing operations. Erosion takes away the outermost layer of pixels in a geometrical structure, which in turn makes the structure more compact. On the other hand, dilation adds extra layers of pixels to a structure. This results in a smoother masked image by removing any tiny blobs left inside and faster execution when constructing the contour around the area of interest, the Sun.

4.3.2.6 Finding Contours

In the field of computer vision contour analysis is a very important tool. When an image is converted into gray-scale and then thresholded, the resulting image is a group of closed paths that take all possible shapes. These shapes are called contours. Contour analysis is used to identify closed shapes and properties in the masked image in order to acquire detailed information from an image. In this case the contour closes around the Sun, and dimensions such as the area and the center of the Sun can be extracted. Figure 4.3.2.6.a shows the center of the detected object is measurable at this stage.

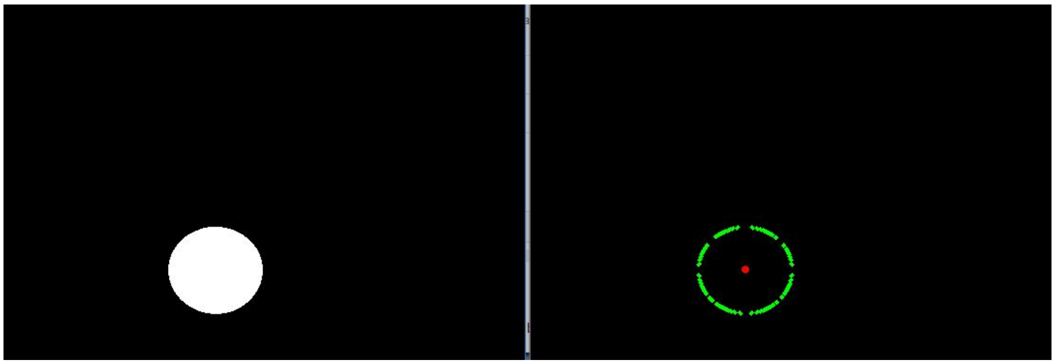


Figure 4.3.2.6.a: Wrapping Contour Around the Detected Object

4.3.3 Tracking process

4.3.3.1 Points of Interest

Once a contour is drawn around the desired object, a calculation of its area is carried out in pixel units. The center of the contour can then be determined and hence the center of the Sun. The centre of the tracking camera frame is calculated simultaneously. Defining the top left corner as the zero point in the Cartesian coordinate system, two main points of the image are determined; the centre of the Sun, represented as a two-by-one vector with each element portraying the position in the x and y coordinates respectively, and the centre of the frame, represented similarly to the centre of the Sun.

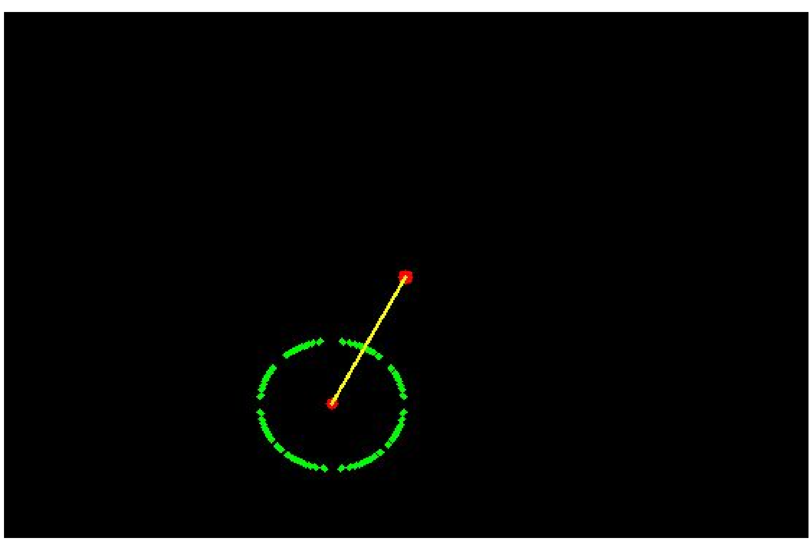


Figure 4.3.3.1.a: Detected object relative distance to the scope center

4.3.3.2 Error Vector

The algorithm then calculates the error vector that is later used as an input to the two motors responsible for the movement in the yaw and pitch axis respectively. The error is defined as the difference in pixels between the centre of the frame and the centre of the contour. Therefore, the error is also a two-by-one vector with the first element being the difference in pixels between the x axis and the second element the difference in the y axis. This is an iterative process, carried out in every frame captured by the tracking camera and within each iteration the error vector is updated.

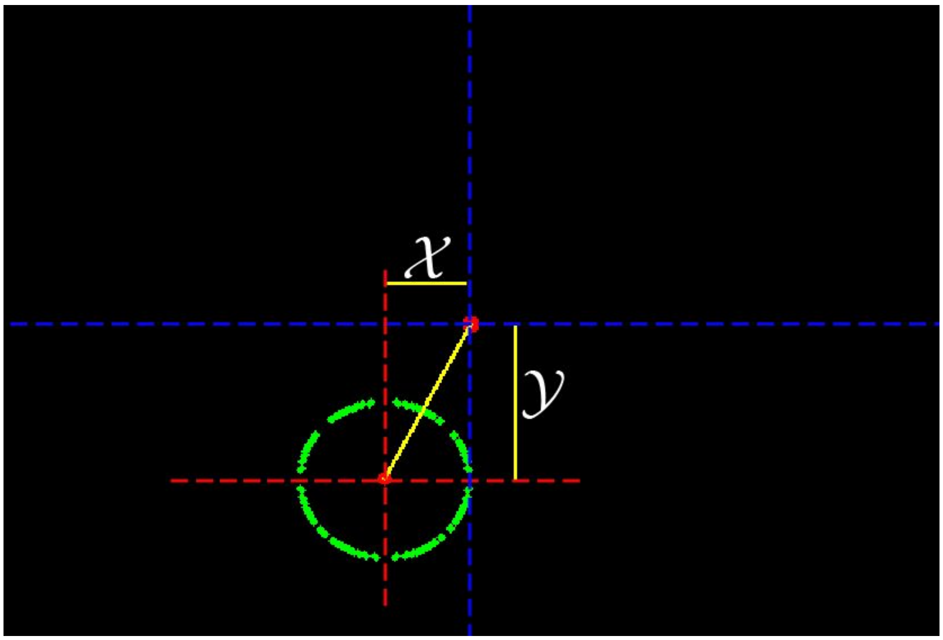


Figure 4.3.3.2.a: Error Vector Calculations

4.3.3.3 Motor Control

The last part of this particular task is associated with the motor movement. Since the error vector is already calculated, both elements of the vector are translated to corresponding angles in degrees. Then, each value is passed to the Teensy 3.6 as a position change command to the respective stepper motor; the first element, corresponding to the x axis value, results in a change in yaw motor position and the second element, corresponding to the y axis value, updates the pitch motor position. The images below are tests carried out using a torch.

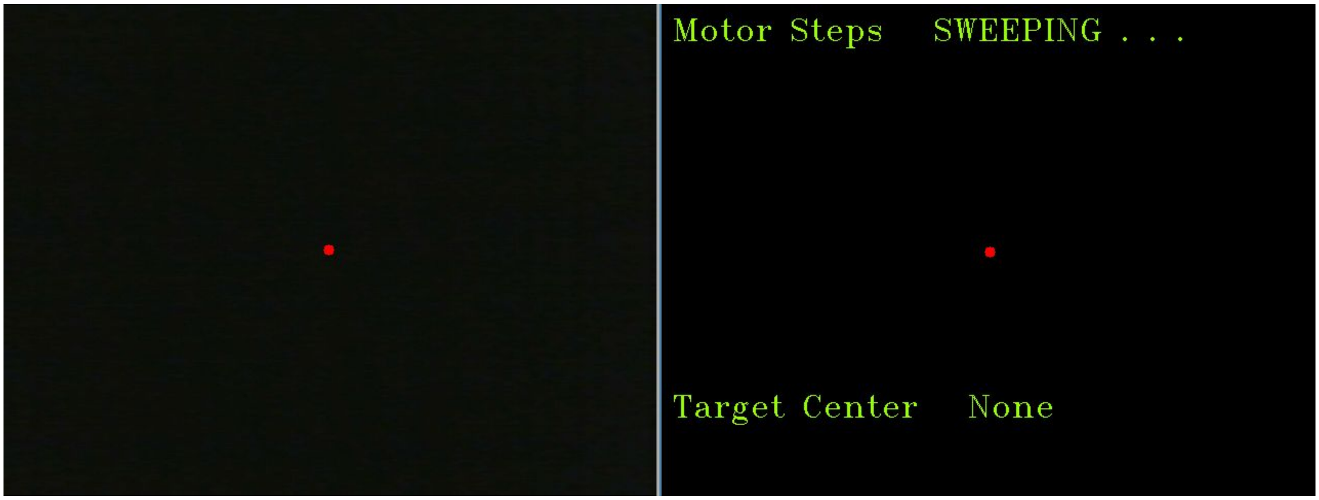


Figure 4.3.3.3.a: If no Sun Detected Within the Image Scope, Start Sweeping

Once the Sun appears within the image FOV, the Sun's centre is found and the required angle adjustment is calculated and sent to the MCU to update the stepper motor positions.

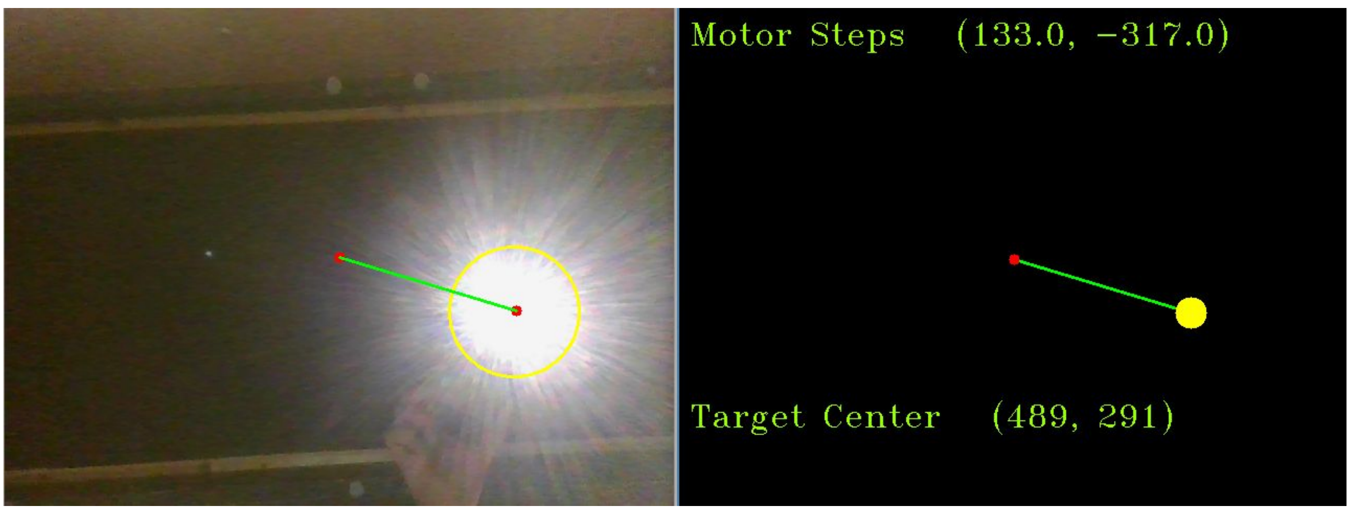


Figure 4.3.3.3.b: Sun Detected, Calculate Error Vector

The hardware required for the process will be a Raspberry Pi, Teensy 3.6 microcontroller, and two 12V DC stepper motors with drivers and encoders. To avoid over-burdening the Raspberry Pi, the stepper motors shall be controlled using the Teensy 3.6.

The stepper motors for pitch and yaw control shall be managed by the Teensy 3.6 through the Big Easy Driver. The Teensy 3.6 shall receive commands from the Raspberry Pi (through I^2C communication) of the new target positions in degrees for the stepper motors to point the telescopes at the Sun. The Teensy 3.6 adjusts the stepper motor positions simultaneously while checking for new serial messages. New target positions shall overwrite old ones to ensure the Sun is always tracked. Using the encoder for position feedback, the stepper motor positions shall be corrected if the target is not reached, due to the stepper motors missing steps.

As seen from Figure 4.3.3.3.c below, the telescope movement has two degrees of freedom created by two motors working on independent planes. The yaw motor works on a vertical axis, while the pitch motor creates rotation around the horizontal axis. The two movements combined create a transformation in the 2D space, which translate a vector (screen center) to the desired point (center of the Sun).
For protective reasons, the movement of the yaw and pitch motors is governed by physical hard limit preventing more than full rotation which could twist the wire connection to HASP around the base of SunbYte III.

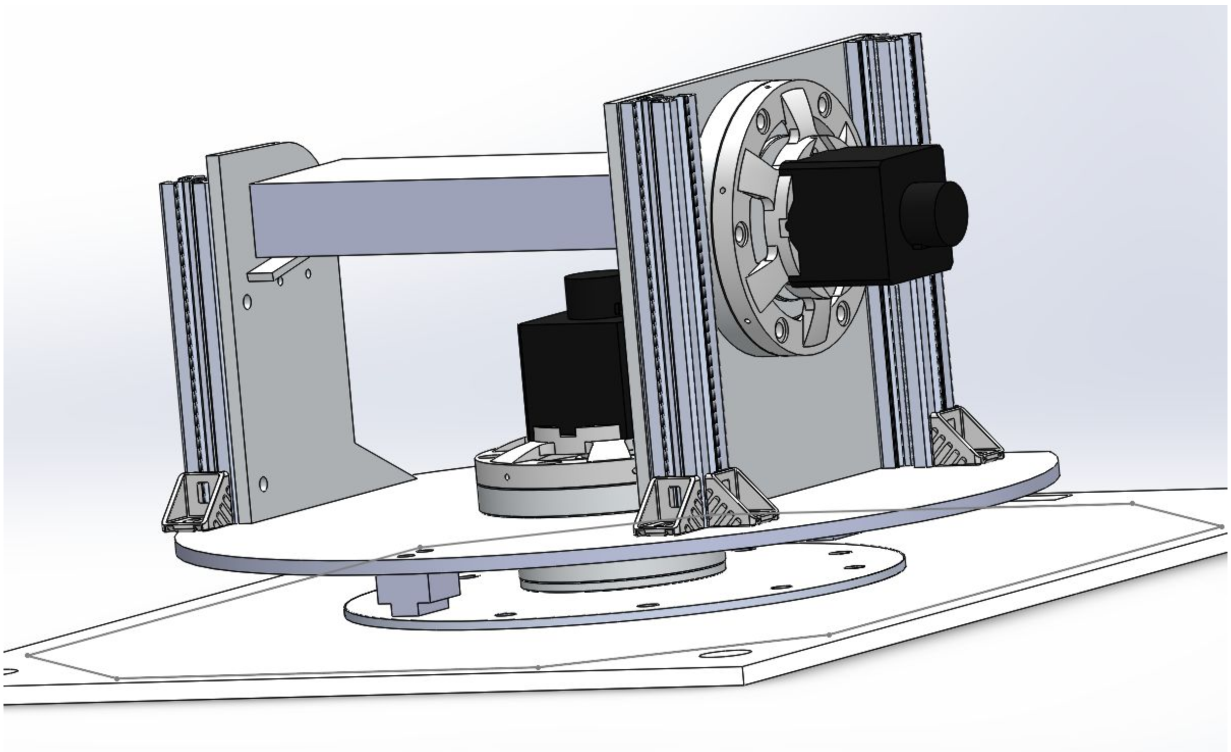


Figure 4.3.3.3.c: Gimbal to Produce Pitch and Yaw Rotation

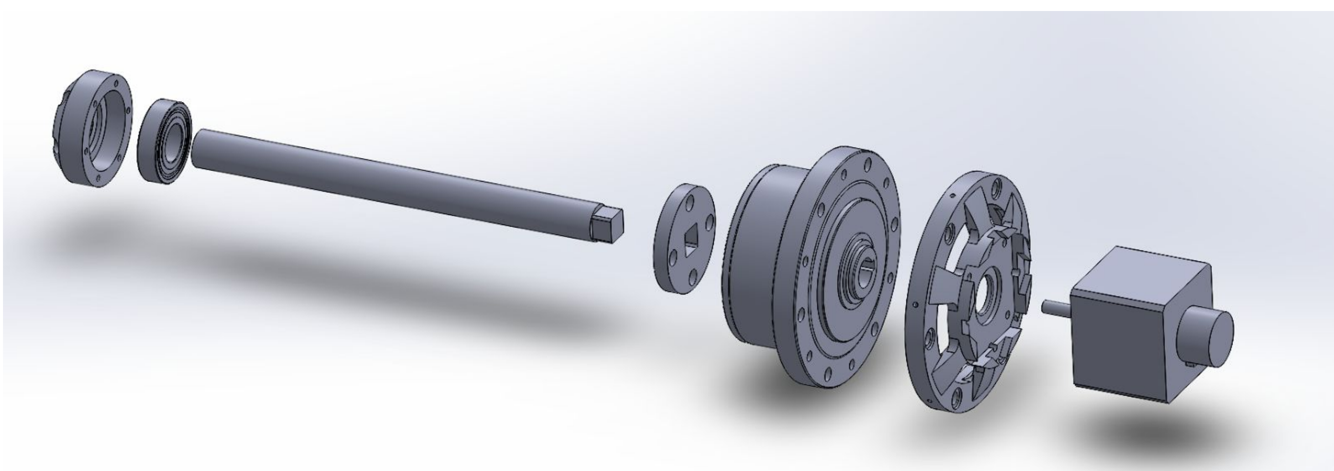


Figure 4.3.3.3.d: Pitch Control Motor

4.3.4 Microcontroller Software Flow Chart

The MCU software shall be architected to allow for simulated microcontroller multi-tasking, enabling multiple operations to be handled by the Teensy 3.6 at the same time. This is made possible by breaking up each operation into small chunks that can be executed quickly at a high frequency. The Teensy 3.6 has a high clock speed of 180MHz enabling it to check the serial buffer for new commands regularly, so they can be acted upon immediately. Figure 4.3.4.a shows the top level MCU multi-tasking algorithm.

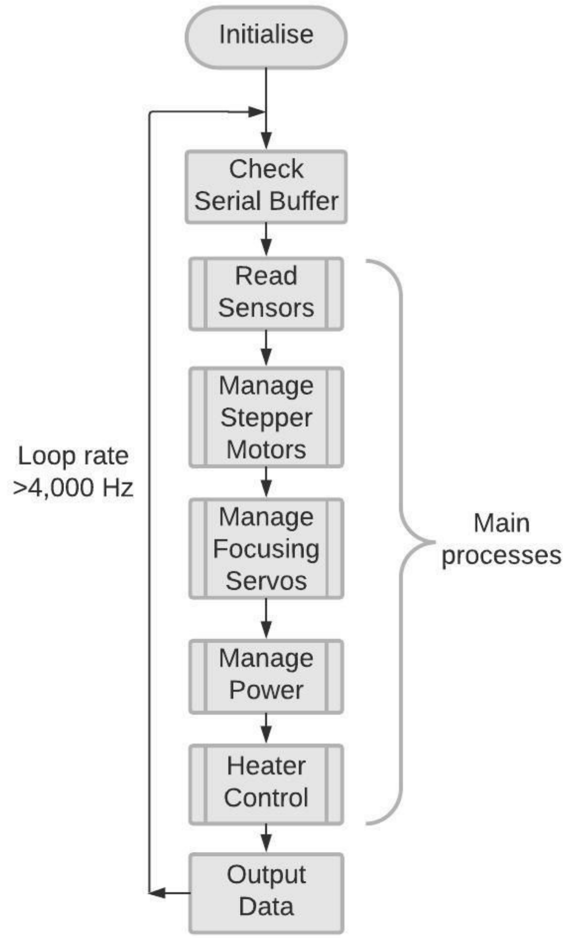


Figure 4.3.4.a: MCU Software Structure

4.3.5 Watchdog Monitoring System

A watchdog timer (WDT) is a piece of hardware that can be used to automatically detect software anomalies and perform a system reset if any occur. SunbYte III will use a WDT to monitor the key processor components, the Raspberry Pi and Teensy 3.6, using the Teensy LC. The Low-Cost Teensy will monitor both devices, which expects to receive pulses at regular time intervals demonstrating normal performance behaviour. A system reset will be generated if no pulse is received for a period of time, sending a reboot command to the device, or if this is unsuccessful, cutting power to the processor before reinstating it as a force reboot. This safety system can be used to automatically reset components after a software or hardware fault. The Teensy LC will perform watchdog monitoring duties, checking for and reading pulses from Raspberry Pi and Teensy 3.6.

4.3.6 Improvements on SunbYte II

Since the number of Raspberry Pi microprocessors has been reduced to one, the software efficiency shall be optimized to run more tasks on the single device. This will be achieved through Object-Oriented programing to perform image processing. A main class will be created containing all other functionalities such as color conversion, filtering, and error calculations, simplifying the addition of extra functionalities.

In terms of hardware, stepper motor movements will be monitored by optical incremental encoders, which will provide position feedback for the motors. If a motor fails to move, this will be detected by the encoder and manual control will be attempted. The encoders will also be used to limit the rotation of the movement, and instead of using hardware limit switches to stop the movement, physical limits have been placed and the encoders shall calibrate on startup to detect these physical limits. Alternatively, absolute encoders could be used.

On SunbYte II, the yaw rotation was limited to prevent the HASP to SunbYte cable from tangling around the base, using limit switches at each end, which caused the yaw sweep to change direction upon contact. The motors on Sunbyte III are equipped with optical encoders which can detect when contact with the hard limit is made from the encoder signal. The hard limit for the yaw axis is shown in Figure 4.3.6.d.

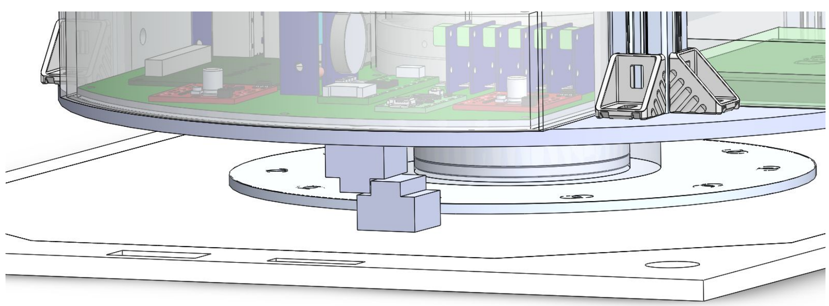


Figure 4.3.6.d: Yaw motion limiting system

4.4 Thermal System

4.4.1 Overview

The thermal system uses a combination of active and passive temperature control methods. The majority of the thermal control system is passive, but it is augmented with active heaters for equipment with a low temperature tolerance. Figure 4.4.1.a shows the essential levels in constructing a thermal insulation system, however not all levels are required for every application. Each component is analysed separately to determine which thermal system layers it requires. Components shall be first assessed on whether they require heating, then for insulation, and finally surface finishes.

Figure 4.4.1.a: Thermal System Diagram

Given that the temperature range outside the SunbYte III structure will vary between -80 and 50 degrees Celsius the following performance requirements have been defined:

- The temperature inside the SunbYte III structure shall be maintained within the range 5 to 50 degrees Celsius.
- An ambient temperature measurement of the SunbYte III structure shall be made at 1 Hz.

4.4.2 Heat loss

Heat loss in space can be estimated using thermal equations such as Planck's Law for black body radiation to estimate the power required to heat components.

$$B_\nu(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$$

The heating effect of the Sun must also be considered, however as the structure will be made of aluminium or titanium, the emissivity of the structure will be relatively low [18].

4.4.3 Active Heating

Heaters are used in satellites during operation to maintain a suitable operating temperature. The additional thermal energy input shall prevent components cooling below their respective operating temperatures in the space environment.

In this case, the subsystems and component temperatures of The Sheffield University Nova Balloon Lifted Solar Telescope need to be analysed to find out their corresponding thermal requirements. The two areas to investigate are the mechanical and electrical components as seen in Table 4.4.3.a.

Table 4.4.3.a: Temperature tolerances of typical spacecraft components

Bearing Mechanisms	-45 to +65°C
Electronics equipment (operating)	-10 to +40°C

Although the bearing mechanisms have a higher temperature range, they do not produce heat like the electronics equipment. It was decided to actively heat the mechanical components of the telescope such as the stepper motors used for pitch and yaw control.

4.4.3.1 Selection Process

Active systems can be mechanical or thermoelectric devices generate heat through moving parts or through electrical resistance respectively. To narrow the variety of options down, the design requirements in table 4.4.3.1.a were used.

Table 4.4.3.1.a**:** Heating design requirements

Size and Shape	Power Consumption	Thermal environment
The heaters need to be small to fit in the payload envelope.	The heaters need to use either the 5V or 12V voltage line supplied by the experiment.	Air density is low, so neither fan heaters nor convection heaters can be used.
The heaters need to be flexible to fit on to the mechanical parts.	The heaters can only use a maximum of 50W. This is allocated by the electrical power systems team as the maximum power consumption of the whole experiment.	The ambient temperature drops to approximately -60 degrees Celsius when the gondola reaches around 20 km so it must be able to heat up quickly.

From the design requirements above, a suitable heater type are ultra-thin flexible heaters [19], which are available in a variety of shapes sizes, with both round and rectangular heaters available. The round heaters would be easy to wrap around but the diameters available are not large enough to fit around the stepper motors. Thus, the chosen shape was rectangular, the optimal size available was 80 mm in length and 20 mm in width to fit onto are NEMA size 17, 43.18 mm by 43.18 mm [20].

Table 4.4.3.1.b. Selected Heater Specifications

Heater Material	Nano Carbon Silicon
Power	4.85 Watts
Power Intensity	0.3 W/cm^2
DC Voltage	12 V
Resistance	29.7 Ω
Current	0.4 A
Reference Temperature Rise	60 ºC

There will be two heaters wrapped around each of the two stepper motors (pitch and yaw), in total there will be 4 heaters consuming 19.4 Watts of power and 1.6 Amps of current. Once the heaters are purchased, they will be tested on the telescope at temperatures below freezing to analyse their effectiveness.

Figure 4.4.3.1.a: Model TSC0320032hR198 heater

4.4.4 Passive Heating

Passive heating is used as insulation for the purpose of maintaining temperatures and locking in the heat. This can be used on top of active heating systems or on its own if the components are expected to maintain heat. It is a priority to always have surface finishes on the top of insulation. Passive heating will be used to insulate the stepper motors, the science cameras, the filters, and the PCB, using multi-layer insulation.

Multi-layer insulation is the general name given to insulation blankets that are built up of multiple separate sheets. It is primarily intended to reduce excessive heat loss by thermal radiation. This insulation is effective as it uses layering of different materials (acoustic membranes and a vapour control layer) along with a shiny surface finish insulate the components. Multi-layer blankets consist of Mylar and Kapton sheets with a single layer of aluminized polyamide facing outside and silver aluminium foil facing in. 10-15 sheets per 5 mm of blanket thickness shall be used. The multi-layered insulation has thin layers of cloth mesh to enhance the insulating ability of the Kapton and Mylar sandwich. Kapton tape will be used to seal the multilayer insulation where it will be needed, primarily around the actively heated components.

An alternative to the above is Airflex insulation, an ultra thin reflective foil [21]. This insulation is versatile and 10.4 mm thick, which suits the needs of the smaller parts of the telescope. It can also be used as a blanket over the top of different components. If needs be, the Airflex can be used with standard insulation to boost insulation performance as well as reduce the overall thickness of the insulation.It is important for the insulation to have a low emissivity because this will reduce the heat output, meaning that more heat is stored within the components of the system.

Table 4.4.4.a: Properties of Airflex

Price	£138.12
Length	12.5 m
Width	1.2 m
Roll size	15 m
Roll Weight	9 kg
Thickness	10.4 mm
Thermal conductivity	0.034 W/mK
Thermal resistance	0.30 m^2K/W.
Emissivity	0.05
Fire resistance	Euroclass B-s3,d0.

Airflex can be used by shaping sections around components to form a layer of insulation around the SunbYte III. However, gaps in the shapes will lead to emissive behaviours and therefore it would be essential to use insulation tape to seal the system. A good supplement is Breather Foil Tape which is also very cheap and malleable [22].

Table 4.4.4.b: Breather Foil Tape Properties

Price	£6.59
Length	50 m
Width	75 mm

Some other excellent heat insulators under the flight conditions are fibreglass, Aerogel, Batt, polyurethane foam, and polystyrene. These may be used inside the multi-layer installation if the insulation is not strong or thick enough.

More research and testing needs to be done to justify the insulating materials that will be used on SunbYte III.

4.4.5 Preventing damage from radiation

The solar radiation incident at right angles on an area of 1 m² at a solar distance of 1 AU (149 598 200 500 km) is approximately 1371.5 W/m², and is called the solar constant.

Solar reflectors such as white paint may be used to reflect the incident solar energy. They have low absorptance and high emittance, Chemglaze A276 is an example of this [23], however it is usually quite expensive, ranging from £250-£750. There is also the option of Quartz mirrors that act as optical Solar Reflectors [24], these are cheap, but are available only in very specific sizes. The chosen material will be aluminium foil, because it provides an excellent surface finish and is a great insulator. Layers of polyimide or polyester coated with thin layers of aluminium foil will be used to prevent radiation damage to the electrical equipment. These sheets are used for their low emissivity, ability to absorb visible light and reflect radiation, therefore the sheets will be used to insulate the PCB.

4.4.6 Heater Control

Negative feedback control will be used to control temperature via Thermocouples and a Teensy USB-based microcontroller, as shown in Figure 4.4.6.a.

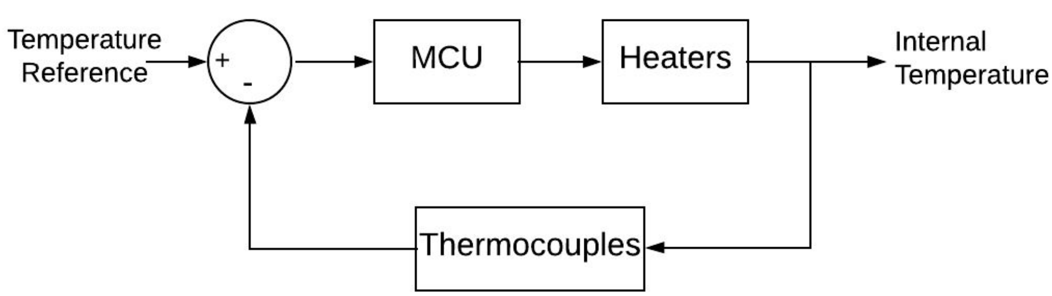


Figure 4.4.6.a: Control System for the heater control

The controller (Teensy 3.6) will implement temperature ranges according to the external temperatures. The thermocouple sensors will measure the internal temperature and calculate the difference between the external and internal temperatures. Thermocouples will be placed around the external surfaces, on the stepper motors that are being actively heated and all other components that generate heat. The thermocouples that will be used are K-type - Adafruit MAX31850. To control the temperature, the MCU will be read the sensors and control relays for the heaters.

The heaters wrapped around the stepper motors are control by the MCU using relays to maintain their temperature between the lower and upper temperature thresholds. While HASP is ascending, heaters shall be prioritised due to the lower temperatures, this is important because the higher air density at lower altitudes leads to higher heat losses. Once sufficient altitude is reached heaters will be used only when necessary to prevent the temperature dipping below the lower temperature threshold, because the priority shall be capturing images, which requires power to be directed to the stepper motors.

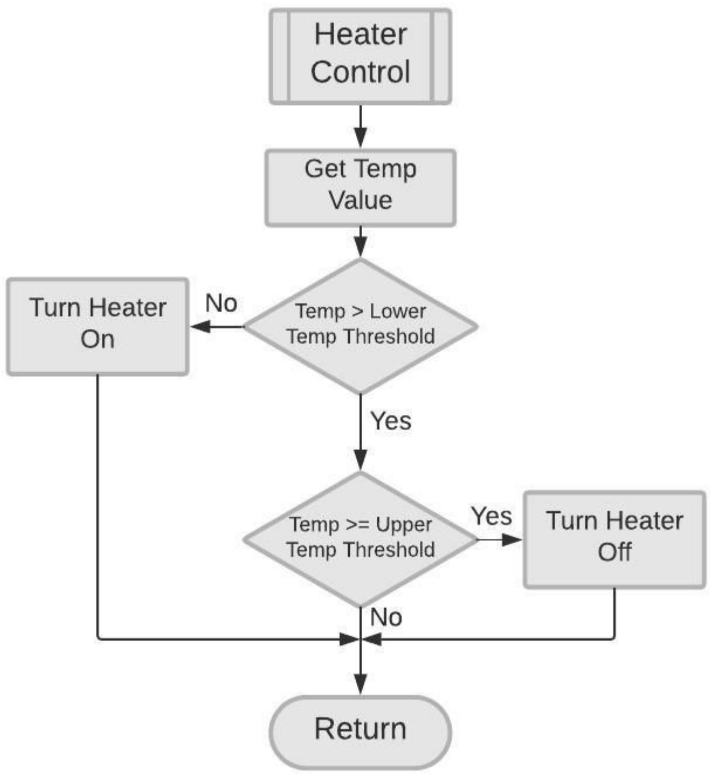


Figure 4.4.6.b: Heating control flow chart

4.4.7 Implementation of thermal management system

Insulating caps will be placed over the components. Depending on the internal heat generation and how critical the components are to operation, this will change which parts are implemented in the thermal system. The most advanced version of the system includes 10 mm thick insulation on the non-dimensionally sensitive areas, with places that require tighter packaging being specifically shaped for the area in Figure 4.4.7.b. Embedded in the insulation are the heaters (shown in red) that will be used to provide warmth to the components, and maintain a suitable operating temperature, shown in figure 4.4.7.a. The heaters will have a specific area of the insulation that they will fit tightly into.

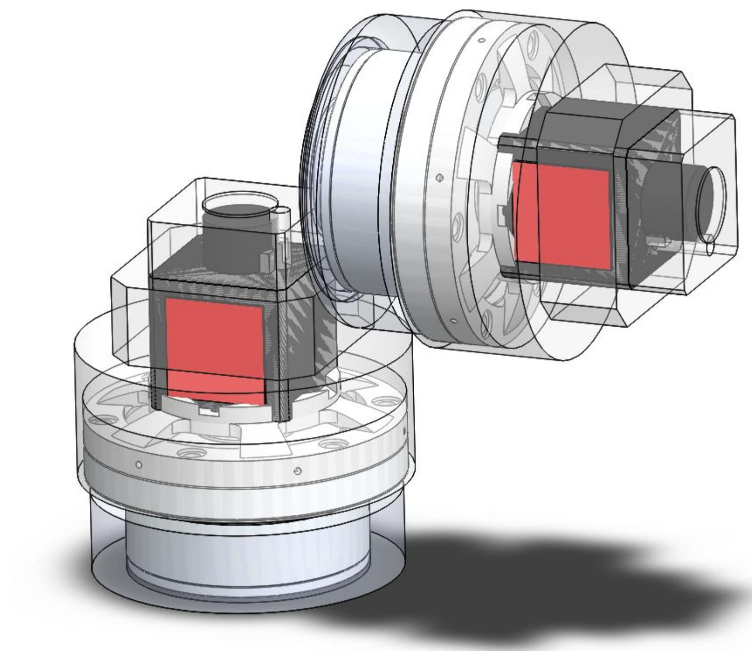


Figure 4.4.7.a: Visualization of Heating System on Motors and Harmonic Drives

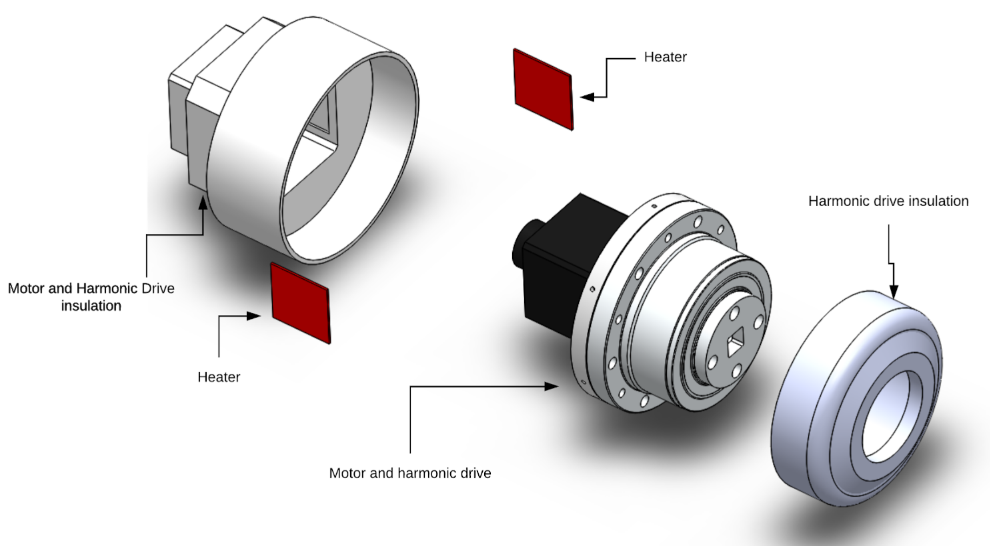


Figure 4.4.7.b: Exploded View of Insulation and Heaters

As can be seen from Figure 4.4.7.c the layout of insulation for the payload can be seen. The insulation around the electrical components is 10 mm thick where space is available, restricted areas, particularly on the sides have 2 mm thick insulation. Since the electronics produce more heat on their own, they don't require a source of additional heat. Figure 4.4.7.d has a sectional view of the harmonic drive and stepper motor insulation and heaters.

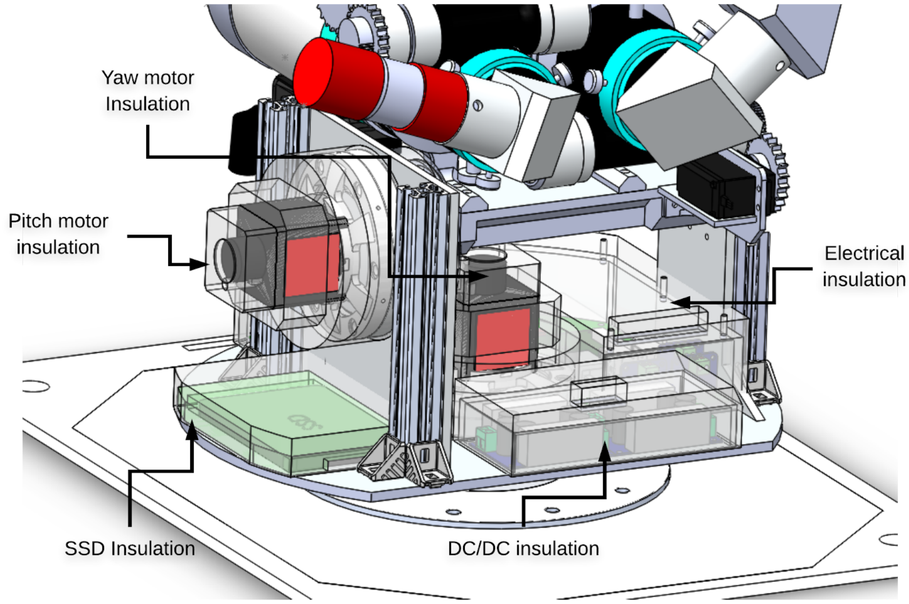


Figure 4.4.7.c: All Insulation on Assembly

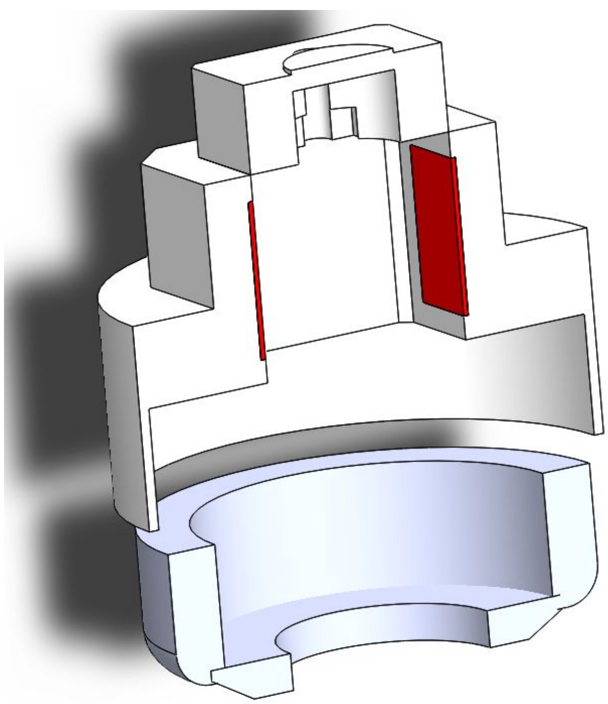


Figure 4.4.7.d: Sectional View of Pitch Motor and Drive Insulation

4.4.8 Improvements on SunbYte II

In SunbYte II, a layer of 15 mm of insulating polyethylene (PE) foam was fixed inside the box covering the electronics to protect them from cold temperatures. The motor driving the yaw of the telescope was mounted onto a square plate, which in turn was mounted to four Bosch-extrude legs. The housing was made of laser-cut acrylic screwed to the sides of the Bosch legs. Its purpose was to enclose a layer of insulating foam around the motor and electronic components. The motor driving the pitch movement of the telescope was enclosed within foam insulation and aluminized Mylar foil which was wrapped around the foam to protect possible damage of the enclosure via solar radiation as shown in Figure 4.4.8.a. There was a hole for cables to escape from the bottom face of the insulation.

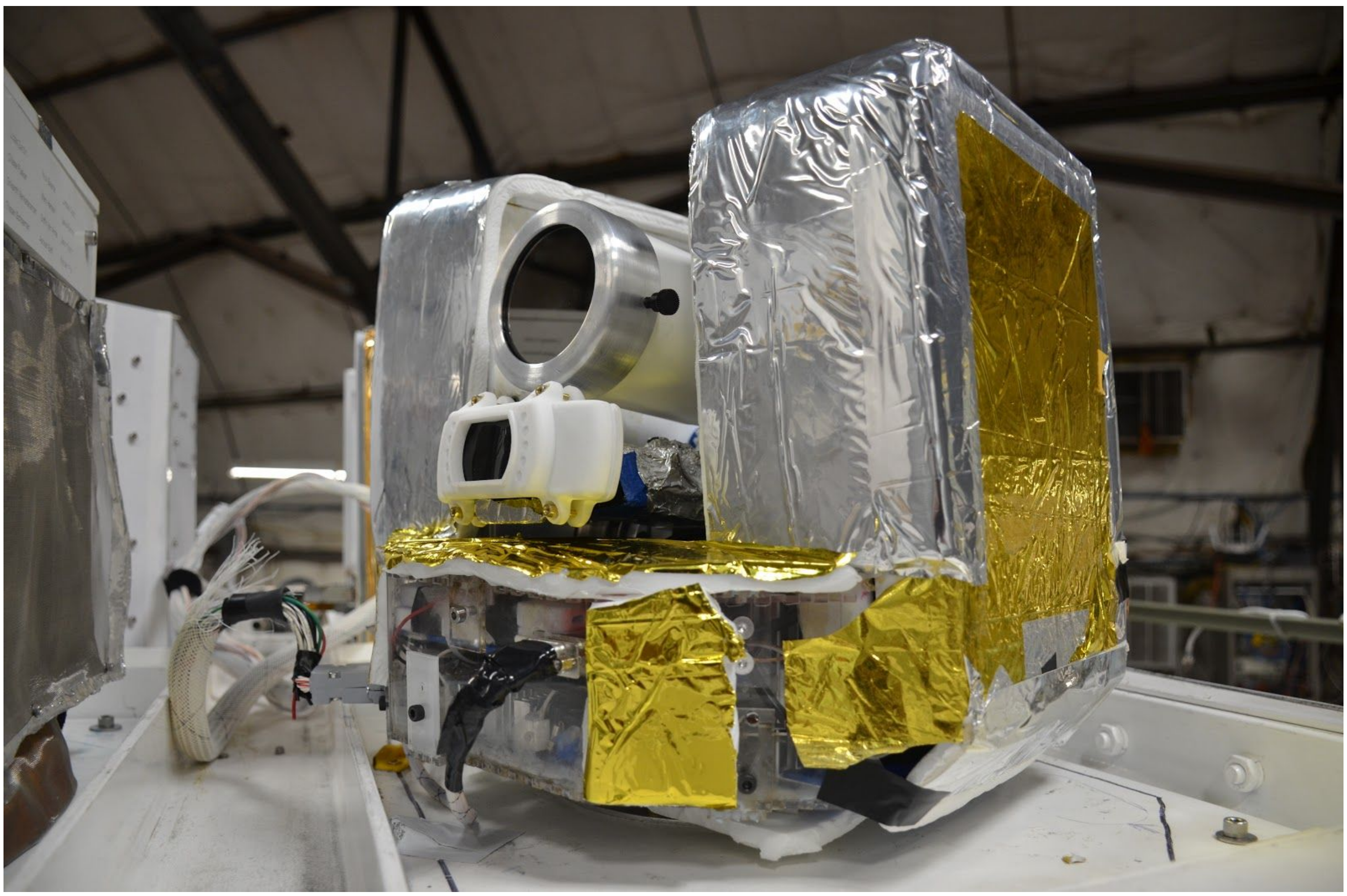


Figure 4.4.8.a: SunbYte II Shown With Insulation

The housekeeping data as shown in Figure 4.4.8.b and Figure 4.4.8.c has been used to analyse the system performance from the SunbYte II's HASP flight in 2018. At an altitude of approximately 10 km, the ambient temperature fell below -20 degrees Celsius. At this point it is believed that the yaw motor experienced difficulties due to a lack of heating and insulation as there was no movement in the recorded data of the yaw motor. The pitch movement data also indicates that the motor was slower than usual and the range of movement was reduced. It can be seen that the ambient temperature oscillates as the gondola rotates and faces the Sun, hence the ambient temperature shall be determined as the average temperature of multiple ambient thermocouples on SunbYte III. The E-box temperature is more stable and suggests the thermal insulation functioned well. It can be concluded that the stepper motors were insufficiently heated and insulated, hence the SunbYte III thermal system has been designed to correct this.

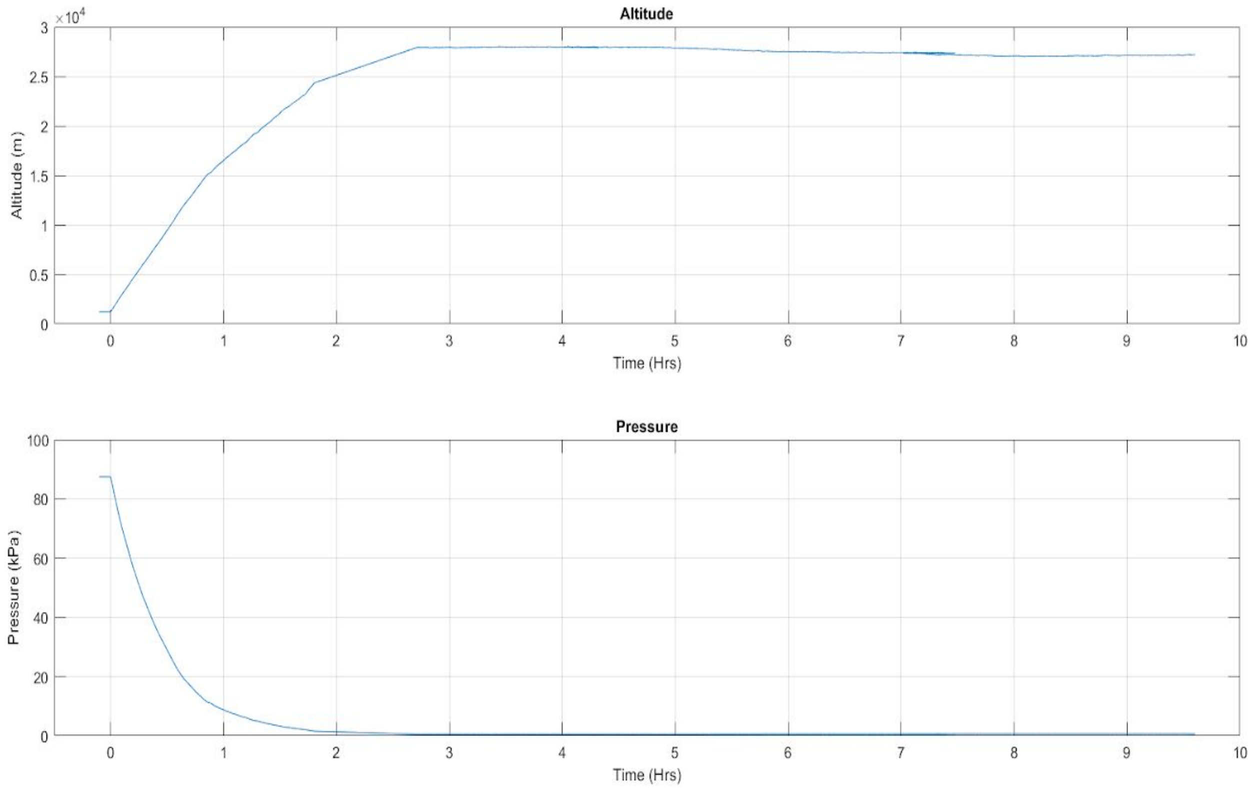


Figure 4.4.8.b: Altitude and Pressure over time

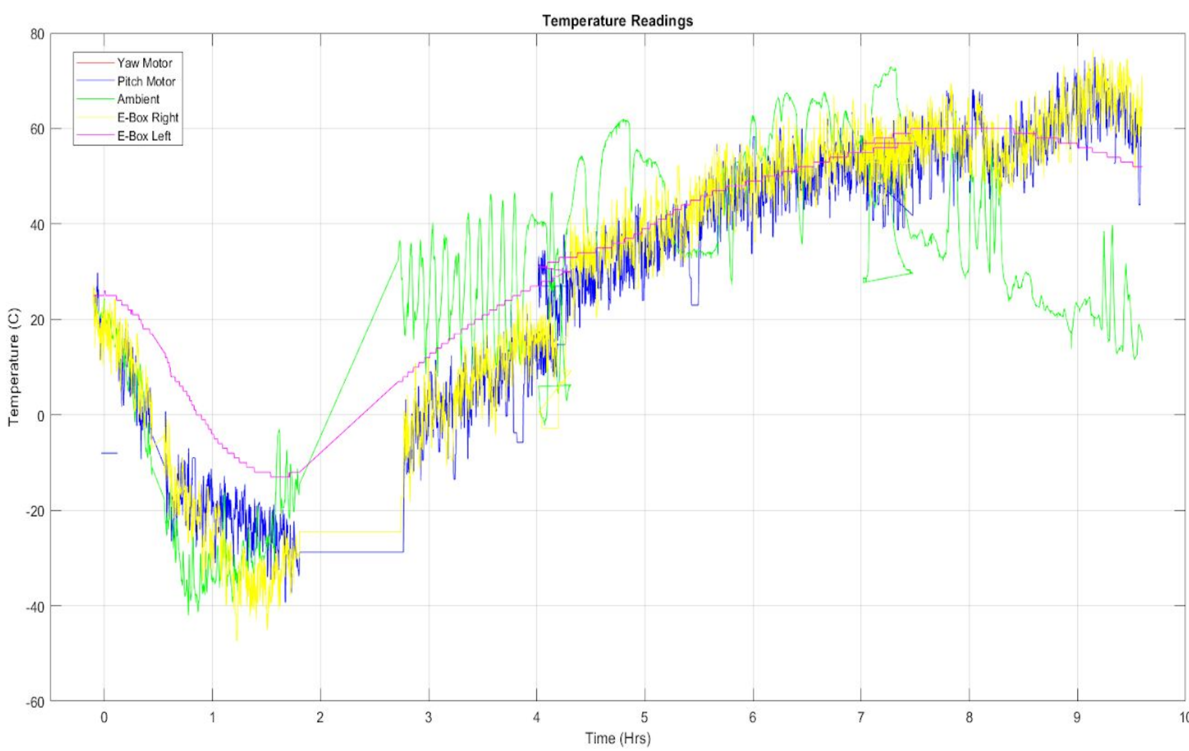


Figure 4.4.8.c: Housekeeping Data from HASP flight 2018

The thermal control issues encountered during the SunbYte II flight will be resolved for SunbYte III with a combination active and passive heating systems. The heaters will be placed around the most exposed parts, which are primarily the pitch and yaw stepper motors. The passive heating components will be placed around the mechanical structure, electrical components, science cameras and filters. Thermocouples will be used to measure the temperature of each stepper motor, the PCB, inside each science camera’s insulation and the external surface of the telescope for ambient temperature.

4.5 Communication System

The SunbYte III system will not use the analog and digital channels, as the Rx, Tx, and ground lines provided by HASP are sufficient. The serial link has a baud rate of 4800 bits per second, standard RS232 communication shall be used to interface between HASP and the SunbYte III system.

4.5.1 Uplink and Downlink

The communication system will provide a telemetry link between the system and the ground station. The function of the downlink will be to provide performance information of the system whilst in flight. Data such as the temperature, pressure and location (x, y, z axis) will be recorded. The data acquired from the sensor readings shall be stored in the SSD. At a minimum of every 5 minutes the latest data is transmitted to the ground station, where it will processed to produce performance graphs, as shown in section 4.5.3, the graphical user interface section.

Based on the feedback from the downlink, the system can be commanded from ground via the uplink capability. The uplink commands will provide the means of controlling the SunbYte III manually, when the autonomous systems fail or malfunction. The communication structure uses the first five bits for redundancy checksum, providing security for the command uplink and ensuring the system is not answering other payload commands. The command only executed is the return of checksum is matched.

Table 4.5.1.a and 4.5.1.b list the commands used for the uplink and the expected data for the downlink, respectively.

Table 4.5.1.a: Uplink Commands

Command	Byte	Notes
CRC redundancy check sum	0x3E 0x00-0x00 0x00	First five bits reserved for CRC check
Ping	0x00 0x00	Ping the Raspberry Pi
Vertical Pan mode on (default)	0x00 0x02	Allows pitch motor to move
Vertical Pan mode off	0x00 0x03	Stops pitch motor
Horizontal Pan mode on (default)	0x00 0x04	Allows yaw motor to move
Horizontal Pan mode off	0x00 0x05	Stops yaw motor
Vertical control	0x00 0x06- 0x01 0x1E	Vertical position of gimbal (0 to 70 deg) 0.25 deg steps
Horizontal control	0x01 0x1F- 0x02 0x7D	Horizontal position of gimbal (+/-175 deg) 1 deg steps

Sweep	0x02 0x7E	A command to move all motor through full range in a set sequence
Restart	0x02 0x7F	Restarts full system
Focus increment	0x03 0x7C - 0x03 0x87	Moving Focuser forward in (0.5mm per step)
Focus decrement	0x03 0x88 - 0x03 0x93	Moving Focuser forward in (0.5mm per step)
Yaw threshold value	0x04 0x5D - 0x04 0x66	9 preset values
Pitch threshold value	0x04 0x67 - 0x04 0x71	9 preset values
Focus set-point value	0x04 0x72 - 0x04 0x7C	9 preset values

Table 4.5.1.b: Downlink Format

Information	Byte	Format	Description
Housekeeping	2 Byte	SR	Start
	1 Byte	X	Record Type Indicator
	10 Byte	TXXXXXXXXXX	Unix Timestamp
	2 Byte	XX	Record Size
	1 Byte	X	8 bits of the record checksum
	1 Byte	X	Watchdog signal
Time and Position Data	125 Byte	String	Requested GPS Time and Position Data
Power Data	5 Byte	AXXXX	Total power
	5 Byte	BXXXX	Pi power
	5 Byte	CXXXX	Teensy Power
	5 Byte	DXXXX	Pitch Motor Power
	5 Byte	EXXXX	Yaw Motor Power

Temperature values	5 Byte	UXXXX	Surrounding Temperature
	5 Byte	FXXXX	Electric box Temperature
	5 Byte	GXXXX	Pitch Motor Temperature
	5 Byte	HXXXX	Yaw Motor Temperature
	5 Byte	IXXXX	Focus Motors Temperature
Pitch Data	5 Byte	JXXXX	Pitch Motor movement recorded
	5 Byte	KXXXX	Pitch Threshold
Yaw Data	5 Byte	LXXXX	Yaw Motor movement recorded
	5 Byte	MXXXX	Yaw Threshold value
Focus Motors data	5 Byte	NXXXX	Focus Motor Power
	5 Byte	OXXXX	Focus Motor Threshold value
Sensor's details	5 Byte	PXXXX	Pressure
	5 Byte	QXXXX	Dosimeter
	5 Byte	RXXXX	Humidity
	36 Byte	S1XXXX - S6XXXX	Compass (IMU)
Picture	24000 Byte	String	Compressed Picture Taken (Estimate)
End	3 Byte	END	End of file

4.5.2 Cyclic Redundancy Check (CRC) Checksum

CRC is a check scheme that used to detect accidental changes to raw data. The CRC checksum has been selected due to its robustness and reliability.

A predetermined number is entered and stored in both the receiver and transmitter. For transmission data of size n-bits, the first k bits is the useful message, the remainder (n-k) bits are the frame check sequence (FCS). The transmitter generates the FCSs by dividing the data by a predetermined pattern and attaching it to the end of the frame.

The receiver performs the identical division using the incoming frame and predetermined pattern. Once the receiver calculates the remainder. If this is identical to the received FCS, the message is shown to be correct, otherwise it is incorrect.

An example of the process is shown in Figure 4.5.2.a:

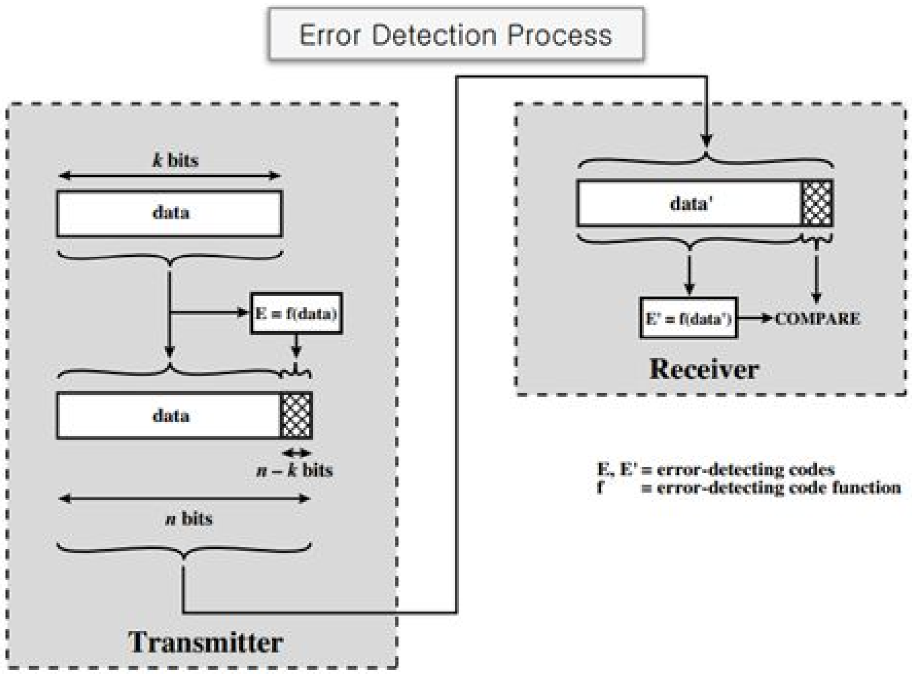


Figure 4.5.2.a: Error Detection

4.5.3 Graphical User Interface (GUI)

A ground based system is planned to be designed and implemented to automatically acquire the data from the URL given, and manipulate it to be properly recorded and displayed on a user interface for visualisation and monitoring by ground control. The software of choice for the development of the GUI will be MATLAB due to its versatility as well as greater functionality.

The GUI will display the following: data temperature, movement of gimbal in x, y, and z axis, altitude, and pressure. It will follow a similar format as shown in Figure 4.5.3.a.

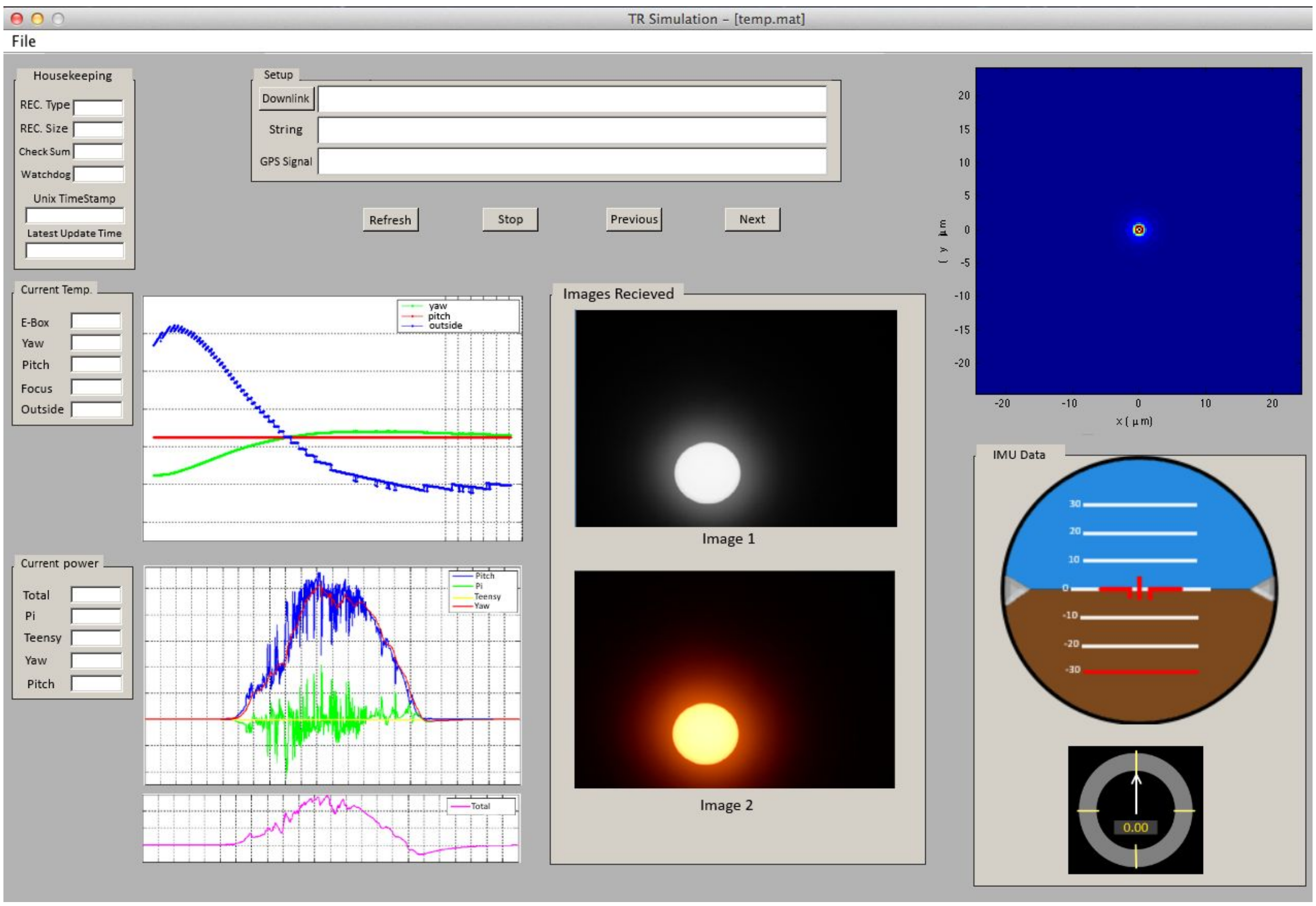


Figure 4.5.3.a: Example of GUI of Downlink Interface

4.5.4 Improvements on SunbYte II

The communication system of SunbYte III will be greatly improved compared to the previous SunbYte II system. The previous system consisted of three Raspberry Pis: a Tracking, Science, and Networking Pi. The Tracking and Science Pis were connected via a serial to the Network Pi. The main issues with this setup were the following: difficulty in debugging, complexity in code, and unreliability in the system. If, for example, the Tracking Pi's serial cable connection to the Networking Pi became loose or failed to work, the entire program would crash. Combining the three computers into one computer will ensure a safe connection between the Raspberry Pi and the NASA serial connection modem. Debugging of the system will become easier as there will only be one point of failure in the system, instead of three points as in the previous system. Furthermore, we will make the code 'object-oriented' to ensure that the system is robust. To do this, we will follow standard design procedures such as developing a UML class diagram and building a test plan to ensure each one of the requirements P9, O3, O5, D12 and D13 are satisfied. The communication system will be tested rigorously by simulating it on the serial monitor of a computer.

4.6 Structure

A significant change from Sunbyte II is the accomodation of two telescopes. It was decided to keep both telescopes attached to one horizontal shaft, which will be positioned closely above the yaw stepper motor. Various components have been resized and moved to allow for this configuration. The circular base plate is cut to allow the extended focusing system of the telescopes pitch up to 60 degrees. Yaw motion will be achieved by actuating the yaw stepper motor, rotating the whole structure.

The shaft, made from titanium is fixed on one end to a bearing and to the other by the pitch harmonic drive, shown in figure 4.6.b. The harmonic drive model has a gear ratio of 160, meaning that after 160 revolutions of the motor, the shaft rotates once. The harmonic drive provides the precision necessary to orientate the telescope towards the Sun and increases the torque in both axes. When combined with the already high holding torque of the bipolar motors, the telescope actuating system is insensitive to outside disturbance.

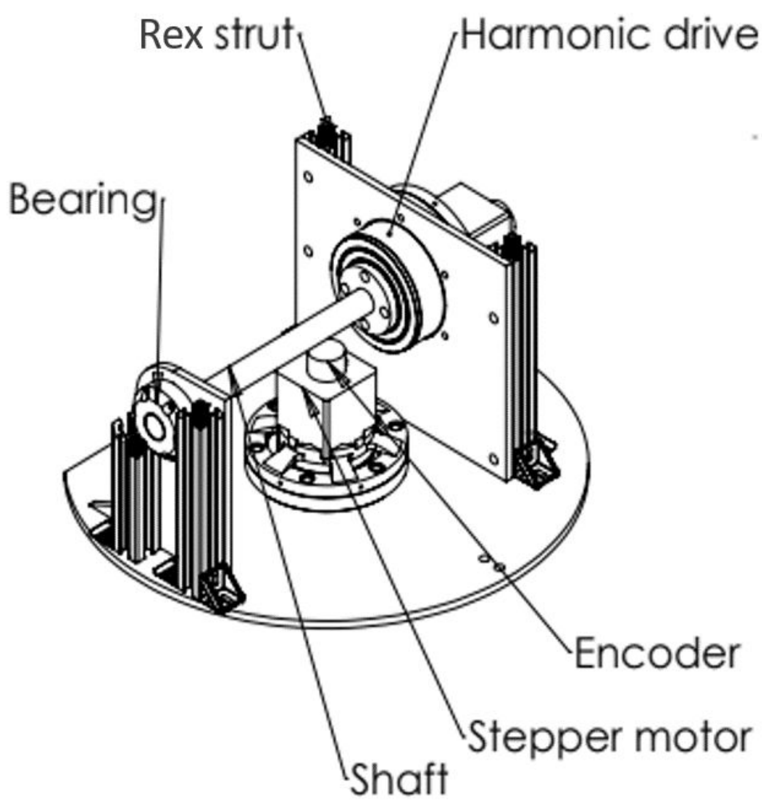


Figure 4.6.a: Actuating Mechanism

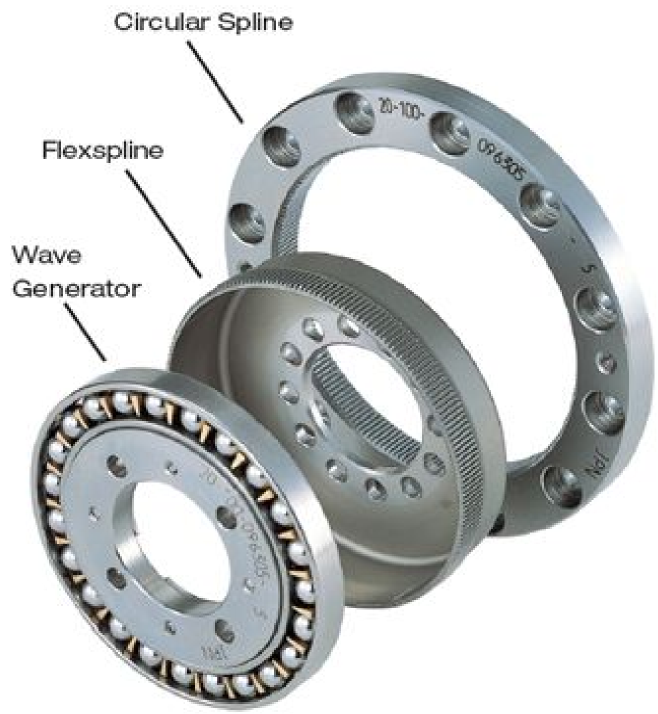


Figure 4.6.b: Harmonic Drive [28]

4.6.1 Assembled System

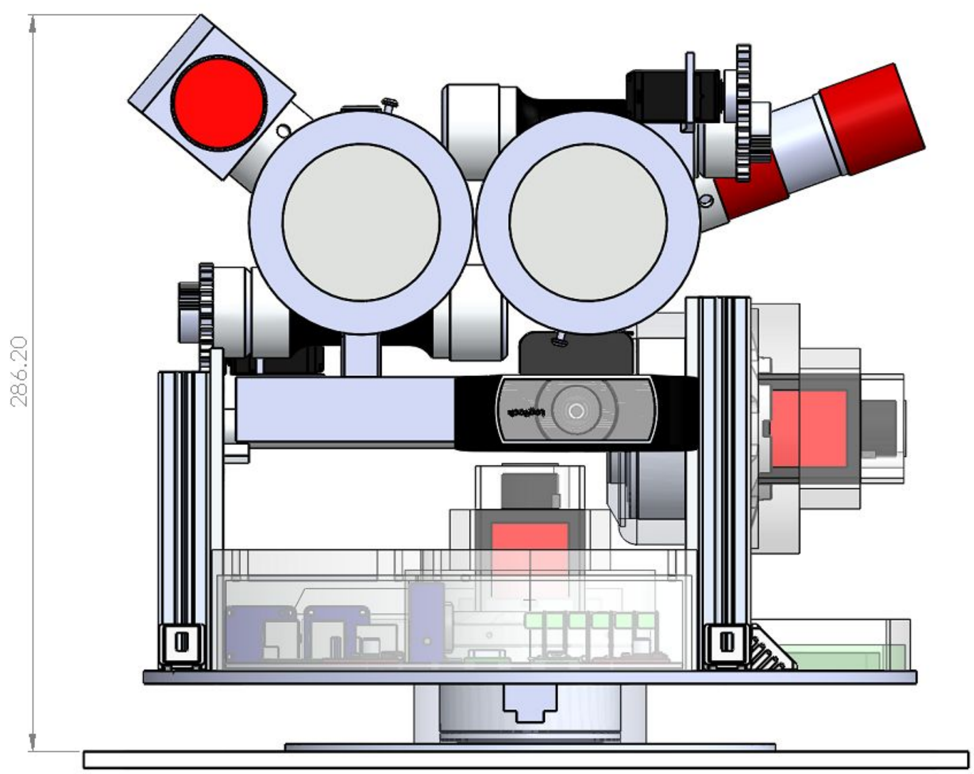


Figure 4.6.1.a: Front view

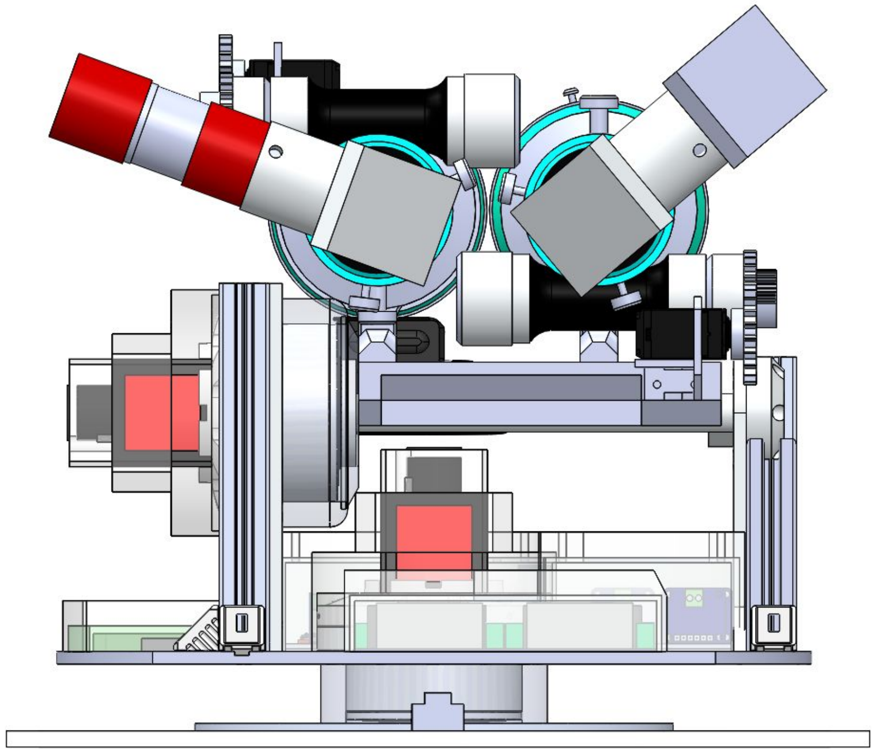


Figure 4.6.1.b: Rear View

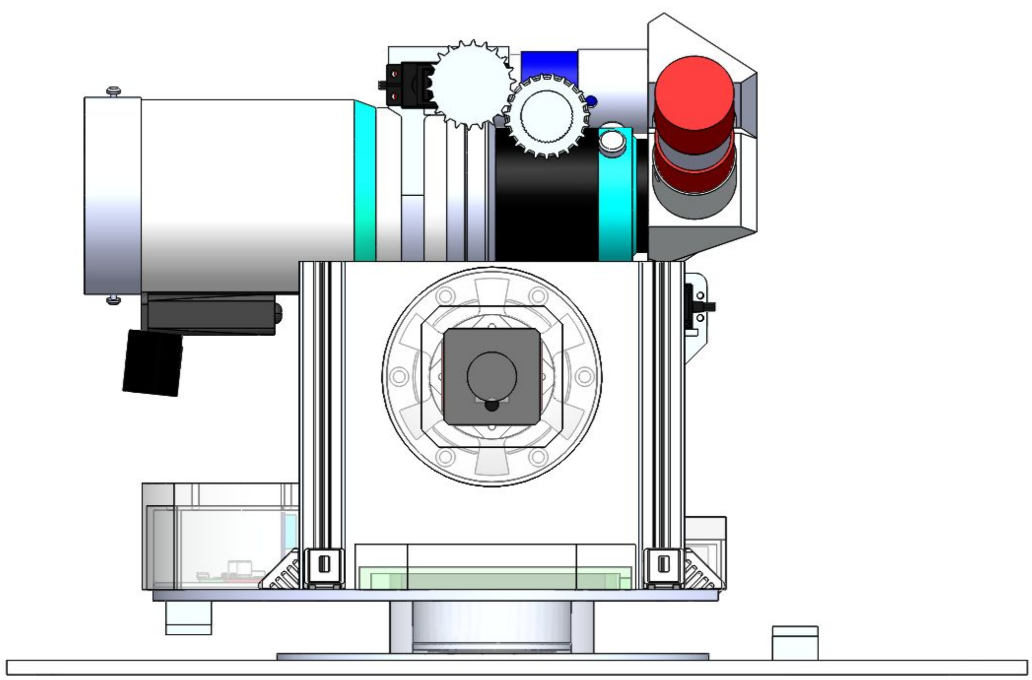


Figure 4.6.1.c: Left view

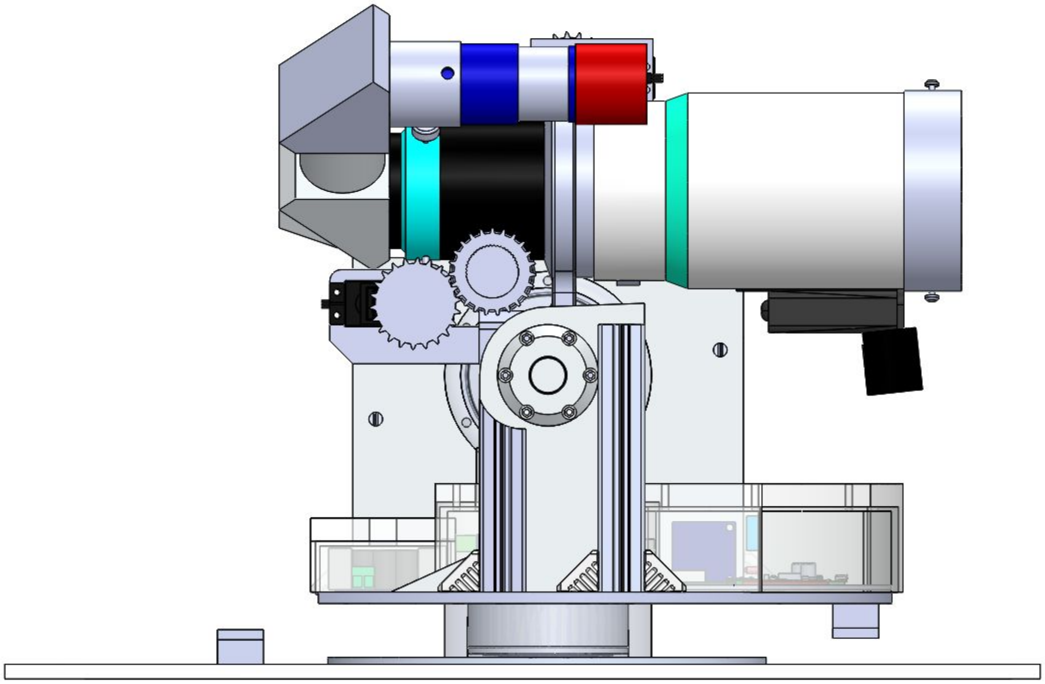


Figure 4.6.1.d: Right View

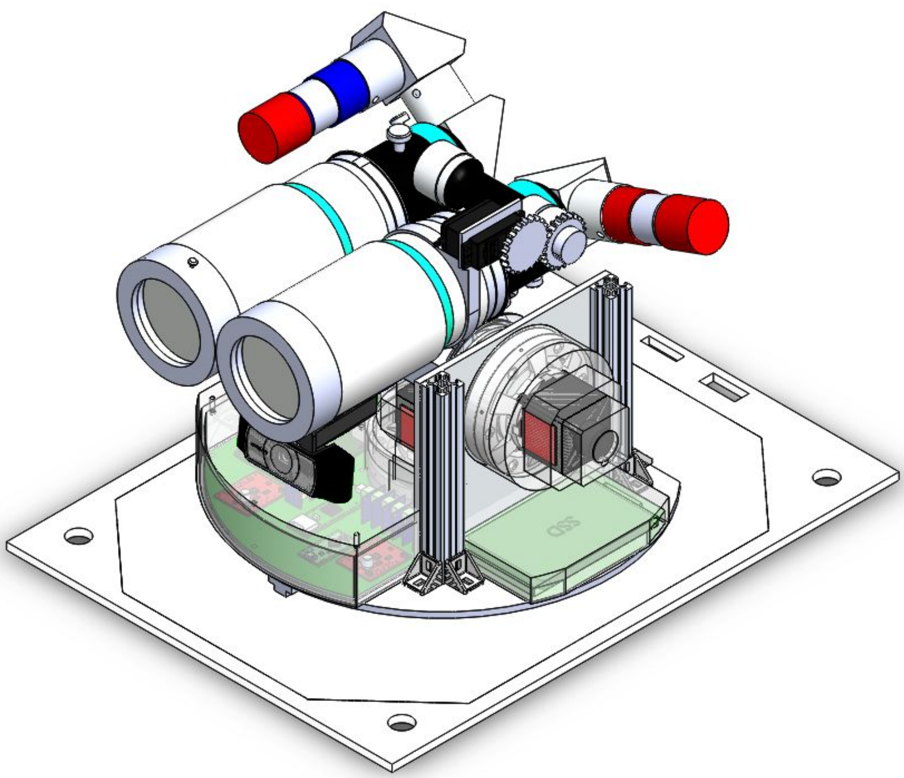


Figure 4.6.1.e: Isometric view

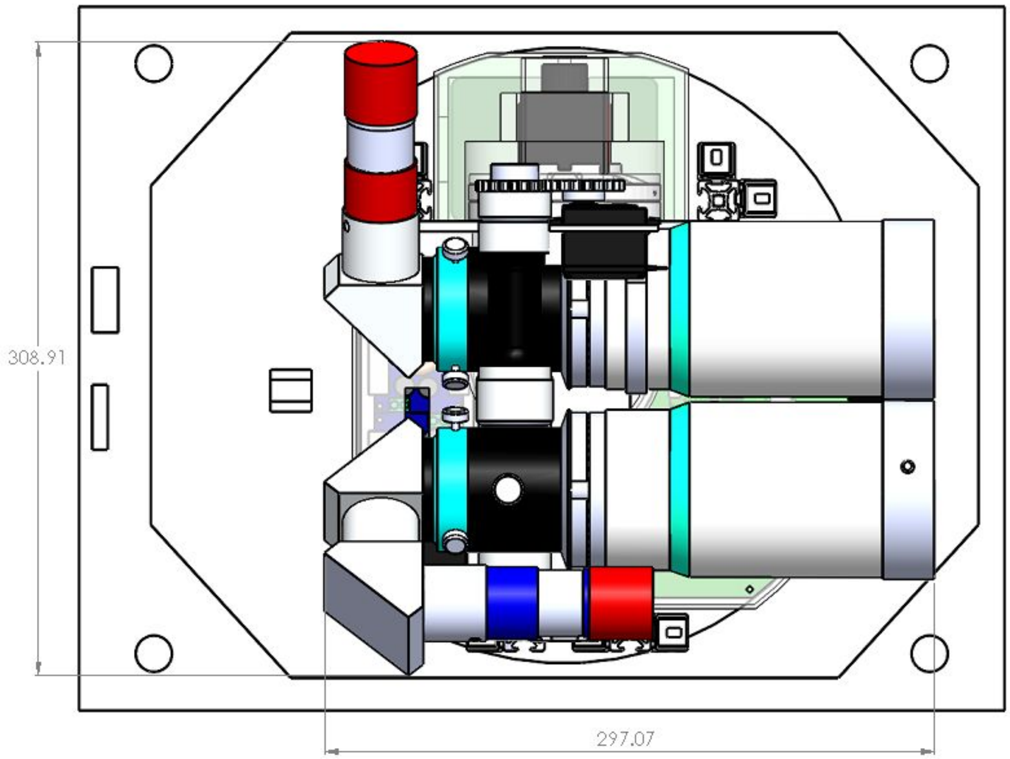


Figure 4.6.1.f: Top view

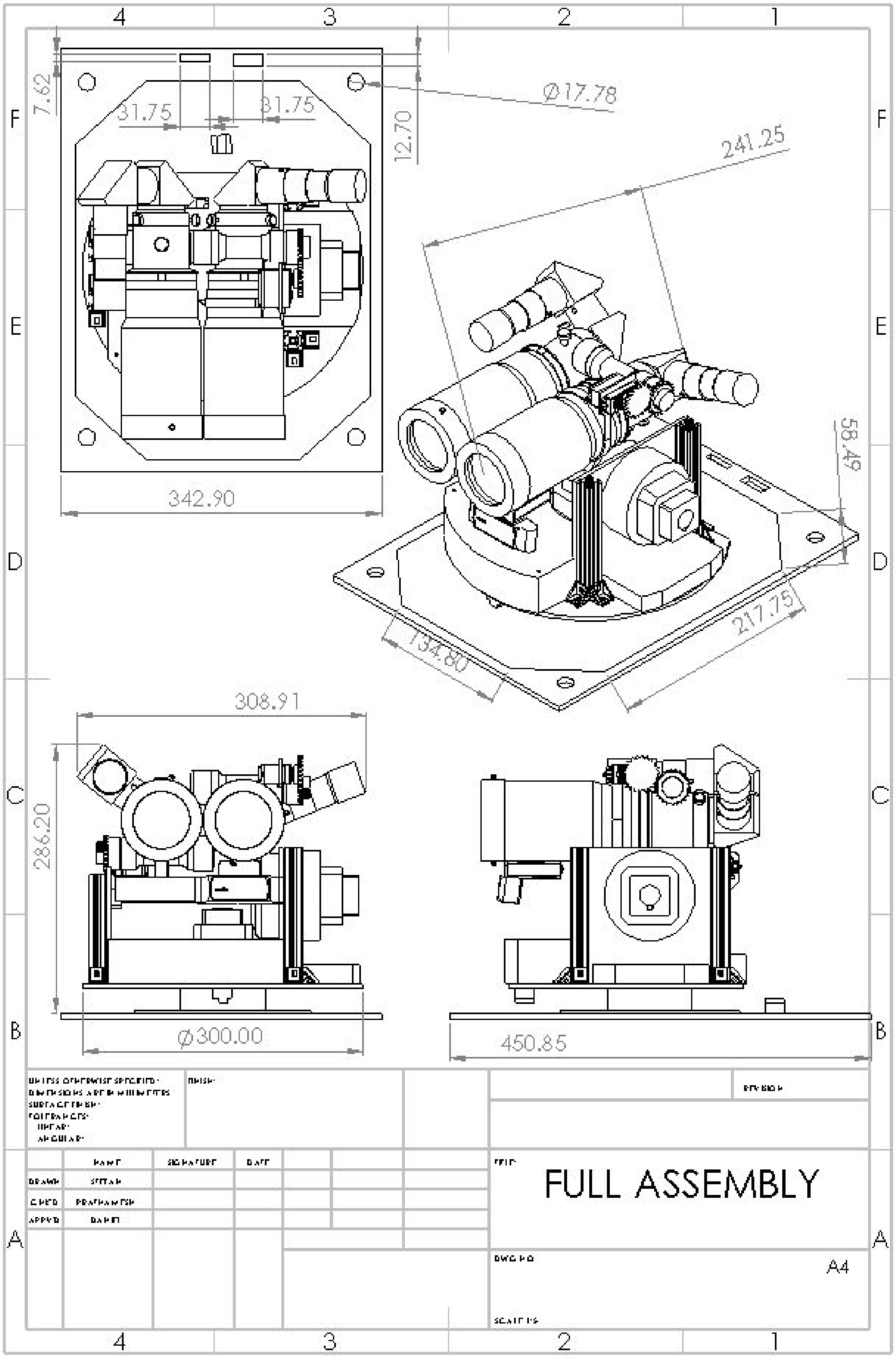


Figure 4.6.1.g: Full Assembly

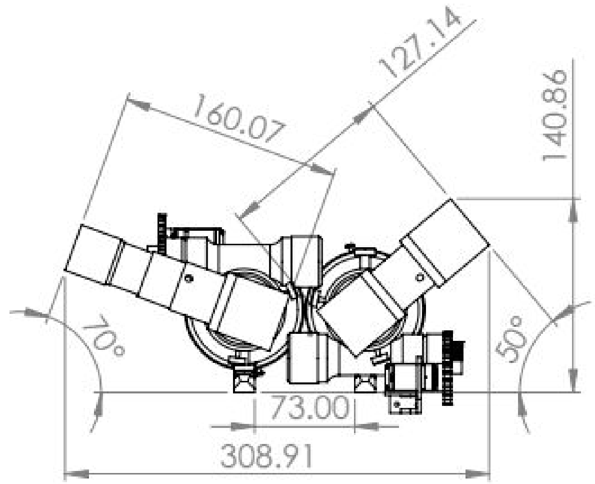


Figure 4.6.1.h: Telescope Angles

For ease of comparison, the final assembly of Sunbyte II is shown in Figure 4.6.1.i. The SunbYte III electronics casings are more compact when compared to the previous generation of SunbYte, reducing the sizes of these casings allows two telescopes to be equipped, to capture images of the Sun at two wavelengths.

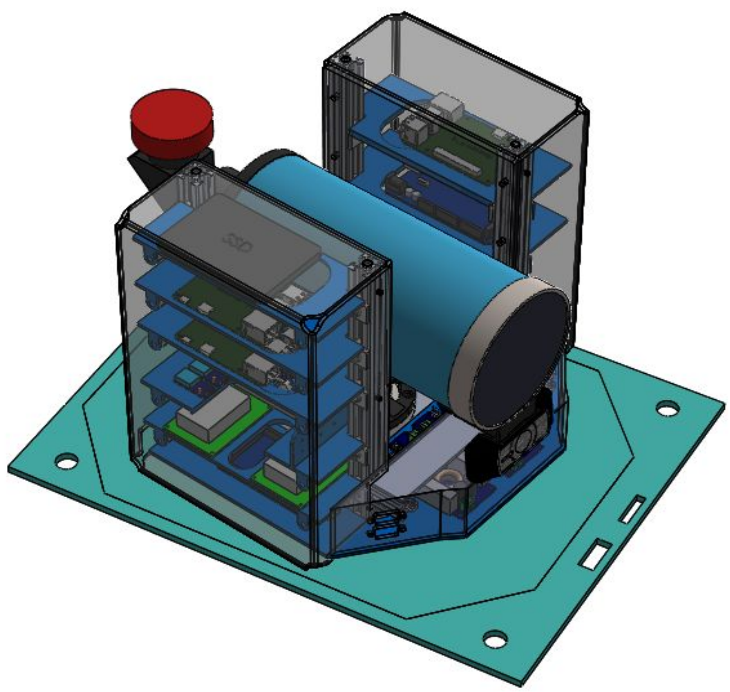


Figure 4.6.1.i: Sunbyte II Final Assembly

4.6.2 Materials

The structure to be used for mounting electronic and mechanical components will be custom made at the University of Sheffield's manufacturing facilities. Table 4.6.2.a illustrates the parameters used to obtain data for material selection from Stage 2 and Stage 3 Material Universe on the CES Edupack 2018 program. The most appropriate materials for this application are identified Figures 4.6.2.a to 4.6.2.d. This data will be used to further analyse failure criteria when the structure is subjected to tensile and compressive loading. Budget constraints and design specifications (D1, D2, D3 and D10) were also factored into the decision. The density of materials has been taken into account to meet the weight requirement (D7) and choose a feasible machining process. The recommended materials are non-magnetic to avoid interference with electronic components. They also exhibit excellent durability against UV radiation and moisture. The final choice of material will be made on approval of the design.

Table 4.6.2.a: Parameters used for material selection

Property Type	**Specification**	
Composition	Bulk Material	Metals (All)
Price (Maximum)	Per Kilogram	£200/kg
Magnetic		Non Magnetic
Thermal	Maximum Service Temperature ℃ (Minimum)	60℃
	Minimum Service Temperature ℃ (Maximum)	-80℃
Mechanical	Young's Modulus GPa (Maximum)	200 GPa
	Yield Strength MPa (Minimum)	500 MPa
	Tensile Strength MPa (Minimum)	500 GPa
Impact and Fracture	Fracture Toughness MPa (Minimum)	40 MPa
	Fracture Toughness MPa (Maximum)	150 MPa
Durability	Water (fresh)	Excellent
	UV Radiation	Excellent
	Flammability	Non-flammable

Table 4.6.2.b: Mass Budget

Mass (Kg)		
Components	**Measurements**	**Calculated**
Raspberry Pi 3 B+	0.04	-
Teensy 3.6	0.005	-
Teensy LC	0.005	-
Big Easy Driver (x2)	2 x 0.005	0.01
Stepper Motor (x2)	2 x 0.29	0.58
Focusing Servo MG996R (x2)	2 x 0.055	0.11
PCB	0.4	-
Harmonic drive HFUC-20-2UH (x2)	2 x 0.98	1.96
DC-DC converters (x2)	2 x 0.2	0.4
DB15 socket (x2)	2 x 0.01	0.2
DB15 wire 0.5m (x2)	2 x 0.01	0.4
Thermocouple Amplifier - MAX31856 (x6)	6 x 0.004	0.06
INA219 High Side DC Current Sensor	0.002	-
9-DOF Accel/Mag/Gyro+Temp Breakout Board	0.003	-
Heating mats (x4)	4 x 0.05	0.2
Scientific camera ZWO ASI 120 mm Mini USB 3.0 CMOS (x2)	0.06 x 2	0.12
Camera cable (x2)	0.05 x 2	0.1

Telescope (Williams Optics Zenithstar 61) (x2)	2 x 1.5	3
Additional optics (filters, ERF, right angle mirrors)	1.5	-
Tracking camera (HD PRO WEBCAM C920)	0.4	-
Tracking camera cable	-	0.05
Gimbal structure (Titanium assumed)	-	3.3
Focusing gears (x4)	4 x 0.03	0.12
Nuts and bolts (assumed 10% of gimbal and focusing gear system mass)	-	0.34
Insulation	-	0.25
Connection wires (~4% of the mass)	-	0.55
Total	**14.51 kg**	

The table 4.6.2.b shows that the predicted mass of the modelled telescope assembly meets the design requirement (D7). The masses of the electronic components were measured using samples from the University of Sheffield. SolidWorks was subsequently used to assign a temporary material (commercially pure Titanium) to every individual component on the gimbal structure. The masses of these components were evaluated using the mass properties function.

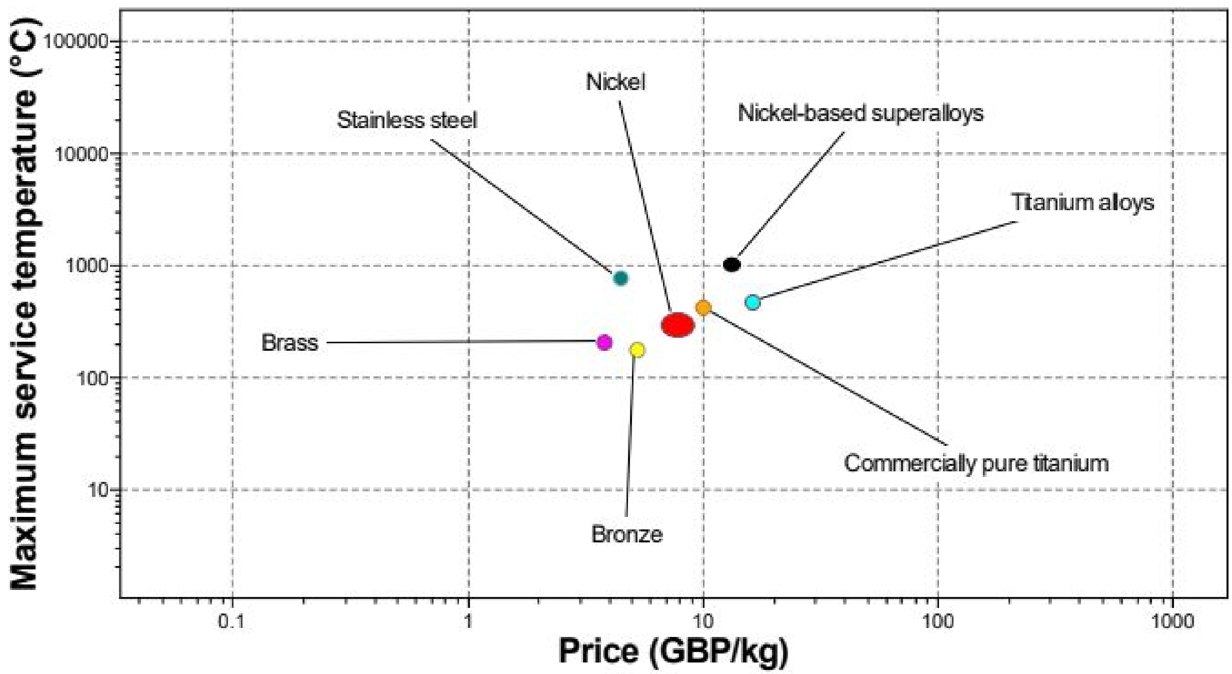


Figure 4.6.2.a: Maximum Service Temperature (℃) vs Price (£/kg)

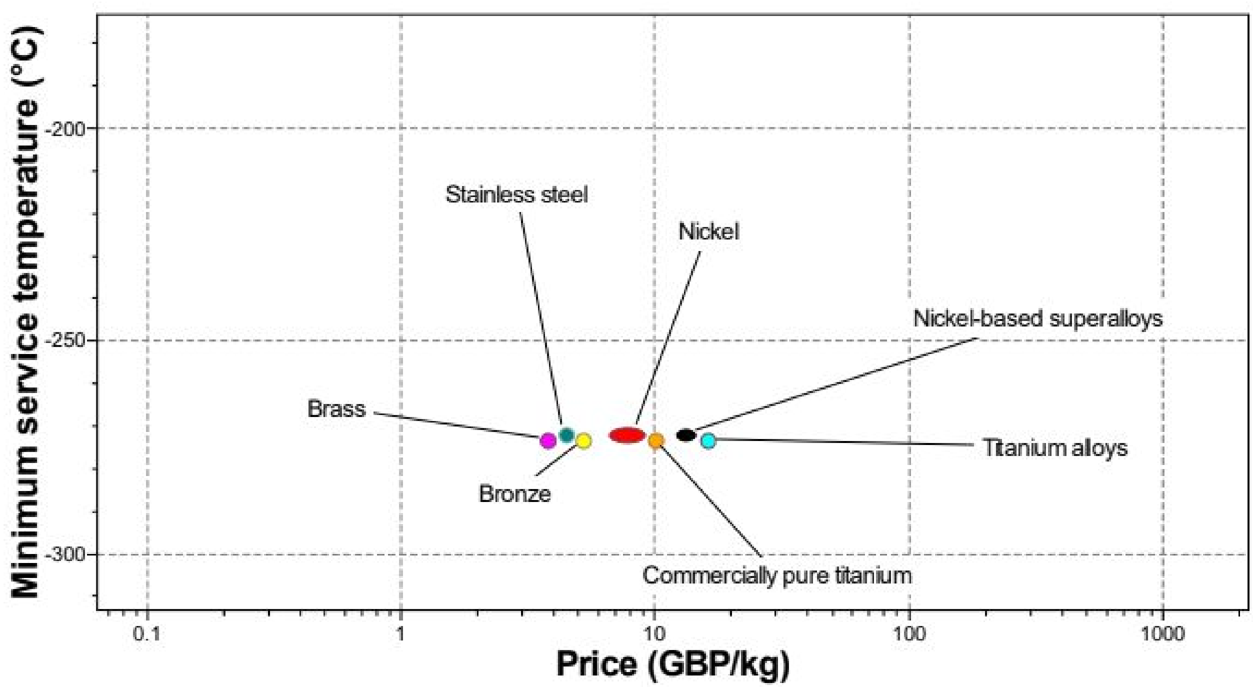


Figure 4.6.2.b: Minimum Service Temperature (℃) vs Price (£/kg)

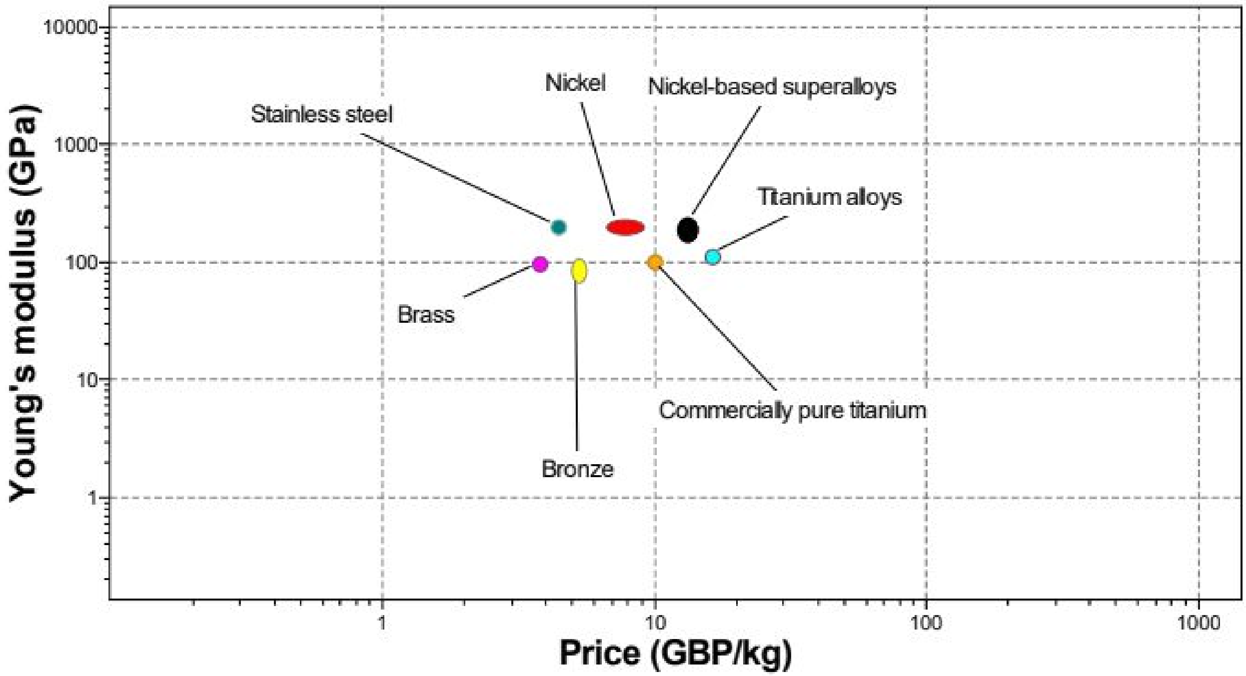


Figure 4.6.2.c: Young's Modulus (GPa) vs Price (£/kg)

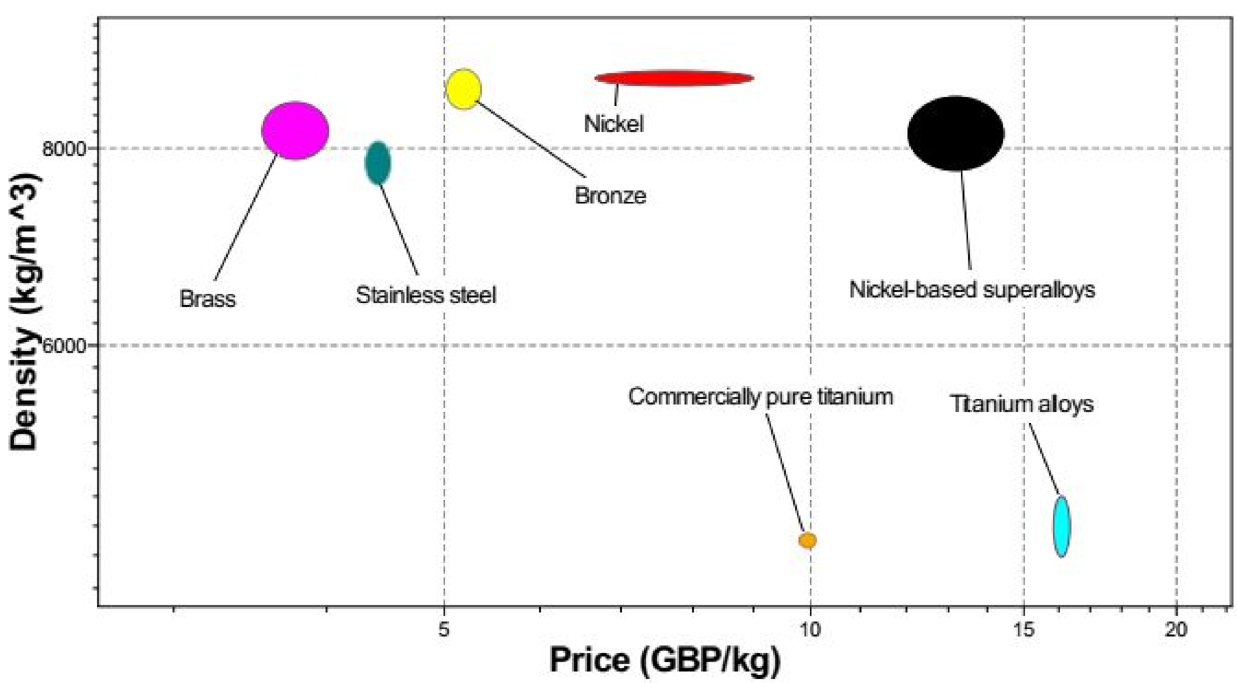


Figure 4.6.2.d: Density (kg/m^3) vs Price (£/kg)

5 Experiment Integration to HASP

5.1 Structure

It is intended to mount the telescope on one of the large slots allocated on the gondola.

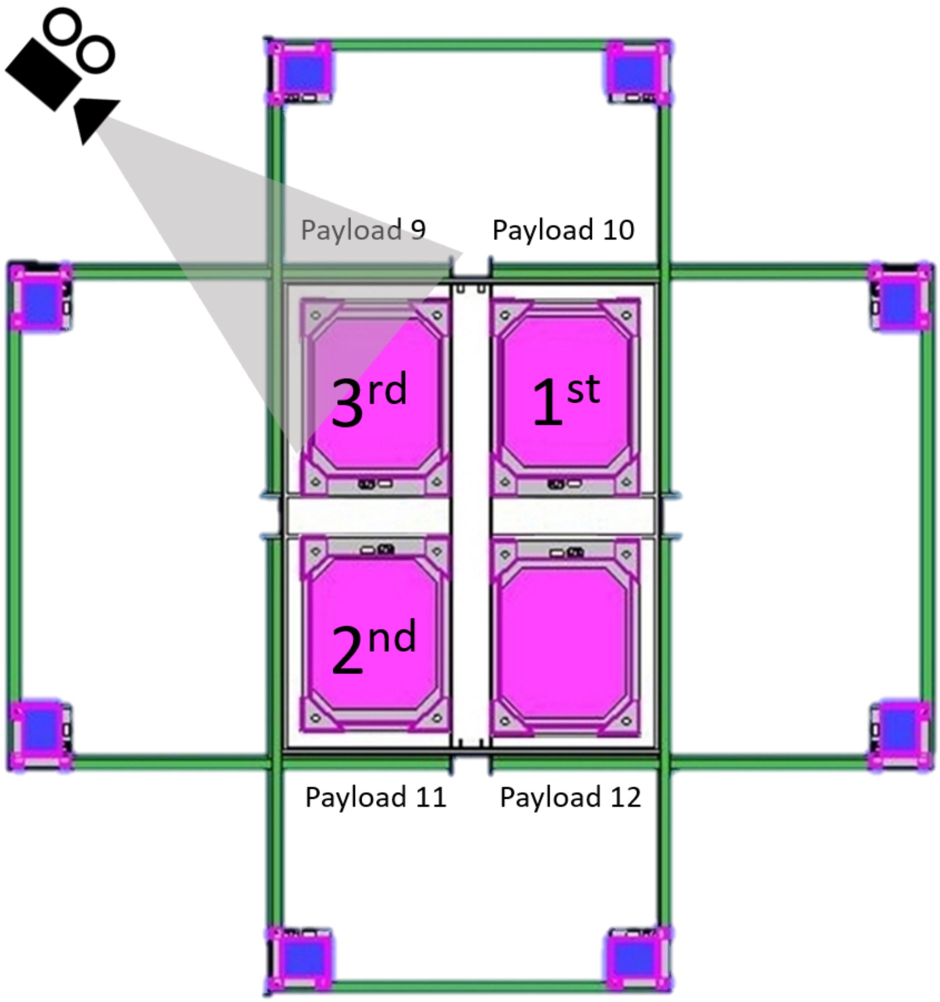


Figure 5.1.a: HASP Gondola Payload Positioning

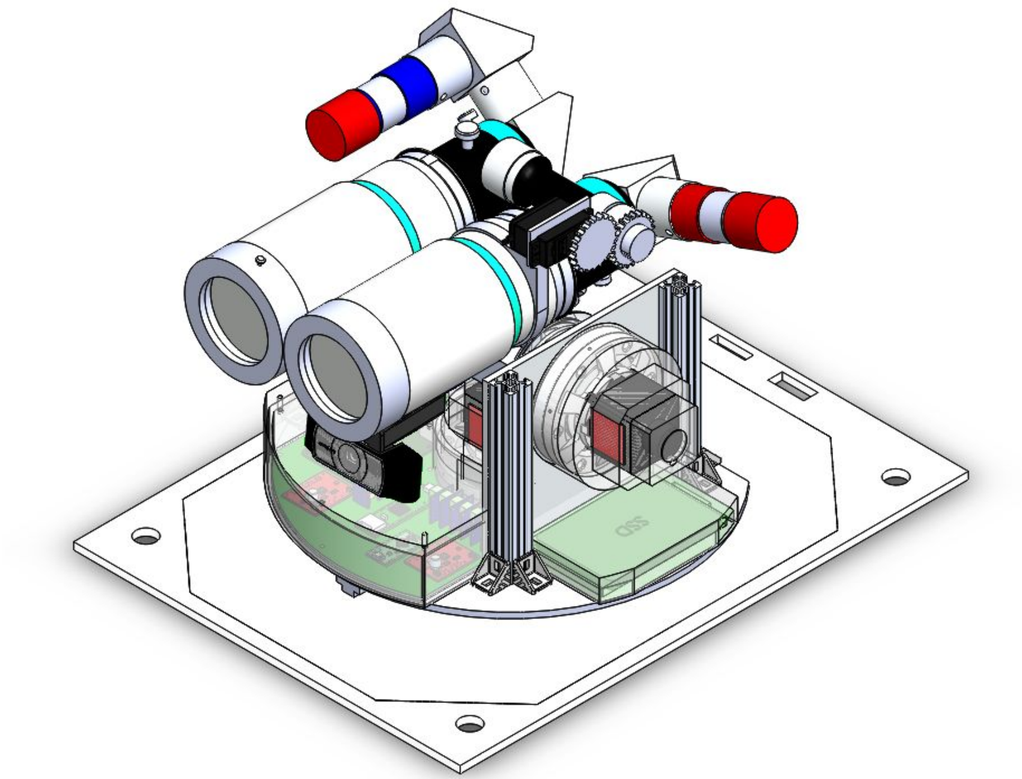


Figure 5.1.b: Payload on Large Payload Base

Payload Slot Choice: (Note Payload numbers in relation to camera based on HASP 2018 flight)

1. Payload 10 - Includes coverage by the camera, to ensure the payload is functioning nominally. SunbYte III's ability to capture images of the Sun is not hindered by the pole supporting the camera.
2. Payload 11 - Same reasoning stated for payload 10, however SunbYte III is further away from the camera so it may be more difficult to see the experiment.
3. Payload 9 - Best coverage by the camera, however the pole will obstruct the view of the Sun at times.

Extra Request: It would be ideal if the payload be positioned away from shiny payloads to ensure the Sun tracking system does not read false positives from reflections.

5.2 Electronics

The electrical power is provided by a 516 series EDAC connector. Two of the four 30 V power lines are converted to 12 V and 5 V by DC to DC converters, then distributed to the electronics. This connection is explained more in depth in Section 4.2.6. The uplink/downlink connection is made through a D-sub 9 serial connector, which links to the RPi. This is explained in more detail in Section 4.5.1. Great care has been taken to ensure that the electrical subsystem is compatible with the available HASP connectors.

6 Operation during Flight

6.1 Uplink via HASP

The payload will be fully autonomous and will not need to be commanded during flight, allowing it to track the Sun, individually focus the telescopes and reset itself should it detect an error. In case the inbuilt safety measures do not solve in-flight problems then there is a list of premade commands to control SunbYte III, as shown in table 4.5.1.a.

6.2 Downlink via HASP

The payload will continuously send image, telemetry, and housekeeping data, as per see table 4.5.1.b, please see section 4.5 for further explanation.

7 Special Requests

7.1 Vertical Extension

At 0 degrees pitch as shown in Figure 7.1.a the payload is within the height requirement, however the dynamic nature of the system means that it overshoots the height requirement by ~45 mm when the telescope is pitching to 60 degrees. A pitch angle of 60 degrees is required because the Sun's elevation peaks at this angle in Fort Sumner on the 2nd of September 2019.

If the height extension is not granted the telescope shall only pitch by angle such that the height limit of 300 mm is not exceeded.

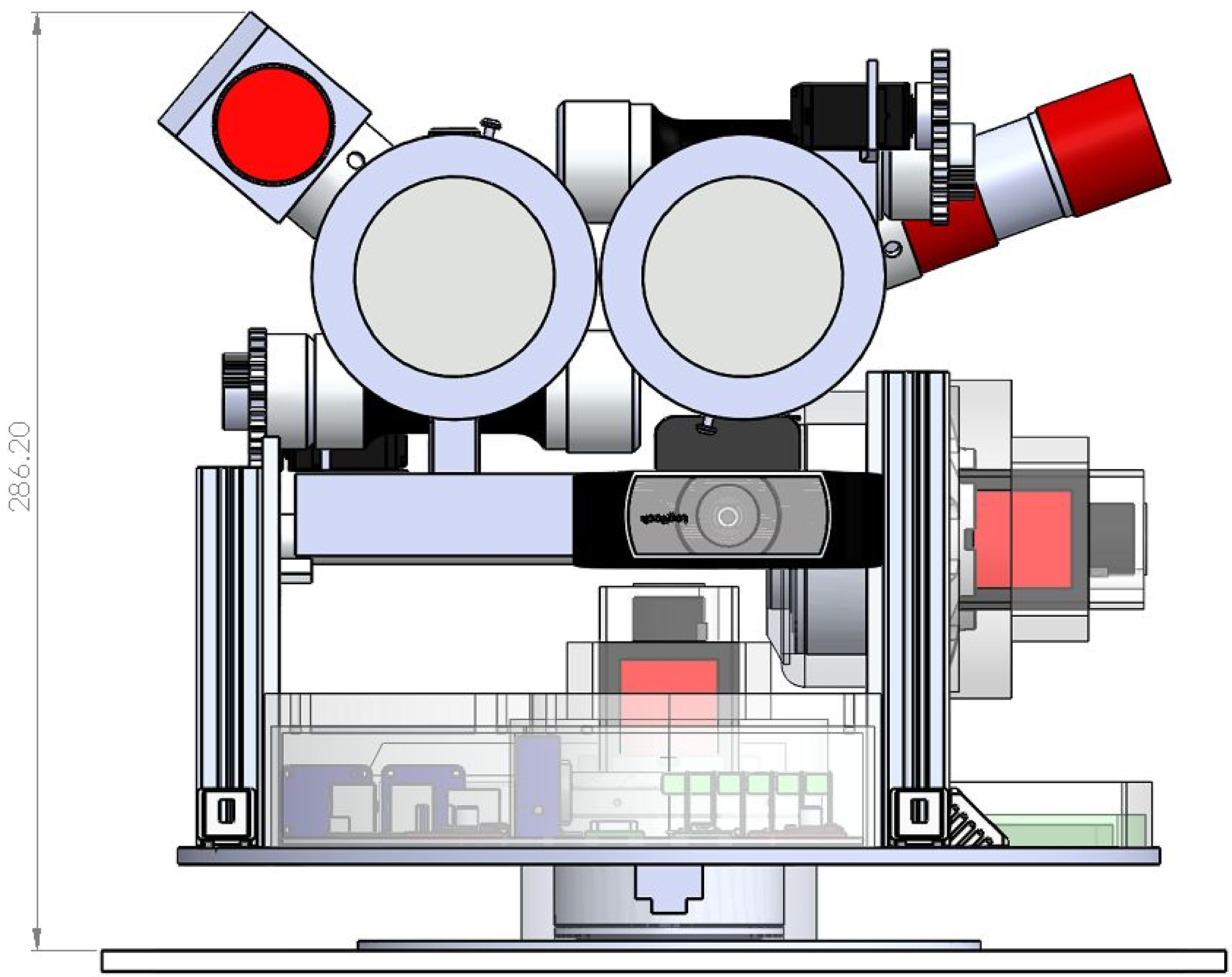


Figure 7.1.a: Telescope at 0 Degrees Pitch and 0 Degrees Yaw

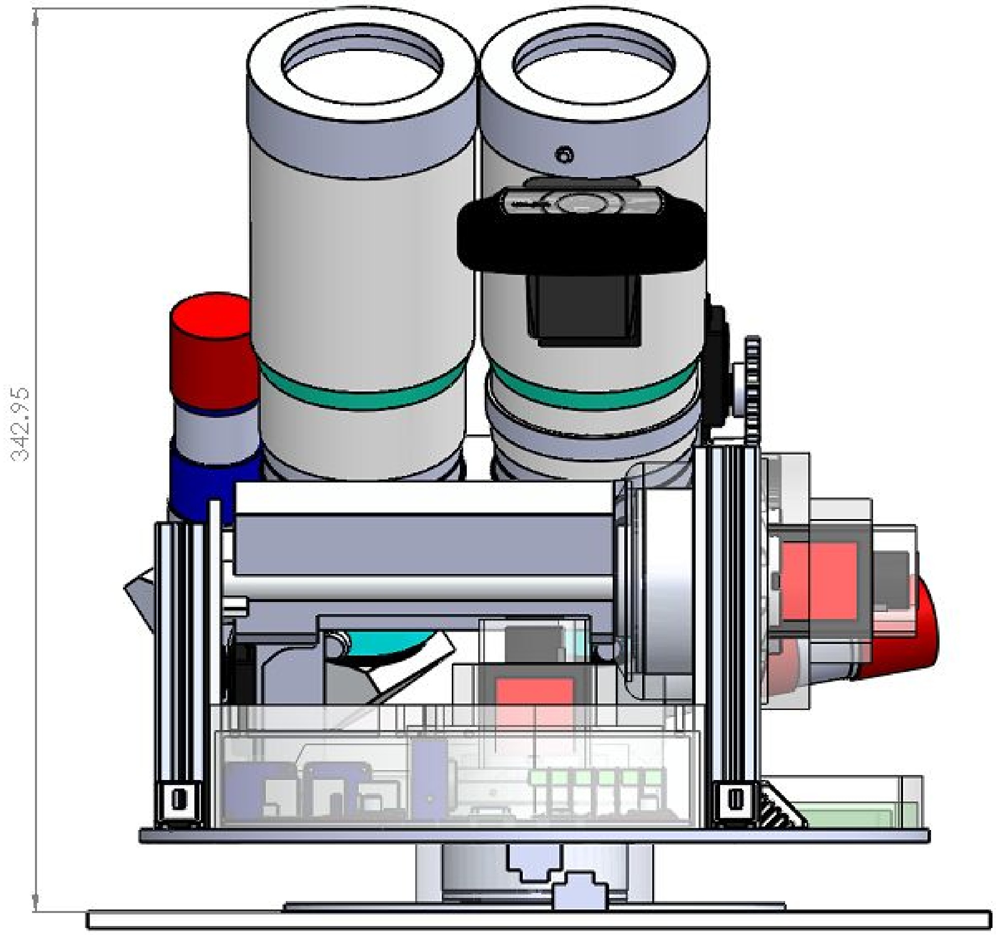


Figure 7.1.b: Telescope at 60 degrees Pitch and 0 degrees Yaw

7.2 Horizontal Extension

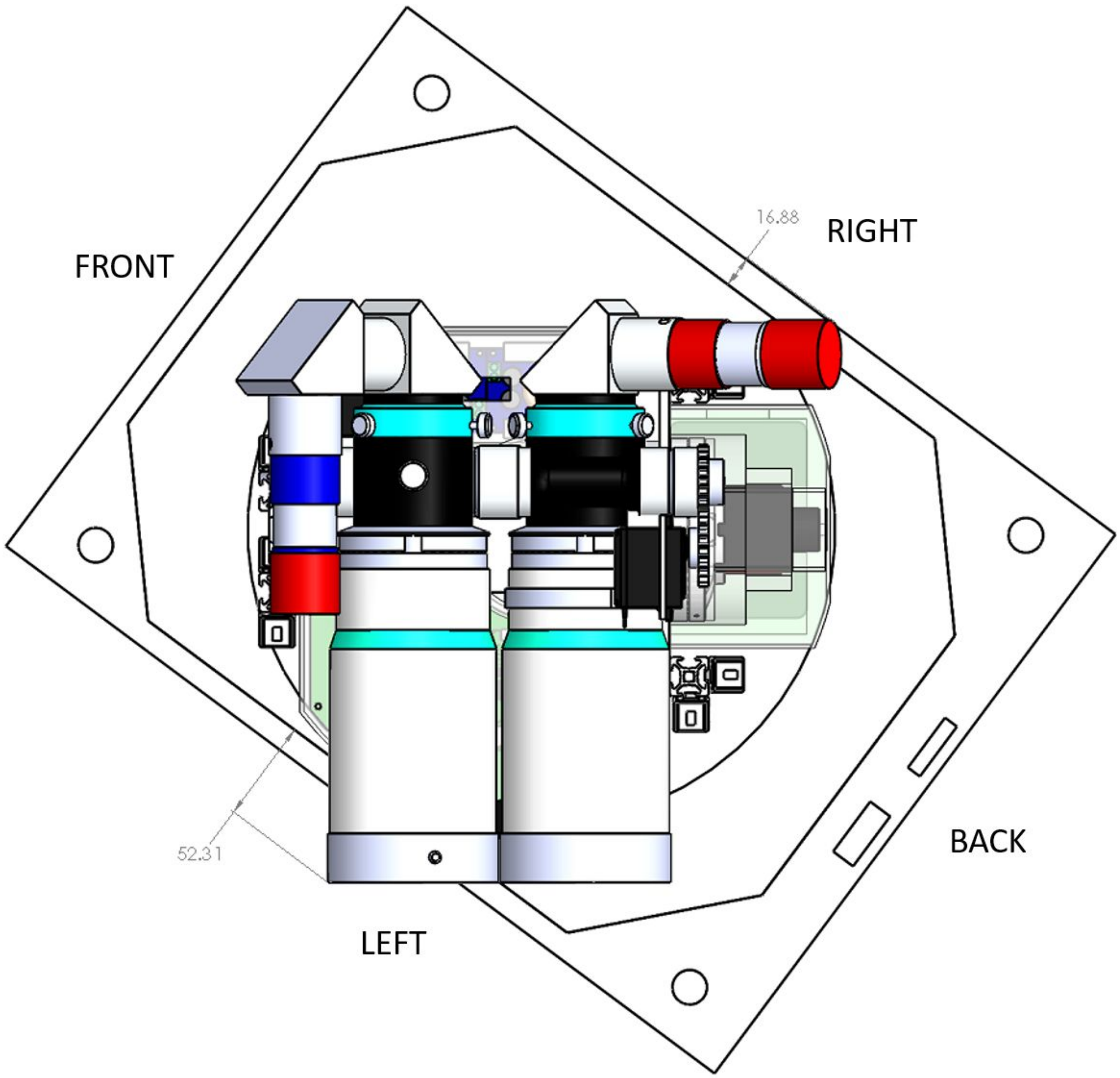


Figure 7.2.a: Telescope at 0 deg Pitch and 225 deg Yaw

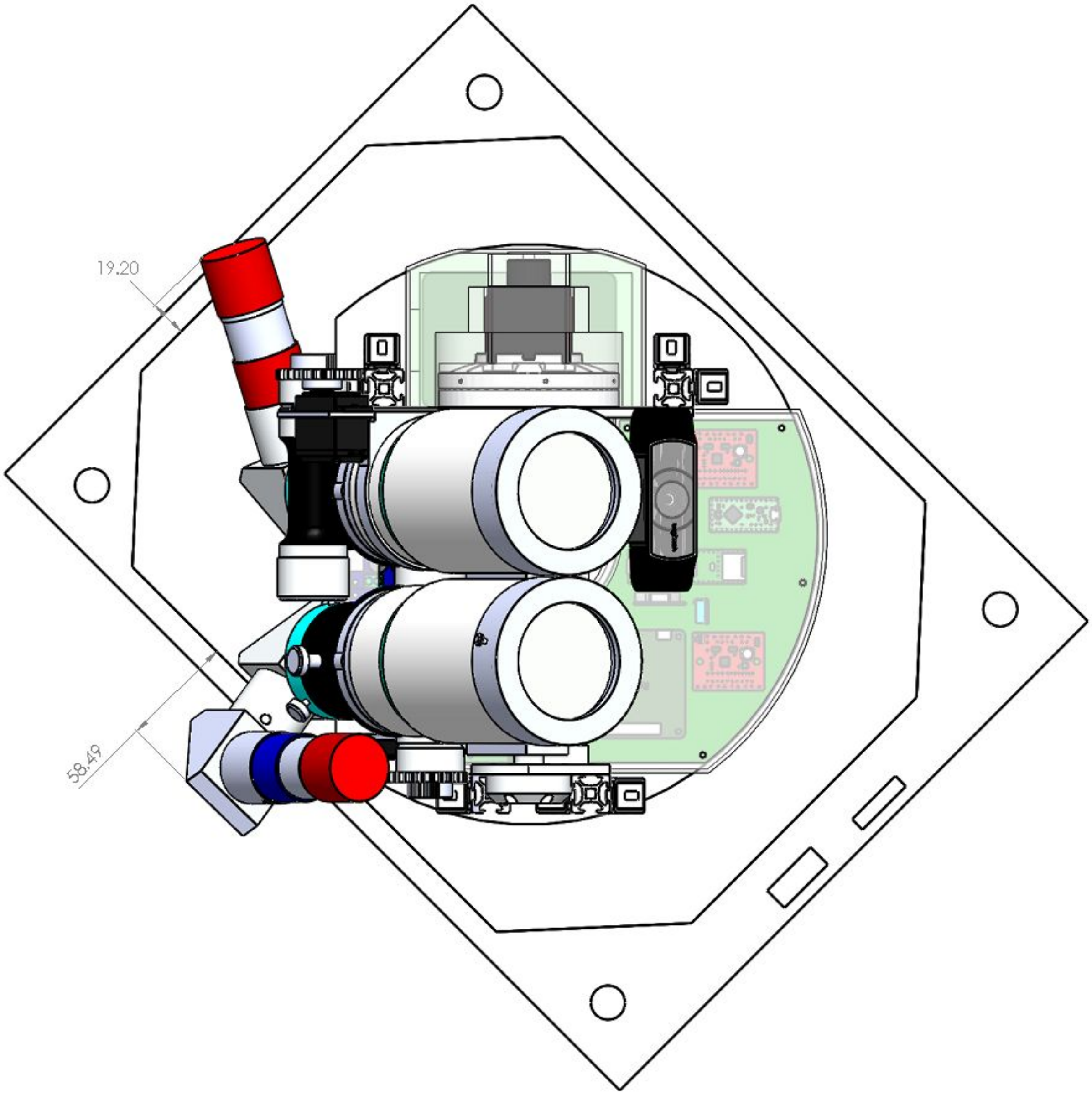


Figure 7.2.b: Telescope at 60 Degrees Pitch and 135 Degrees Yaw

The design has been made to fit within the constraints stated by HASP, however there are some cases where this is exceeded due to the dynamic nature of the payload. The requested extensions are 20mm on the right side (see figure 7.2.a), 20 mm on the front and 60 mm on the left.

If the horizontal extensions are not authorised and the orientation of the cameras and optical filters are unable to be positioned within the limits, the yaw motion shall be restricted to stay within the constraints.

7.3 GPS Time and Position Request from HASP

SunbYte requests access to GPS, time and position, to ensure data is time stamped correctly.

8 Post Fight Activities

8.1 Image Processing

Following recovery of the SSD, image processing can begin. The images will first be converted into a single still frame, and reference points added so that the images can be stacked, using a program such as Autostakkert. All images are then combined with the master flatfield taken just before the flight to correct for non-uniformities in the optical components. Using a program such as Registax, the images can be sharpened, window adjusted, stacked, and combined as is shown in Figure 8.1.a [28]. Colour may also be added at this point. The best 20% of images are taken from each exposure, and are stacked combined to give the maximum image quality. The images will be then analysed for solar events or features such as solar flares or prominences/filaments. The simultaneous images of solar processes and features in two different wavelengths will be of scientific value. The images taken during the flight will be compared to the images taken from the ground in order to determine the increase in image quality. The images will also be used during outreach activities to promote SunbYte, The Sheffield Space Initiative, and The University of Sheffield.

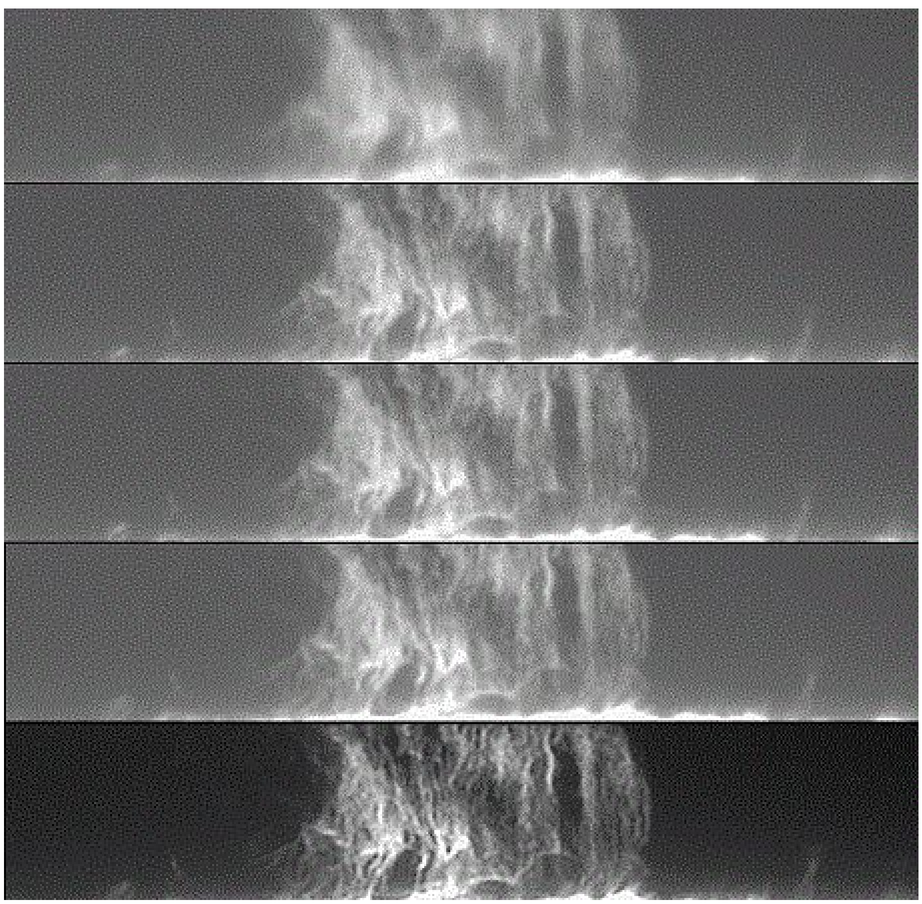


Figure 8.1.a: An example of monochrome solar prominence image processing using Registax. The images have been stacked and sharpened.

8.2 Radiation

Once the TLDs have been recovered and their positions recorded, the dose to each of the TLDs can be measured using an annealing machine (consisting of an annealing oven and photomultiplier tube). This data will be used to determine the radiation dose that SunbYte III encountered, and assess the efficacy of the insulation / shielding that was used.

8.3 Thermal Systems Analysis

The ‘Housekeeping Data’, consisting of temperature, pressure, and altitude measurements, will be analysed alongside the pitch and yaw motor data, to determine the effectiveness of the thermal control systems. This data will be used to improve future iterations or SunbYte and other space projects.

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