SunbYte III HASP 2019 Science Report

Abstract

SunbYte III's mission on HASP 2019 was to prove that it is possible to observe the Sun using a system which is launched on a high-altitude balloon. With the capability of such a system the cost to observe the Sun can be dramatically reduced, since the method can reduce the need for large ground-based telescopes or costly launches and maintenance of space-based telescopes. SunbYte III was equipped with a h-alpha filter to allow the telescope to capture pictures of the Sun in the deep red visible spectral line in the Balmer series. SunbYte III launched on the 5th September 2019 at 13:03:15 UTC from Fort Sumner, NM. The flight time was 07:37 hours (2.7×10^4 s).

Date: 31st January 2020

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1 SunbYte III Experiment Plan

1.1 SunbYte Mission Aims

- Acquire scientifically valuable images of the Sun
- Inspire the next generation of space engineers

1.2 SunbYte Objectives

- Design and develop a low-cost solar telescope
- Track and image the Sun autonomously
- Acquire a launch provider and fly
- Survive the harsh environment of the upper atmosphere
- Conduct outreach

2 Implementation

SunbYte III is the third iteration of the Sheffield University Nova Balloon Lifted Telescope. The previous two versions were flown on BEXUS 25 in 2017, and on HASP 2018. The aim of the project is to develop a low-cost telescope system capable of being lifted by a high altitude 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 structure and the ADCS system, therefore SunbYte III aims to build on this and take high resolution images of the Sun using the Hydrogen-alpha spectral line (656.28 nm). By studying this spectral line, it is hoped that we will observe solar features which will give us an insight into magnetic and plasma processes within.

2.1 Electronics and Power System

Electronics and power system objectives:

- Actuate, power and control pitch and yaw axis movement
- Provide an electronics platform to communicate using uplink and downlink.
- Provide an electronics platform to track and image the Sun.
- Implement sensors to gather data about the payload and environment.
- Provide electrical power where required, while maintaining the power constraints set by HASP (33-29VDC at 2.5A).

2.1.1 Electronics Hardware

The electronics system was specifically designed to power and control the pitch and yaw motors, connect the science camera and tracking camera (webcam), communicate with the HASP payload and gather information via sensors to coordinate the system. The system described below was designed to bring these components together, while providing enough computational power to process the necessary information.

The electronics circuit utilised the components in table 2.1.1.a, which were required to meet the objectives of this system. The specific components were carefully selected for their ease of integration, power requirements, cost, size and functionality.

Table 2.1.1.a Electronics Circuit Components

Category	Component	Purpose
Power Electronics	DCDC Converter (5V & 12V)	Step down voltages from 30VDC input, for low voltage components
	Switching Regulator 5V to 3.3V	Step down voltage to power sensors using minimal power
Processors	Raspberry Pi (RPi)	Perform computationally intensive tasks, such as image processing. Act as master of overall system, managing communications and files.
	Teensy 3.6	High speed microcontroller to interface and control hardware, removing computational load from the main processor (RPi). Acts as main microcontroller, mainly managing real-time control of stepper motors
	Teensy LC	Read sensors, allowing main microcontroller to focus on real-time tasks. Watchdog for overall system
Actuation	Bipolar Stepper Motors (Pitch and Yaw Axes)	Manipulate payload in the pitch and yaw axes
	Big Easy Driver Stepper Motor Driver	Drive stepper motors from digital signals, adjusting power as necessary
Sensors	Thermocouples	Gather temperature information for active heating system and about the environment
	Current & Voltage Sensors	Monitor power consumption, infer information about electronics system
	GPS	Track position and altitude of payload
	(IMU)	Compute payload orientation to calculate Sun's position. (Not implemented due to magnetic field disturbances from stepper motors)
Thermal Control	12V 0.4A Flexible Heating Pads (2 per motor)	Active thermals control of motor temperatures, to ensure motor operating temperatures are maintained
	Solid State Relays	Digital control over heater states
Communi-cations	MAX3232 RS232 to TTL	Translate communication protocols between RPi and HASP system

The DCDC step down converters were selected for their integrated heatsink, weather resistance and low cost, the models used are typically used in vehicles. While the 3.3V to 5V switching regulator by Traco

Power is a highly compact and robust component. They also included a heatsink for efficient thermal management.
The processors were each chosen for their user-friendly interfaces, compactness and flexible set of inputs and outputs. The Raspberry Pi is a well-known microprocessor with high computational power, while the Teensy range is the microcontroller equivalent and is designed to integrate with the Arduino platform. The Raspberry Pi was utilised for intense computational tasks, including image processing and file management, while the more powerful Teensy 3.6 microcontroller handled the lower level inputs and outputs, such as the real-time stepper motor control and active heating system, reducing the dependency on the RPi. A second low cost Teensy microcontroller was used to perform tasks that would otherwise interfere with the real-time operations running on the Teensy 3.6, such as reading sensors. Additionally, this device was used to monitor the other systems as a watchdog making the system more robust.
Stepper motors were chosen for actuation due to their high holding torque to maintain positions and their movement repeatability. The big easy driver is a low cost, compact stepper motor driver, which was ideal for the requirements of the system.
The sensors used were meticulously selected to provide the information desired, while meeting the requirements of the electrical system. All sensors were designed for quick and efficient integration by Adafruit, making them optimal for the tight time constraints of development.
The heaters were selected to run at 12V, to match the stepper motor power level, while the 0.4 A model was selected for its optimal size and suitable power requirements. The main reason for implementation of these heaters was to address the issue of the stepper motors becoming too cold during the flight of SunbYte II in 2018. Although, it became evident during integration testing there was far more to this issue than was initially estimated from limited SunbYte II telemetry data.
Finally, the MAX3232 chip matched communication interfaces between the RPi and HASP flight system to enable the uplink and downlink communication during the flight, a fundamental aspect of the system.

2.1.2 Circuit Design and Layout

The electronics circuit was required to fit within a small area, due to the tight size constraints, alongside the necessity of the central yaw stepper motor and side pitch axis supports. Resulting in a less than ideal shape and small volume to house the electronics. The final design was the result of a large amount of structural and layout optimisation, requiring two tier PCB to fit in all the components, shown in figures 2.1.2.a and 2.1.2.b. Once fully specified and tested in the circuit prototyping phase a stripboard circuit was developed, which met the size constraints and all the electronics requirements, although lacked robustness and design flexibility. This was the reason for developing a printed circuit board (PCB), providing robust reliable connections, back up circuit boards and a baseline for future development of the electronics.

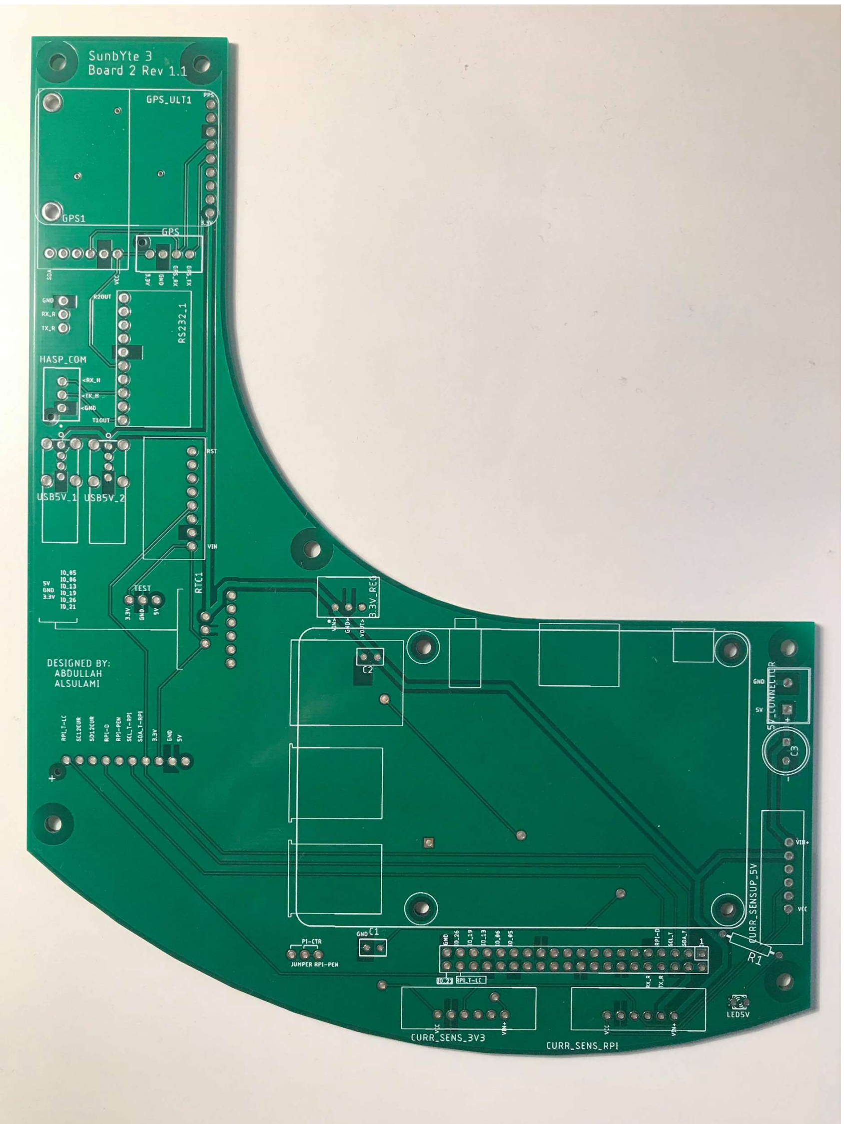

Figure 2.1.2.a Upper PCB

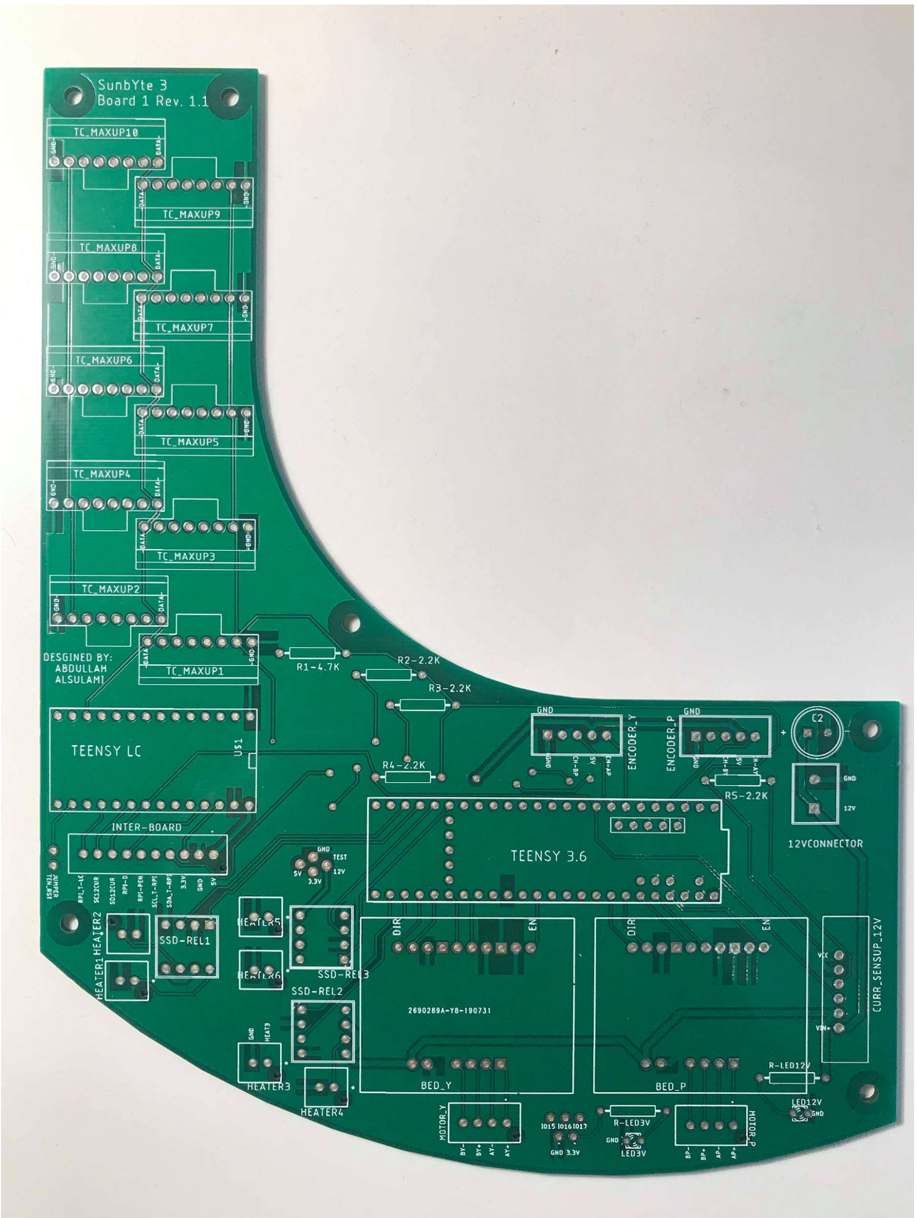

Figure 2.1.2.b Lower PCB

2.1.3 Power Distribution and Management

All components are powered from three voltage rails, 3.3V, 5V or 12V. A higher voltage for components with larger power requirements, the standard 5V level for computational and control circuitry and 3.3V for sensors, When all components are turned on, the power draw can range from 2A at 30VDC to more than 2.5A, due to the change in power draw from the heaters and motors based on temperature. As a result, the total power draw of the system required monitoring and controlling. Overall voltage and current draw could not easily be monitored directly, hence it was estimated by measuring the current at 12V and 5V factoring in the efficiency of the DCDC converters. From these values the total current draw could be reliably determined and used as a guide to control optional components, such as heaters. A motor current draw estimator was later added to ensure there would always be enough power available to turn the motors on, if they were currently turned off. This was because it was desirable for the motor control system to remain independent of the power management system to maximise scientific and thermal objective efficiency. The motor power estimator allowed a safety margin of current to be reserved to drive the motors if they were turned off, preventing a scenario where the motors suddenly turn on, surpassing the power budget. The distribution of power to the various electronics components is shown in figure 2.1.3.a. A full schematic is provided in figure 2.1.3.b.

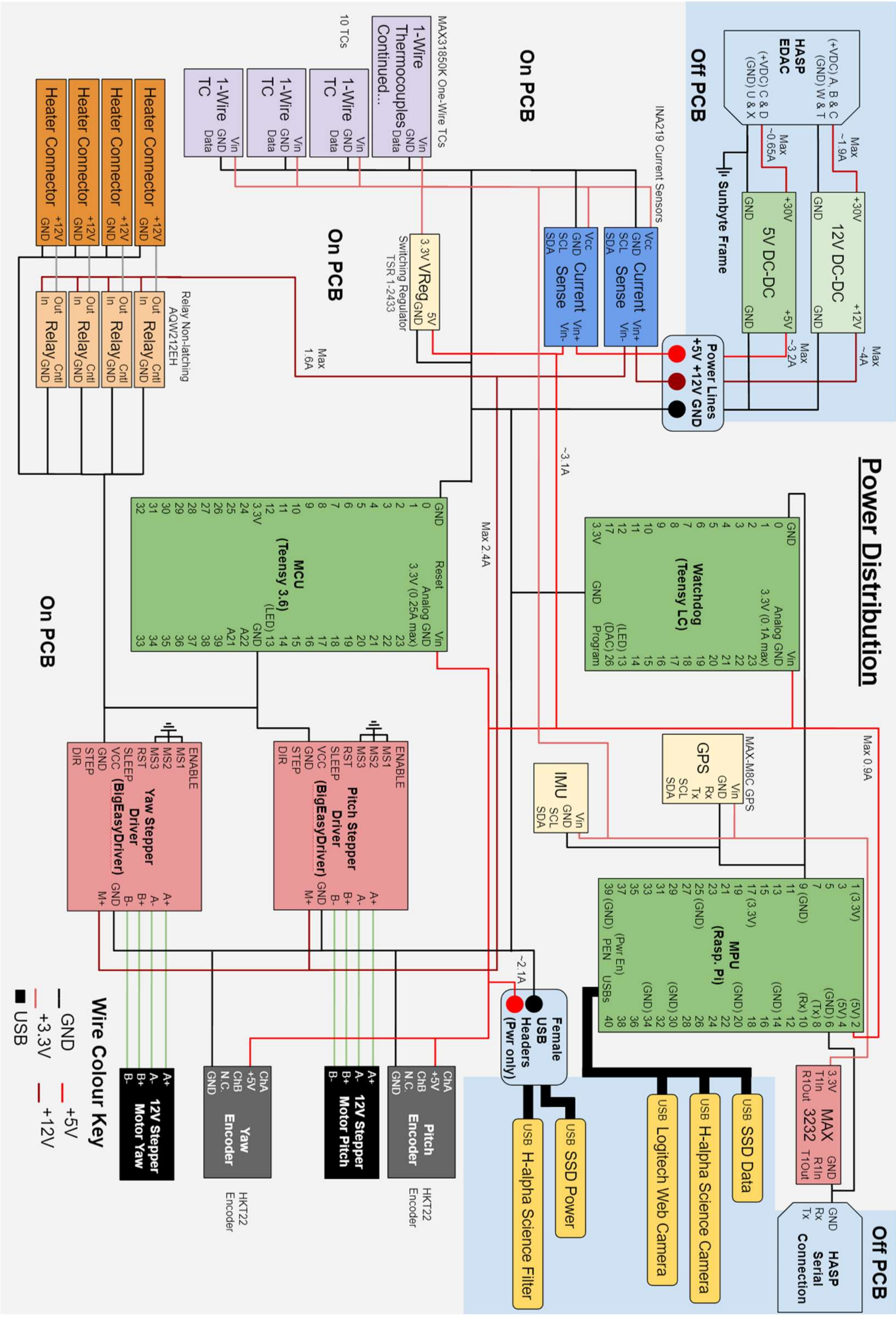

Figure 2.1.3.a Power Distribution Wiring Schematic

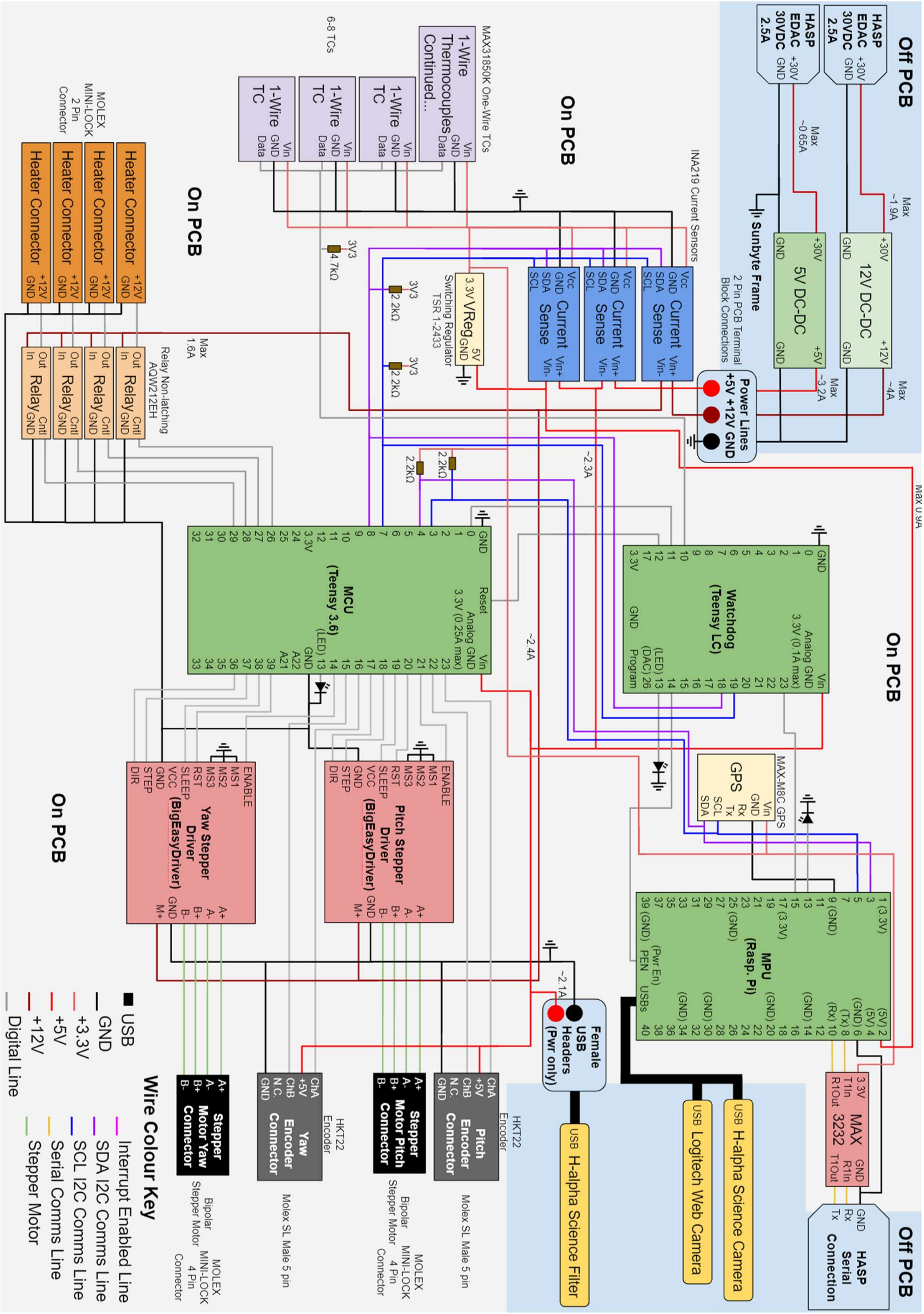

Figure 2.1.3.b Electronic Schematics Diagram

2.2 Attitude Determination and Control System

Attitude Determination and Control Systems (ADCS) objectives:

- Locate the Sun
- Track the Sun as the gondola rotates
- Ensure Sun is in the FOV of the telescope

2.2.1 Tracking Algorithm

The Attitude Determination and Control System will use image processing to localize and track the position of the Sun. Images are taken at 30 FPS with a webcam interfaced with a Raspberry Pi (RPi) microprocessor. Tracking of the Sun is carried out in two steps. Firstly, the pitch and yaw motors sweep the camera across the sky. Meanwhile, an image processing algorithm running on the RPi scans the incoming webcam video feed, isolating the largest brightest object, sweeping continues until an object is located.

Once the Sun is detected the tracking algorithm takes over, centring the telescope on the Sun by continuously adjusting pitch and yaw motor positions. The RPi calculates the offset in orientation of the Sun from the centre of the image and translates the difference into corrections for the yaw and pitch angles (shown in figure 1.3.2.a), sending them to the Teensy 3.6 microcontroller (MCU) to adjust the motor positions.

The tracking algorithm used a proportional controller in each of the vertical (pitch) and horizontal (yaw) directions to convert the offset in pixels to stepper motor steps. This algorithm would continually update multiple times every second to ensure the tracking was smooth.

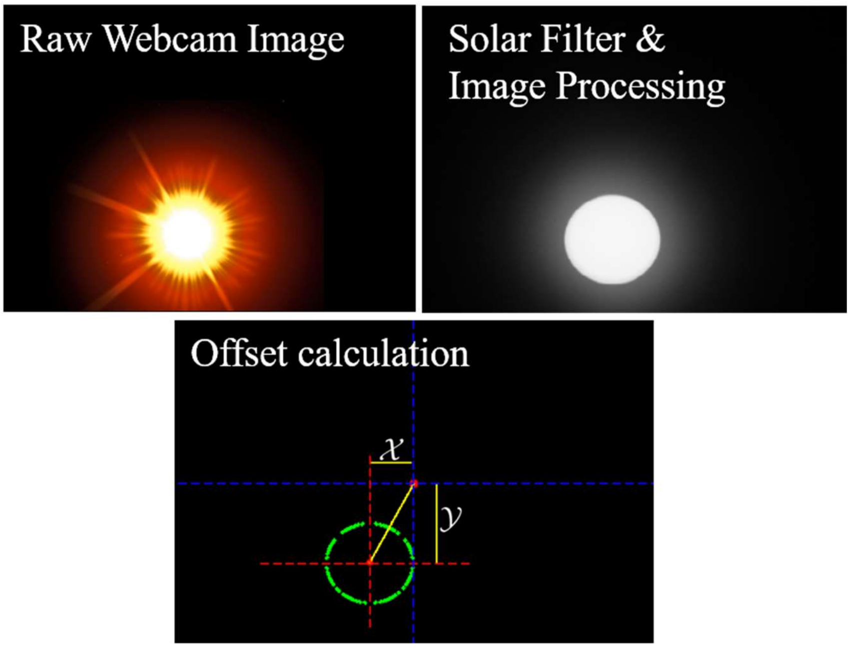

Figure 2.2.1.a: Tracking Image Processing Algorithm

During development, minor adjustments were made to this algorithm as the system changed, for example an estimation of the Sun's initial position based on magnetometer and GPS data, was originally going to be used as a start location for the search of the Sun's position. Although after testing the magnetic interference from the stepper motors meant the inertial measurement unit (IMU) with the magnetometer was unusable and was thus removed.

A webcam to telescope offset was also later added due to the physical precision limitations of directly the webcam and telescope in the same direction. A centre offset was added to correct for this, which needed to be calibrated after any critical adjustments to the payload.

2.3 Communications System

Communications system objectives:

- Provide a platform to downlink information to determine the status and actions of the payload during operation.
- Provide a platform to manually control the payload during operation, via uplink commands.
- Be able to detect and react quickly to problems during operation through uplink and downlink

2.3.1 Downlink

Tables 2.3.1.a-c show the format that either a telemetry or image data packet was transmitted. A standard header and footer contained the metadata for each packet, while the data content was dependent on the packet type. The image and the sensor data were never sent in the same packet, since the two were processed separately. The separation of the two data packets made the process of decoding the data much simpler. The rate of telemetry packets and image packets sent through downlink was one every 2 seconds each.

Table 2.3.1.a Downlink Format

Downlink Packet Metadata			
Section	**Data type**	**Byte size**	**Description**
Header	**unsigned char**	1	**Start of transmission**
	unisgned char	1	**HASP SunbYte III Payload ID**
	unsigned char	1	**Record type indicator**
	unsigned int	15	**DateTime timestamp from RTC**
	unsigned int	13	**UNIX timestamp from RTC**
	unsigned int	4	**Record size (number of bytes)**
Data		n	**Data (telemetry or image)**
Footer	**unsigned char**	1	**Checksum**
	unsigned char	1	**End of transmission**

Table 2.3.1.b Downlink Format for Image Data

Compressed Image Data Chunk		
Data type	**Byte size**	**Description**
unsigned int	13	**Image Time Taken UNIX**
unsigned int	4	**Image ID**
unsigned int	4	**Exposure**
unsigned int	4	**Average Pixel Value**
	x	**Image Data**

Table 2.3.1.c Downlink Format for Telemetry Data

Telemetry data chunk		
Data type	**Byte size**	**Description**
float	4	Rasberry Pi input current
float	4	5V rail input current
float	4	12V rail input current
float	4	3.3V rail input current
float	4	Rasberry Pi input voltage
float	4	5V rail input voltage
float	4	12V rail input voltage
float	4	3.3V rail input voltage
float	4	Above Pitch Plate Ambient temperature
float	4	Yaw motor temperature
float	4	5V DCDC converter temperature
float	4	12V DCDC converter temperature
float	4	Electric box bottom temperature
float	4	Pitch Harmonic Drive Plate
float	4	Sci Cam Filter temperature
float	4	Ebox Top
float	4	Pitch Harmonic Drive
float	4	Pitch motor temperature
float	4	Pitch motor position
float	4	Yaw motor position
float	4	Motor max speed
float	4	Motor acceleration
unsigned char	1	Heater status
float	4	Raspberry Pi Internal temperature
unsigned char	1	Sun tracking status
unsigned int	4	Total images taken
float	4	Latitude
float	4	Longitude
float	4	Altitude

2.3.2 Uplink

The uplink commands integrated to provide manual control over the payload's systems are found in tables 2.3.3.a-e. A wide range of SunbYte III's systems could be manually controlled from the ground, from power cycles, heaters and motors to the science camera image settings. A simple ping test, stated in table 2.3.2.a was used to verify the uplink was being received correctly, while the prepare for shutdown command was essential to power down systems safely.

The Electrical, ADCS, Thermal and Optics subsystems were all able to be controlled in various ways as outlined by tables 2.3.3.b-e.

Table 2.3.2.a Uplink Test Command

Communications system commands					
Command		Command Byte 1 ID/Checksum	Command Byte 2 Uplink Command	Command Byte 2 Decimal Value	Description
Ping	Downlink	0xaa	0x00	0	Toggle LED to demonstrate uplink functionality

Table 2.3.2.b Uplink Commands for Electrical System

Electrical system commands					
Command		Command Byte 1	Command Byte 2	Command Byte 2	Description
Prepare for Shutdown		0xa2	0x08	8	Prepare for shutdown (Does not power off the system)
RPi MPU	Reset	0xa3	0x09	9	Commands the Raspberry Pi to reset
Teensy 3.6 MCU	Reset	0xa4	0x0a	10	The RPi will command the Teensy to turn reset
Manual Power Control	Disable	0xa5	0x0b	11	Disable Power Management System (Manual on)
	Enable	0xa6	0x0c	12	Enable Power Management System (Manual off)

Table 2.3.2.c Uplink Commands for ADCS

ADCS system commands					
Command		Command Byte 1	Command Byte 2	Command Byte 2	Description
Force Pitch Motor	Increment	0xa1	0x07	7	Forces the pitch motor to rotate 0.1 degree
	Decrement	0xa7	0x0d	13	Forces the pitch motor to rotate -0.1 degree
	Increment	0xaa	0x10	16	Forces the pitch motor to rotate 1 degree
	Decrement	0xab	0x11	17	Forces the pitch motor to rotate -1 degree
	Increment	0xac	0x12	18	Forces the pitch motor to rotate 5 degree
	Decrement	0xad	0x13	19	Forces the pitch motor to rotate -5 degree
	Increment	0xae	0x14	20	Forces the pitch motor to rotate 20 degree
	Decrement	0xaf	0x15	21	Forces the pitch motor to rotate -20 degree
Force Yaw Motor	Increment	0xa8	0x0e	14	Forces the yaw motor to rotate 0.1 degree
	Decrement	0xa9	0x0f	15	Forces the yaw motor to rotate -0.1 degree
	Increment	0xa0	0x16	22	Forces the yaw motor to rotate 1 degree
	Decrement	0xa1	0x17	23	Forces the yaw motor to rotate -1 degree
	Increment	0xa2	0x18	24	Forces the yaw motor to rotate 5 degree
	Decrement	0xa3	0x19	25	Forces the yaw motor to rotate -5 degree
	Increment	0xa4	0x1a	26	Forces the yaw motor to rotate 20 degree
	Decrement	0xa5	0x1b	27	Forces the yaw motor to rotate -20 degree
	Increment	0xa6	0x1c	28	Forces the yaw motor to rotate 90 degree
	Decrement	0xa7	0x1d	29	Forces the yaw motor to rotate -90 degree
Pitch Motor	Off	0xa8	0x1e	30	Disable the pitch motor
	On	0xa9	0x1f	31	Enables the pitch motor
Yaw Motor	Off	0xaa	0x20	32	Disable the yaw motor
	On	0xab	0x21	33	Enable the yaw motor
Motors	Off	0xac	0x22	34	Disable all motors
	On	0xad	0x23	35	Enable all motors
Skysweep Control	Off	0xae	0x24	36	Turns sweeping motion off
	On	0xaf	0x25	37	Turns sweeping motion on
Calibrate Motors	Pitch	0xa0	0x26	38	Calibrate Pitch Motor
	Yaw	0xa1	0x27	39	Calibrate Yaw Motor
Set Default Position	Pitched Down	0xa2	0x28	40	Points Telescope to Default Position at minimum pitch
	Pitched Up	0xa3	0x29	41	Points Telescope to Default Position at maximum pitch
Pitch Motor Position		Range	0x2a to 0x6b	42 to 107	Set pitch motor position angle (0-65 increments of 1 degree, 65 commands)
Yaw Motor Position		Range	0x6c to 0xe4	108 to 228	Set yaw motor position angle (0-360 increments of 3 degrees, 120 commands)
Motor Tracking	Disable	0xaf	0xe5	229	Disable tracking commands
	Enable	0xa0	0xe6	230	Enable tracking commands
Object Detection	Disable	0xa1	0xe7	231	Disable automatic calibration of motors when object detected
	Enable	0xa2	0xe8	232	Enable automatic calibration of motors when object detected
Encoder Freeze Detection	Disable	0xa3	0xe9	233	Disable encoder freeze detection
	Enable	0xa4	0xea	234	Enable encoder freeze detection
Motor Speeds	Increment	0xaf	0x05	5	Increases the maximum speed of both motors by 50
	Decrement	0xa0	0x06	6	Increases the maximum speed of both motors by 50
	Increment	0xa5	0xeb	235	Increases the maximum speed of both motors by 250
	Decrement	0xa6	0xec	236	Decreases the maximum speed of both motors by 250
Motor Accelerations	Increment	0xab	0x01	1	Increases the acceleration of both motors by 200
	Decrement	0xae	0x04	4	Decreases the acceleration of both motors by 200
	Increment	0xa7	0xed	237	Increases the acceleration of both motors by 1000
	Decrement	0xa8	0xee	238	Decreases the acceleration of both motors by 1000
Reset Speed Defaults		0xa9	0xef	239	Reset Speed Default Values
Reset Acceleration Defaults		0xa1	0xf7	247	Reset Acceleration Default Values
Set low speed and acceleration		0xa2	0xf8	248	Set low speed and acceleration values
Set high speed and acceleration		0xa3	0xf9	249	Set high speed and acceleration values

Table 2.3.2.d Uplink Commands for Thermal System

Thermal system commands					
Command		Command Byte 1	Command Byte 2	Command Byte 2	Description
Automatic Heating System Control	Enable	0xaa	0xf0	240	Reset heaters & Enable Thermal Management System
	Disable, Heaters on	0xab	0xf1	241	Turn on all heaters & disable Thermal Management System
	Disable, Heaters off	0xac	0xf2	242	Turn off all heaters & disable Thermal Management System
Power on individual heaters	Pitch Heater 1	0xad	0xf3	243	Turn on Pitch Heater 1 & disable Thermal Management System
	Pitch Heater 2	0xae	0xf4	244	Turn on Pitch Heater 2 & disable Thermal Management System
	Yaw Heater 1	0xaf	0xf5	245	Turn on Yaw Heater 1 & disable Thermal Management System
	Yaw Heater 2	0xa0	0xf6	246	Turn on Yaw Heater 2 & disable Thermal Management System
	Pitch Heaters	0xab	0x02	2	Turn on Pitch Heaters & disable Thermal Management System
	Yaw Heaters	0xad	0x03	3	Turn on Yaw Heaters & disable Thermal Management System

Table 2.3.2.e Uplink Commands for Optics

Optics system commands					
Command		Command Byte 1 ID/Checksum	Command Byte 2 Uplink Command	Command Byte 2 Decimal Value	Description
Adjust Image Exposure	Increment	0xa4	0xfa	250	Increase Image Exposure
	Decrement	0xa5	0xfb	251	Decrease Image Exposure
Adjust Telescope Offset Yaw	Increment	0xa8	0xfe	252	Increase Telescope offset size yaw
	Decrement	0xa9	0xff	253	Decrease Telescope offset size yaw
Adjust Telescope Offset Pitch	Increment	0xa8	0xfe	254	Increase Telescope offset size pitch
	Decrement	0xa9	0xff	255	Decrease Telescope offset size pitch

2.3.3 Internal Communications

Internal communication between components, such as RPi and Teensy 3.6, was done using I2C communication, using human readable command strings followed by comma separated data items, finishing in a new line character. Although there is additional computational cost to using human readable commands to communicate, the cost was sufficiently small that the benefit was worthwhile, enabling more efficient debugging and data logging.

2.3.4 Ground Station

Requirements:

- Decode downlinked data from SunbYte III.
- Present data in a human readable format to monitor payload condition.
- Fully automated process to ensure no time is wasted downloading data and sifting errors manually.

The first part of the ground station was a script that was run to download all new information that was uploaded on the HASP webpage for the SunbYte III downlinked data. This script would extract all the new data from the .raw files and sort the lines of data depending if the line of data contained telemetry data or image data. This data was subsequently saved to a text file that accumulated the full flight data. After the data has been separated into image and telemetry data, a MATLAB script was run, that took in the telemetry data from the text file. The MATLAB script represented several parameters against time elapsed so that diagnostics can be performed, to provide insight into the status of SunbYte.

2.4 Thermal System

Thermal system objectives:

- Maintain the temperature of components within their operating ranges.
- Control an active heating system to maintain safe motor operating temperatures.
- Acquire temperature data to evaluate the thermal performance during flight.

The most temperature critical components on SunbYte III by categorisation are primarily the motors, followed by the electronics. Both sets of components included thermal management systems, each designed in anticipation of the thermal behaviour in the near-space environment.
Other temperature sensitive components, such as the optics filter and cameras required less complex thermal management, requiring mostly insulation to protect against the Sun's intense heat. The optics filter has an integrated thermal management system, requiring power through USB.

2.4.1 Heating System

2.4.1.1 Motor Thermal Management

The active heating system for the motor's consisted of four heaters controlled by a Teensy microcontroller. Two heaters were used for each motor to ensure the temperature was kept to an optimum temperature, as shown in figure 2.4.1.1.a. Thermocouples were used to monitor the temperature of the motors, with relay to toggle the heater states as required. Table 2.4.1.1.a indicates at which motor temperatures the heaters are toggled.

Table 2.4.1.1.a Conditions for Heaters to Toggle

Temperature of Motor, T, (ºC)	Number of Heaters On per Motor
$T > 40$	0
$20 < T < 40$	1
$T < 20$	2

Heaters could only be turned on if power was available to do so, such that no more than 2.5A (at 30VDC) would be drawn by the payload. As a result, heaters were prioritised based on the coldest motor. The system turns on the heater with the highest priority first, then any remaining heaters which are required (given by table 2.4.1.1.a) while power is available.
Once a heater was turned on, the current & voltage sensors would need time to update, to include the change of power draw, hence a limitation was implemented preventing additional heaters from being turned on for 3 seconds after a heater was turned on.

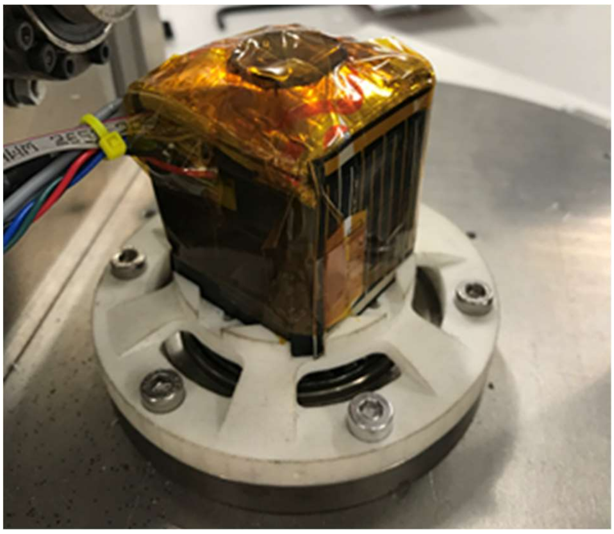

Figure 2.4.1.1.a Stepper Motor with Heaters Attached

2.4.1.2 Insulation

MLI (Multi Layered Insulation) was used to insulate the optics, motor and wave strain gear components. The insulation consisted of layers of thin foam sheets and reflective foil. This provides insulation from all three methods of heat transfer and evenly spreads out thermal energy through each layer via the foil sheets. Kapton tape, which itself is a thermal insulator, was used to secure the multi-layer insulation.

2.4.1.3 PCB Case

The PCB case was made from aluminium, which will reflect much of the radiation hitting the outside surface of the metal from the Sun, while reflecting thermal radiation from the electronics inside the box. The electronics would not need an additional heat source as enough heat is generated by the components themselves during operation.

2.4.2 Heat Transfer System

2.4.2.1 Heat Pipe and RPi Heatsink

To prevent the CPU (Central Processing Unit) of the RPi (Raspberry Pi) from overheating a heatsink was attached to the top and bottom of the RPi which made contact with the CPU and I/O (input / output) chip, dispersing the concentration of thermal energy away from the main integrated chips. A heat pipe was routed from the heatsink to an internal wall of the PCB case, which would always be hidden from sunlight. This provided a cool surface for heat transfer from the RPi, via the heat pipe and conduction, to the metal frame of the payload, acting as a larger heatsink. The connections between the RPi and heatsink were made through thermal pads, designed for high heat transfer and thermal paste applied at the connection between the heatsink and heat pipe.

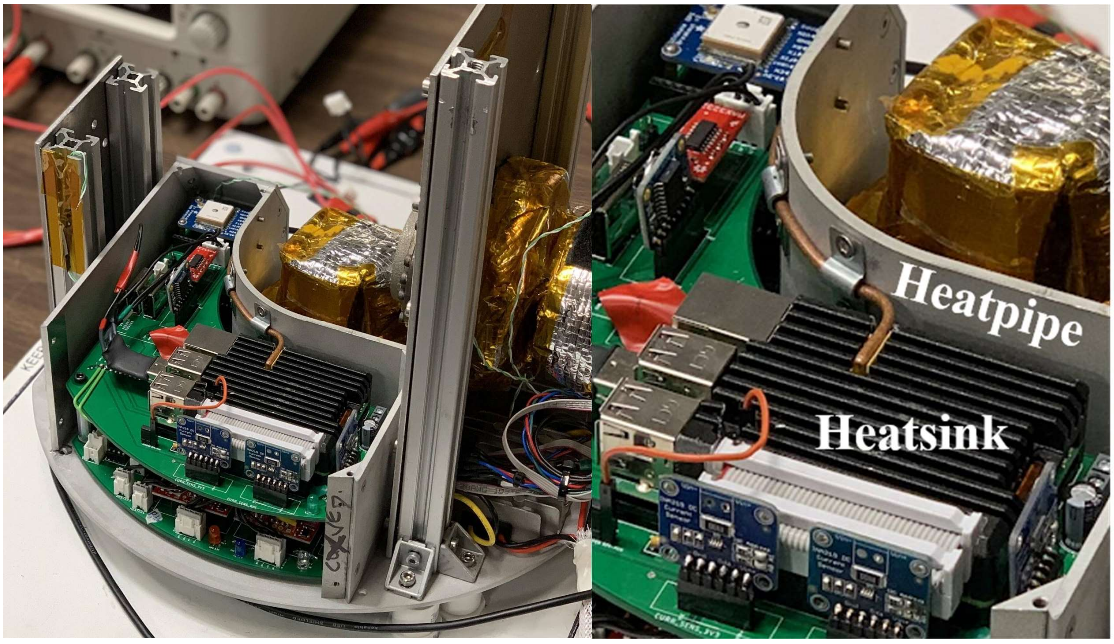

Figure 2.4.2.1.a Raspberry Pi Heat Transfer System

2.5 Optics System

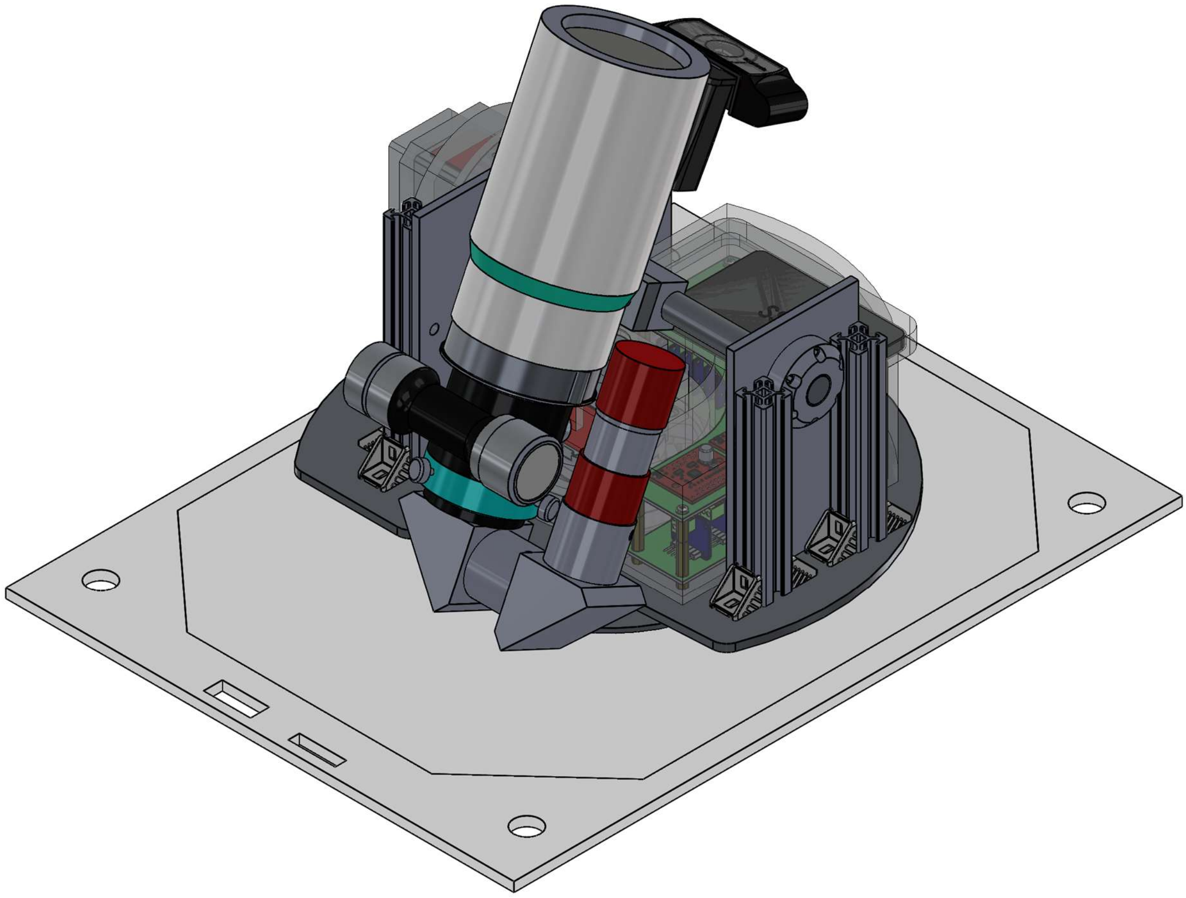

Figure 2.5.a Full SunbYte III Assembly CAD

2.5.1 Telescope

The telescope that was used on the SunbYte II launch, was recovered and re-flown as part of SunbYte III. The telescope was a Williams Optics Zenith Star 61mm apochromatic refractor. The telescope was reused as it was in good condition after the flight and was the largest telescope that could be flown while still fitting within the HASP size limits.

2.5.2 Science Camera

The science camera flown was a Zwo ASI MINI 120 mm monochromatic CMOS chip camera which was powered by a 5V USB-C connector. This camera as chosen for its compact size, low power, and cost.

2.5.3 H-alpha Filter

The H-Alpha filter was a Daystar Quark H-Alpha chromosphere filter. Power transfer was facilitated by a 5V USB connector. The H-alpha wavelength was chosen as it transmits light from the chromosphere of the Sun and blocks out wavelengths from the bright photosphere. This can allow interesting surface features such as filaments and sunspots to be visualised. The Daystar Quark filter was chosen as it compact, low cost, and low power.

2.5.4 Mirrors

The volume constraints of the HASP platform and the relatively large optical components necessitated the use of two 90-degree mirrors in order to fit within the allowed dimensions. One of the mirrors was previously flown on SunbYte II.

2.6 Structure

Objectives of the payload structure:

- The structure shall meet the requirements for size and mass constraints set by HASP
- The structure shall provide a platform to contain the necessary components
- The structure shall be able to orientate the telescope between 0 and 65 degrees in the pitch axis.
- The structure shall be able to orientate the telescope between 0 and 360 degrees in the yaw axis.

Requirements of the payload structure:

- Hold things in place, strong enough to survive landing & environment conditions

2.6.1 Load Bearing Structures

2.6.1.1 Design

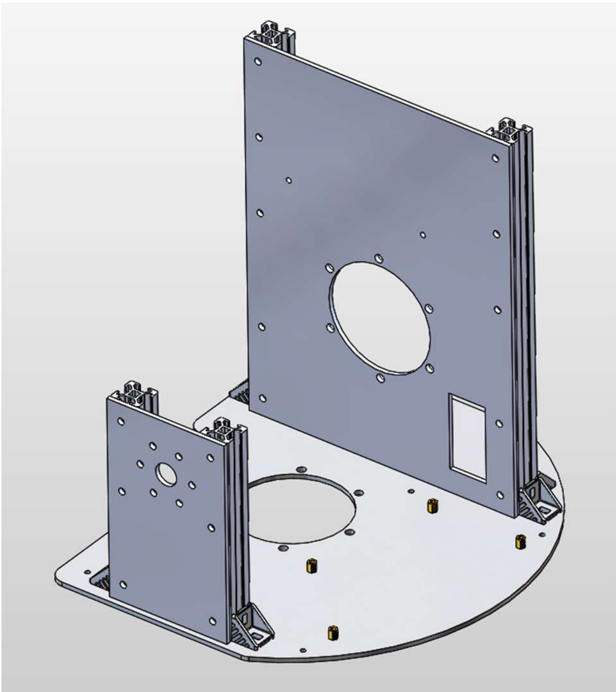

Figure 2.6.1.1.a Main Load Bearing Structure

The Main load bearing structure was manufactured out of aerospace grade aluminium. It consisted of four flex link struts. These struts attached the two vertically mounted plates to the base plate. The vertical plates are there to support the pitch actuation assembly. This includes the pitch wave strain gear, pitch motor, shaft and the full telescope assembly.

The pitch shaft assembly structure consisted of a metal shaft which connected to the telescope clamp via two metal blocks that secured the telescope clamp to the shaft. All these parts were made from aluminium. The shaft connected to a bearing on one end and connected to the wave strain gear adapted on the opposing side. The wave strain gear adapter was made from 3D printed titanium and attached to the wave strain gear via four bolts.

2.6.1.2 Manufacturing

The struts did not need to be manufactured; these were simply re-flown parts from SunbYte II. The base plates and the side plates were all water jet cut from a larger aluminium sheet.
The shaft was machined via a lathe and the two parts that made the clamp for the shaft were milled out of solid aluminium blocks. The wave strain gear adapter was made with additive layer manufacturing.

2.6.2 Casings Structure

2.6.2.1 Design

2.6.2.1.1 PCB Case

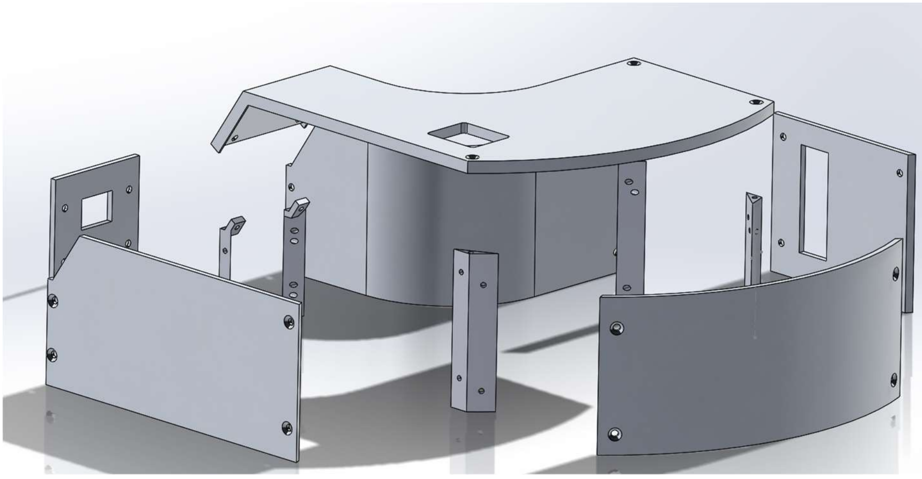

Figure 2.6.2.1.1.a PCB Case Exploded View

The PCB case was designed such that each panel can be taken off independently, this allows easy access to the electronics. The PCB case is a set of five panels, which are all secured by five bespoke struts. The lid is attached to the top of the struts with countersunk bolts. The lid has a lip so the lid slightly overlaps the outside of the side plates. This is to ensure the case is rigid and sturdy.

2.6.2.1.2 Webcam Case

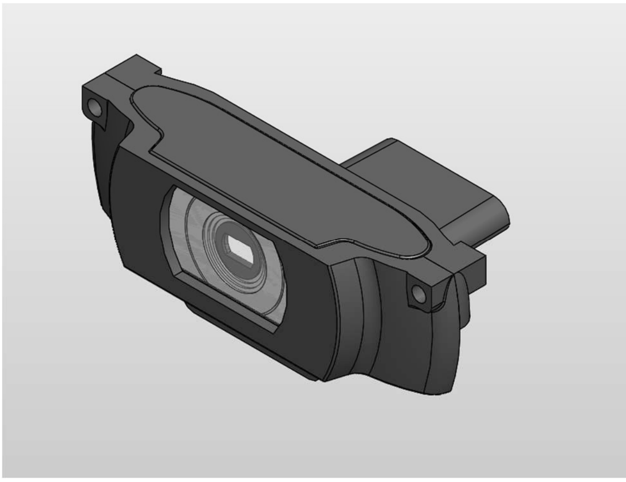

Figure 2.6.2.1.2.a Webcam Case Front

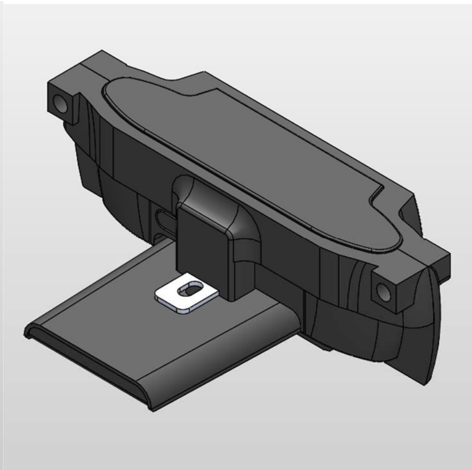

Figure 2.6.1.2.b Webcam Case Rear

The webcam case was two separate pieces which screw together to hold the webcam in a perfect 90º angle. The front half matches the contour of the webcam, this is to ensure the webcam does not rattle in the case. The rear part is a hugging "T". This acts as a brace for the webcam, the front and the rear are screwed together through the two holes on the top left and right of the casings.

2.6.2.1.3 Wave Strain Gear Covers

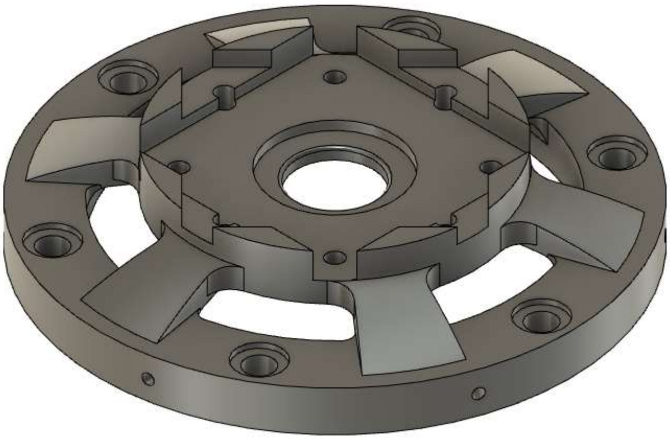

Figure 2.6.2.1.3.a Wave Strain Gear Cover

Each wave strain gear had a cover/seating for the stepper motor that drove the gears. The harmonic drives and covers were secured together using six bolts, figure 2.6.2.1.3.a shows the six holes used located on the outer ring of the case.

2.6.2.1.4 Bearing Case

Figure 2.6.2.1.4.a Bearing Case

The bearing case was used the pitch shaft assembly to prevent the pitch shaft from moving laterally. This was designed such that the bearing is secured by press fitting it into the case, the press fit nature meant that no adhesive would be required to secure the bearing in place.

2.6.2.2 Manufacturing

2.6.2.2.1 PCB Case

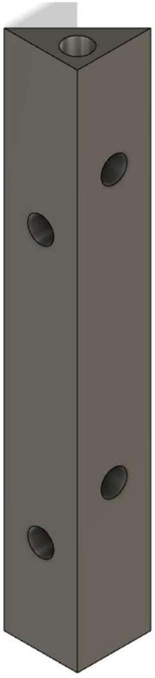

Figure 2.6.2.2.1.a One of the Bespoke Struts for PCB Case

The side panels and the bespoke struts were made using wire electrical discharge machining (EDM). The lid was made by CNC machining. The whole PCB case is made from aerospace grade aluminium.

2.6.2.2.2 Webcam Case

The webcam case was manufactured using standard 3D printing using PLA plastic.

2.6.2.2.3 Wave Strain Gear Covers

The covers were 3D printed out of PLA plastic for SunbYte II and were re-flown parts on SunbYte III.

2.6.2.2.4 Bearing Case

The bearing case was turned from a short cylinder of aerospace grade aluminium.

2.6.3 Strain Wave Gears

To ensure that the movement of the gimballed telescope is accurate, two strain wave gears, one for pitch and one for yaw were used. Each gear had a ratio of 160:1.

2.6.4 Mounting to HASP Plate

2.6.4.1 Design

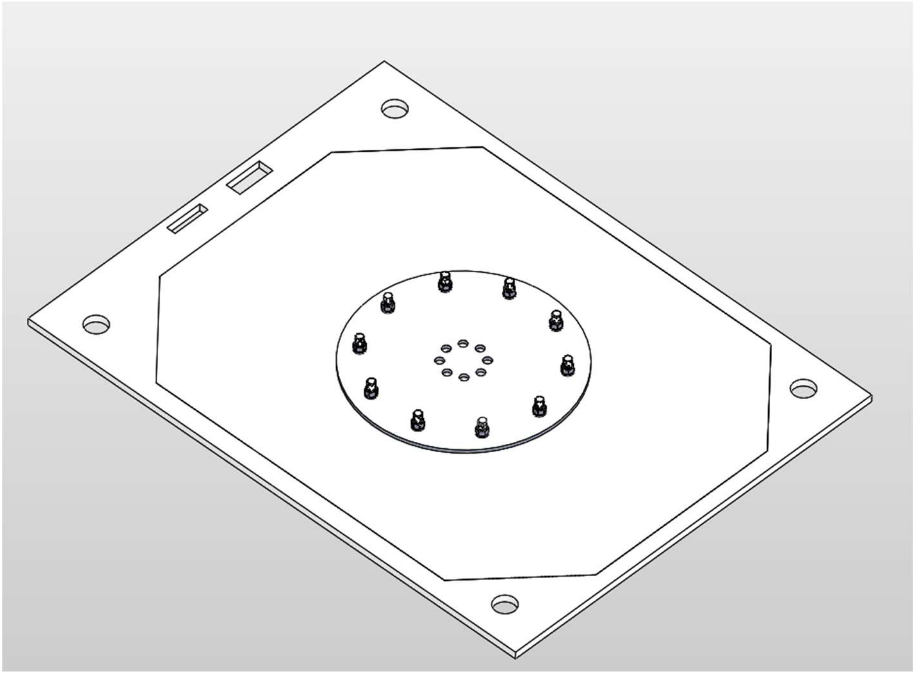

Figure 2.6.4.1.a Support Plate attached to HASP Plate

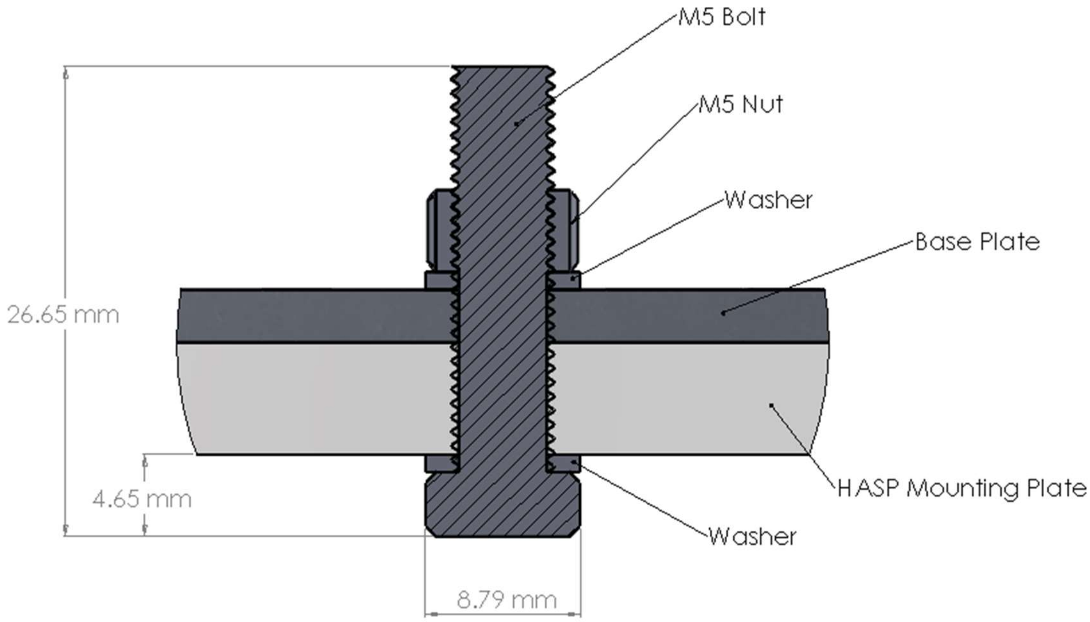

Figure 2.6.4.1.b Section view of Support Plate connection to HASP Plate

SunbYte mounts onto the HASP plate using 10 M5 bolts and nuts. Figures 1.6.4.1.a-b show how the support plate is connected to the HASP plate.

2.6.4.2 Manufacturing

The support plate used was manufactured out of the same aerospace grade aluminium which was used for the side plates and base plate for the main load bearing structure. The support plate was too water jet cut.

3 Pre-flight Known Issues

This section details the state of the payload prior to flight, focusing on the limitations and areas where SunbYte was not performing as expected or desired. Several of the issues were identified for the first time during the integration testing, only 6 weeks before launch, leaving little time to implement robust solutions to many of the problems. The majority of SunbYte's systems were fully functional or satisfactorily functional, such that they would not negatively impact the flight performance, although a number of challenging and time-consuming problems remained, which could not be fully dealt with prior to launch, despite the hard work of the remaining available team members.

3.1 Electronics and Power System

Motor calibration loss – Encoders were used in the motor control to provide closed-loop positional feedback to track movement. Due to the nature of the incremental encoders used, the positional data is required to be stored in non-volatile memory prior to shut down, and due to the lengthy operation of writing this data, it could be run only while no motors were not moving. If the payload lost power during a movement then the correct position of that motor would not be updated, and the precision of the calibration would be lost. This would require a recalibration manually, through uplink commands.

Motor torque limitations – During the first thermal chamber test in the cold phase we became aware that the stepper motors could no longer rotate their respective loads in the colder temperatures. SunbYte II experienced a similar issue, but lacked data to understand the problem, hence we concluded the problem was due to the motors being exposed without temperature control. We implemented this alongside multi-layer insulation and expected the motors to be able to perform consistently in the well-controlled thermal environment. Investigation led us to perform an expensive upgrade of the lubricant in the harmonic drives as these components were most likely the reason for requiring more torque at lower temperatures. It would not have been feasible to heat the harmonic drives and it was too late in the development to change to more powerful motors, while maintaining the tight size restrictions.
As a result, prior to flight we expected some issues with movement during the ascent phase, expecting these to resolve at the warmer higher altitude.

Microcontroller Resets – On the final day of testing, before leaving for New Mexico to launch, a new problem was identified, resulting in a fix to reboot the main microcontroller when the issue occurred. While the payload was moving, this happened randomly every 1 to 5 minutes, the main repercussion of this was the settings manually controlled through uplink were lost upon each reboot. Hence, manual control capabilities of the payload were reduced for the actual flight, though the positioning ability of the payload through uplink commands was not lost. The full details of this issue are incredibly complex, and the true cause has still not been identified.

3.2 Attitude Determination and Control System

Webcam/Science Cam Centre Offset – Due to the precision required to align the telescope to the sun's position via the webcam, the alignment of the telescope and webcam lines of sight needed to be as parallel as possible. Realistically this shall never be reliable enough without adjustment. Hence, once constructed a fixed offset was programmed into the software through manual testing. If more time was available, an automatic system would have been implemented.

3.3 Communications System

Message Corruption – Occasionally downlink messages would be corrupted in such a way that the data could not be gathered from the message. Due to the high frequency of downlink messages sent and low error rate, jumbled or erroneous messages could be ignored, although the cause of this was never identified.

3.4 Thermal System

Cold Phase Motor Lock – Upon testing in the thermal chamber, during the cold phase when the harmonic drives would reach approximately -20 degrees Celsius, the motors would no longer be capable of turning the drives (despite the motors being heated to 20 degrees), due to the stiffening of the drives. To combat this, old lubricant was cleaned out professionally and expensive new lubricant, specified for our purpose, replaced it. Testing was not possible prior to the flight, though the intention was that this would reduce the increase in torque required to rotate the drives during flight, such that the motors would be able to continue adjusting the pitch and yaw throughout the flight.

3.5 Optics System

Camera Image Quality – Due to the size limitations of the HASP payload slots, the camera and filter were only able to fit within the limits if two 90-degree mirrors were used. The use of two sets of mirrors caused magnification of the image entering the telescope, meaning that only a small portion of the solar disk could be imaged. Furthermore, the use of a CMOS chip camera meant that the Newton's Rings phenomenon often appeared on images of the Sun, further degrading the quality.

In addition to this issue, the scientific camera had no auto-exposure setting, such that images of the Sun were almost always completely black or completely white due to over or under exposure. This was not fixed before launch, due to time constraints. During the final stages of ground testing, one image was taken, with the final payload assembly using the tracking algorithm, that appears as if it could be the edge of the sun against the darker background of space. The science camera image and webcam data are consistent, suggesting this is truly the case, indicating how close SunbYte III was to achieving the science objective overall.

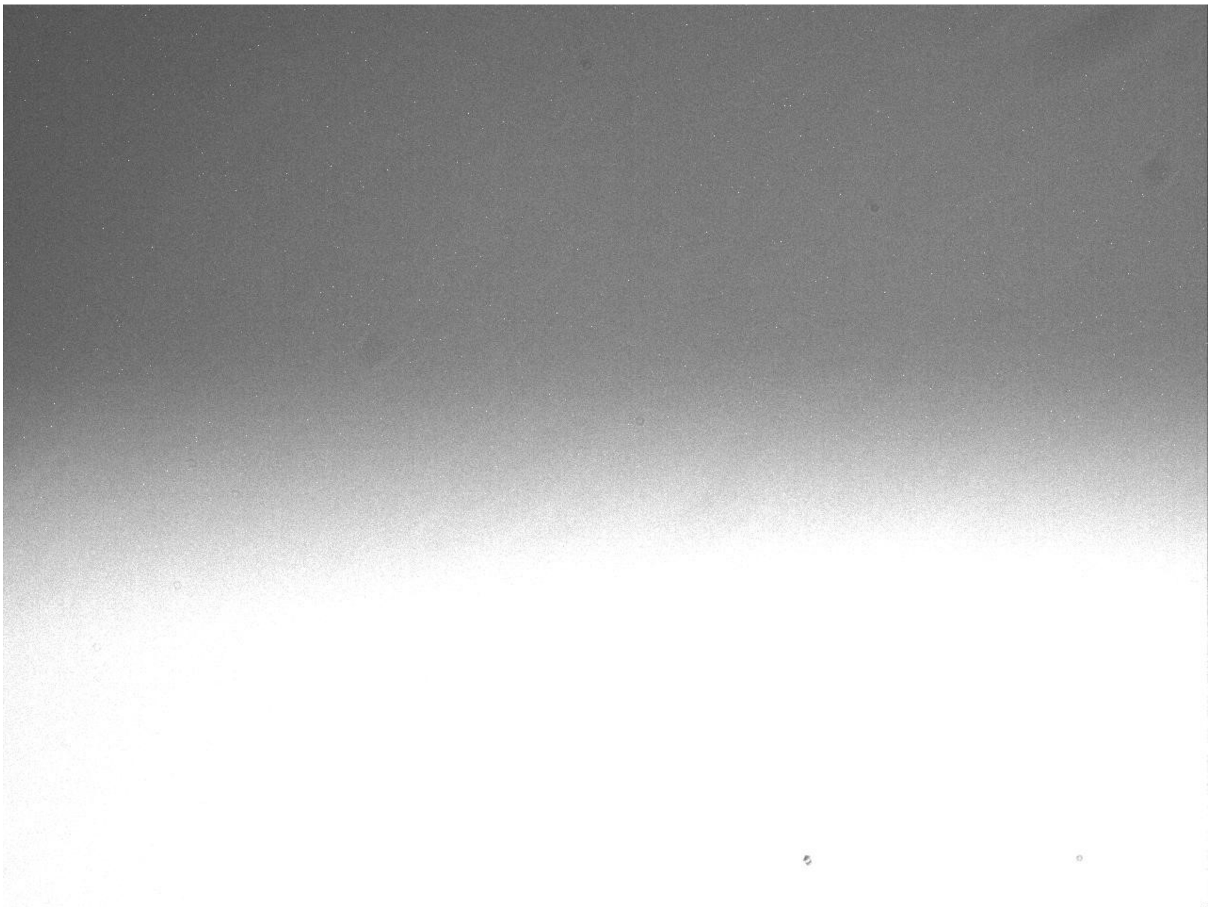

Figure 3.5.a Science camera image from ground testing

Science Camera Sensor Chip Damage – During outdoor testing of the optics equipment, attempting to capture the images of the Sun, the telescope and camera were directly manually, without the optics filter to remove most of the electromagnetic spectrum from the camera image. It is possible that the sensitivity of the CMOS sensor on the camera was damaged, as after that time, captured images showed no gradient of intensity following on from this.

4 Flight Performance

The following section details the performance of SunbYte III's hardware and flight systems, alongside an analysis of the camera and sensor data from the flight.

The anticipated flight performance was optimistic, given fixes had been implemented for each issue prior to launch, although a lack of time meant verification of many aspects was cut short. There was a possibility that the new lubricant would remove the issue of the motors becoming stuck entirely, thus massively improving the behaviour since integration. Additionally, electronics thermal management was improved by adding a heatsink and heat pipe, with the intention of conducting the heat to the cooler parts of the payload.

4.1 Hardware

4.1.1 Load Bearing Structure

Upon recovery there was no damage to the load bearing structure was mostly intact. The whole aluminium frame survived. However, the telescope clamp cracked and catastrophically failed, it is suspected this happened during the landing. The clamp may have sustained internal damage from SunbYte II's flight and since the part was re-flown the second landing from SunbYte III's flight caused the internal damage to propagate causing the clamp to break.

4.1.2 Casings

All casings that housed the electronics survived the full flight; no damage was sustained.

4.2 Flight Systems

4.2.1 Thermal Control

During the "cold phase", both motors slowed down to the point that tracking could not take place. Even after warming up, the motors/harmonic drives remained sluggish, as if the lubricant had seized or had become vicious inside the drives.

The pitch motor overheated to 110 degrees Celsius soon after entering the "hot zone". The motor was not operational for the remainder of the flight. Without the pitch motor, no tracking could be performed. The Rpi core temperature reached around 90 degrees Celsius during flight. Observations from the thermal chamber showed that the processor throttles automatically to avoid overheating completely, because of this, the processor did not shut down during the flight. Post-flight analysis showed the thermal paste connection from the Rpi heatsink to the heat pipe had failed, essentially isolating the Rpi from any form of conduction away from its heatsink. This meant the component stayed cooler for longer, but ultimately became too hot and began throttling its clock speed.

4.2.2 Motor Control

The motor control system was functional at the beginning of the flight and for a period after warming from the cold ascent. Between these points, the temperature of the system being driven by the motors dropped, increasing the viscosity of the lubricant alongside other factors, resulting in needing more torque to turn the payload, which the motors could not provide.

Later in the flight, after shutting down the tracking to resolve other issues, the pitch motor was heated by the Sun, through protective insulation to a temperature at which it would no longer function, leaving the pitch axis pointing well above the Sun's position for the remainder of the flight.

Post-flight analysis of the data demonstrated the lubricant alone was not enough to reduce the increase in torque required as the payload cooled, however the system was more tolerant of temperature than it had proven to be previously.

4.2.3 Optics

There were limited opportunities to capture images of the Sun during the flight due to issues with the thermal control and motor systems which meant that the system could not keep the Sun within the camera sensor. The science camera settings were suboptimal for flight due to insufficient and difficulty when testing. These factors coupled with the potential damage to the science camera before flight meant that the system did not perform as initially specified and no scientifically useful images were captured.

4.2.4 Communication Uplink

The following table details the timings, reason and action of the uplink commands sent during flight.

Table 4.2.5.a Uplink Commands Used During Flight

Time (Mountain Time)	Command Sent	Command Description	Reason for Command	Outcome
04:00	A309	RPi Reset	No Images being Downlinked	Images began being downlinked
05:41	AFE5	Disable Tracking Commands	*Sent by HASP Team*	
07:01	**LAUNCH**			
07:08	A309	RPi Reset	No Images being Downlinked	RPi Restart messed up timestamp and no images downlinked
07:22	A228	Point to Default Position at Minimum Pitch	To Check Initial Position	
07:26	Power Cycled	Turning SunbYte Off and On from HASP End		Small Pitch motion only
07:56	A2F8	Set Low Speed and Acceleration	Try to make SunbYte move in cold conditions	
08:07	AC12 (Twice)	Pitch Motor Rotate 5 degrees	To move pitch to calibratable position	
08:08	A026	Calibrate Pitch Motor	To calibrate pitch	
08:14	A228	Point to Default Position at Minimum Pitch	To Check Default Position	Payload rotated but was off by 90 degrees from default Yaw. Pitch kept twitching
08:19	AFE5	Disable Tracking Commands	*Sent by HASP Team*	
09:40	**FLOAT REACHED**			
09:40 – 09:52	A319	Yaw Motor Rotate -5 Degrees	To Check if Yaw moves 5 degrees	
09:52	Power Cycled	Turning SunbYte Off and On from HASP End		
10:02	A2F8	Set Low Speed and Acceleration	Slow Motor Speed for Cold Environment	
10:03	A228	Point to Default Position at Minimum Pitch	Test to go to default position	
10:10	A51B	Yaw Motor Rotate -20 Degrees		
10:16	A127	Calibrate Yaw Motor	Calibrate Yaw	
10:18	A51B	Yaw Motor Rotate -20 Degrees		No movement
10:35	A0E6	Enable Tracking	Start Tracking	

		Commands		
10:47	ACF2	Turn off Heaters and Disable Thermal System	Prevent Overheating	
11:15	A329	Point to Default Position at Maximum Pitch	To Cool Pitch	
11:17	A2A8	Position Yaw motor at 180 degrees		
11:30	A66C	Position Yaw motor at 0 degrees		
11:33	A71D	Yaw Motor Rotate -90 Degrees		
11:37	A71D	Yaw Motor Rotate -90 Degrees		
11:55	A42A	Position Yaw motor to 0 degrees		
15:14	A71D	Yaw Motor Rotate -90 Degrees		
15:16	AF15	Pitch Motor Rotate -20 degrees		
15:28	A127	Calibrate Yaw Motor		
15:32	A81E	Disable Pitch Motor		Rotated 20 degrees CCW
15:16	Power Cycled	Turning SunbYte Off and On from HASP End	To recover data as it zeroed	Regained data
17:17	**TERMINATION**			

4.3 Flight Data

From the flight, SunbYte III collected data from various sensors and the behaviour of its autonomous systems, as well as a webcam, science camera, uplink and downlink messages. Video feeds from HASP from various angles were available alongside the HASP system's environment and payload data.

A summary of the datasets from SunbYte III is as follows:

- Telemetry downlink – 13,367 telemetry messages, from 29 different sources, including 19 sensors and various status indicators. A total of 387,643 data points.
- Tracking camera – 53,726 images saved. Recorded at a rate of ~2 images per second
- Science camera – 16,926 images saved, with 1 image that stands out.

4.3.1 Telemetry Data

Figures 4.3.1.a-h show all the downlinked data from the flight. The data contains what appears as a gap in time at T+2:47:00 for 35 minutes, though this was instead a period when identical data was logged, due to a malfunction in the software. There are also multiple locations where the data drops to 0, this is when the Teensy microcontroller was reset, causing an interruption in the incoming data.

Figures 4.3.1.a-c show current, voltage and power data from the 4 current sensors located on the 12V, 5V and 3.3V lines, alongside the RPi power input. The voltage data is as expected for all except the 12V line, which dips in the early-mid-flight, while the most 12V components were active.

The current data is highly variable over large timescales due to high current draw components frequently turning on and off in time scale ranges of seconds to tens of seconds. These components are the science filter (5V), heaters (12V) and motors (12V). The plot indicates some brief moments where the current rises to well above the rest of the data and the safe limits, though these were found to be inaccurate measurements. The total current never truly exceeded 2.5A at 30V and hovered between 1 and 2 Amps. This resulted in a mean power draw of 32W, which was safely below the limits for a large payload.

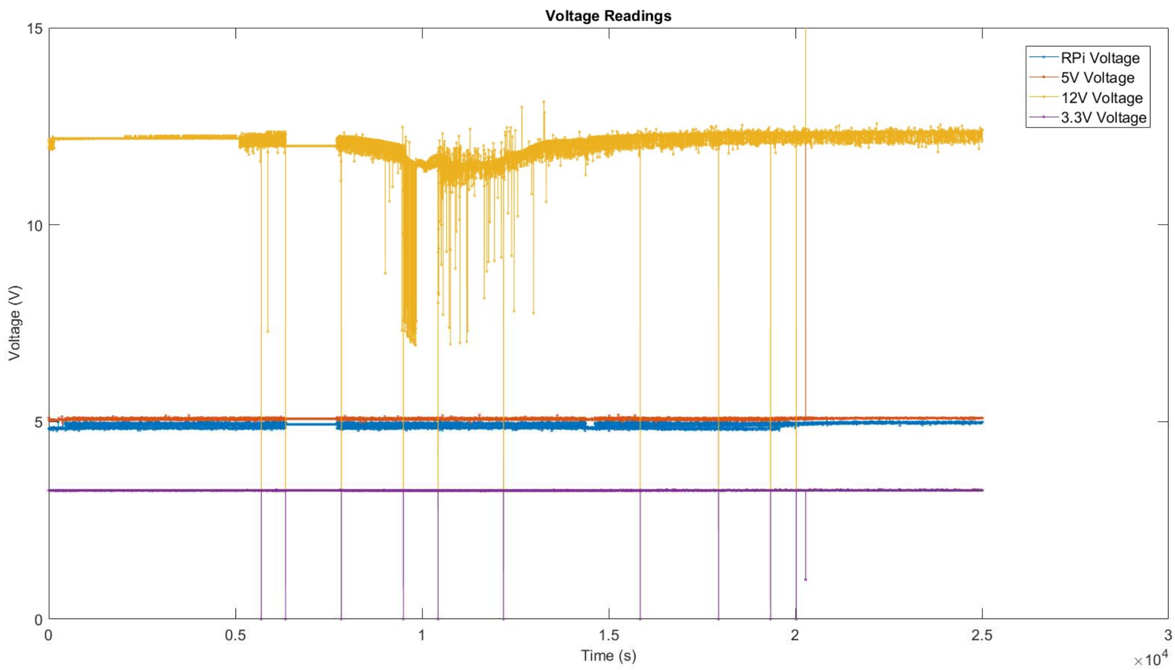

Figure 4.3.1.a Voltage Readings

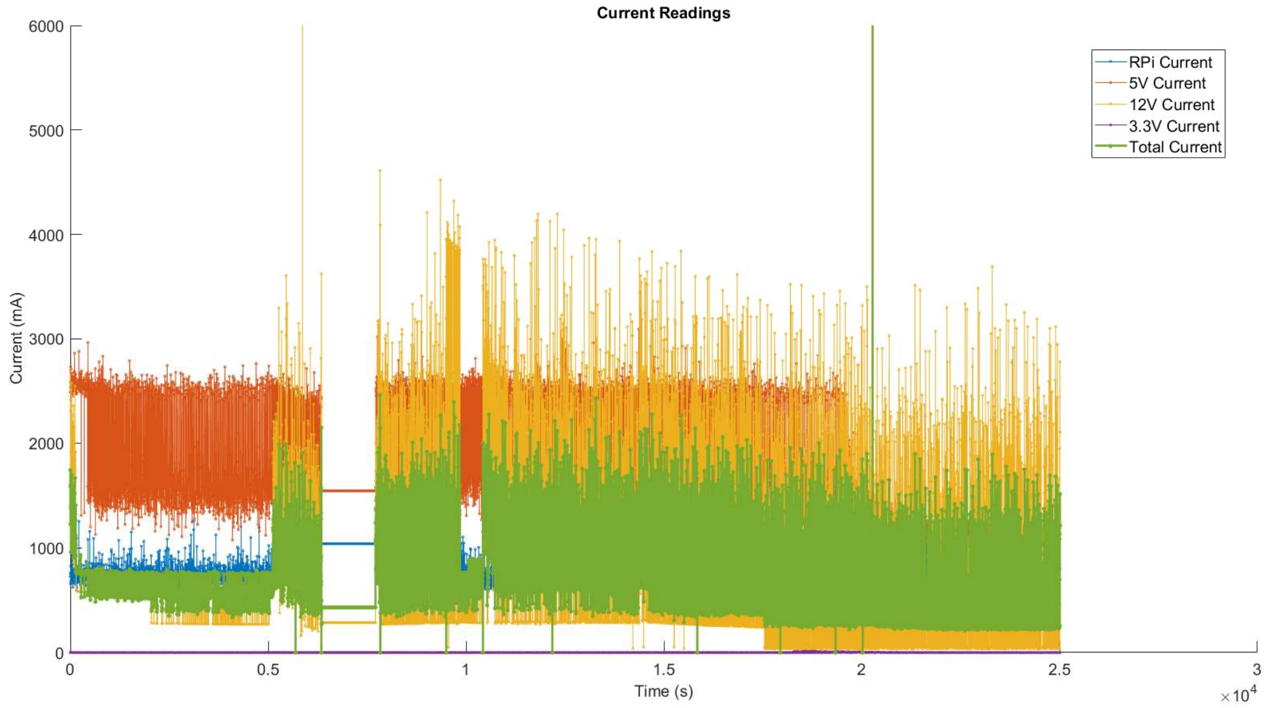

Figure 4.3.1.b Current Readings

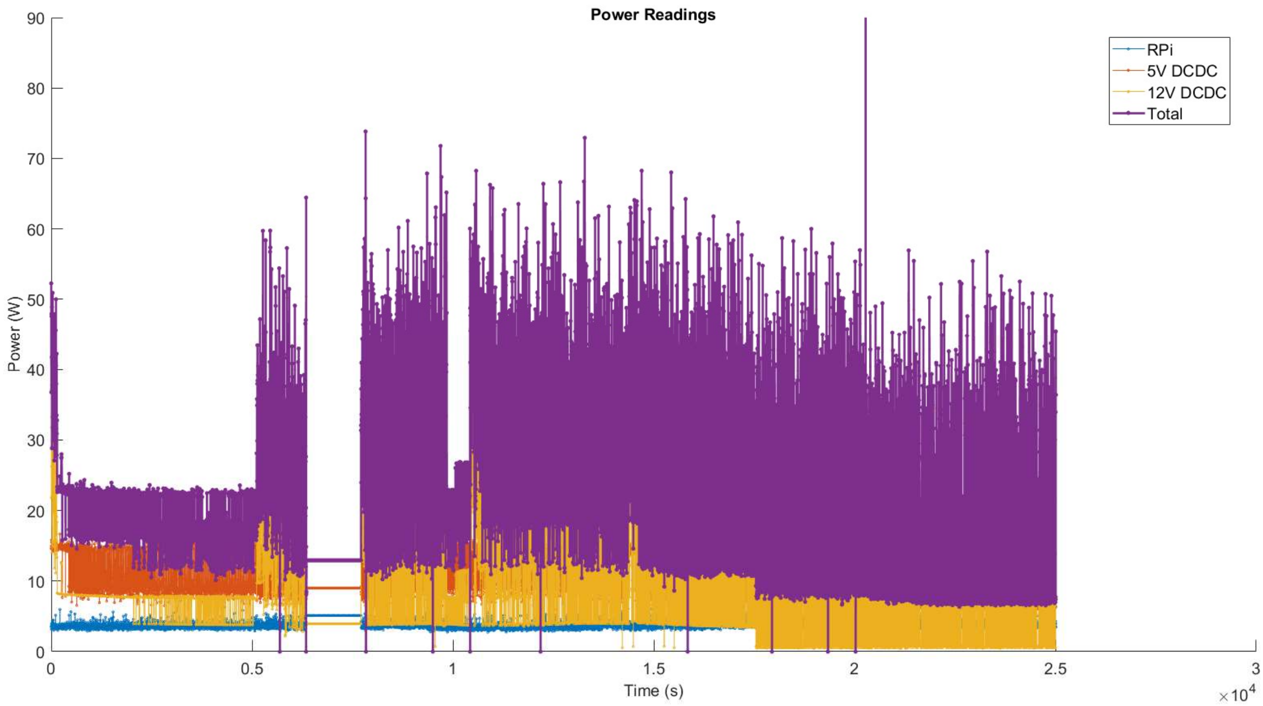

Figure 4.3.1.c Power Readings

The temperature data shows a large range of temperatures were present across the payload, spreading out from the initial temperatures at launch. Despite issues in the measurement records, particularly in the 'Ebox Top' sensor, a profile of temperature from each sensor is present.

From the temperature data, it is clear the heating system was successful in maintaining the motor temperatures above 0 degrees, holding the yaw motor at 20 degrees for several hours, despite an ambient temperature of -60 degrees (brown). The pitch harmonic drive temperature (turquoise) tracks the ambient temperature with a fairly consistent offset of 20 degrees and although it cooled significantly, it warmed sufficiently that there was a window, between 10 and 60 degrees that tracking might have succeeded. Unfortunately, the pitch motor was out of calibration due to various shutdowns, leading to the 'motor calibration loss' problem (from Section 3.1). During the time addressing this issue, the Sun heated the side of SunbYte III, causing the pitch motor (blue) to rapidly heat up above operational temperatures, until the yaw axis was rotated, causing other temperatures to increase.

The electronics were held at a safe temperature for most of the flight, although they heated up towards the end of the flight. After the yaw axis was rotated to shade the pitch motor, the Sun heated up the electronics as can be seen by the sudden rise in temperature, towards the end of the flight in the 'Ebox Top' and 'Ebox Bottom' traces. Additionally, the heat pipe to the RPi lacked an effective thermal connection, hence was unable to distribute heat.

The 5V and 12V DCDC converters maintained suitable operating temperature, even while in direct sunlight due to their external metal heatsink and large conductive surface on the payload.

The optics equipment was well insulated using the MLI and remained within its thermal operating range and below 50 degrees for the duration of the flight.

In summary, the large number of thermocouples provided significant insight into how the payload behaved during the flight. This can influence future design decisions to improve thermal performance of the payload, particularly given the temperatures appear to reach a steady state towards the end of the flight.

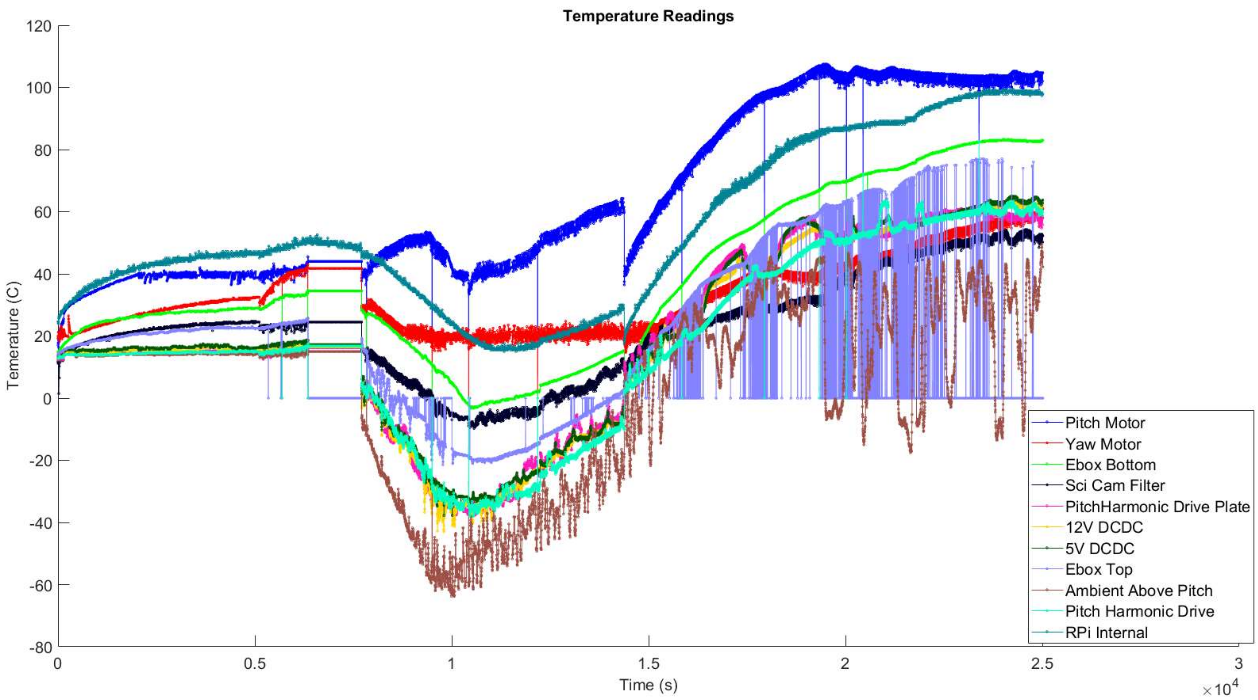

Figure 4.3.1.d Temperature Readings

The record of heater status indicates more heating was required on the yaw motor than the pitch motor. The secondary heaters for both motors were barely used, with plot 2 remaining off for the entire flight and plot 4 indicating minimal heating at the beginning and midway through, with the heater turning on and off frequently. As the temperature was on the threshold for two heaters (20 degrees), which matches the temperature plot, this heater's total on time was minimal. The primary heaters capably maintained the temperature using a simple threshold condition as a control method, demonstrating the success of this system.

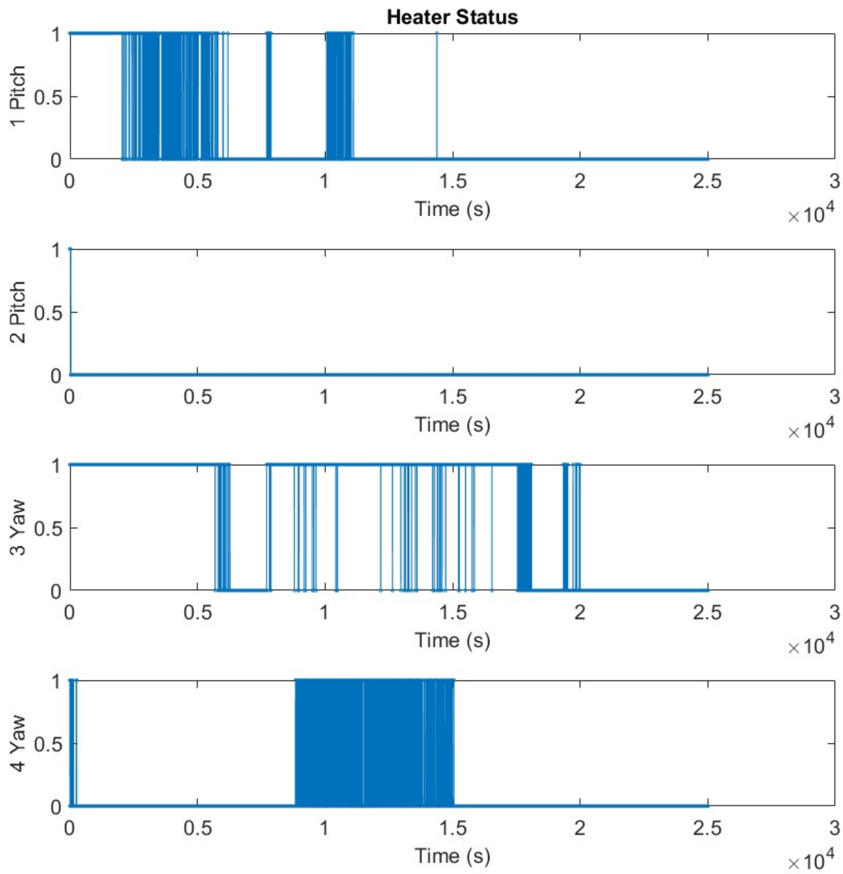

Figure 4.3.1.e Heater Status

The following three plots 4.3.1.f-h show the pitch and yaw motor positions combined with their temperature readings, followed by the settings for motor speed and acceleration. At the beginning of the flight the system was operating successfully. Once it became sluggish, it was manually turned off for the remainder of the ascent, due to the system cooling and becoming too difficult for the motors to move. This was due to reaching the torque limit for the motors used, alongside colder components becoming increasingly difficult to turn. Shortly after reaching ascent, the movement resumed as planned, sweeping successfully multiple times, then tracking the Sun. However, this did not last long before problems began occurring.

Upon losing power, the calibration became out sync, this was fixed through manual uplink commands, although the motors were unable to resume their activities, due to the aforementioned issues. Despite these limitations, attempts were being made to move the motors. The speed and accelerations were lowered through uplink commands, which had been demonstrated to help the motors rotate against higher larger loads. Although, the microcontroller reset issue (section 3.1) meant every few minutes these values were reset, rendering this action unsuccessful. The pitch motor, nevertheless, was able to move slowly, as had been seen in the thermal chamber testing, resulting in a gradual change around the middle of the flight.

While the pitch motor is moving, during sweep, the yaw motor is stationary. In normal operation this works well to systematically search the sky, although here this meant the yaw was stationary for a long

period of time. Over this time the Sun shone on the more exposed pitch motor for a long duration heating the motor up, through the insulation, to well over 110 degrees.
Initially this was thought to be a problem with the heating system, though upon reaching over 70 degrees we become doubtful of this, realising the cause of the temperature increase was due to the Sun, despite expectations that the gondola's constant rotation would not allow this to happen. We attempted to correct the issue by repositioning the still functional yaw motor, to shade the pitch motor. Due to the excess heat and lack of convection the motor did not cool enough to resume operation, remaining stuck, pointing well above the Sun's location.

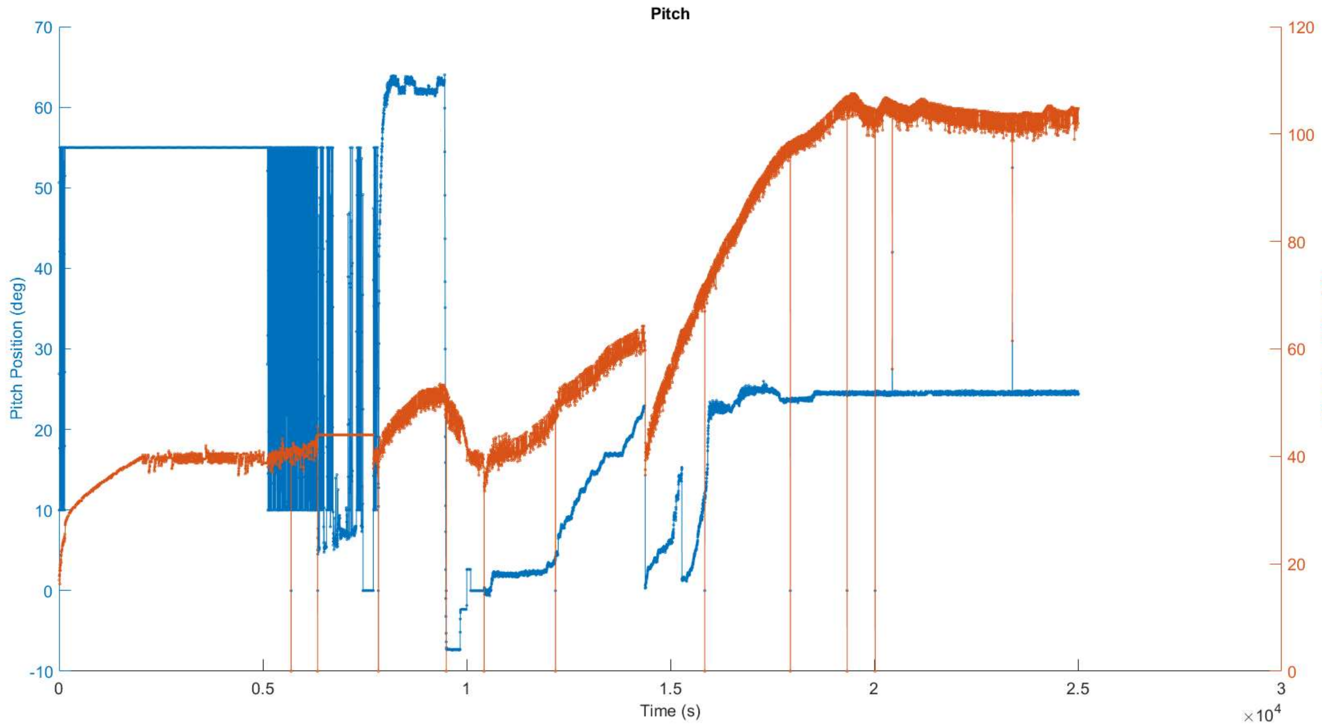

Figure 4.3.1.f Pitch Motor Position and Temperature

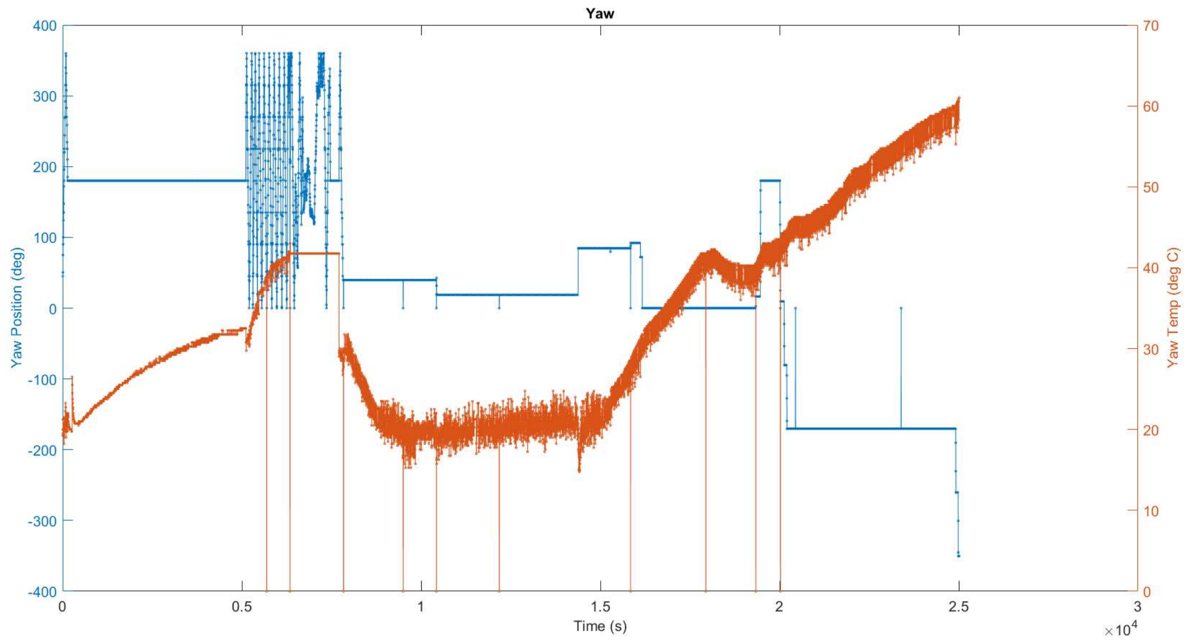

Figure 4.3.1.g Yaw Motor Position and Temperature

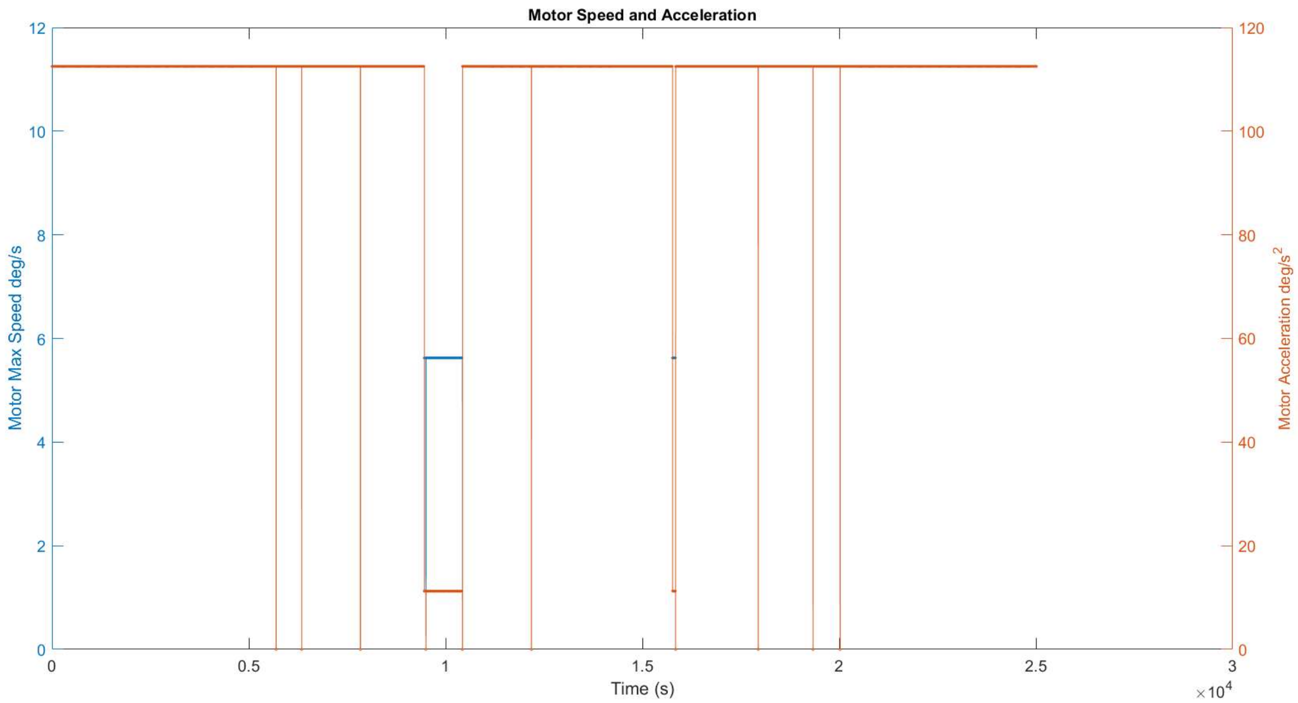

Figure 4.3.1.h Motor Speeds and Acceleration

4.3.2 Tracking Camera

The tracking camera recorded 53,726 images during the flight, which are incredibly like the nature of the images taken from the SunbYte II tracking camera. Images were taken at a rate of roughly 2 images per second, with occasional breaks while the payload was powered down.
On several occasions the Sun can be seen moving gradually across the camera in a set of images. Sometimes the Sun moves in a more unique pattern relative to the camera, which coincides with when the tracking algorithm was in action.
The images with the Sun and plain black images make up most of the logged images, though there are also some unusual images recorded.

- 25.88% of images show the Sun in varying positions in the camera frame. Totalling 27 unique sequences as well as a scattering of sightings of the Sun in the first 4,500 images. Some example figures are shown in 4.3.2.a-b.
- 1.54% of the images of the Sun, 0.298% of the overall number of images, appear distinctly different to the majority of the other Sun images, and are no longer circular. These images are most likely an unusual capture of the Sun due to wrinkles in the solar filter or movement of the payload. The intensity appears the same, indicating that the bright body is the Sun. (Example figures 4.3.2.c-d)
- 0.711% of images had white/grey reflections of varying appearance, these occurred in 10 unique groups. Of the images with reflections, a sequence of 24 images show what appears as a cable on the right side of the image (figure 4.3.2.e), which makes sense given the thickness of wire and the physical layout. This is likely due to the movement of the payload and the flexible wiring, necessary to support the movement. With this information it is likely the other images, shown in figures 4.3.2.f-h, are a result of the same problem, although they are visually quite different. This is most likely due to how close the cable was to the tracking camera lens.
- 23.36% of webcam images have a strange purple tint. This occurred in 2 groups gradually fading in for both instances, but fading out for only one sequence, due to the second persisting to the end of the flight, having begun quite late in the flight. This feature occurred independently of the other features. (Figures 4.3.2.i-j)
- The remaining images were black and corrupted images, of which the number of corrupted images was tiny.

Figure 4.3.2.a – The Sun

Figure 4.3.2.b – The Sun


Figure 4.3.2.c – Distorted Sun


Figure 4.3.2.d – Distorted Sun


Figure 4.3.2.e – Cable Obstruction


Figure 4.3.2.f – Camera Reflections


Figure 4.3.2.g – Camera Reflections


Figure 4.3.2.h – Camera Reflections

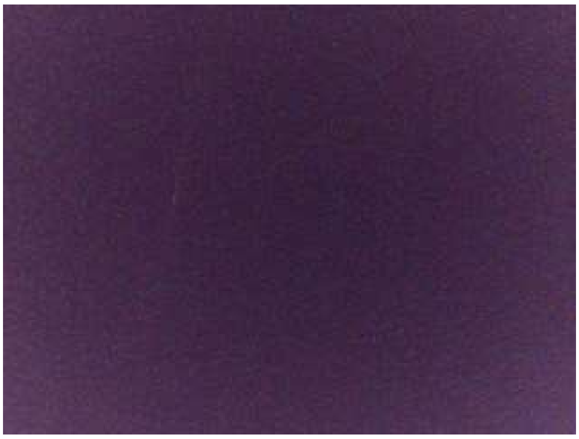

Figure 4.3.2.i – Pink Tinted Image Fading In

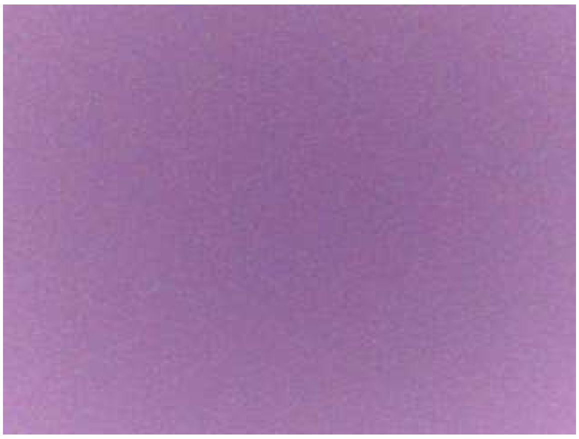

Figure 4.3.2.j – Pink Tinted Image Max Brightness

4.3.3 Scientific Images

The Scientific camera captured 16,926 images in total. The occurrence of software issues and a lower sampling rate is the reason for capturing fewer of these images, as well as their larger size. The action log shows a problem with the saving of science camera images, which has been narrowed down to a software error.

Unfortunately, all but one of the science camera images were completely black, shown in figure 4.3.3.a. The image is clearly much brighter than the other recorded images, with a gradient across it. Also, imperfections are present in the image, which are likely to be specs of dust, which were otherwise not visible in the darkness and other particles and marks on the lens.

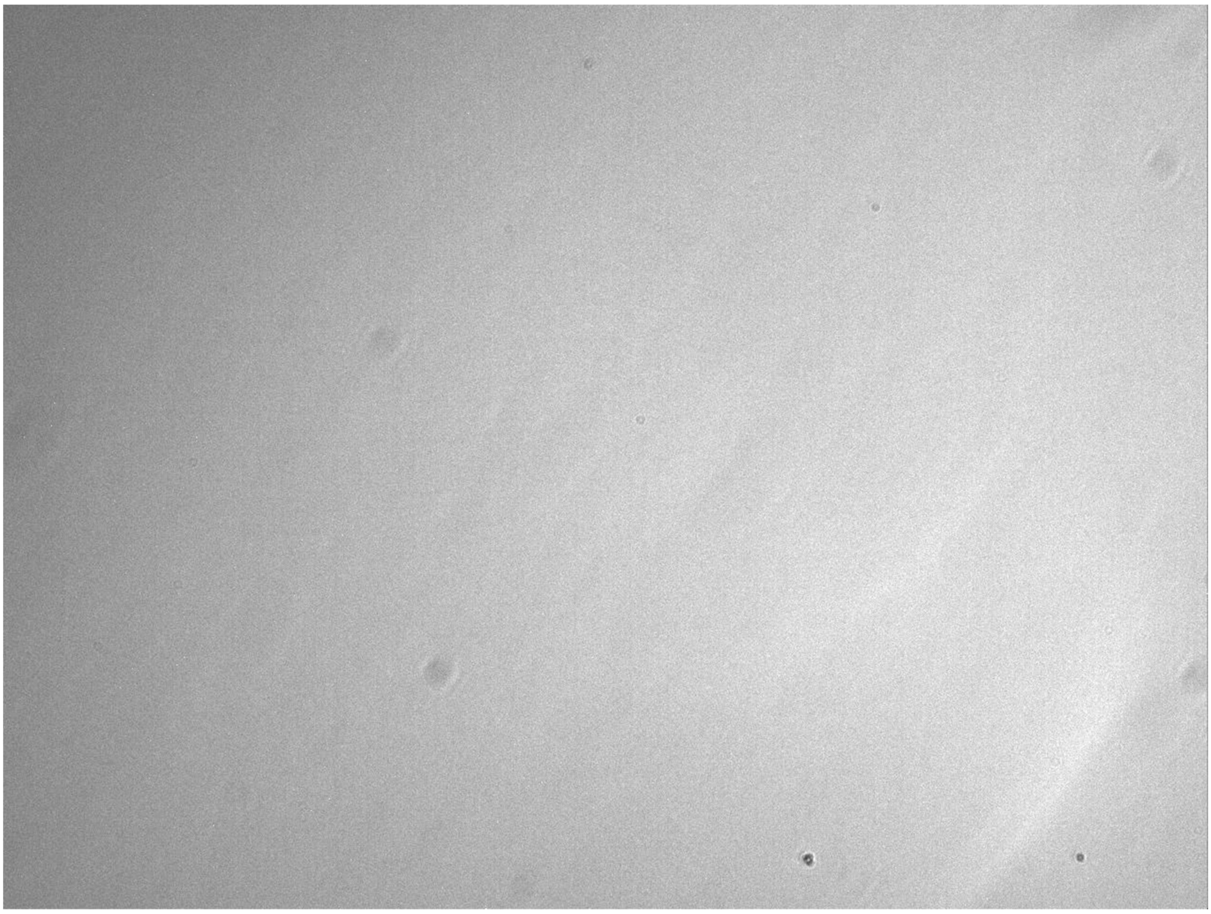

Figure 4.3.3.a Only Non-Black Telescope Image at 1567688588.27 UNIX

Correlating the timings of the image from the science camera with the images from the tracking camera, the Sun lines up with the webcam, factoring in the calibrated offset to account for the positioning of the two cameras. The webcam image (figure 4.3.3.b) was taken at 1567688588.25 UNIX time, while the science camera image was taken at 1567688588.27 (UNIX time), only 0.02 milliseconds apart. The science camera image may not be well focused or clear, but for the short period the tracking system was operational and not sweeping to find the Sun, this single image demonstrates a successful implementation of the tracking system and the SunbYte project as a proof of concept.
The timing of the image coincides with 6,347 seconds in the telemetry data, which match the section where tracking took over from sweeping, before an issue occurred with the motors.

Figure 4.3.3.b Tracking/Webcam image at 1567688588.25 UNIX

The sequence of tracking camera images leading up to the capture of the non-black science camera image is shown in figure 4.3.3.c, demonstrating the capability of the tracking system to home in on the Sun by making small adjustments.

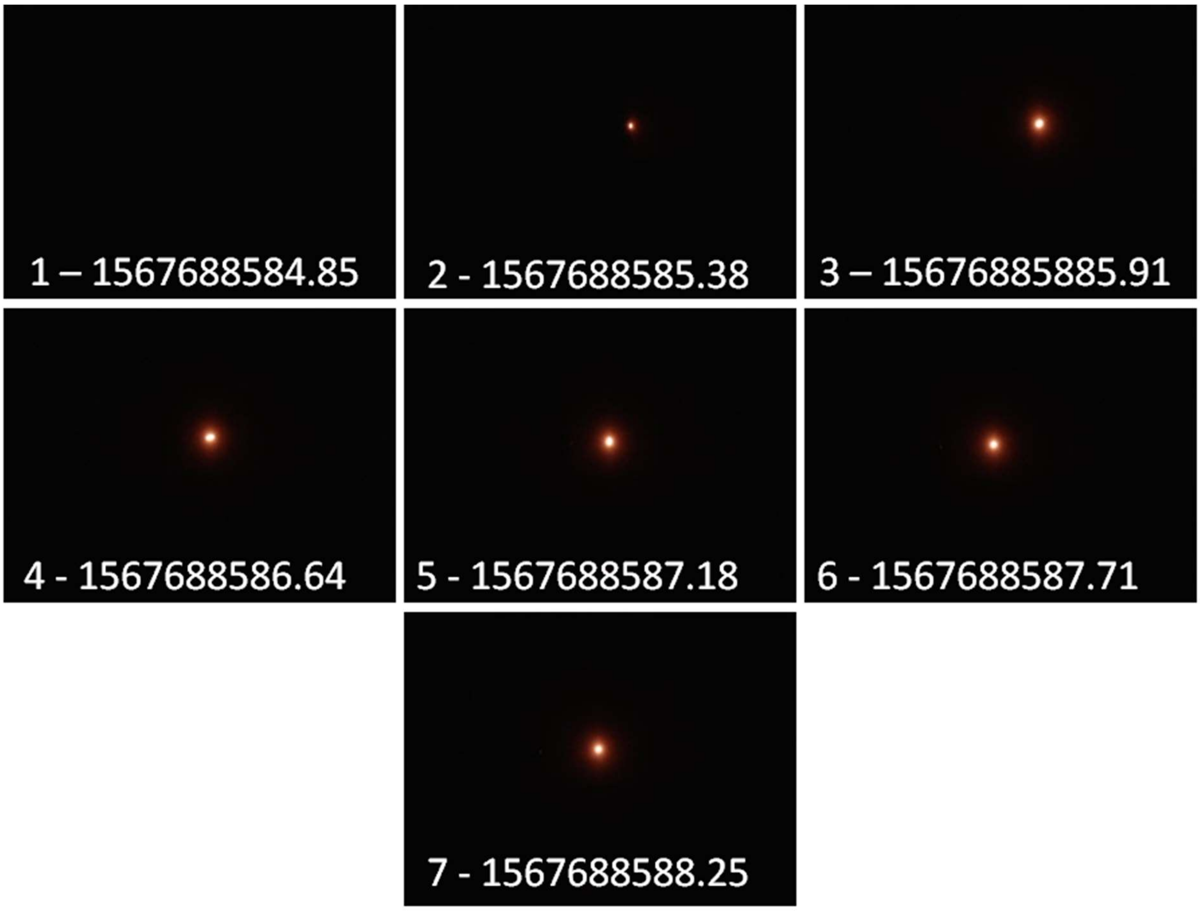

Figure 4.3.3.c Tracking Camera Sequence

The only observation from the remaining science camera photos (figures 4.3.3.d-e) is that they vary between black and dark shades of grey, with a few white specs on the image, which increases over the duration of the flight. The specs appear to each be only the size of one pixel in the image, some of the specs vary in brightness and they never move between photos. The most likely explanation for this is that individual pixels on the camera's CMOS chip have failed or become stuck reporting a particular brightness. This could be the result of high energy particle interactions, given the number of specs increases very gradually during the flight. An alternative theory is that tiny particles gathered on a lens, most likely the front of the telescope, although the dust particles are very consistently 1 pixel in size with little to no variance and theoretically there would not be enough light to see these features, given dust does not emit light and reflections are unlikely. Also, the features that appear more clearly as dust and lens markings are made clear in figure 4.3.3.a and these appear significantly different.

Figure 4.3.3.d - Science camera image from 1st hour of flight

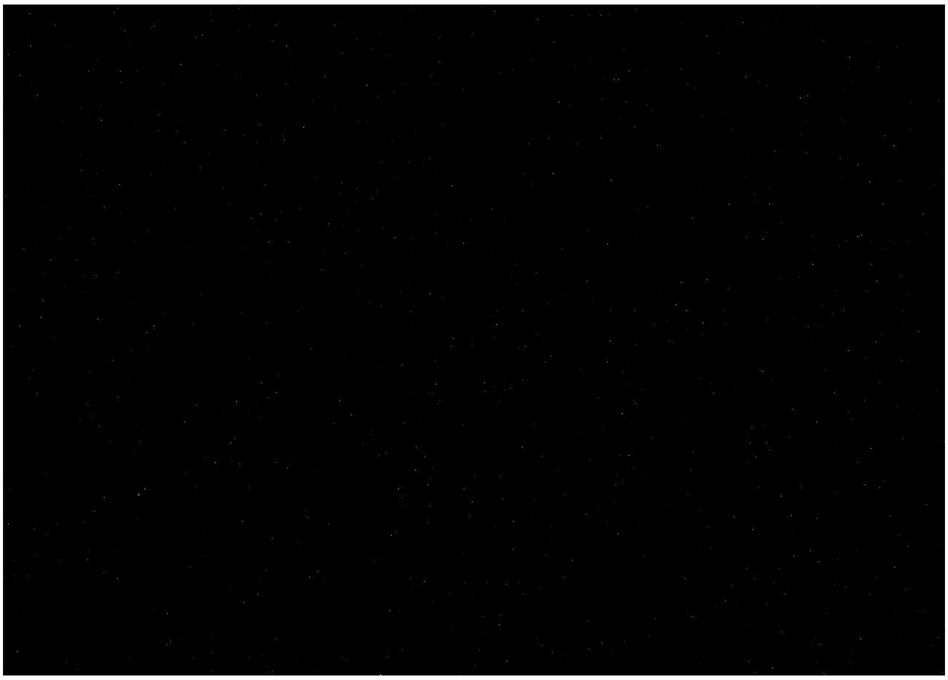

Figure 4.3.3.e - Science camera image from final hour of flight

5 Future Plans

The SunbYte project will continue its development journey in the next iteration of the payload, SunbYte IV, launching with HEMERA in August 2020, allowing the new team of students to expand upon the current design capabilities.

5.1 Electronics and Power System

Upgrades to the stepper motors will be implemented, to significantly increase overall torque output. This will mean the motors will be much larger, but this is not an issue for SunbYte IV. The stepper motors will be fully integrated, meaning the low-level control is handled by the controller, onboard the stepper motor. Closed loop feedback and position correction are also included and managed internally by the motor. The stepper motor receives commands through ethernet, which could be done directly from the RPi, removing the need for additional electronics.

Due to the proposed upgrades to the optics sub-system a more powerful processor will be needed to process and handle the storage of the images produced by the scientific camera on an SSD. New hardware has been released to update the RPi 3B+ to the RPi 4 and the Teensy 3.6 and LC to the significantly more powerful Teensy 4.0, providing significantly more computational power.

The power for the next iteration of the SunbYte payload will be drawn from an internal battery, meaning our power budget will have to be carefully managed to ensure that we have enough power for the entire flight. This means that the objective should be on minimising the power draw of the payload and maximising the amount of charge we are able to carry. In order to determine the charge left in the battery and more closely monitor the circuit, extra sensors will be added to the payload to inform the processor what is going on and if any circuits need to be switched on or off in order to reserve power, and how long is left in the battery charge.

5.2 Attitude Determination and Control System

The ADCS subsystem will be improved by fine tuning the current tracking system, including adjusting the speeds and accelerations as the tracking camera homes in on the Sun. The tracking software shall be maximised for robustness and efficiency. This will allow higher resolution tracking camera images to be used, providing greater precision, provided the software and processor can handle the increased computational load.

5.3 Communications System

The communications system shall be upgraded to be more robust and efficient, to improve its capability of sending a constant stream of information. Additional data will be added to the telemetry downlink and the ground station software shall be further optimised and automated. The communications image downlink will also include a method of lossy compression to send what the sci-camera is seeing back to the ground, as tiff files will be used for SunbYte IV rather than jpegs.

5.4 Thermal System

The primary focus of the next generation thermal system should be passive insulation for the components and the structure. This should be coupled with active heating to provide the payload with a robust and efficient heating system. As the payload improves at tracking the Sun, it will require more advanced thermal protection on the Sun-seeing side of the payload to shield itself from the Sun's exposure.

5.5 Optics System

The next generation of SunbYte will have an improved scientific camera, with higher resolution and framerate for capturing higher quality images through the telescope; this new optical system will be in line with the telescope, improving the potential image quality of the payload as distortions will not be introduced by mirrors.

The optics will be configured for a wider view of the Sun, and will potentially include a variable focusing system, which would enable the telescope to focus in on areas of particular interest, enabling higher quality resolution images of the Sun's photosphere and chromosphere to be captured and reducing the number of aberrations on the photographs that we collect.

The images will be stored in a lossless or uncompressed format on an SSD, for fast and shockproof storage. The lossless compression ensures that the images are not reduced in quality before they can be analysed by the team.

5.6 Structure

The compressed design of SunbYte III will be changed slightly for component accessibility, as the same limiting size restrictions don't apply to the next generation. This should also have the added benefit of simplifying the payload design, meaning it's easier to manage. The maximised space also means the optics for SunbYte IV can be placed in line, reducing the number of aberrations seen in the sensor data, meaning the data collected is clearer.

6 Publicity

Table 6.a Outreach events Attended*

Date	Event Name	Event Location	Activities Conducted
October 2018	Talk at the University of Hong Kong	Hong Kong	Presentation about SunbYte
March 2019	Get Up to Speed with STEM	Sheffield, United Kingdom	Hosted a stall to talk about SunbYte to local school children.
March 2019	STEM for Girls	Sheffield, United Kingdom	Hosted a stall to talk about SunbYte to secondary school girls.
April 2019	BBC Radio Sheffield Morning News	Sheffield, United Kingdom	Spoke about SunbYte live on the radio in the morning.
April 2019	BBC Radio Sheffield Weather Show Talk	Sheffield, United Kingdom	Pre-recorded interview for a weather show on BBC Radio Sheffield.
June 2019	24th ESA Symposium on European Rocket & Balloon Programmes and Related Research	Essen, Germany	Conducted a presentation for SunbYte's aims and accomplishments.
June 2019	Sheffield University Open Day	Sheffield, United Kingdom	Hosted a stall to talk about SunbYte and other extracurricular projects available.
July 2019	Sheffield University Open Day	Sheffield, United Kingdom	Hosted a stall to talk about SunbYte and other extracurricular projects available.
July 2019	IET Young Professionals Exhibition	Hong Kong	Presentation about SunbYte

* In all these events HASP was mentioned

In addition to attending events SunbYte posted frequently on social media (Facebook, Instagram and LinkedIn) and maintained their website to promote what has been done with HASP.

7 Conclusion

Overall, SunbYte III was significantly more successful than the previous iteration. SunbYte III brought together the many complex systems into a fully autonomous and functional payload, passing all ground tests prior to integration.

The relatively simple problem of motors without enough torque at lower temperatures, led to the ultimate failure of the tracking system and hence the payload's ability to excel at its main objective. Although, this problem was difficult to foresee prior to thermal testing, and harder still to implement a fix in the 6 weeks between integration and launch.

Ultimately, the majority of SunbYte III's performed well and as expected, introducing many new features into the payload design. Unfortunately, some issues had a significant impact on the flight performance, though these can be mitigated and resolved with relatively simple changes in the future.

The SunbYte mission aim to inspire the next generation of space engineers was highly successful, by encouraging 32 members to take part in the project and even more to continue the project as SunbYte IV. Additionally, the team participated and represented SunbYte in multiple outreach activities throughout the project, including a BBC radio interview, spreading the message that space projects are fun and that a small team of student engineers can achieve a lot in a short timeframe.

While the project was unsuccessful in acquiring scientifically valuable images of the Sun, an image was obtained during the short operational period the tracking system was functional, capturing an image on the ground and during the flight. Although expectations were higher, this demonstrates a proof of concept for the project and a marked improvement upon previous iterations of the design.

8 Team Demographics

Name	Start Date	End Date	Role	Student Status	Race	Ethnicity	Gender	Disabled
Sagar Shah	1/05/18	Present	Project Leader	Undergrad	Asian	Not Hispanic	Male	No
Roisin Clear	1/10/18	Present	Substitute Project Leader / Optics Team Leader	Postgrad	White	Not Hispanic	Female	No
Joshua Brownlow	17/10/18	Present	Technical Lead	Undergrad	White	Not Hispanic	Male	No
Stefan Stoian	1/10/18	Present	Communications Team Leader	Undergrad	White	Not Hispanic	Male	No
Wayel Kamal	1/10/18	Present	ADCS Team Leader	Postgrad	Black	Not Hispanic	Male	No
Emillie Brannan	1/10/18	14/6/19	Thermal Team Leader	Undergrad	White	Not Hispanic	Female	No
Prathamesh Khatavkar	17/10/18	Present	Structures Co-team Leader	Postgrad	Asian	Not Hispanic	Male	No
Kevin Kristianto	4/25/18	Present	Structures Co-team Leader	Undergrad	Asian	Not Hispanic	Male	No
Chun Iao Tai	1/10/18	06/06/19	ADCS Team Member	Undergrad	Asian	Not Hispanic	Male	No
George Basta	17/10/18	14/6/19	Electronics/ Communication Team Member	Undergrad	White	Not Hispanic	Male	No
Abdullah Alsulami	1/10/18	Present	Electronic Team Member	Postgrad	Asian	Not Hispanic	Male	No
Daniel Pickering	14/02/19	Present	Structures Team Member	Undergrad	White	Not Hispanic	Male	No
Jack Cheng Ding Han	17/10/18	06/06/19	Communications Team Member	Undergrad	Asian	Not Hispanic	Male	No
Abdel Al-Omari	17/10/18	Present	Communication Team Member	Undergrad	Asian	Not Hispanic	Male	No
Omar Mohamed	17/10/18	06/06/19	ADCS Team Member	Undergrad	Asian	Not Hispanic	Male	No
David Chung	17/10/18	Present	Communications Team Member	Undergrad	Asian	Not Hispanic	Male	No
Grigorios Michos	1/10/18	14/6/19	ADCS Team Member	Postgrad	White	Not Hispanic	Male	No
Khalid Tubeileh	17/10/18	06/06/19	ADCS Team Member	Undergrad	Asian	Not Hispanic	Male	No
Vaiva Zokaite	17/10/18	14/6/19	Optics Team Member	Undergrad	White	Not Hispanic	Female	No
Gabriel Mason	17/10/18	14/6/19	Optics Team Member	Undergrad	White	Not Hispanic	Male	No
Robert Brailsford	17/10/18	06/06/19	Thermal Team Member	Undergrad	White	Not Hispanic	Male	No
Abdullah Omaruddin	01/02/18	06/06/19	Communication Team Member	Undergrad	Asian	Not Hispanic	Male	No
Dana Arabiyat	17/10/18	06/06/19	Thermal Team Member	Undergrad	Asian	Not Hispanic	Female	No

Oscar Downing	17/10/18	06/06/19	Thermal Team Member	Undergrad	White	Not Hispanic	Male	No
Jahid Ahmed	17/10/18	14/6/19	Electronic Team Member	Postgrad	Asian	Not Hispanic	Male	No
Tom Dowson	14/02/19	14/6/19	Structures Team Member	Undergrad	White	Not Hispanic	Male	No
Daniele Ferretti	17/10/18	23/06/19	Structures Team Member	Undergrad	White	Not Hispanic	Male	No
Chengping Xia	17/10/18	30/04/19	Structures Team Member	Undergrad	Asian	Not Hispanic	Male	No
William Matthews	11/03/19	Present	Outreach	Undergrad	White	Not Hispanic	Male	No
Joseph Middleton	09/03/19	Present	Finance	Undergrad	White	Not Hispanic	Male	No
Ciara Barrett	09/03/19	14/6/19	Finance	Undergrad	White	Not Hispanic	Female	No
Joycelyn Fontanilla	06/04/19	Present	Structures	Undergrad	Asian	Not Hispanic	Female	No

9 Team After HASP

Table 9.a Students now on Exchange

Name	Institute	Country
Sagar Shah	University of NSW (UNSW)	Australia
Daniel Pickering	Hong Kong University of Science and Technology	Hong Kong
William Matthews	University of Texas at Austin	USA

Table 9.b Students now on an Internship

Name	Company	Country
Kevin Kristianto	Airbus	UK

Table 9.c Students who are in Graduate Employment

Name	Company	Country
Joshua Brownlow	Dyson	UK
Roisin Clear	Goonhilly Earth Station	UK

Table 9.d Students who continued onto SunbYte IV

Name	SunbYte III Role	SunbYte IV Role
Joseph Middleton	Finance Team Member	Project Leader
Vaiva Zokaite	Optics / Finance Team Member	ADCS / Outreach Team Member