High Elevation Light Intensity Observation System V

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Abstract
Currently, solar observation is done either from the ground, where it is subjected to extensive atmospheric interference, or from satellites, which are extremely expensive. Observing the Sun from a high altitude balloon platform mitigates almost all atmospheric interference at a fraction of the cost of actually placing a payload into orbit. High Elevation Light Intensity Observation System V (HELIOS V) is a continuation of the University of Colorado’s HELIOS missions. It will use the solar tracking system developed during the HELIOS IV mission to capture valuable science and engineering data. Its science objectives include capturing high quality images of the Sun in the Hydrogen-Alpaga wavelength to observe sunspots and possibly solar flares. The minimum criteria for success is to show that the HELIOS V system can take images with a higher angular resolution quality in the stratosphere than on the ground with the same optics system. The payload will also be hosting a star tracker from the University of Colorado at Boulder’s PolarCube team to demonstrate that the HELIOS V upper housing can be used as a bus for other science missions.

1. Introduction

1.1 The HELIOS Program

Solar observation is done primarily via two methods—ground observatories and satellites—both of which have major drawbacks. Ground observatories are limited by the amount of interference caused by the atmosphere. While this interference is usually minimal at night for star and planet observation, it increases during the day, making observation of the Sun challenging. Satellite telescopes overcome this issue, but cost far more to create, put into orbit, and maintain. The HELIOS program was created to solve both of these major issues by proving the viability of solar observation via a high altitude balloon platform. This method allows the telescope to be above 99.5% of Earth’s atmosphere, and it is far less expensive than satellite telescopes. Starting in 2012 with the first HELIOS mission, the team set out with a goal to capture images of the Sun in the Hydrogen Alpha (H-ɑ) and Calcium K (CaK) wavelengths. These wavelengths allow the imaging camera to penetrate through the upper
layers of the Sun to view solar features such as sunspots and solar flares in H-α, and see magnetic activity on the Sun in the CaK wavelengths. This mission was not as successful as they had hoped, so the next two missions, HELIOS II and III, were dedicated to developing a strong Attitude Determination and Control System (ADCS) algorithm so that the payload was better able to track the Sun throughout its flight. These missions also switched to only imaging in the H-α wavelength to simplify the necessary optics equipment. Last year, HELIOS IV’s mission was to prove the upgraded tracking capabilities of the payload, and demonstrate that HELIOS would have enough accuracy to capture images of the Sun if an optics system was added. HELIOS IV did not fly such an optics system because their focus was to prove the tracking ability of the payload. This is HELIOS V’s mission: to implement the new optics system, including a telescope, several filters, and a science camera, so that the payload can capture images of the Sun in the H-α wavelength. The new system is built off the success of HELIOS IV¹; therefore, the HELIOS V team is changing very little about the payload. The goal is to accommodate the new optics system and add only small other changes that will improve the performance of the payload to produce the best quality images.

1.2 Mission Objectives

HELIOS V will use the HELIOS IV tracking system to track and take pictures of the Sun in the H-α wavelength.

Primary Objectives:
- Take advantage of the successful HELIOS IV system to gather science data
- Capture images of the Sun in the H-α wavelength

Secondary Objectives:
- Demonstrate that the upper housing can serve as a bus for other science missions

1.3 The HASP Program

HELIOS V is a large payload project that will fly on the 2016 High Altitude Student Platform (HASP). It will be the ninth payload that the Colorado Space Grant Consortium (COSGC) at the University of Colorado at Boulder has flown with the HASP team. This program is supported by the NASA Balloon Program Office and the Louisiana Space Grant Consortium as a vehicle that student projects can travel on to run experiments in the high atmosphere. The platform flies in late August out of Fort Sumner, New Mexico. It will travel to an altitude of about 36 km where it will stay at float for anywhere between 5 to 24 hours depending on weather conditions.

2. Concept of Operations

Figure 3 shows the concept of operations for HELIOS V. This concept of operations is based on a 7 am launch time on August 29th, which is the current projected launch date. The HASP platform will ascend to 36 km in the first two hours of flight. During this time the HELIOS V payload will be powered on, tracking, and capturing images. The optimal tracking time will be during float, which is from 2 to about 12.5 hours into flight. At float the payload is the most stable, meaning that HELIOS can be centered on the Sun for longer periods of time than what is usually possible during ascent. At about 12.5 hours into flight is sunset. At this time, the ADCS system and the science camera shall be powered off. Additionally, the payload will be locked at a predetermined azimuth and elevation. The Star Tracker will then be powered throughout the night until sunrise. Sunrise occurs at about 23.5 hours after launch, at which point the Star Tracker shall be powered off. If possible, the ADCS and science camera systems will be powered on again for additional Sun tracking, though this may not be possible if the system is too cold in the morning. At this point, the platform may be cut down at any time. Prior to cut down, all payloads onboard the platform will be powered off for descent, which lasts about one to two hours. The payload will be recovered sometime after. This diagram details the optimal mission, so all of the times indicated may be different than in the actual flight because HASP flights vary in time.

3. System Details
HELIOS V will take advantage of the tracking system developed for HELIOS IV in order to track the Sun during its flight on HASP. HELIOS is equipped with an elevation and azimuth motor, which it uses to orient the upper housing to face the Sun. The Sun-tracking system on HELIOS V will use photodiodes to find the Sun and guide HELIOS to center the Sun in front of the payload. Once there, the ADCS camera will place the Sun within the field of view (FOV) of the science camera.

In order to take images of the Sun in the H-α wavelength, HELIOS V will fly a telescope in addition to a camera. The telescope will be equipped with several filters in order to isolate the desired wavelength. Once the ADCS camera has centered the Sun into the FOV of the camera, the camera will take pictures of the Sun, ideally capturing images of sunspots which can be used for scientific purposes.

The command and data handling (CDH) subsystem will use two Raspberry Pi 2’s to receive, store, and output data to the other systems and the HASP platform. To power the systems, the electrical power system (EPS) will receive power from HASP, trim the voltage to the appropriate number, and delegate that power to the other systems.

3.1. Optics

The HELIOS V optics system is composed of two camera systems with separate objectives. The ADCS camera system is used in tracking the Sun for the ADCS algorithm while the science camera system is designed to capture images of the Sun in the H-α wavelength. These two camera systems will be mounted parallel to each other in the upper housing of the payload.

3.1.1 ADCS Camera

The ADCS camera is a See3CAM_10CUG, shown in Figure 4, with a neutral density filter over the lens. The filter removes excess light from coming into the camera, which helps the camera clearly define the disk of the Sun and also lowers the temperature of the camera. This camera has a very large field of view of 22.9° x 17.2° so that it has a higher chance of capturing the Sun in an image. Once the ADCS camera sees the Sun in its FOV, the tracking algorithm (further details in section 3.3) aims the payload at the Sun.

3.1.2 Science Optics System

The science optics system is comprised of three major pieces: the telescope, filters, and science camera. This system is building off of the optics design originally created for HELIOS III. The telescope is an Orion telescope selected because of its Maksutov-Cassegrain set up. A Maksutov-Cassegrain telescope doubles the effective focal length of the camera by reflecting the light back onto a mirror on the main lens before going through the eyepiece. This allows the system to be shorter in length while producing a more focused image. The system includes several filters, the first of which goes over the camera lens. This is the neutral density filter, which, like on the ADCS camera, filters out excess light and keeps the system cool. The next several filters are mounted in the barrel behind the telescope. The first of these is the H-α filter, which only allows wavelengths within 3 nm of 656.28 nm (the wavelength of H-α) through. After this is a .44x focal reducer, which helps to further shorten the optics system so that it fits on the HELIOS structure. The focal reducer is a change from the previous HELIOS III design which had a .5x focal reducer. The change increases the FOV from .779° x .623° to .885° x .708°, which gives the science camera a better chance to capture an image of the Sun.
3.1.3 Star Tracker

The HELIOS V system will be hosting a Star Tracker from COSGC’s PolarCube team. The Star Tracker will demonstrate that the HELIOS payload can be used as a bus for other science missions, fulfilling the secondary mission objective, as well as giving the HELIOS payload a nighttime mission. Due to the excess space in the upper housing behind the ADCS camera, the HELIOS team wants to utilize that space for other science missions. Last year, HELIOS IV’s flight lasted nearly 26 hours, meaning that for a large time period, the HELIOS payload was dormant during the night. The star tracker allows the HELIOS payload to use all of its flight time.

The Star Tracker is primarily being handled by the PolarCube team, meaning the HELIOS team will only be supplying it with 5 volts of power as well as a USB connection to the upper Raspberry Pi 2 for saving images.

3.1.4 Expected Images

The ultimate goal of the payload is to capture images of the Sun in the H-α wavelength. Figure 6 shows the expected image that shows how large the sun will be with the radius of the Sun being 0.5°.

For the expected images in H-α, the pictures will appear in grayscale. The two images below are test images from HELIOS III (Figure 7) and HELIOS V before the .44x reducer was added (Figure 8). Dark sunspots are marked in red. Other markings on the image are caused by dust particles on the lens. To reduce interference from dust particles, the telescope and camera will be cleaned thoroughly before launch.
3.2. Structures

The majority of the structure from HELIOS IV will be reused in the HELIOS V mission. The structure proved sufficient for sustained tracking. The upper housing, however, is to be elongated from 16.51 cm to 22.86 cm to accommodate for the larger telescope system.

The HELIOS structure consists of three separate sections: lower housing, intermediate housing, and upper housing. The lower housing begins with an aluminum 6061 baseplate, cut to fit the specifications from HASP. This rigid board serves as a steady base for the payload as well as an efficient heat sink. The electronics board and Raspberry Pi, both of which are secured onto the baseplate, heat up during flight. This heat sink provides a means for the energy to be dissipated, protecting the equipment. Also in the lower housing is the azimuth motor. The azimuth motor precisely rotates the upper and intermediate housing with a 4:1 gear ratio.

HELIOS V’s intermediate housing holds the key structure together. Able to freely rotate, the intermediate housing joins the lower housing to the upper housing. This housing turns with the upper housing in the azimuth direction, as well as providing a base for the upper housing to turn in the elevation direction. The wires running from the lower housing to the upper housing are threaded through the intermediate housing.

The core section of the structure is the upper housing, home to the camera systems. The ADCS tracking system includes the two photodiode housings and the ADCS camera. These will be mounted on the outside of the upper housing, and inside the upper housing, respectively. The ADCS camera and the telescope system will be mounted in parallel with each other, so they are both capturing images of the same point. The telescope will be secured on the right of the upper housing, leaving space for the existing ADCS camera on the left. The Raspberry Pi in the upper housing will be secured to the floor of the upper housing, and PolarCube’s Star Tracker will be integrated to the back of the payload.

HELIOS IV experienced an issue with a counterweight falling prior to flight. This caused a large source of error in the mission because it limited tracking capabilities. Due to this, the HELIOS V team will thoroughly address this issue by redesigning the counterweight system.

3.3. Altitude Determination and Control Systems

The Sun-tracking system on HELIOS IV had two components: a coarse-tracking system and a fine-tracking system. The coarse tracking used photodiodes to find the Sun and guide HELIOS to center the Sun in front of the payload. The fine tracking was accomplished using the ADCS camera, which took images of the Sun, analyzed them, and indicated how the payload should move so that the disk of the Sun is centered in the pictures taken by the ADCS camera. This subsystem plays an especially critical role, since the science camera has a small field of view.

HELIOS uses four photodiodes to find and center the Sun within the FOV of the ADCS camera. The diodes have a 30° FOV through their encasement and are at a 90° angle relative to each other, meaning a perfectly centered Sun will strike each diode at 45°. When the Sun is not centered, the sunlight strikes the diodes at different angles, leading to a difference in intensity. This
difference in intensity is quickly calculated and the payload moves in a direction towards the Sun accordingly. Once the photodiodes have successfully brought the Sun within the ADCS camera’s field of view, the ADCS camera takes over and begins fine tracking.

Improved on the most recent iteration of HELIOS will include smoothing the tracking motion of the camera, and ensuring the ability of the payload to focus on the Sun for an extended period of time. After analysis of the counter-weight failure of the previous mission, a physical reset switch will be implemented to avoid the possibility of a similar failure in the future. This mechanism will give the payload the ability to reset its internal counter in case of another mechanical problem, ensuring that the mission will still be successful.

3.4. Command and Data Handling

The CDH system aboard HELIOS V will be responsible for communications with the HASP platform, collecting and managing data from the other subsystems. The CDH system shall utilize two Raspberry Pi 2 microcontrollers and flight code written in Python. Previous HELIOS missions flew a single Raspberry Pi 2 in the lower housing. The second Raspberry Pi 2 is a new addition, which will be placed in the upper housing to help with the increased processing necessitated by the Star Tracker and science camera. For HELIOS V, the code efficiency will be optimized and the communication will be more efficient and robust. Figure 13 shows how all the components of the system interact with regards to power and data flow.

3.4.1 Raspberry Pi 2’s

The Raspberry Pi 2 in the lower housing is the primary component in the CDH subsystem. It is responsible for controlling communications with the HASP platform, capturing and storing ADCS images, supporting the ADCS subsystem, monitoring the photodiode arrays, controlling the motor drivers, and tracking the Sun. For serial communication with the HASP platform, it shall be connected using a RS232 to USB serial converter. For serial communication to the ADCS subsystem, the ADCS
camera shall be connected to the Raspberry Pi with a USB 2.0. In order to accomplish this wide variety of goals, the Raspberry Pi shall run flight software that is separated into distinct threads, which run concurrently on the processor. The Raspberry Pi in the upper housing shall be responsible for saving images directly from the science camera and the Star Tracker. This image data will be saved to an internal SD card. The purpose for using a secondary Raspberry Pi 2 in the upper housing is to minimize changes to the software that was successfully implemented on the lower Raspberry Pi 2 for previous HELIOS missions, as well as avoid burdening the lower Raspberry Pi with additional tasks.

Each Raspberry Pi 2 runs off Inter-­integrated Circuit (I^C). With only two wires, a clock line (SCL) and data line (SDA), all of the Pi’s sensors can communicate to each other with ease. Previous HELIOS missions used I^C, and HELIOS V will do the same to reduce changes to the EPS board. I^C is sufficient for the mission, for it allows a few bytes of data to be sent at a time, adequate for commands and simple health checks. If there are any issues concerning the performance of the Raspberry Pi in the upper housing, it shall be rebooted manually via the Raspberry Pi in the lower housing.

The two Raspberry Pi’s will communicate with each other using universal asynchronous receiver/transmitter (UART). I^C communication between two Pi’s requires one to be a “slave” device to a “master”. This could prove problematic because both Pi’s are usually “masters”, which is where UART comes in. UART will allow for more complex data and commands to be sent between the two Pi’s. Detailed health checks need to be written so that the health of the upper Raspberry Pi and Star Tracker can be monitored effectively. Most importantly, however, is that UART will allow for the two Pi’s to read from the same real time clock (RTC), which is necessary for synchronized timestamp of data and pictures. Both Pi’s have their UART pins available, therefore connection shall be simple.

### 3.4.2 Uplink Thread

The uplink thread is responsible for awaiting two-byte serial commands uplinked by the ground station. It is idle until it detects data in the serial buffers. When it detects data in the serial buffers, relevant data will be passed to the appropriate threads, and a confirmation will be downlinked to the ground. If there are any issues with the uplinked command, it shall downlink an error to the ground.

### 3.4.3 Downlink Thread

The downlink thread will process and downlink data from the other threads to the ground. The payload shall allow serial downlink functioning at 4800 baud. It is idle until it is passed a data package from another thread with the correct identifier, record type, and data. Once a complete and correct data package has been passed, it will format the information in the package into the downlink format. The downlink thread will identify any data loss or corruption, as well as allow for easy sorting of data. The packetized data will be downlinked at about 350 bit/s.

### 3.4.4 Sun Tracking Thread

The Sun tracking thread is the most expansive and resource intensive thread. It shall analyze readings from the photodiodes and analyze all pictures taken on the ADCS camera in order to provide direction for both the azimuth and elevation motors.

### 3.4.5 Sense Thread

The sense thread shall sample data from each sensor, including health checks on the upper Raspberry Pi and Star Tracker. This will allow the HELIOS team to monitor the status of the payload during flight. The data will be packaged and downlinked to the HASP platform. This thread will also handle any commands necessary to operate the Raspberry Pi in the upper housing. Additionally, it will save data to the SD cards.

### 3.5 Electrical Systems

HELIOS V will receive 30 volts DC from the HASP platform to be dispersed throughout the payload. Two DC-DC buck converters will be used to step down the voltage to 12 volts and 5 volts. A trimming resistor will trim the 12 volts to the 10.8 volts necessary to operate the motor drivers while the 5 volt line is sent to the upper housing and Raspberry Pi. All components of the system will be equipped with individual power protection systems to eliminate the need for external monitoring of the power systems.

The power budget in Figure 14 includes all major components of the system at maximum voltage and current draw. The maximum power of the system is 49.82 watts. Therefore, the maximum current draw from the platform is 1.66 amps, which is well under HASP’s limit of 2.5 amps, so this will not be a risk. As many of the components flying on HELIOS V were flown on HELIOS III and HELIOS IV, no major revisions to the printed circuit board will be necessary. Instead of designing, implementing, and testing a new circuit board, HELIOS V will use the board designed for HELIOS III, with a few minor changes to accommodate the new systems.

The new components on HELIOS V are the Raspberry Pi in the upper housing, the science camera, and the Star Tracker. The Raspberry Pi 2 will be connected to the
main PCB board for power by repurposing the power line for the GoPro flown on HELIOS IV. The science camera and the Star Tracker will each receive 5 volts from the Raspberry Pi 2 in the upper housing via USB.

<table>
<thead>
<tr>
<th>Component</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry Pi 2</td>
<td>5</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Raspberry Pi 2</td>
<td>5</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Elevation Motor Driver</td>
<td>10.8</td>
<td>1.2</td>
<td>12.96</td>
</tr>
<tr>
<td>Azimuth Motor Driver</td>
<td>10.8</td>
<td>1.2</td>
<td>12.96</td>
</tr>
<tr>
<td>ADCS Camera</td>
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<td>.75</td>
<td>3.75</td>
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<tr>
<td>CMOS Monochrome Camera</td>
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<td>1.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Star Tracker</td>
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<td>.33</td>
<td>1.65</td>
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<tr>
<td><strong>Total Power</strong></td>
<td></td>
<td></td>
<td><strong>49.82</strong></td>
</tr>
</tbody>
</table>

Figure 14: HELIOS V power budget

4. Conclusions

The basis of the HELIOS program is to provide an alternative to ground based solar observation and satellite telescopes. After four previous missions, the primary tracking system has been proven successful. Now, HELIOS V has the tools necessary to achieve the program’s objectives, ultimately capturing images in the H-α wavelength.

Future mission objectives could include collaborating with researchers in the field of solar observation, photographing the Sun in different wavelengths, and improving the nighttime functionality of HELIOS.

5. References