Development of a star simulator for CubeSat star trackers

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ABSTRACT

As small satellites are being deployed for more and more highly demanding applications, the requirements on both pointing accuracy and knowledge have become more stringent. Arcsec developed a star tracker to achieve a high degree of pointing knowledge and incorporated this into a full ADCS to provide high pointing accuracy. In order to guarantee the performance of these components, they must be extensively tested before launch. For this purpose, a star simulation testbed has been developed. This tool will accurately reproduce the nightsky as seen in orbit, along with different image perturbations to allow for validation of the star tracker accuracy.

The test setup consists of 3 main components: the software for displaying the star scenarios, the optical setup to project these images on the star tracker sensor and a 3-axis rotation stage to allow for testing the full ADCS.

The software consists of an android application running on an OLED tablet. The relatively low cost of tablets when compared to standalone OLED screens was the main motivation behind running the software on android. The OLED screen is necessary to have a dark background in the star scenarios. On top of displaying accurate star scenarios, the software also includes various perturbations, such as stray light, false stars, hot/dead pixels and lens distortions.

The optical setup consists of 3 custom lenses in a 3D-printed mount in order to refocus the star scenario image onto the star tracker, which is focused on infinity. The focal distance of the setup has been chosen to project a 1024x1024 pixel image on the tablet onto the 2048x2048 pixel star tracker. An investigation of commercially available lenses for this purpose lead to the conclusion that low-distortion focusing onto the star tracker requires a set of custom lenses.

Finally, the whole optical setup is mounted into a 3-axis rotation stage in which both the star tracker and the full ADCS can be mounted. This can allow for subsystem-level tests of the ADCS, combining measurements from magnetometers, Sun sensors and the star tracker, all while the ADCS is rotating.

This setup will allow arcsec to validate the performance of the star tracker as well as the ADCS on ground, and can be used to quickly test new features in an accurate representation of the space environment in which they will eventually operate.

1 INTRODUCTION

A CubeSat contains an Attitude Determination and Control System (ADCS) to control its orientation in space. Estimation and control of the attitude is crucial to allow the satellite to point the payload to the different targets, to point to solar panels to the sun for energy supply, to aim its antennas to the ground station for communication etc. Therefore, the ADCS itself contains various sensors to measure different environmental properties and actuators to apply torques on the satellite. Furthermore, all those components interact with each other by estimators and controllers. The combination of these software and hardware elements determines the pointing performance of the ADCS. As a spin-off company of the KU Leuven in Belgium founded in 2020, arcsec develops and sells high accuracy ADCSs for CubeSats and SmallSats.

A crucial component of the arcsec ADCS is a star tracker. Star trackers can provide high accuracy attitude knowledge. In order to aid in the development of the arcsec Sagitta star tracker, a testing setup has been developed in order to assess the star tracker performance in a realistic scenario.

2 SAGITTA STAR TRACKER

The Sagitta Star Tracker (Figure 1) is the first arcsec star tracker and is designed to provide a 5” cross-boresight attitude knowledge (3σ). The optical and electronics elements are all contained within a 95 x 45 x 50mm aluminum enclosure. The image sensor can detect stars up to magnitude 7 and has a sun exclusion angle of 45°. This informs the design of the test setup that will be discussed in the next 3 chapters.

Figure 1: Sagitta star tracker

3 OPTICAL TEST SETUP

In order to accurately assess the performance of the sagitta star tracker, a star image needs to be projected onto the star tracker image sensor. In orbital operations, the stars are located at such distances from the star tracker lens, that the light can be assumed to originate infinitely far away. This leads to the light beams arriving at the star tracker in parallel beams. A screen showing a star image will not exhibit the same properties. This can be solved by placing a lens system in between the star tracker and the lens system. The optics system consists of one meniscus, one concave and convex lens, and is designed to project a full image of 200mm x 200mm onto the star tracker image sensor with a focal length for the optical system of 300mm. This allows for the whole system to be contained within a 50cm long enclosure. The lens design, along with the 3D-printed lens enclosure can be seen in Figure 2.

The screen that is used to show the star scenarios is an 8-inch android tablet with an OLED screen. The OLED screen is necessary to avoid background light. This option was chosen because development for android was straightforward enough and the hardware would be widely available off the shelf for the foreseeable future.

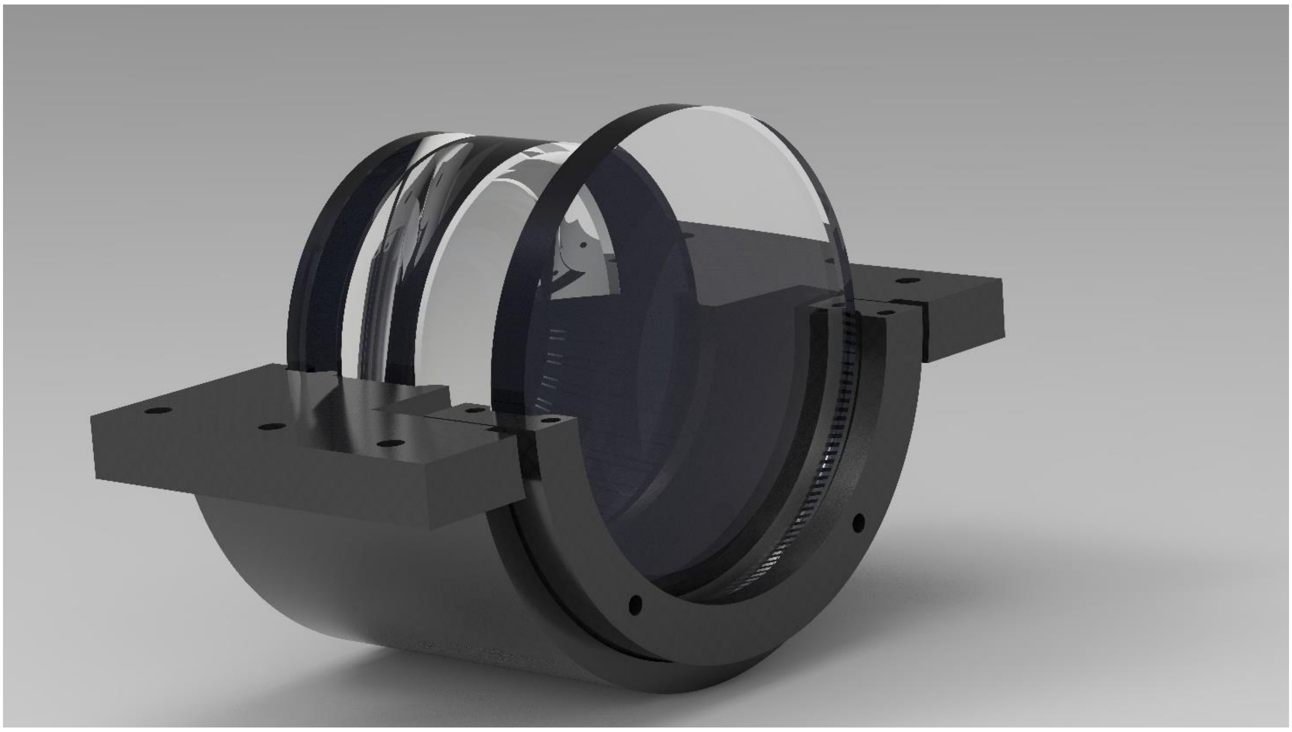

Figure 2: Lens and enclosure design

4 STAR SIMULATION SOFTWARE

A second crucial part of the testing setup is the software which is used to simulate the star scenarios. This software will display accurate images of the nightsky according to user-provided inputs. The scenarios have to correspond to the actual nightsky at the provided orientation in order for the star tracker algorithms to work. The star positions are therefore gathered from the Hipparchos library. Furthermore, several possible disturbance sources have been added to the software library. This includes the following:

- False stars
- Hot & dead pixels
- Stray light
- Lens distortion
- Shot & read noise
- Constant DC noise

The starting quaternion, as well as a fixed roll, pitch and yaw rate can be supplied to the software in order to test star tracker performance during satellite manoeuvres.

Finally, the software can also communicate with the star tracker by setting up a tcp server. This can be used to check the star tracker solutions against the quaternions used to simulate the star scenario.

An example scenario can be seen in Figure 3.

Figure 3: Example star scenario [1, 0, 0 ,0]

5 Mechanical setup

On top of the optical setup, the whole test will be made compatible with a custom-built 3-axis rotation stage which can accommodate the entire arcsec ADCS. This consists of an aluminum frame along with 3 precise computer-controlled rotation stages to allow for full rotational control at speeds of up to 5°/s. The star simulation setup will be used to provide real-time inputs to the ADCS star tracker during rotation. This allows for system-level tests of the ADCS sensor array, which includes magnetometers, gyroscopes, photodiodes and a star tracker. The design of the rotation stage can be seen in Figure 4

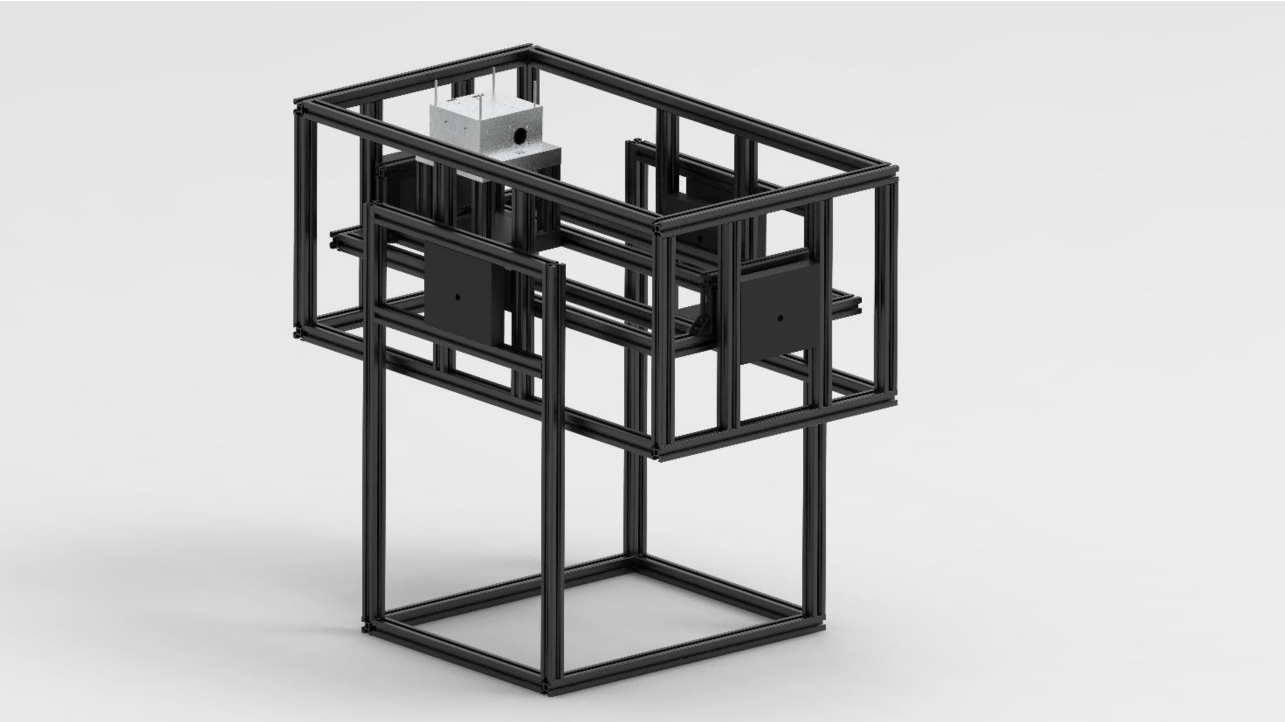

Figure 4: Rotation stage design

6 CONCLUSION

The combination of an accurate star simulation setup, which can produce realistic images of the nightsky with various possible disturbances, and a full 3-axis rotation stage will allow for better and more realistic system-level testing of the arcsec ADCS. This setup can be used in the future for quick testing of novel attitude determination or control algorithms and will be used to improve the accuracy of the arcsec ADCS and star tracker through more rigorous testing and validation.

7 REFERENCES

[1] arcsec, "ARCSEC SPACE," 8 March 2022. [Online]. Available: arcsec.space.