LEDsats: LEO CubeSats with LEDs for Optical Tracking

Patrick Seitzer
University of Michigan
James Cutler
University of Michigan
Fabrizio Piergentili
Sapienza University Rome
Fabio Santoni
Sapienza University Rome
Lorenzo Arena
Sapienza University Rome
Tommaso Cardona
Sapienza University Rome
Heather Cowardin
University of Texas El Paso, Jacobs-JETS Contract, NASA JSC
Chris H. Lee
University of Michigan
Srinagesh Sharma
University of Michigan

ABSTRACT

We describe a project to launch 1U CubeSats equipped with Light Emitting Diodes (LEDs) into Low Earth Orbit (LEO) for optical tracking with ground-based telescopes. Active illumination on the satellites increases tremendously the number of passes where the LEO satellite is visible when the ground-based telescope is in darkness. The restriction that the satellite is in direct Sun is removed, and so tracking can take place all night long rather than just in twilight. The inspiration for this project came from the Japanese CubeSat *FITSAT-1* that carried red and green high-powered LED arrays, and was clearly visible from the ground with small telescopes.

There are two goals: 1) increase the accuracy and precision of LEO orbits by increasing the number and length of passes that satellite is visible, and 2) minimize the confusion between objects in the case of multiple CubeSats being launched at the same time.

Technical issues to be discussed include the power level required for detection by small (20 - 40 cm) ground based telescopes, the optimum flash pattern for astrometry against star fields, and the timing of the flash pattern to millisecond or better accuracy and precision.

We propose to deploy two such LEDsats simultaneously from the International Space Station: the first to be built at the University of Michigan, and the second to be built at Sapienza University Rome. One experiment is to see how we can distinguish these two CubeSats shortly after deployment solely from optical tracking, and so the CubeSats will have different flash patterns.

1. INTRODUCTION

Ground-based optical tracking of satellites in Low Earth Orbit (LEO) faces multiple challenges. The satellite must be in sunlight, while the ground-based telescope must be in darkness. This limits the time for tracking to typically 90 minutes in evening and morning twilight. The topocentric solar phase angle of the satellite can be 90 degrees or greater, meaning that it appears several magnitudes fainter than if tracked at an angle near 0 degrees, as is customary for objects at geosynchronous Earth orbit (GEO). The advantages of optical tracking, however, are significant in that the full resolution of optical observations can be used.

A way around these limitations was suggested by the successful Japanese 1U CubeSat *FITSAT-1* which carried high-powered green and red LEDs, and was observed with small ground-based telescopes [1]. The primary objective of *FITSAT*-1 was detection of the light signal.

Here we outline a proposal for using 1U CubeSats equipped with LEDs (LEDsat) for two specific reasons:

- Astrometry of the light signal against a reference star field, which should improve the orbital accuracy and precision. Critical here is that the timing of the light signal is generated on the spacecraft itself, so that simple ground-based systems can return useful astrometric information.
- If each CubeSat has different and unique light signals of the same wavelength, then it would be possible to distinguish them shortly after deployment even if they appear in the same image separated by a few arc-seconds. This is important when there are large numbers of satellites deployed at the same time. It satisfies the request of JSpOC for markers on CubeSats in the case of such large numbers being deployed in a very short time [2].

2. DISCUSSION

For this example, we simulate a LEDsat launched from the International Space Station (ISS). Assuming the orbit is close to that of the ISS for a short time, and then we can ask how many passes such a satellite would be detected with LEDs and without LEDs. The study was done for a two-week period beginning at 1700UT on 9 March 2016. The ground-based telescopic site was Ann Arbor, Michigan (latitude = 42 degrees North).

1. Sun > 18 degrees below the horizon (astronomical twilight), and ISS > 30 degrees above horizon (this is the most restrictive case – darkest sky and object highest above horizon):
   a. 0 passes visible by reflected sunlight only.
   b. 15 passes visible if equipped with LEDs.
2. Sun > 18 degrees below the horizon and ISS > 15 degrees above horizon:
   a. 10 passes visible by reflected sunlight only.
   b. 36 passes visible by either reflected sunlight or LEDs.
3. Sun > 12 degrees below the horizon (nautical twilight, only brighter stars are visible), and ISS > 15 degrees above horizon:
   a. 13 passes visible by reflected sunlight only.
   b. 38 passes visible by reflected sunlight or LEDs.

The potential tracking gain from having the satellite equipped with LEDs is tremendous. The number of passes goes from 0 to 15 (average one per night) in the most restrictive case (darkest sky, highest apparent elevation of the CubeSat), to almost 3 passes per night in the case of a brighter sky and a lower apparent elevation. We would expect the number of passes with LEDs to be less in summer (shorter nights), and more in winter (longer nights).

A simulation of how a pass of two LEDsats in close orbits would appear in a ground-based image is presented below in Fig 1. The original image is a real 5 sec image in a V+R filter from the 0.6-m MODEST (Michigan Orbital DEbris Survey Telescope) at Cerro Tololo in Chile, with two simulated LEDsats added in. One LEDsat is sending the Morse letter 'R', the other the Morse letter 'K'. Distinguishing the satellites is easy. The field of view is approximately 0.44 degrees square. The satellite trails are separated by 2 arc-minutes, which is approximately 0.5 km at a range of 800 km.

It would be best to keep the optical flashes as brief as possible so be like stars. The more concentrated the flash, the better the centroiding will be.

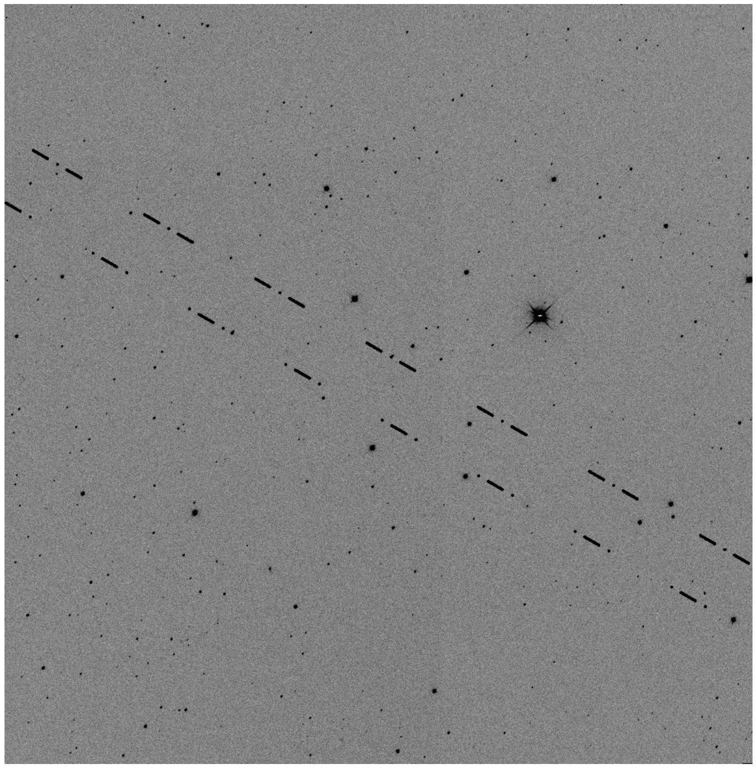

Fig. 1. Simulation of two LEDsats in a 5 second V+R image obtained with the 0.6-m MODEST in Chile. Field of view is approximately 0.44 degrees on a side. The LEDsats are separated by 2 arc-minutes, approximately 0.5 km at a range of 800 km. The top LEDsat is transmitting the Morse letter 'K', the lower LEDsat is sending the Morse letter 'R'.

3. PROPOSAL

We propose to build and deploy two 1U Cubesats (LEDsats) from the ISS. One would be built at the University of Michigan's Department of Aerospace Engineering, the second at the Sapienza University of Rome.

The LEDsats would have the following characteristics:

1. Equipped with LEDs of the same wavelength, preferably one that is in the center of a standard red astronomical filter (~640 -670 nm)
2. For accurate and precise timing, the LEDsats would have onboard clocks (either GPS or ones that could be set from the ground). If the timing is on the spacecraft, and we know when a particular pulse was generated, then even simple ground-based telescopes that can take sidereally tracked images can be used in image acquisition. It is not necessary to have milli-second timing accuracy and precision at the telescope.
3. Programmable timing such that the LEDs can be turned on when they are expected to be over suitable ground stations. Given the power levels required, it may not be practical to have the LEDs on all the time during night-time passes when the LEDs are powered by batteries.

It would be highly desirable to have additional features on each LEDsat for more general problems in orbit determination comparison:

1. GPS receivers that log their positions and velocity. In addition to serving as the time base on the spacecraft, the position and velocity will be transmitted to the ground for orbit determination.
2. A laser retro-reflector for range measurements.

3. Stable RF transmitter to enable Doppler-based tracking and orbit determination.

Then one could compare the orbit determined by passive optical tracking (sunlight), active optical tracking (LEDs on against a reference star field for astrometry), GPS data (likely to be of the highest accuracy and precision), laser ranging, and radio data. It would immediately reveal the biases and precision in one's orbit determination software. One hopes that the same answer is obtained from all techniques, but with different random errors.

To better track the small satellite in orbit, pre-flight optical characterization is also proposed to be completed at NASA\JSC. The goal would be collect BRDF photometric data provided known phase angles. Spectral measurements will also be acquired for specific material analysis, but can also be integrated into known photometric filter bands for comparison. That data will be used to compare with telescopic data for better characterization and understanding laboratory and on-orbit differences.

4. SUMMARY

We propose to launch two 1U CubeSats from the ISS equipped with LEDs (LEDsats) for optical tracking. The gain in number of passes that the spacecraft is now observable with such active illumination of the spacecraft is very large. In the case of multiple CubeSats being launched at once, LEDs would allow identification of the spacecraft immediately after deployment to assist in cataloging.

In early 2017, the Sapienza group expects to launch *URSA MAIOR* (University of Rome la SApienza Micro Attitude In ORbit testing), a 3U CubeSat designed and developed in the framework of QB50, an international project led by the Von Karman Institute for Fluid Dynamics. The main goal of the project is to perform multi-point and in-situ measurements in the lower thermosphere, which is the least explored layer of the Earth atmosphere, by using a network of fifty nanosatellites (2U and 3U CubeSats) provided by universities and research centers all around the world. For that aim, *URSA MAIOR* will board as main payload the multi-Needle Langmuir Probes (mNLP) science unit, provided by University of Oslo, that will be used to determine the electron temperature, electron density, and electric potential of plasma.

The nano-satellite is also a technological demonstrator. It boards a cold gas micro-thruster for attitude control equipped with innovative MEMS nozzle and valves, an autonomous deorbiting system based on a drag sail and in-house developed OBCs/OBDH and an EPS based on a reliable dual PIC18 microcontroller/FPGA architecture, designed with proper hardware and software strategies allowing to mitigate single event effect (SEEs). *URSA MAIOR* will also board two high power red LEDs on one face and two high power green LEDs on another one. Both the component selection, the switching strategies and the performance degradation will be evaluated. Hence, it will be a valuable test of the concepts presented here.

1. Tanaka, K., Kawamura, Y., and Tanaka, T., Development and operations of nano-satellite FITSAT-1 (NIWAKA), Acta Astronautica, Vol. 107, 112-129, 2015.
2. JSpOC Recommendations for Optimal CubeSat Operations V2, published August 4, 2015, available at https://file.space-track.org/documents/Recommendations_Optimal_Cubesat_Operations_V2.pdf