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Automation and Enhancements to the ERAU OSCOM System Space Situational Awareness

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Cover Page Footnote

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Abstract

The OSCOM system, Optical tracking and Spectral characterization of CubeSats for Operational Missions, is a system developed at Embry-Riddle Aeronautical University to produce time-resolved photometry of small satellites using commercial-off-the-shelf hardware. The OSCOM system has been able to observe resident space objects (RSOs) as small as CubeSats using a Celestron 11" RASA and a CMOS machine vision camera from Allied Vision. By obtaining photometric measurements of satellites, a light curve can be constructed and used to help determine satellite characteristics such as spin rate, satellite state, and even satellite attitude. To enhance the OSCOM system's ability to observe small satellites, there is ongoing development towards an automated and more capable tracking system. This includes upgrading OSCOM's tracking software, Auriga, planned development of an automated data analysis software and demonstrating the capabilities of a newly acquired Celestron 14" Edge HD (C14), which can be used for resolved imaging of large satellites and rockets and with a Starizona Hyperstar, and also can be used to observe dimmer RSOs that have low signal to noise ratio when detected by the 11" RASA. This paper discusses the software improvements to the OSCOM system and results acquired from the default C14 and C14 with Hyperstar configurations.

Introduction

The OSCOM system, Optical tracking and Spectral characterization of CubeSats for Operational Missions, is a system that was developed at Embry-Riddle in 2014 to allow for observations of resident space objects (RSOs) using low cost commercial-off-the-shelf (COTS) hardware and custom tracking and analysis software. The system can produce time-resolved photometry of small RSOs such as 1U (10 cm x 10 cm x 11 cm) CubeSats using a Celestron 11" RASA with an inexpensive, CMOS machine vision camera from Allied Vision. Figure 1 shows the OSCOM system. The photometry results lead to light curves that can help satellite operators verify or better understand the state of their satellite or even be used to determine a satellite's attitude. OSCOM tracks RSOs using rate-track modes through the telescope mounts it uses and can captures frames of the satellite at several frames per second. The portability of the system also allows for simultaneous multi-site observations of satellites. The OSCOM team demonstrated this when observing the tumbling Japanese X-ray satellite, ASTRO-H or Hitomi, simultaneously from two locations, Daytona Beach, FL and West Palm Beach, FL [1]

Despite OSCOM's current capabilities, there is ongoing improvement towards a more sensitive system that can track and analyze data automatically with little user assistance. There are various areas of improvement, but the area with the most improvement required was OSCOM's tracking program Auriga. This custom made software for satellite tracking lacked a graphical user interface (GUI) and the ability to find observable satellites prior to a designated observation time window efficiently. Automation of this component of OSCOM made it easier for future modifications and maintenanceand maintenance. Another area

Figure 1. Shows the telescope mounts that the OSCOM system currently supports.

of improvement is the planned development of an automatous data analysis software that can correct the satellite brightness based off background stars in the image.

Early in the year, the OSCOM team was able to acquire a Celestron 14" Edge HD telescope. This dual purpose telescope would allow the OSCOM system to observe dimmer RSOs and perform resolved imaging of either larger satellites such as the International Space Station (ISS) or rockets. The OSCOM team has produced results which show the capabilities of this telescope for both space situational awareness (SSA) and resolved imaging purposes.

Methodology

The OSCOM system's first successful tracking program, Auriga, allowed the OSCOM team to demonstrate the capability of using small telescope systems for RSO observations. However, it required extensive user interaction. The research team sought out to reduce the amount of human interaction by instituting a GUI for easier use and added new features that would allow observable satellites to be discovered more easily.

Joint Space Operations Center (JSpOC) tracks satellites that are currently in Earth orbit and provide two-line elements (TLEs) for each satellite that describe its orbit characteristics. Libraries such as the Simplified General Perturbations (SGP4) propagator can be used to predict when satellite passes will occur for a specific time and location on the Earth. It can then propagate the path of the satellite to determine where the telescope needs to be pointed during an observation [2]. This element in Auriga enables the OSCOM system to know where a given satellite will be for an observation.

For the new version of Auriga, SGP4 was used not just for the actual tracking of satellites, but was also used to predict all available satellite passes for a given observation date and time range. This addition to Auriga prevented the need for the user to manually search for available passes on databases such as Celestrak and Heavens Above. Separate from the tracking software, observers can now search for satellite passes based off the class of the satellite, science, CubeSat, and military. Other search parameters are available such as the orbit type, low, medium or geostationary orbits, the maximum elevation the satellite passes over the local horizon, and whether the satellite is illuminated by the sun. Since the latter is required in order for it to be visible, this parameter is always active. This program obtains the satellite TLEs from Celestrak and uses SGP4 to determine which satellites pass over the observation site at the maximum

Figure 2. Shows the program for selecting satellites to observe. Satellites for specific classes such as CubeSats can be shown only. The user also has the option to change the location of the observation site and the observing time window. The top list is the satellites that the user can choose from while the bottom list contains the satellites the user has selected to observe.

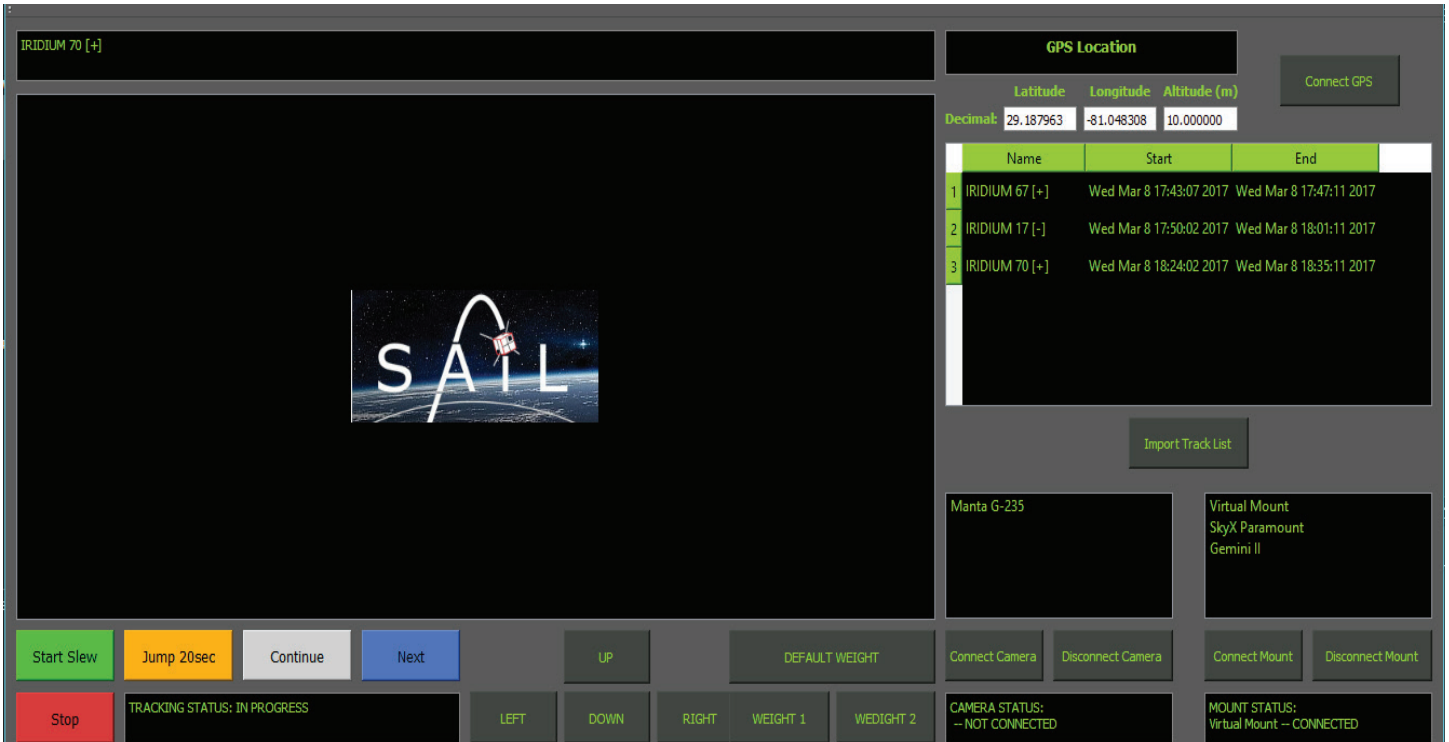

Figure 3. Shows the tracking window where the user would load the TLEs they selected in Figure 2. The GUI allows for easy control of the mount during observations.

elevation angle. The GUI, written in C++/Qt, then passes the satellites, based off their class, orbit and lighting conditions, to the user to choose from. Figure 2 shows the program responsible for TLE selection. After selecting the satellites to observe, a final list of TLEs is generated and passed to the tracking program.

The updated tracking software, also with a GUI, is shown in Figure 3. Here the user can load the TLEs they obtained from the TLE search program. The GUI allows for simple control of the mount in use during the tracking process. The user can start and stop tracking or jump ahead of the satellite. The user also has the option to adjust the slew rates of the mount to keep the satellite in the field of view since not all TLEs are perfectly accurate.

This version of the tracking software does not yet support optical feedback loop tracking. Future versions of the tracking software will include the ability to use images taken by the camera to track the RSO in each frame and automatically adjust the mount's slew rates based off whether the RSO is drifting out of the frame. By supporting this feature in the future, OSCOM will be able to track RSOs automatically with little to no user input.

The calibration of RSO photometry has always been a challenge for the optical SSA community [3]. However, tools such as Source Extractor, Astrometry.net and Tetra will enable the OSCOM team to produce an automated data analysis software to replace its current version of Optical Satellite Analysis Tools (OSAT), which requires large amounts of user interaction as well. The OSCOM team plans to calibrate an RSO's brightness using the known and measured brightness of background stars in each image acquired by the camera. These stars appear as streaks due to the movement of the telescope mount and length of camera exposure times. The OSCOM system will incorporate Source Extractor into OSAT to perform streak detection on each image and use either Astrometry.net or Tetra to identify the detected stars in the image. A regression based off the measured and catalog star brightness values will be used to calculate the calibrated brightness of the RSO.

In addition to performing software upgrades, the OSCOM team demonstrated the capabilities of the Celestron 14" Edge HD telescope (C14) for both resolved imaging and photometric observations. In its out-of-the-box configuration, the C14 has a focal length of 4000 mm, allowing it to be used for imaging large distant objects. However, the secondary mirror can be removed to allow Starizona's Hyperstar to be installed. This reduces the focal length, but increases the throughput of the telescope, allowing it to see dimmer objects.

Results

The amount of magnification in the C14's default state is ideal for imaging large satellites and rockets. The OSCOM system used the C14 in March, 2017 to capture images of SpaceX's Falcon 9 launch vehicle. There was a separation distance of over 150 km (90 miles) between rocket launch site (Cape Canaveral, FL) and telescope location (top of COAS building on ERAU Campus in Daytona Beach, FL). This launch was the first reflight of the reusable Falcon 9 rocket [4]. The images of the rocket are shown in Figure 4, and were taken with an even larger separation distance as the rocket was mid-flight and headed away from Daytona Beach. Since no optical tracking method is used with the OSCOM system yet, the rocket was tracked manually using a joystick.

The C14 was also used with the Hyperstar to collect photometric data of satellites. Figure 5 shows observation data of the satellite OSCAR-11, collected by both the 11" RASA and C14 using identical cameras with similar gain and exposure length settings. OSCAR-11 is a 60 kg, 0.75 m x 0.45 m x 0.45 m Amateur Radio satellite that was launched in 1984 [5]. Based off Heavens Above its current orbit is 615 km x 625 km with an inclination of 97.7° [6].

Development towards a more efficient tracking system has produced a more sophisticated tracking program that enables faster searching of observable satellites over a given observation site and time window. The modularization of the mount communication protocols and commands will enable easier integration of future TCP/IP based telescope mounts while a GUI based program will allow for easier mount control by the user. While no automated tracking methods are integrated into this upgraded version of Auriga, there is ongoing progress towards optical feedback loop tracking for hands off tracking. In addition to upgrading the tracking software, there is planned development towards an automated data analysis software for photometric calibration. This will allow for quicker and more efficient data processing. The OSCOM team has also demonstrated the capabilities of the C14 telescope for photometric measurements of RSOs and resolved imaging of large satellites and rockets

Figure 4. Shows three inverted images of the Falcon 9 launch vehicle, acquired on March 30, 2017. These images were acquired from the veranda of the College of Arts and Sciences building at Embry-Riddle's Daytona Beach campus, over 150 km (90 miles) away from the rocket's launch site.

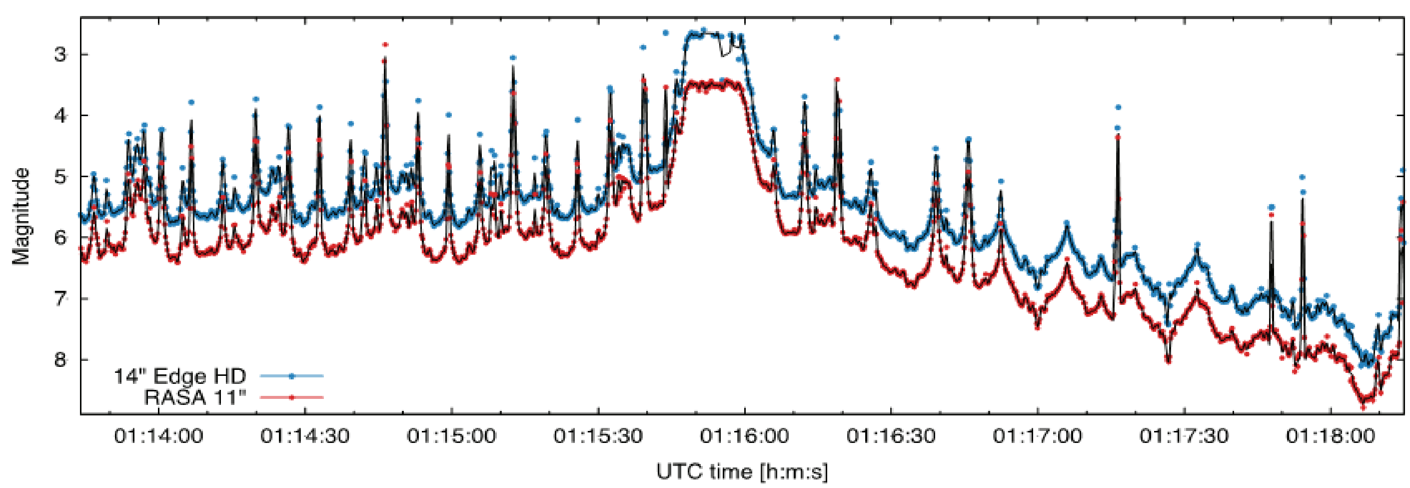

Figure 5. Shows the photometric results of the satellite OSCAR-11 from data collected using the 11" RASA and C14 telescope systems. The simultaneous observation occurred on May 25, 2017. The exposure length on both cameras was set to 200 ms.

Conclusion

The OSCOM system has shown over the years its ability to perform temporally resolved photometry of small satellites in low Earth orbit. Improvement to OSCOM's tracking software and evaluation of the C14 help make OSCOM a more capable and efficient system. The team's current effort of producing a more automated OSCOM system through the enhancement of its custom satellite tracking program and its data analysis pipeline will enable it to produce more useful, consistent information about RSOs to better support small satellite operators.

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