NITELite: A High-Altitude Balloon Light Pollution Research Mission

Ken Walczak[a,1,2]**, Geza Gyuk**[a,1]**, Mark Hammergren**[a,1]**, and Cynthia Tarr**[a,1]

This manuscript was compiled on May 10, 2019

The NITELite (Night Imaging of Terrestrial Environments Lite) system provides a means for acquiring high-quality light pollution data at a relatively low cost from a High Altitude Balloon (HAB). NITELite is a self-contained, automated light pollution imaging system flown to altitudes between 25-30 km. The goal of the system is to image large areas (100s km2) in multiple color bands at high spatial resolution (<10m/px) and sensitivity (~10-8W/cm2/sr) for a relatively low cost (<$3000). The relatively low operating costs in particular permit repeated missions studying changes in light pollution over time, or variations in lighting depending on the time of night. Here we detail the systems, challenges, mission operations and initial results from the NITELite mission.

High Altitude Ballooning / Education / Imaging / Scientific Research / Light Pollution

Introduction

Studies of light pollution or Artificial Light At Night (ALAN) have demonstrated its effect in diverse fields of research. ALAN has been shown to impact flora and fauna[1], human health[2], the quality of the night sky[3] and ecosystems[4]. It has also been used to quantify the economic expenditure of municipalities and countries with nighttime lighting[5] and gauge the climatic impact via greenhouse gas emissions from ALAN[6]

The study of ALAN relies on consistent, high-quality data. Remote sensing can provide that data in a way that ground-based methods cannot. Satellite observations have increased our understanding of the large scale effects of ALAN. Although we have become familiar with imagery of Earth from satellites for decades, remotely sensed data of the Earth *at night* is a relatively recent development. The first large scale quantification of ALAN was derived from data collected on orbit from the OLS (Operational Line Scan) instrument on board a series of Defence Department Meteorological Satellite Program (DMSP) missions in the late 1990's[7]. After the launch of NOAA's Suomi NPP satellite with its VIIRS instrument in 2012, the data available to researchers saw a marked improvement[3]. Work has also been done to use images taken by astronauts on board the International Space Station[8]. In addition to orbital data, a handful of aerial surveys have been performed to create valuable municipal scale datasets[9],[10].

Each of the above methods has its own limitations for research, such as very high cost (aerial surveys), lack of calibration (ISS), limited spatial resolution or no color information (OLS, VIIRS). The NITELite system provides an option for acquiring high-quality light pollution data at a relatively low cost from a High Altitude Balloon (HAB) platform. NITELite is a self-contained, automated light pollution imaging system flown to altitudes between 25-30 km. The mission goals of NITELite include producing a high-quality map of light pollution sources on a regional scale and monitoring the transition of Chicago from HPS (High Pressure Sodium) to LED streetlights. The technical goals of the mission to meet the science objectives are to image large regions (100s km2) in multiple color bands (RGB) with high resolution (5m/px) and sensitivity (10e-8 W/cm2/sr) for a relatively low cost

(<$3000). This system also affords opportunities to study light pollution in a wide range of time-dependent settings as repeated missions can be performed for ~$1000.

A sample of NITELite mission test flight results from a 2018 mission flown over Kankakee, IL can be seen in Figure 1. This uncalibrated image demonstrates the capacity of the NITELite system to achieve the resolution, sensitivity, color definition and stability to perform valuable scientific research with a high altitude balloon platform.

System Components

A NITELite mission consists of three main systems: the Imaging System, the On Board Computer (OBC) and the Altitude Control System (ACS).

Figure 1 Sample image of Kankakee, IL from NITELite test flight April 29, 2018

The imaging system consists of three Basler Ace model acA1920–40uc RGB CMOS cameras with a 1920x1200 pixel resolution. Each camera is equipped with a 25mm f/1.4 lens producing a 22°x14° field of view. For our prototype system one camera is nadir pointing and two are pointed symmetrically off-axis. This corresponds to a 40x8 km footprint at altitude (27km). In our use case - imaging Chicago - this multiple camera configuration is required to capture the entire city which has a roughly 3:1 N/S to E/W orientation. The cameras are controlled by an ODROID-XU4 single-board computer, which triggers the image acquisition sequence, records the RAW images and collects instantaneous state data from the OBC for each image.

The On Board Computer (OBC) is built on a Teensy 3.5 microcontroller architecture. It provides state data to the imaging system from a Copernicus 2 GPS and a MPU2950 9DoF IMU. The OBC collects state data at a rate of approximately 7 samples/s. The data is logged by the ODROID as images are acquired.

The Altitude Control System (ACS) automatically vents helium from the balloon via a custom design balloon nozzle as the payload approaches a predetermined target altitude. Once neutral buoyancy is achieved the vent closes. It is during this neutrally buoyant period that the primary imaging mission is performed. After a predetermined dwell time sufficient to complete imaging, the ACS reopens the vent and a controlled descent begins. Not only does this system permit long-duration, level flights at specific altitudes, but maintaining neutral buoyancy dramatically improves payload stability - critically needed for the high-quality, long exposure imaging requirements of NITELite.
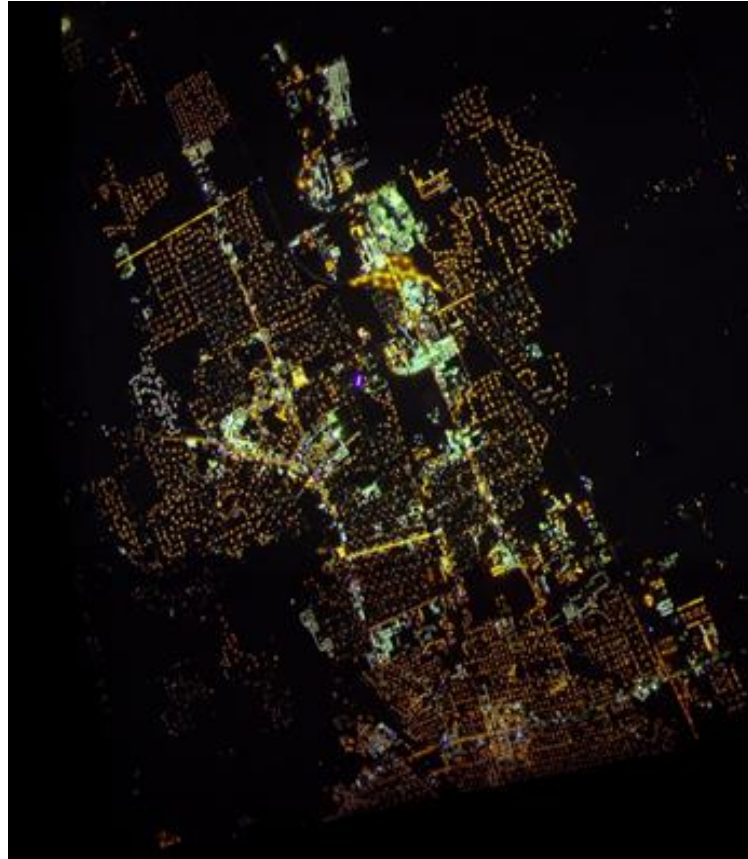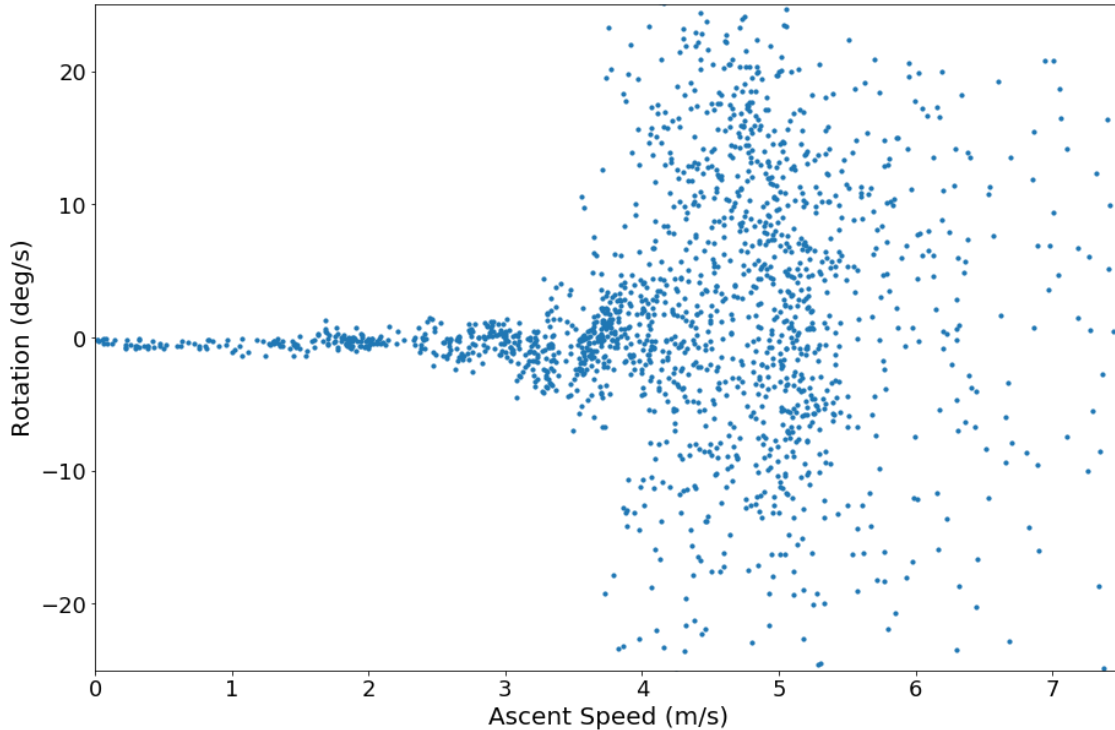
Figure 2 Z-axis rotation vs ascent speed during NITELite test flight demonstrating the relationship between ascent V and rotation.

Turbulent airflow during ascent (or descent) excites rotation and vibration in the payload. As can be seen in Figure 2, rotational movement is strongly correlated with vertical velocity.

Imaging Concept

To achieve the goals of the NITELite mission regarding resolution, we determined that a resolution of 10m/pixel would be sufficient to resolve each municipal street light in Chicago. Street lights in Chicago are spaced at an average distance of ~50m, yet alternating from each side of the street at roughly 50% that distance means an effective distance of 25m [ref].

To confirm our system meets this requirement we can calculate our expected resolution. We can determine the flat field angular pixel scale with:

$$px\theta = FOV/pxN \qquad\qquad\qquad (1)$$

Where *FOV* is the field of view in degrees from the lens captured on the sensor and *px* is the number of pixels across that field. The NITELite camera has 1920 pixels in the horizontal with a field of view of 22 degrees resulting in a $px\theta = 0.011$ degrees or 41.2 arcsec. To calculate GSD (Ground Sample Distance) in meters at altitude we use:

$$GSD = (px*H/f)/100 \qquad\qquad\qquad (2)$$

where *px* is the pixel size in microns, *H* is the imaging altitude in meters and *f* is the focal length of the lens in mm. So, for the NITELite system with a pixel size of 5.4μ, imaging

altitude of 27,000m and a focal length of 25mm using Eq.(2) results in a GSD of 5.8m/px well within our desired resolution.

The other dominant limiting factor to our resolution is blur due to motion. As described above, latex HAB payloads are notoriously unstable. Utilizing the ACS system to achieve neutral buoyancy in the relatively slow stratospheric winds and eliminating the turbulent flow of ascent we have demonstrated that the ACS system can help reduce payload motion and stabilize the imaging platform [Fig. 3]. The predominant motion affecting the resolution of the NITELite system comes from z-axis rotation (rotation on the upward pointing axis).
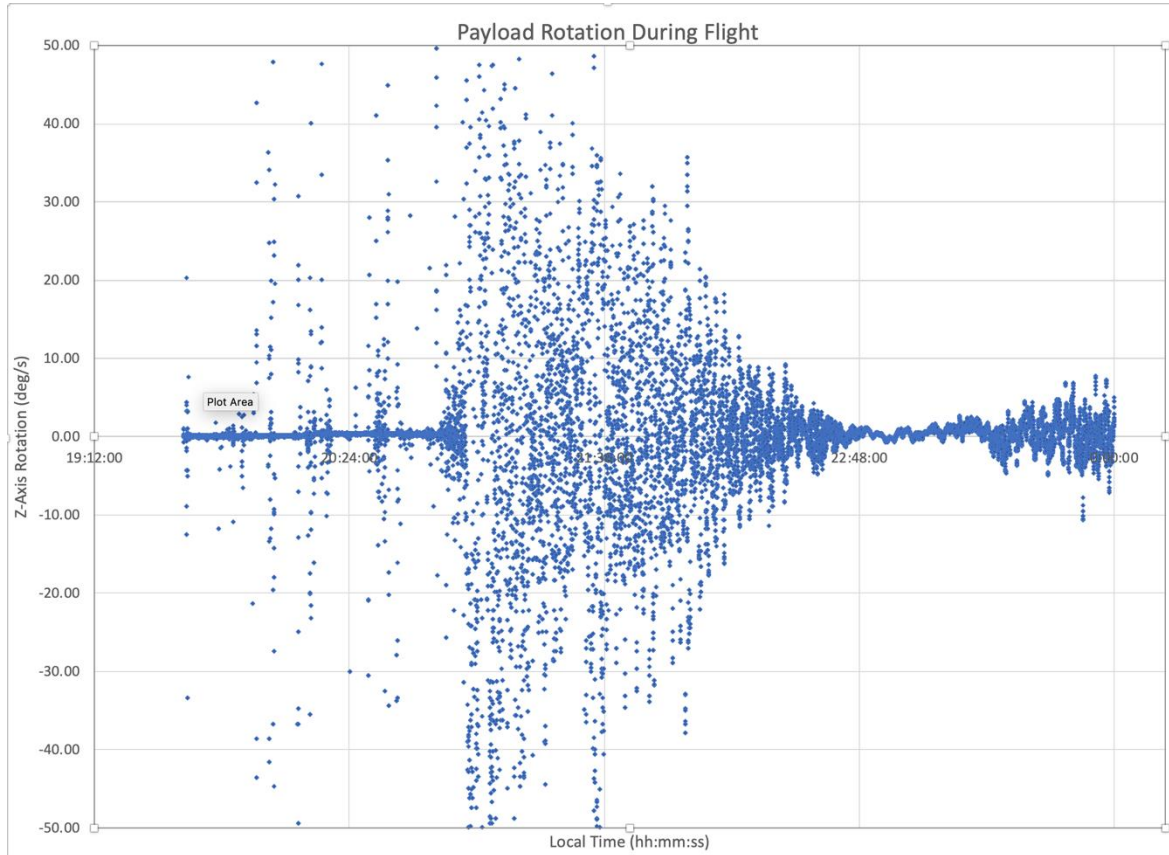

Figure 3 Z-axis payload rotation (degrees/s) throughout NITELite flight.

To determine the rotation limited resolution (Rθ) we can use:

$$R\theta = (\Delta\theta z/s)*t \tag{3}$$

where $\Delta\theta z$ is angular change in z-axis per second and t is length of exposure in seconds. To mitigate rotational blurring in the NITELite system we perform a rapid (<2s) sequence of 5 images from each camera with 50ms exposures. Using the results from test flights where at the period neutral buoyancy we were able to achieve z-axis angular stability <1°/s we can use Eq.(3) to calculate our rotation limited resolution to be less than 20 arcsec - well within the resolution of the angular pixel scale of the system defined above.

Flight Results

We have tested the fully integrated system over multiple flights and have obtained results meeting our mission goals on at least two of those preliminary "shakedown" flights. Results from one test flight collected over 600 km2 of imagery with an average resolution of 5m/pixel. A sensitivity better than 10e-8 W/cm2/sr can be confirmed from the detection of road surfaces only illuminated by a quarter phase moon - effectively a standard candle - on a September 10, 2016 night mission.

With these proofs of concepts in hand, flights to image the city of Chicago are scheduled for the summer of 2019.

Improvements, simplifications and documentation of the system are ongoing with a goal of providing the data we collect to researchers in all ALAN fields. Additionally, we are working to provide our designs and software as open source resources so interested researchers and the HAB community can reproduce this mission for their own scientific surveys.

Acknowledgments

References

1. Longcore T, Rich C. Ecological light pollution. *Front Ecol Environ*. 2004;2(4):191-198. doi:10.1890/1540-9295(2004)002[0191:ELP]2.0.CO;2
2. Marvin FS. Breast Cancer and Circadian Disruption from Electric Lighting in the Modern World. 2014;64(3):xi, 320 p. doi:10.3322/caac.21218.Breast
3. Falchi F, Cinzano P, Duriscoe D, et al. The new world atlas of artificial night sky brightness. *Sci Adv*. 2016;2(6):e1600377-e1600377. doi:10.1126/sciadv.1600377
4. Irwin A. The dark side of light: how artificial lighting is harming the natural world. *Nature*. 2018;553(7688):268-270. doi:10.1038/d41586-018-00665-7
5. Gallaway T, Olsen RN, Mitchell DM. The economics of global light pollution. *Ecol Econ*. 2010;69(3):658-665. doi:10.1016/j.ecolecon.2009.10.003
6. Gandy M. Negative Luminescence. *Ann Am Assoc Geogr*. 2017;107(5):1090-1107. doi:10.1080/24694452.2017.1308767
7. Cinzano P. The Propagation of Light Pollution in Diffusely Urbanised Areas. 1998:20. http://arxiv.org/abs/astro-ph/9811293.
8. Kyba C, Garz S, Kuechly H, et al. High-Resolution Imagery of Earth at Night: New Sources, Opportunities and Challenges. *Remote Sens*. 2014;7(1):1-23. doi:10.3390/rs70100001
9. Kuechly HU, Kyba CCM, Ruhtz T, et al. Aerial survey and spatial analysis of sources of light pollution in Berlin, Germany. *Remote Sens Environ*. 2012;126:39-50. doi:10.1016/j.rse.2012.08.008
10. Hale JD, Davies G, Fairbrass AJ, Matthews TJ, Rogers CDF, Sadler JP. Mapping Lightscapes : Spatial Patterning of Artificial Lighting in an Urban Landscape. 2013;8(5). doi:10.1371/journal.pone.0061460