Survey, Design, and High-Altitude Testing of Novel CubeSat Earth Horizon Sensors

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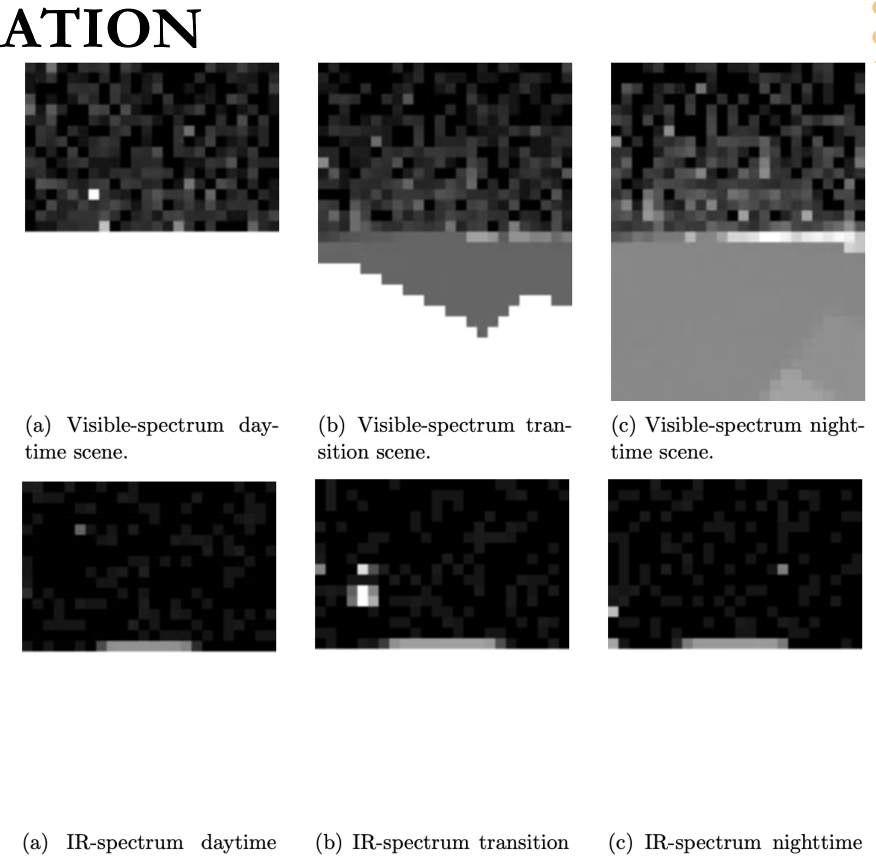
ABSTRACT:

Determining the attitude, or pointing direction, of a spacecraft is imperative in its ability to operate according to mission goals. This thesis aims to support the Princeton TigerSats Lab's CubeSat development by designing, simulating, iterating on, and validating an Earth horizon sensor for the spacecraft. The horizon sensor will validate the passively stabilizing gravity boom on the spacecraft after the deployment of the system by monitoring the location of Earth's horizon from Low Earth Orbit. Sensor selection aimed to minimize volume, mass, and power demands in support of the TigerSats goal of developing a student-accessible and minimal-cost 1U CubeSat.

SYNTHETIC SCENE GENERATION

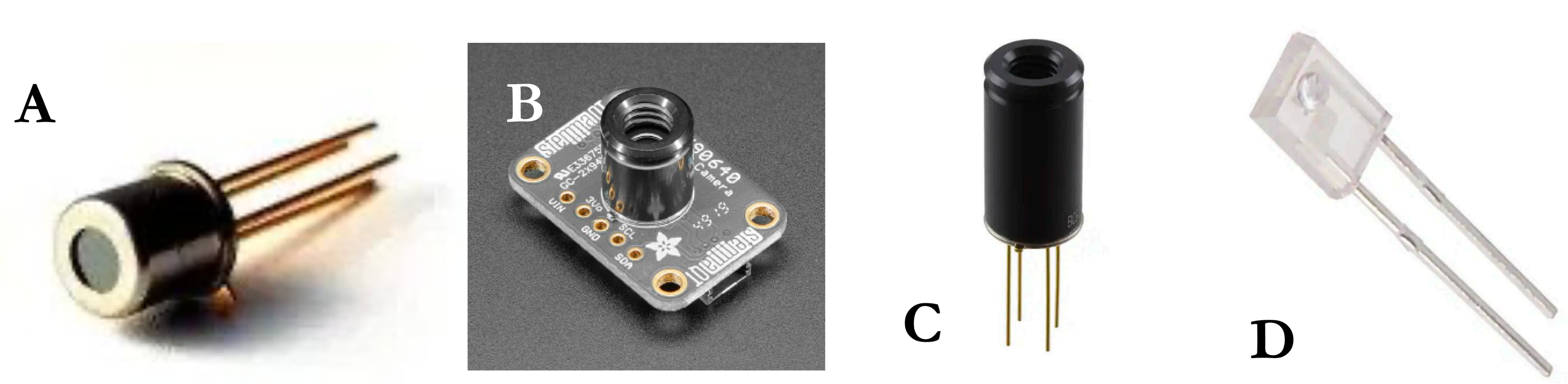
- STK EOIR was used to produce synthetic scenes for a 32 x 24 pixel camera-type sensor in ISS orbit in both visible-light and IR spectrum [1].
- Demonstrates IR spectrum consistency across day-night line compared to visible light.
- Allows for qualitative comparison with flight data from IR camera sensors.



(a) Visible-spectrum daytime scene. (b) Visible-spectrum transition scene. (c) Visible-spectrum nighttime scene.

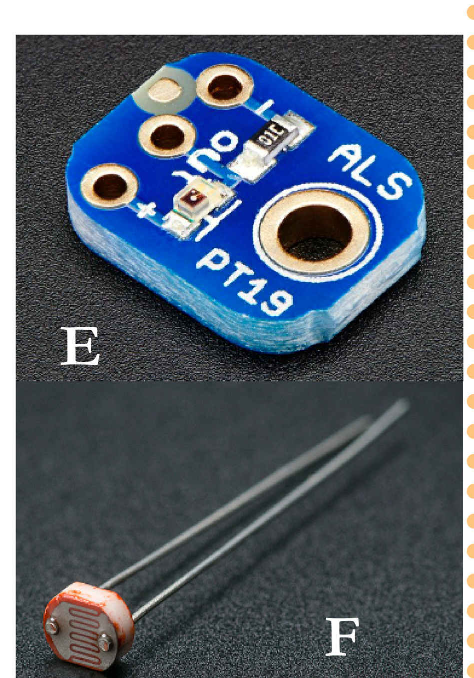
(a) IR-spectrum daytime scene. (b) IR-spectrum transition scene. (c) IR-spectrum nighttime scene.

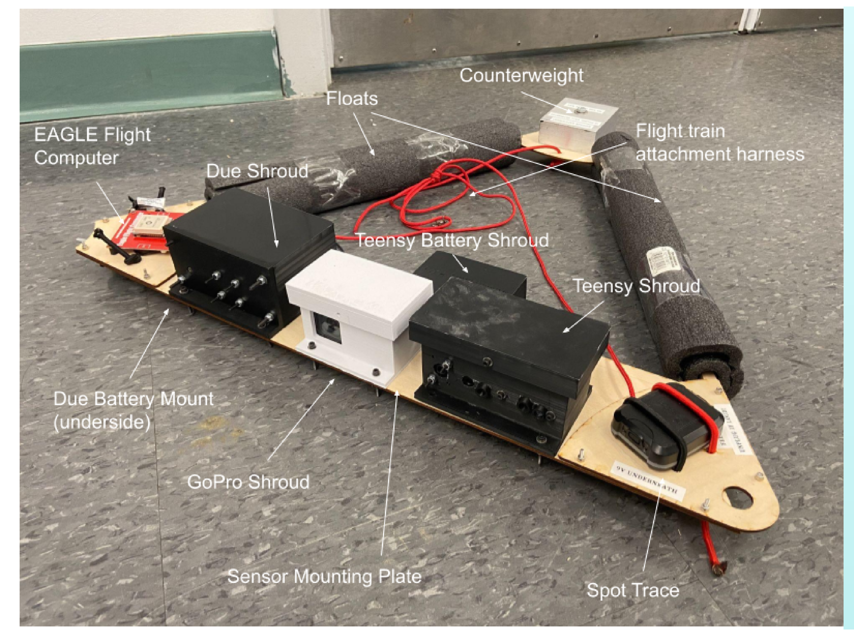
SENSOR SELECTION

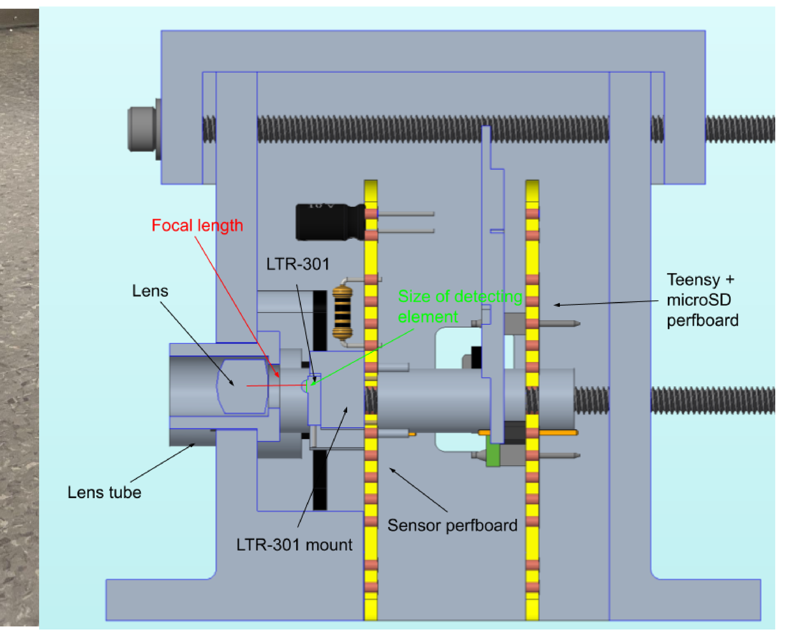


Six sensors were selected using trade studies for high altitude testing, broadly categorized into two types:

- Camera-type sensors:
  - A: HTPA 8x8 IR imager [2]
  - B: MLX 90640 IR imager [3]
- Single-diode sensors:
  - C: MLX 90614 IR sensor [4]
  - D: LTRR 301 IR sensor [5]
  - E: ALS-PT19 visible-light photocell [6]
  - F: CdS photoresistor [7]





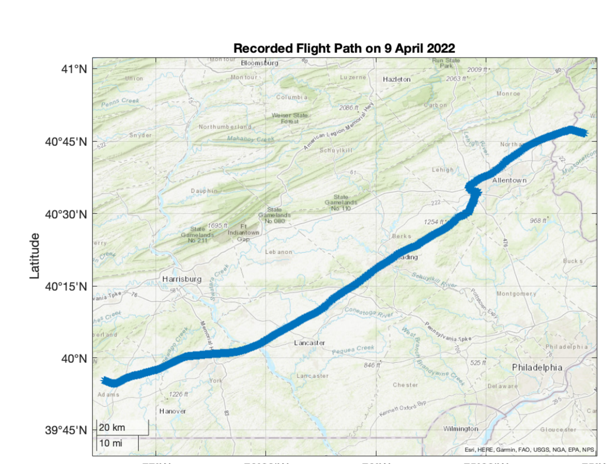


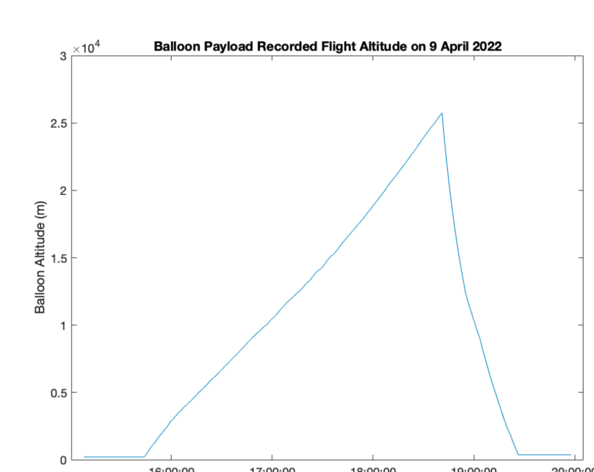
HIGH ALTITUDE BALLOON PAYLOAD DESIGN AND MANUFACTURE

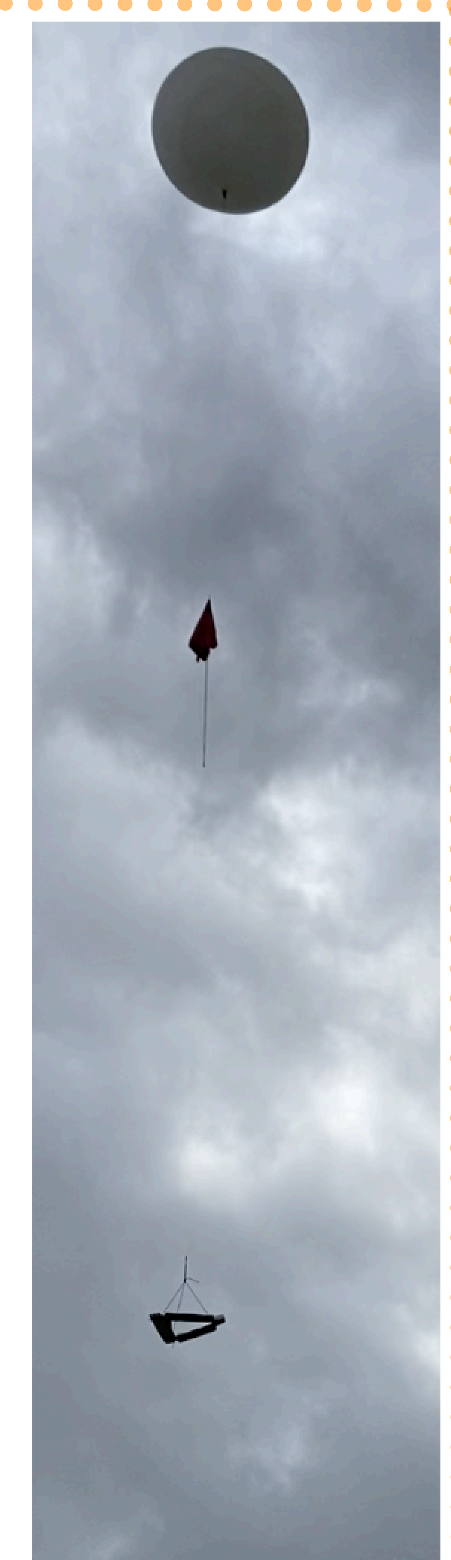
- Sensor control circuits running flight software on the Arduino Due and Teensy 3.2 based sensor suites.
- Sensor suite shrouds for protection against winds during ascent (3D printed in PLA).
- Optical design for single-diode sensors without built-in lens tubes.
- Sensor mounting plate (laser cut from wood).
- Gondola stabilization and counterweight (milled from aluminum).

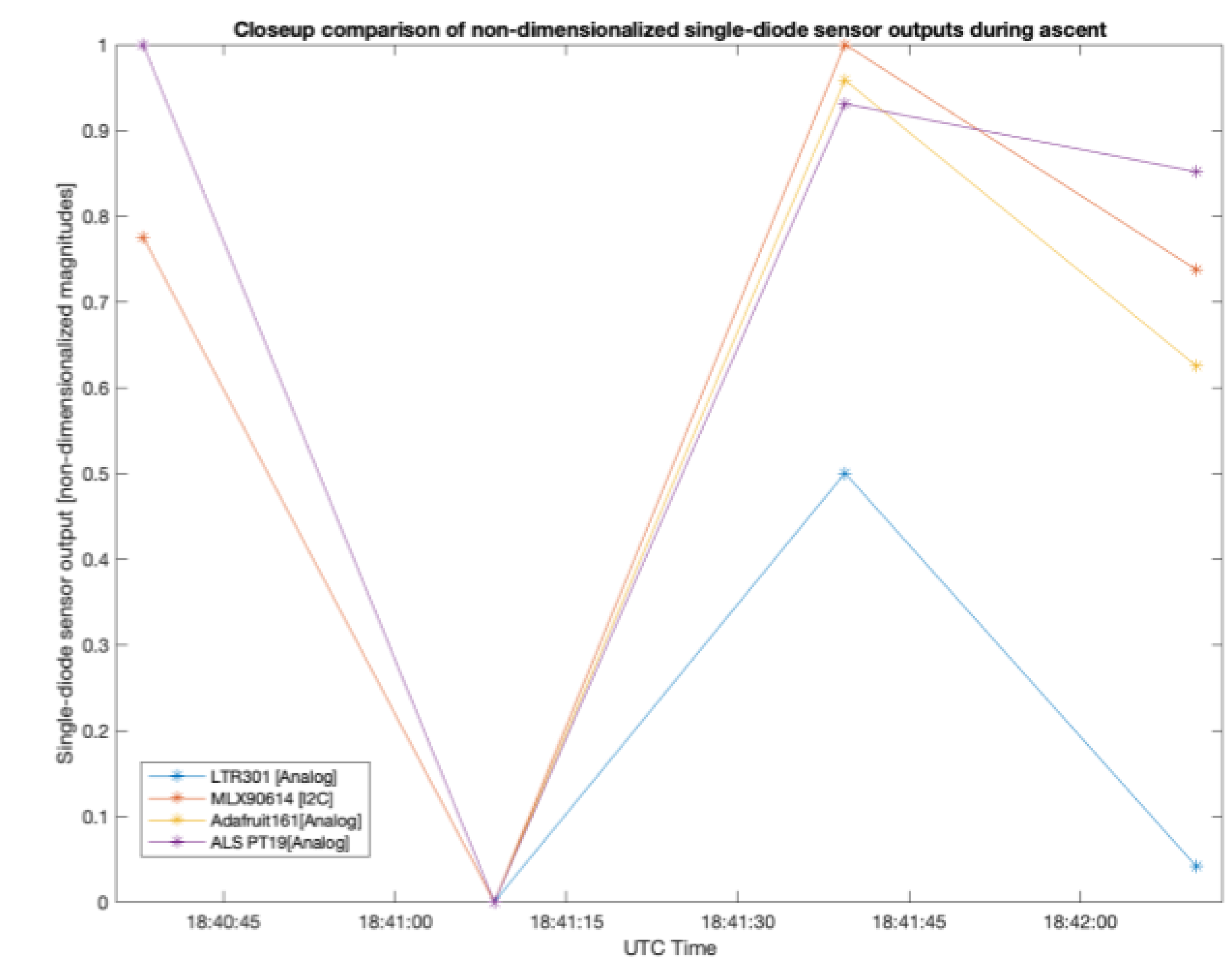
BALLOON LAUNCH

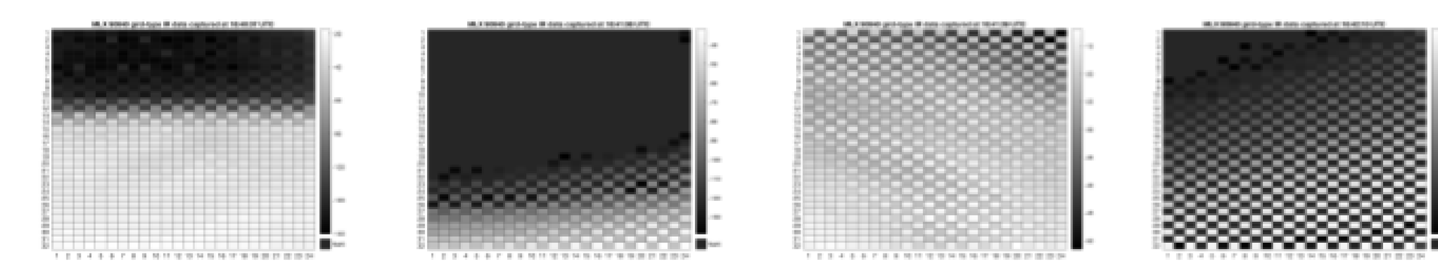
- Pre-flight preparations:
  - Balloon helium requirement calculation
  - Launch path prediction
  - Pre-flight dress rehearsal
  - Flight train layout and checks
- Balloon launched outside of Gettysburg, PA at 11:42 AM ET on April 9, 2022, following all launch procedures.
- Balloon drifted off the predicted course during flight and traveled further east than expected, although still within FAA safety parameters.
- Successful recovery on the same day of launch.
- Maximum altitude: 25731 m above sea level at 2:41:06 PM ET.











18:40:37 UTC 18:41:08 UTC 18:41:39 UTC 18:42:10 UTC

FLIGHT DATA ANALYSIS AND CONCLUSION

Analysis of Flight Data:

- HTPA 8x8 IR sensor lost early in flight, possibly due to moisture-induced short circuit during ascent.
- Single-diode sensors behave mostly in unison as the gondola sways, data non-dimensionalized for comparison using $y_{ND}(t) = \frac{y(t) - min(y(t_0 : t_f))}{R(t_0 : t_f)}$
- Heatmaps in grayscale produced for MLX 90640, in-line with synthetic scenes produced by STK EOIR.
- Data taken around maximum altitude (i.e. balloon burst) by single-diode sensors correlated with MLX 90640 low-resolution IR captures as shown above.

Final Sensor Selection: MLX 90614 for smaller missions such as TigerSat 1U tech demo, MLX 90640 for larger spacecraft with higher datarate and power allowances.

Future work: Selected sensors will be integrated into PC104 flight modules, space-qualified, and then launched into orbit aboard the first Princeton CubeSat.

REFERENCES: [1] Analytical Graphics Inc. "Model electro-optical and infrared sensor performance." (n.d.) [2] Heimann Sensor. "8x8 thermopile infrared array." (n.d.) [3] Adafruit Industries. "Adafruit mlx90640 ir thermal camera breakout." (n.d.) [4] DigiKey Electronics. "Mlx90614esf-bcf-000-sp." (n.d.) [5] DigiKey Electronics. "Ltr-301." (n.d.) [6] Adafruit Industries. "Adafruit als-pt19 analog light sensor breakout." (n.d.) [7] Adafruit Industries. "Photo cell (cds photoresistor)." (n.d.)