20190900: LWIR Sensors for TAT-C demo

Background

Instrument parameters to vary:

Long Wave Infrared Wavelength (LWIR) thermal imager (passive optical sensor class) is considered. The reason I did not go for a visible imager is that presently the coverage from Orbits does not filter out observations taken during night time (not meeting the user specified SNR threshold requirement) and hence coverage metrics is skewed. With thermal imaging though all observations would meet the requirement.

Only the optics (telescope specs) of the instrument is varied (electronics specifications are kept fixed).

1. *Focal Length:* Influences ground-pixel resolution
2. *Aperture Diameter:* Influences SNR

Data metrics considered:

1. *Signal to Noise Ratio (SNR):* Indicates “brightness” of image. A higher SNR for a given imaging imaging geometry (observation range, zenith angle), conditions (fixed Sun zenith angle). **Higher** is better.
2. Noise Equivalent Delta Temperature (NEDT): Primary metric to measure performance of thermal sensors. Minimal is better.
3. *Ground pixel resolution:* Indicates extent to which objects can be discerned spatially. **Lower** is better.

Notes on expected trends:

- *Vs Altitude:* As Altitude increases for a given Focal length and Aperture diameter the ground-pixel resolution worsens (gets larger in value). The SNR remains the same or will improve.
- *Vs Aperture Diameter:* As aperture diameter is increased for given Focal length, Altitude, the SNR improves. The pixel resolution remains the same.
- *Vs Focal Length:* As Focal length increases for a given Aperture diameter, Altitude the resolution improves (reduces), but SNR degrades.

As the Aperture diameter and/or Focal Length increases, the mass and volume of the instrument increase. This will affect the satellite bus specs too.

The Altitude has big effects on the coverage metrics. It would be useful to see the tradeoff between the coverage metrics and data metrics. In general I expect a negative relation since higher altitude gives better coverage but worser data.

Other orbital parameters too may show some trends, because of of different imaging geometries and conditions resulting from different orbits for a given Point of Interest (POI).

Instrument specifications design

The imager maybe divided into two parts: electronics & optics. In my understanding both the parts are sold *separately* by commercial companies . In this study we vary only the Optics part, i.e. use different telescopes. Practically available COTS electronics and telescopes are considered and the specs derived from them.

- **Imager electronics (fixed):**
  - Part name: BOSON 640, 32 deg HFOV LWIR Thermal Camera core (without optics) https://www.flir.com/products/boson/?model=20640A032
    - power consumption of
    - volume: 21 x 21 x 11 mm3
    - mass: 7.5
    - detector length: 12um
    - wavelength: 7.5um to 13.5um
    - QE:
    - # pixels: 640 x 512
    - # readout electrons assumed:
    - bits per pixel:
    - price: 3520 USD
- **Imager Optics (vary):**
  - Ronar Smith Optics LWIR lenses. They have big collection of lenses of different aperture diameter and focal length.

https://wavelength-tech.com/IR-Optics/LWIRLens.jsp

Telescopes search space (each row corresponds to different instrument):

- The satellite bus form factor is chosen assuming the satellite bus stuff take up 1U mass and rest is taken by payload. Then seeing the length of the lens, appropriate Us are allocated.
- The search parameters are not “uniform”, i.e. we do not have a fixed focal length, varying aperture diameter, or fixed aperture diameter and varying focal length. primarily because they are based on real available components. I suppose it is reasonable to assume the

manufacturer has a reason to produce the given distribution of lens specs (i.e. the focal length and aperture diameter do not have a uniform mesh sort of relationship).

- There are totally 6 options, two 2Us, 3Us, 4Us.
- Compare entry #1 and #5, (same focal length) while #1 corresponds to only SWIR, #5 is for both SWIR and NIR. #5 underperforms in terms of mass, but outperforms in terms of size. probably. Maybe cause #1 has larger aperture diameter. Still it looks strange.

Index	Instrument name	Focal length (f) (mm)	F number F#	Aperture diameter (D) Note: D = f/F#	Mass (g)	Size	Satellite Bus required
1	LSW05014640 Heat1	50	1.4	35.71429	400	Length77mm, Ø72mm	2U
2	LSW07515640 Heat2	75	1.5	50	1200	Length131.64mm, Ø91mm	3U
3	LSW20024640 Heat3	200	2.4	83.33333	2100	Length202.97mm, Ø108mm	4U
4	LSW10020640 (variable F#: 2 to 16) Heat4	100	10	10	2000	Length163.7mm, Ø100mm	3U
5	Infra-SW502.0-30 Heat5	50	2	25	135	Length49mm, Ø36mm	2U
6	Infra-SW2002.0-30 Heat6	200	2	100	650	Length244.1mm, Ø116mm	4U

- All the lens in the table have the same average transmission as 80% (optical efficiency).

Specs of Sat 1

For Sat 1 the optics chosen is Heat1
d → detector length
f → focal length
D → aperture diameter
N_AT → number of detectors along-track
N_CT → number of detectors cross-track

Specs of Satellite #1:

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  "commBand": [
    "X"
  ],
  "name": "Sat1",
  "acronym": "Sat1",
  "mass": 5,
  "dryMass": 5,
  "volume": 3U Cubesat = 0.0034,
  "power": 53.39,
  "techReadinessLevel": 9,
  "isGroundCommand": true,
  "isSpare": false,
  "propellantType": "None",
  "stabilizationType": "AXIS_3",
  "@type": "Satellite",
  "agency": [],
  "payload": [
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    "name": "Heat1",
    "mass": electronics + telescope = 0.150 + 0.4 = 0.55,
    "volume": electronics + telescope = 0.04x0.04x0.04 + 0.07*0.072 =
0.005104,
    "power": electronics = 4,
    "fieldOfView": {
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        "alongTrackFieldOfView": (d/f)*N_AT*180/pi = (20e-6/50e-3)*51
2*180/pi = 11.73,
        "crossTrackFieldOfView":(d/f)*N_CT*180/pi = (20e-6/50e-3)*640
*180/pi = 14.66
    },
    "scanTechnique": "MATRIX_IMAGER",
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    "orientation": {
        "convention": "SIDE_LOOK",
        "sideLookAngle": 0
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    "dataRate": frame-rate x num detectors x bit resolution = 20*640*
512*14e-6= 92,
    "numberOfDetectorsRowsAlongTrack": 512,
    "numberOfDetectorsColsCrossTrack":  640,
    "detectorWidth": 20e-6,
    "focalLength": 50e-3,
    "operatingWavelength": 1.3e-6,
    "bandwidth": 0.8e-6,
    "quantumEff": 0.9,
    "targetBlackBodyTemp": 290,
    "bitsPerPixel": 14,
    "opticsSysEff": 0.8,
    "numOfReadOutE": 65,
    "apertureDia": 35.71429e-3,
    "Fnum": 1.4,
    "snrThreshold": 1,
}]
}
```

References:

1. Rønning, S. S. (2012). *Optimizing an infrared camera for observing atmospheric gravity waves from a cubesat platform* (Master's thesis, Institutt for fysikk).

Collection of specific references: