20190900: SWIR Sensors for TAT-C demo

Background

Instrument type:

SWIR imager (passive optical sensor class) is considered.
"SWIR is similar to visible light in that photons are reflected or absorbed by an object, providing the strong contrast needed for higher resolution imaging."

This wavelength can be imaged during both day and night by the same instrument. However during night the exposure time needs to be more (to collect more photons to meet the required SNR levels). The same exposure cannot be used day-time since it would saturate the image. We do not have facility currently in TATC to change the instrument parameters on the go. So the current specs shall be set for only day-time capture.

Instrument parameters to vary:

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

1. *Focal Length:* Influences ground-pixel resolution and SNR
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. *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 in general remains the same or increase. For our specific simulation the SNR will remain the same.
- *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 telescopes are considered and the specs derived from them.

- **Imager electronics (fixed):**
    - Part name: Xenics Bobcat-640-GigE. Based on [1] it is viable thermal (SWIR) sensor for Cubesat missions. Cost: 23600 euros = 26125 USD
        - power consumption of 4W
        - volume: 40x40x40 mm3
        - mass: 150g
        - detector length: 20um
        - operating wavelength, bandwidth: 1.3um, 0.8um. Filter is placed on top to reduce bandwidth to 0.2um.
        - QE: 0.9
        - # pixels: 640 x 512
        - # readout electrons assumed: 65
        - bits per pixel: 14
- **Imager Optics (vary):**
    - Optical specifications based on Ronar Smith Optics SWIR lenses are chosen based on results from of Google search. Not entirely sure if this is OK. They specify a small circular FOV for the lens (smaller than the imager FOV), so not sure if it is OK.

https://wavelength-tech.com/IR-Optics/SWIRLens.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.

Following are the bus specifications used:

2U: Volume: 10x10x20 cm3, Bus Mass: 2 kg
3U: Volume: 10x10x30 cm3, Bus Mass: 3 kg
4U: Volume: 10x10x40 cm3, Bus Mass: 4 kg

- 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 #5 and #6, (same focal length) while #5 corresponds to only SWIR, #6 is for both SWIR and NIR. #5 underperforms in terms of mass, but outperforms in terms of size. probably. Still it looks strange.
- All the lens in the table have the same average transmission as 80% (optical efficiency).

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

Specs of Sat 1

For Sat 1 the instrument 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:

```
{
  "commBand": [
    "X"
  ],
  "name": "Sat1",
  "acronym": "Sat1",
  "mass": bus mass + electronics mass + optics mass = 2+0.4+0.15 = 2.5
5,
  "dryMass": mass = 2.55,
  "volume": 2U Cubesat = 10*10*20*1e-6 = 0.002,
  "power": 53.39,
  "techReadinessLevel": 9,
  "isGroundCommand": true,
  "isSpare": false,
  "propellantType": "None",
  "stabilizationType": "AXIS_3",
  "@type": "Satellite",
  "agency": [],
  "payload": [
{
    "@type": "Passive Optical Scanner",
    "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": {
        "sensorGeometry": "RECTANGULAR",
```

```
        "alongTrackFieldOfView": (d/f)*N_AT*180/pi = (20e-6/50e-3)*512
*180/pi = 11.73,
        "crossTrackFieldOfView":(d/f)*N_CT*180/pi = (20e-6/50e-3)*640*
180/pi = 14.66
    },
    "scanTechnique": "MATRIX_IMAGER",
    "orientation": {
        "convention": "SIDE_LOOK",
        "sideLookAngle": 0
    },
    "dataRate": frame-rate x num detectors x bit resolution = 20*640*5
12*14e-6= 92,
    "numberOfDetectorsRowsAlongTrack": 512,
    "numberOfDetectorsColsCrossTrack":  640,
    "detectorWidth": 20e-6,
    "focalLength": 50e-3,
    "operatingWavelength": 1.3e-6,
    "bandwidth": 0.2e-6,
    "quantumEff": 0.9,
    "targetBlackBodyTemp": 290,
    "bitsPerPixel": 14,
    "opticsSysEff": 0.8,
    "numOfReadOutE": 65,
    "apertureDia": 35.71429e-3,
    "Fnum": 1.4,
    "snrThreshold": 10,
    '"maxDetectorExposureTime":0.5e-3,'
}]
}
```

Similarly for other 5 satellites.

Simulated data metrics at 700km altitude, Nadir pointing for the different instruments:

- Unity reflection from surface of Earth is assumed.

```
#1

{'Ground Pixel Along-Track Resolution [m]': 181.23070333504768, 'Ground Pixel Cross-Track Resolution [m]': 181.31816965793425, 'SNR': 1113.1243989927148, 'DR': 19127.024896981693, 'Noise-Equivalent Delta T [K]': 278362557.04056203, 'Coverage [T/F]': True}

#2

{'Ground Pixel Along-Track Resolution [m]': 181.23070333504768, 'Ground Pixel Cross-Track Resolution [m]': 181.31816965793425, 'SNR': 777.8172644660931, 'DR': 9372.239950183308, 'Noise-Equivalent Delta T [K]': 397682448.50304013, 'Coverage [T/F]': True}

#3

{'Ground Pixel Along-Track Resolution [m]': 120.82883941863426, 'Ground Pixel Cross-Track Resolution [m]': 120.88774956673328, 'SNR': 1037.851673358541, 'DR': 16636.071574422534, 'Noise-Equivalent Delta T [K]': 298027405.0688062, 'Coverage [T/F]': True}

#4

{'Ground Pixel Along-Track Resolution [m]': 90.62477067805322, 'Ground Pixel Cross-Track Resolution [m]': 90.66917819386755, 'SNR': 143.91628869891684, 'DR': 374.02089933318564, 'Noise-Equivalent Delta T [K]': 1985970915.0970597, 'Coverage [T/F]': True}

#5

{'Ground Pixel Along-Track Resolution [m]': 45.31474306881983, 'Ground Pixel Cross-Track Resolution [m]': 45.33711565647851, 'SNR': 646.0749857663251, 'DR': 6486.091795994119, 'Noise-Equivalent Delta T [K]': 476443066.48585844, 'Coverage [T/F]': True}

#6

{'Ground Pixel Along-Track Resolution [m]': 45.31474306881983, 'Ground Pixel Cross-Track Resolution [m]': 45.33711565647851, 'SNR': 776.4679263502234, 'DR': 9339.972933429352, 'Noise-Equivalent Delta T [K]': 396997281.9917629, 'Coverage [T/F]': True}
```

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:

From [1]: *The Norwegian University of Science and Technology (NTNU) Test Satellite (NUTS) project is aiming to launch a nanosatellite into Low Earth Orbit (LEO) by 2014.*
The satellite is a double CubeSat, measuring 10×10×20 cm3 and weighing less than 2.66 kg, which conforms to the CubeSat standard [13]. The satellite will carry an IR-camera for atmospheric observations as its main payload.

From [1] Table 4.2: Xenics Bobcat-640-GigE

Sensor type	InGaAS
Resolution	640×512
Pixel pitch	20 μm x 20 μm
Spectral response	0.9-1.7 μm
Quantum efficiency	0.90
Frame ratemax	120 Hz
Power consumption	4 W
Power supply	12 V
Digital output	14 bit
Operating temperature	-40 ◦C to 70 ◦C
Weight (lens not included)	≤ 150 g
Size dimensions	40 x 40 x 40 mm3

Table 4.5: Xenics Bobcat-640-GigE

Parameter	Result
Focal length	16 mm
F-number	1.4
GSD	2.25 km
Resolution	213×170
Binning factor	9
Bmax	17
FOV	46◦ and 37◦
round segment one image	479 km and 383 km
Blurred wavelengths	≤15 km

Integration time	3 s
∆SNR for one image	0.6
Effective FOV	479 km and 115 km
Nimages	12
∆ SNR average	2

Table 3.5: Noise Parameters **(not particularly of the chosen electronics)**

D(pixel electrons -seconds)	Nr(electron rms pixel)
10000	65