Level 2 Requirements & Interfaces

Vision Subteam

Camera Hardware & Calibration

1. **The camera system shall be optimized for capturing images between 450-700 km altitude.**

> Verification/test: Simulate the space environment and lighting conditions expected between 450-700 km altitude. Capture images and assess their clarity, focus, and overall quality.

2. **The camera system, in collaboration with the onboard ML model, shall support the GNC subteam in attitude determination with errors less than 15 degrees, and orbit determination with errors less than 50 kilometers.**

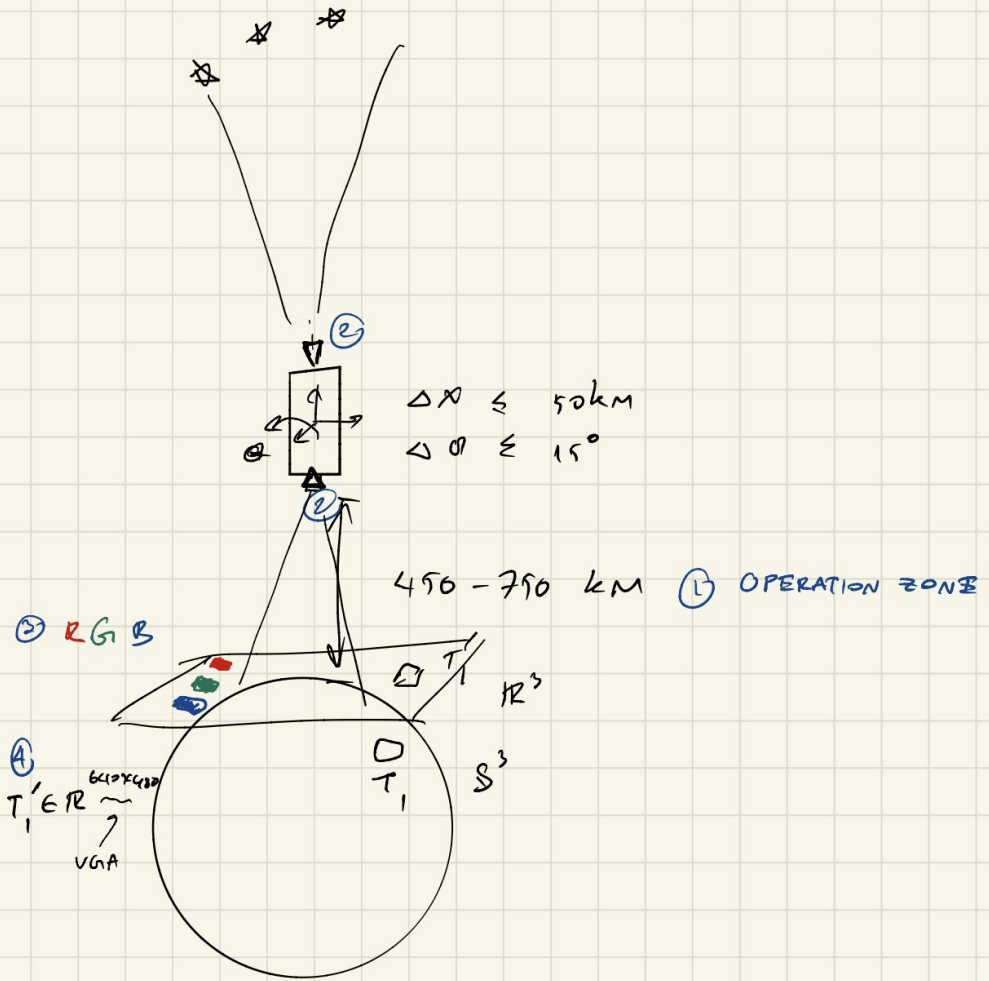
> Verification/test: Use a star tracker or another high-precision attitude determination system as a reference. Use simulated imagery with known landmarks and process these images with the onboard ML model to determine the spacecraft's attitude and orbit. Compare the attitude and orbit determined by the vision system to the reference to ensure errors are within 15 degrees and 50 kilometers.

3. **The camera shall capture RGB images (need to check the hardware).**

> Verification/test: Capture images using the camera system and verify that it can capture image in different wavelengths.

4. **The camera shall capture images with a minimum resolution of VGA (640x480), but higher resolution is preferred (Need to check the hardware).**

> Verification/test: Capture images using the camera system and verify that the resolution is at least VGA (640x480).


2
Δx ≤ 50km
Δθ ≤ 15°
450 - 750 km
1 OPERATION ZONE
3 RGB
T
IR³
4
T₁' ∈ IR
VGA
T₁
S³

5. **The camera system shall have an onboard image compression capability to reduce the downlink bandwidth requirement.**

> Verification/test: Capture multiple images in quick succession without downlinking. Ensure the system stores them without loss or corruption by then downlinking and verifying their integrity.

6. **The camera system shall feature a buffer or storage system to temporarily hold captured images before they are downlinked. (Give flexibility in when to downlink, in case of interruptions or priorities in communication)**

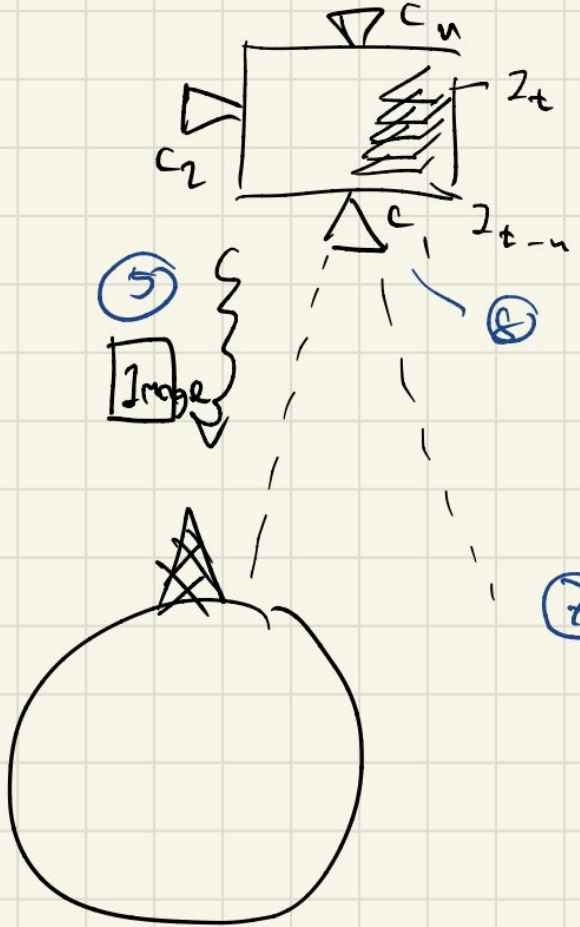
> Verification/test: Capture multiple images in quick succession without downlinking. Ensure the system stores them without loss or corruption by then downlinking and verifying their integrity.

7. **The camera system shall be optimized for Earth observation, considering factors like focal length, sensor sensitivity, and field of view.**

> Verification/test: Simulate an Earth-like test environment, and assess the camera's focal length, sensor sensitivity, and field of view. Capture images and ensure they meet the desired quality and specifications, and compare image quality with existing Earth-image datasets at similar orbit conditions.

8. **At all times, there must be at least one camera pointing to the earth and one pointing to stars.**

> Verification/test: Distribute the cameras with enough FOV accordingly.



⑥ STORAGE

$= \{ I_t, \ldots I_{t-n} \}$

④ $\forall t$, c_i exists to see W

intrinsic params

⑦ FoV + K

Machine Learning Model for Feature Recognition

1. **The machine learning model inference time shall not exceed the time of the GPU uptime, shall account for GPU launch overhead, and shall account for slack room in device degradation in the expected lifetime.**

> Verification/test: profile machine learning inference time on the corresponding GPU type.

2. **The size of the model shall fit within the given memory system.**

> Verification/test: profile size of the model

3. **The machine learning model shall output ECEF/pixel correspondences in a format processable by the GNC team.**

> Verification/test: Decide on a data format with GNC and maintain ongoing communication with them about the interface between Vision and GNC.

4. **The system shall have a confidence value for the output.**

> Verification/test: Testable and simulated during training and testing.

5. **The system shall output landmark classification result from input image**

> Verification/tests: pipe sample output to GNC team to verify the format of the output.

6. **The model shall pass XXX terrestrial features (with ECEF 3D pixel correspondence) to the GNC team for orbit determination.**

> Verification/test: Testable and simulated during training and testing. Depends on the method for extracting terrestrial features.

7. **The model shall perform pre-processing on the images. This pre-processing will include the detection of blur and glare, blur recovery, for example, and will correct or throw out images that are unusable.**

> Verification/test: Laplacian Variance: A common method to detect blur is by computing the variance of the Laplacian of the image. Low variance indicates a blurred image.

Downlink, Power, & Storage

1. **The system shall be able to identify and downlink earth-facing images (of *various* locations on Earth) to feed to the landmark inference model (i.e., images in which the Earth occupies at least 75% of the image).**

> Verification/test: software test with arbitrary sets of images to test the selection algorithm.

2. **The system shall process raw input images with adjustments on exposure, brightness, sharpness etc....(when required)**

> Verification/test: Simulate various different possible condition for input images. Feed into the system and test the performance of the ML model with and without filters, and test the performance of the ML model.

3. **The system shall transmit raw input image onto the GPU**

> Verification/test: deploy the ML model on device, verify that 1) the model has access to the image on GPU, 2) the communication/launch overhead time on GPU.

4. **The system shall control input image rate into the ML model inference, e.g.: if the power can support 6X (where x is int) inference, at what ratios should we feed the next set of six images for inference?**

> Possible verification/test: test with different range of input rate and measure the model performance to find the best rate. The challenge is to have input images that emulate that scenario.

5. **The camera unit shall require at most TODO TB of memory on the camera capture board, corresponding to at most 1 high-FOV-low-res and 10 low-FOV-high-res images.**

> These are stored in batches so that the Jetson can batch process these images.

Interfaces

Vision → GNC

1. ECEF coordinates of detected landmarks
2. 3D pixel correspondences within 1 km mean absolute error to these ECEF coordinates
3. TBD features per frame
4. TBD fps (will be determined by how much we can store on the camera capture board)
5. TBD FOV to get spread apart region detections (but not so high that the spatial resolution is reduced)

GNC → Vision

1. Attitude knowledge within max. 1 km mean absolute error
2. Attitude tumbling rate lower than 3 deg/sec

Avionics → Vision

1. Separate camera capture board that stores images before passing them over to the Jetson (so that we can be more efficient and use batch processing)
2. Determine the GPU

Vision → Avionics

1. Indication of when images can be cleared from the camera capture board
2. Need to let avionics know the power requirements for the ML models to determine which Jetson we will be using

Vision → Mechanical

1. TBD lens dimensions
2. Heat dissipation from Jetson Orin

Vision → Comms & Ops

1. 10 images to be downlinked to Earth