Hyperspectral Thermal Imaging CubeSat for SSA applications

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ABSTRACT

Hyperspectral thermal imagers provide characteristic information that conventional spectral imagers cannot offer. The proliferation of space assets and debris will require “eyes in the sky" to track objects effectively. The current estimates as of 2022 state that more than 27,000 pieces of orbital debris are tracked by the Department of Defense's global Space Surveillance Network (SSN). This number is expected to double in the next ten years with 57,000 satellites expected to be launched by 2029. Ground-based assets will not be able to track this vast number of orbital debris, and space-based monitoring capabilities will have to complement the tracking of assets and debris in the years to come. In this work, we present the Hyperspectral Thermal Imager (HyTI) CubeSat design, initially developed for Earth Observation, that can be adapted for Space Situational Awareness (SSA) applications with machine learning algorithms for fast object detection. With new advances in machine learning hardware and software, the categorization of orbital objects can help reveal features such as geometry, thermal signature, and size, among others. For example, spectral signatures can be leveraged to identify plumes of thrusters and unique characteristics of various materials used in different objects.

HyTI is a 6U CubeSat funded by NASA's Earth Science Technology Office (ESTO) In-Space Validation of Earth Science Technologies (InVEST) program. HyTI demonstrates how high spectral and spatial longwave infrared image data can be acquired from a 6U CubeSat platform. The long wave infrared detector uses a push-broom technique for producing accurate spectral and spatial data for moving targets. HyTI will demonstrate advanced on-orbit real-time data processing and the creation of scientific and operational data products. The payload uses a spatially modulated interferometric imaging technique to produce spectro-radiometrically calibrated image cubes, with 25 bands between 8-10.7 microns. The HyTI performance model indicates narrow band NEDTs of < 0.3 K. The small form factor of HyTI is made possible via the use of a no-moving-parts Fabry-Perot interferometer developed by the Hawai'i Institute of Geophysics and Planetology (HIGP) at the University of Hawai'i at Mānoa (UHM), and a Jet Propulsion Laboratory (JPL) cryogenically cooled High Operating Temperature (HOT) Barrier Infrared Detector (BIRD) focal plane array (FPA) technology. The level 0 (L0) data rate of the HyTI instrument is large. As a result, HyTI processes data from L0 to level 1 (L1, calibrated spectral radiance cubes) onboard. This is achieved using an advanced radiation-tolerant heterogeneous computer, the Unibap iX5-100 space computer, which offers CPU, GPU, and FPGA processing capability and has the option to add one or more neural network accelerators [12]. In this way, the L0 data volume is reduced by a factor of 13 before transmission to the ground as L1 data. Fully equipped, the iX5-100 can achieve several trillion computational operations per second (TOPS), which is essential for on-orbit detection of objects [13]. In this paper we provide an overview of the HyTI design and how it can be adapted for SSA observations and applications. We expand on the onboard data reduction and object detection approach, then provide an overview of the SpaceCloud Framework containerization of mission management and data applications.

1. INTRODUCTION

As the number of satellites and other objects in orbit around Earth continues to grow, so does the need for effective space situational awareness (SSA) tools. Hyperspectral thermal imaging is a technology that can provide valuable information for SSA applications. The Hyperspectral Thermal Imager technology has been developed at the University of Hawai'i at Mānoa and JPL to address the need for high spectral and spatial resolution long-wave infrared (LWIR) image data to quantify the chemical composition and temperature of the Earth's solid surface, oceans, and atmosphere [1]. The goal of the HyTI mission is to demonstrate high spectral, high spatial, and high SNR longwave infrared imaging, as well as a high performance on-board computer to process the resulting data in a 6U CubeSat platform. This technology will be demonstrated in space with the first HyTI mission expected to launch in the Spring of 2023 as a NASA Earth Observation Mission. HyTI will observe phenomena such as the Earth's evapotranspiration, volcanic degassing, and urban heat pollution, and will demonstrate that repetitive global-scale measurements are needed to quantify the critical physicochemical processes of the Earth, leading towards a pathway for future satellite constellations to monitor the Earth on a continuous basis with a fast revisit time (< 7 days). The mission will use a spatially modulated interferometric imaging technique to produce spectro-radiometrically calibrated image cubes, with 25 channels between 8-10.7 µm, at 13 cm-1 resolution, at a ground sample distance of ~60 m. The HyTI performance model indicates narrow band NEΔTs of <0.3 K.

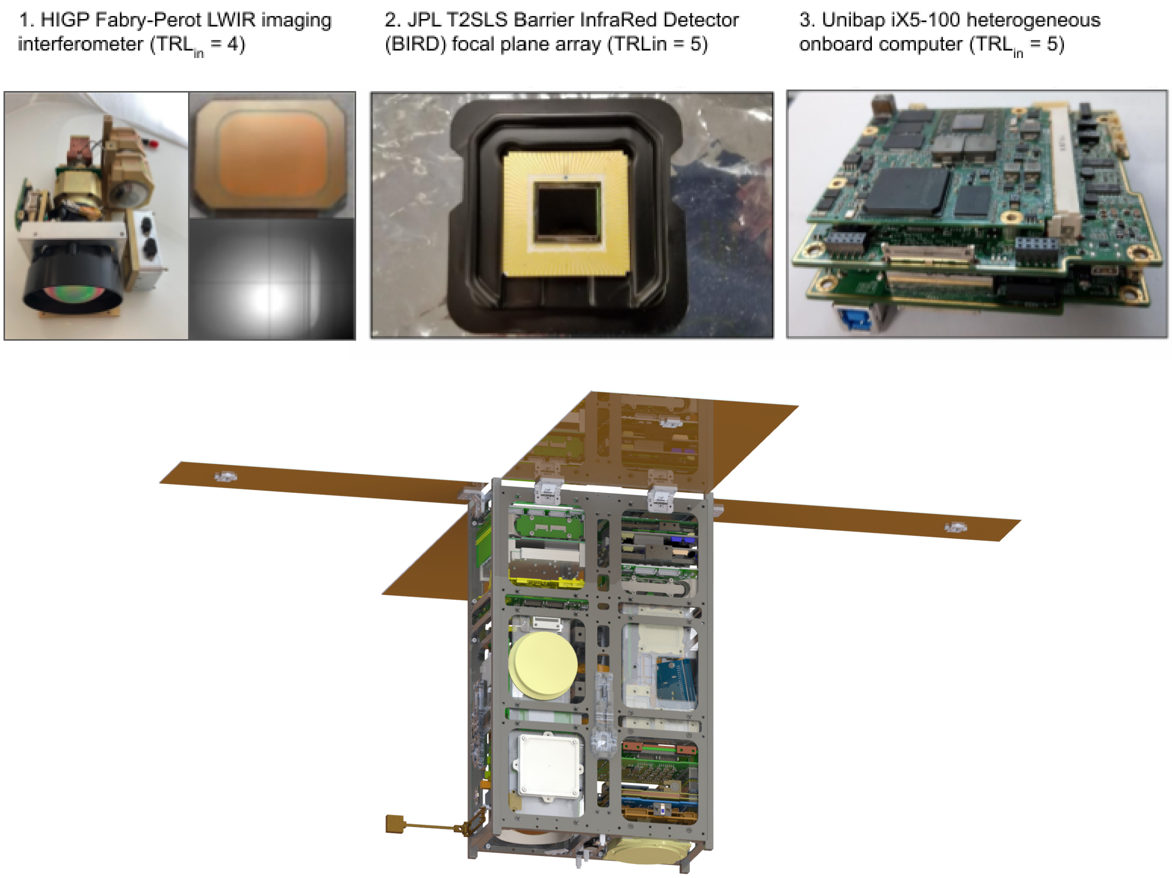

Fig. 1. HyTI will demonstrate three main technologies: 1. A Fabry-Perot LWIR interferometer developed by HIGP; 2. T2SLS Barrier Infrared Detector focal plane array developed by JPL; 3. The Unibap iX5 heterogeneous onboard computer with an advanced FPGA, CPU and GPU combined. Bottom figure shows a rendering of the completed HyTI 6U CubeSat.

HyTI will demonstrate a novel hyperspectral imager with three main technologies. Fig. 1 identifies the three main technologies for HyTI: 1. A no-moving-parts Fabry-Perot LWIR interferometer was developed by HIGP [2,3] and instruments based on this technology were developed using funding from DoD and NASA; 2. A T2SLS Barrier Infrared Detector focal plane array developed by JPL; 3. The Unibap iX5 heterogeneous onboard computer with an advanced FPGA, CPU and GPU combined to enable L0 data collection and processing in near real time and implement machine learning applications for feature detection from L2 data.

The combination of these technologies will enable the availability of data with low latency to allow their use in an operational capacity. Such data is currently unavailable to Earth scientists, with few LWIR sensors in orbit (ASTER is nearing the end of life and planned Landsat mission offering only bi-spectral measurements in the LWIR). This barely scratches the surface of the potential that the LWIR region of the spectrum has for quantifying physical processes and threats. Operational acquisition of high spatial and spectral resolution LWIR data for SSA will allow for mapping the chemistry of foreign objects, such as the composition of gas/thruster plumes. Small satellite constellations, especially CubeSats, and alternative mission architectures must be explored to provide, or complement, these critical data.

The amount of data generated by the HyTI sensor is in the order of several GB per target collection and with limited data download capabilities this can easily overwhelm the communication link to the earth. One other factor to consider is the data may contain no useful spectral signal (i.e., data acquired over cloudy areas or no target of interest). Therefore, to increase the operational return for the LWIR instrument we leverage the Unibap onboard heterogeneous computer using the central processing units (CPU) and the graphical processing unit (GPU) to reduce the L0 data to L1 products, significantly reducing the amount of data to be downlinked by a factor of 10 or more. The L1 data is then processed utilizing machine learning algorithms to produce L2 data products, reducing the data volume even further. The iX5 onboard computer architecture allows for the implementation of advanced machine learning algorithms such as the computation of target object detection, cloud detection, plume detection among other feature identification. Features of the data can be identified for future processing or storage, and non-useful features can be identified for removal to further optimize data management. The HyTI mission will demonstrate how recent innovations in LWIR imaging technologies can be combined to provide high spatial and spectral resolution LWIR image data from a small 6U CubeSat platform.

2. HYTI PAYLOAD

The HyTI imager was originally developed using funding from DARPA and NASA as a novel hyperspectral imager. The imager has evolved to become part of a very small package that can fit into a 2U volume making it a payload capable of fitting in a 6U CubeSat. The LWIR radiated energy/light from the target scene is focused by a refractive lens and passed through a Fabry-Perot interferometer mounted directly above the focal plane array (FPA) and the readout integrated circuit (ROIC) within the Integrated Dewar Cooler Assembly (IDCA), as shown in Fig. 2. The ROIC will acquire the frames at ~130 Hz for a full composition of the data cube. The next figure illustrates the target image data collection process. The Fabry-Perot interferometer is made of two anti-reflective coated pieces of germanium connected on one side of the wedge and with a slope gap that splits the photons into different path lengths as light comes in the Dewar. The light rays are then reflected and transmitted through the interferometer gap to produce interference that is sampled at the focal plane array.

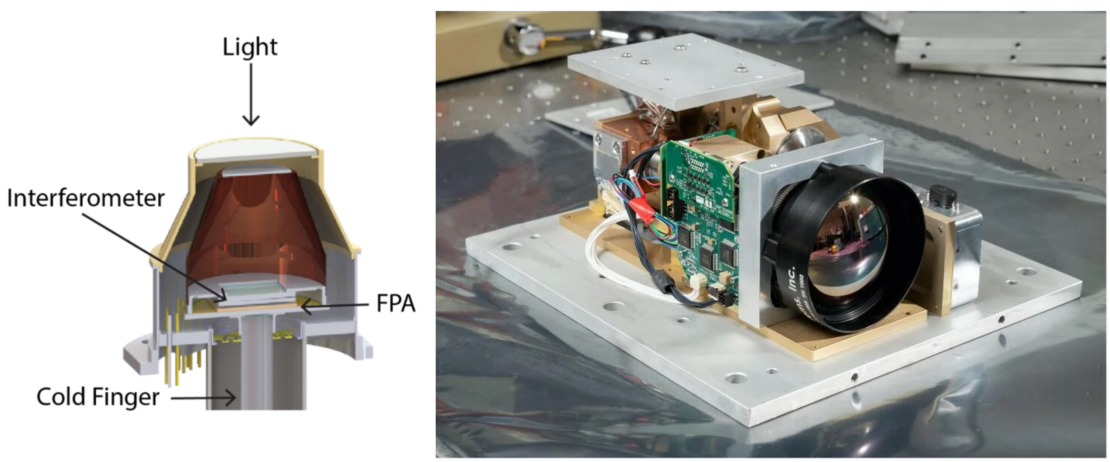

Fig. 2. Left side: Light path of the HyTI interferometer and FPA within the Dewar. Right side: integrated HyTI payload with Lens, IDCA, camera electronics.

The “forward motion” of the platform allows interferograms of targets to be reconstructed, as each target is imaged at a succession of optical path differences as the fixed interference pattern is pushed along the ground in the in-track flight direction. This provides a challenge to be addressed for SSA given that the target object will have to be scanned in a particular direction from the detector point of view, requiring some agility from the spacecraft platform.

The slope of the interferometer wedge is designed such that the optical path difference, or fringe period, will vary linearly across the fringe gap. A single frame of data (shown as an example on the top left of Fig. 3) records light from each scene element modulated at one optical path difference per column of the array, starting at the right of the image where the dark vertical stripe is the area where the wedge pieces of Germanium are contacted. There is no modulation in this dark region but the pixel arrays on the left of the interferometer contain a portion of an interferogram for each scene element. By translating the FPA detector towards the left, the scene light is then recorded with a modulation at each optical path difference. The next step in the process is to co-register the image frames by stacking them in a data cube. Standard Fourier Transform techniques are then used to produce a spectro-radiometrically calibrated image cube.

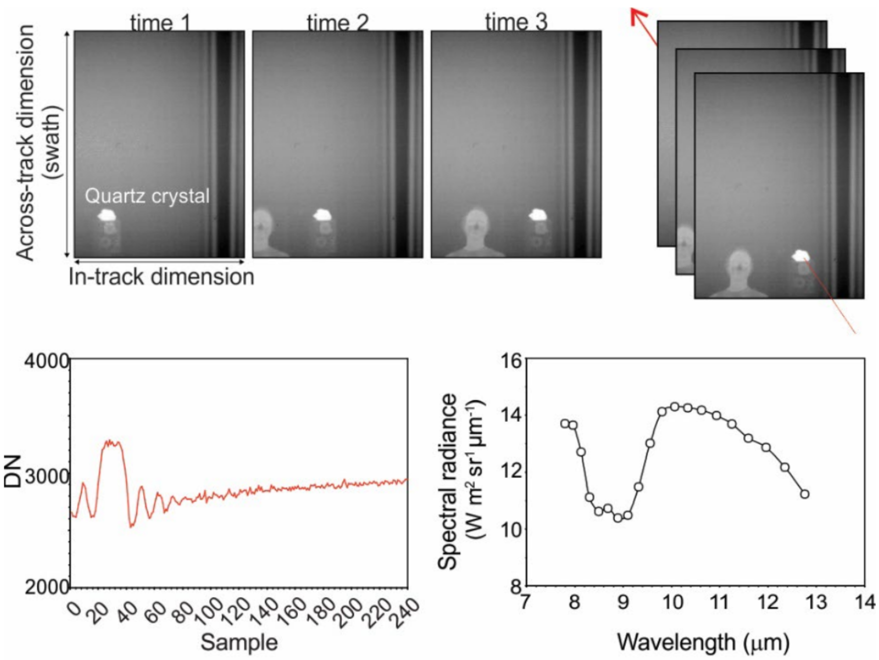

Fig. 3. Top left: the images of a quartz cube are acquired at successive time steps (t1, t2, t3, …), as the interference pattern is scanned across the scene. Co-registration of the frames (top right) allows an interferogram (lower left) to be obtained for each pixel in the image cube, from which a radiance spectrum (lower right) can be retrieved.

The HyTI LWIR sensor produces high spatial and spectral resolution by combining the advantage of the UH interferometer with the sensitivity of JPL's Barrier Infra-Red Detector FPA technology [5]. The JPL BIRD detectors are a new generation of high-performance, low cost and high yield III-V compound semiconductor. These FPAs have excellent uniformity and pixel-to-pixel operability. The antimony (Sb) compound-based BIRD detectors outperform existing TIR detectors including Quantum Well Infrared Photodetectors (QWIPs). In order to achieve acceptable dark current levels, the FPA is maintained at a temperature of 68 K with an AIM SF070 cryocooler, although the HyTI performance model indicates that the FPA can run at temperatures up to ~72 K, allowing for flexibility in the design. The spectral sensitivity is in the range of 8-10.7 µm, and we assume a worst-case quantum efficiency of 10%. For the current HyTI design, the detector size is 640 × 512 elements. The HyTI ROIC cannot read the entire array at the required frame rate (139 Hz), and so we use a window frame of 256 pixel columns to define the field of view (swath), with 512 pixels used to sample the interference pattern generated by the interferometer.

The SSA version of HyTI could rotate along the orbital plane angular momentum vector at a angular rate of 1-2 deg/sec, imaging objects below the satellite (looking in the nadir direction) or above the satellite (looking at the zenith direction). For initial analysis we assume the target object is not moving with respect to HyTI. This will ensure the FPA sensor will collect target data by moving the FPA through all the optical paths of the spectrum as this is required to create an interferogram.

HyTI is able to acquire 25 spectral bands between 8-10.7 µm with a sampling distance of 60 meters per pixel (spectral resolution of 13 cm-1) at a 400 km distance. The instrument's performance model indicates that NEΔTs of <<0.3 K are attainable for source temperatures in the range 0-50 deg C. T2SLS detectors are very stable for long time durations [6], so the first HyTI mission will have no on-board calibration mechanism given the volume constraints of the 6U platform. Calibration can instead come from intermittent deep space looks that calculate radiometric offsets with pre launch look up tables of gain vs FPA temperature and integration time. Validation will use intermittent Lunar scans, and vicarious calibration using Landsat and ASTER images.

3. HyTI MISSION

The HyTI mission is led by the University of Hawaiʻi at Mānoa and will collect LWIR data as an Earth observing mission using a novel hyperspectral imager. The integration of a cryocooler into a 6U CubeSat bus has been a significant technical development in SWaP, volume integration, power consumption, and exported vibration mitigation. Initially thought impossible, the integration of a cryogenically cooled detector in a 6U CubeSat has been demonstrated with the HyTI bus [4]. HyTI is a technology demonstration mission for innovative technologies making Earth science measurements, which is a strategic development for space science [6]. The science focus of HyTI is a derivation of Landsat Surface Temperature (LST), volcanic sulfur dioxide emissions, and precision agriculture metrics. An image of the HYTI satellite is shown in Fig. 4.

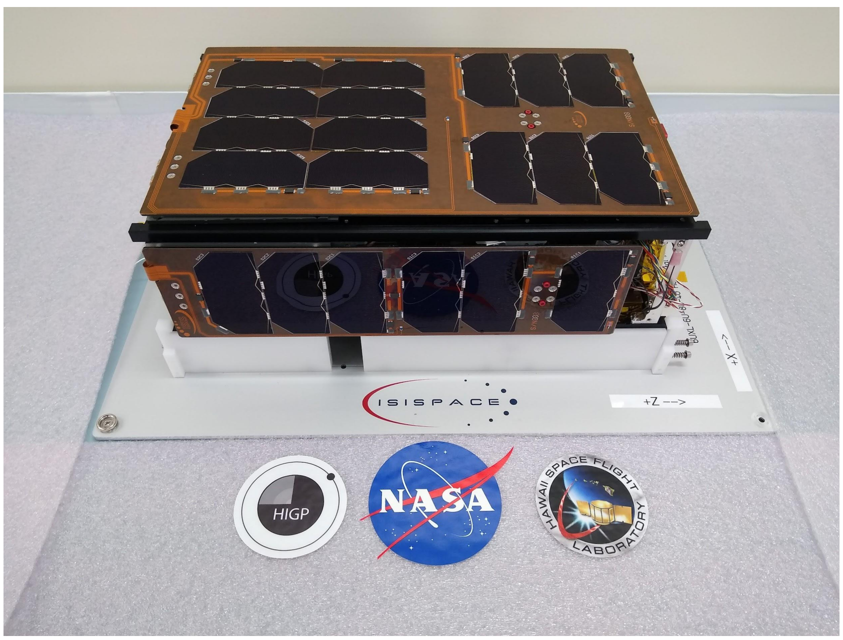

Fig. 4. HyTI spacecraft during solar panel fit check tests

The onboard processing of raw sensor frames (L0) to Level 1 calibrated radiance cubes is achieved with a 10x reduction in data volume. This becomes possible by offloading L0-L1 data processing on the SpaceCloud iX5-100 heterogeneous computing platform, which includes frame-to-frame co-registration, FFT, and spectral calibration. The SpaceCloud iX5-100 analytics computer incorporates edge computing, storage, and cloud software at a weight of approximately 600 grams, dimensions of 100 x 100 x 50 mm3, and up to 20 W of power at full load. The HyTI software can use CPU, GPU, and FPGA resources together with 256 GB of solid-state storage with M.2 SSD drives. The iX5-100 compute resources are provided by AMD 64-bit system-on-chip CPU and GPU and Microsemi FPGA. Initial benchmarking indicates that using the GPU capabilities, the data can be processed from L0 to L1 in real-time (i.e., 1 sec of L0 camera data at 139 Hz can be processed to its L1 equivalent). The L1 to L2 processing is also going to be computed onboard, and this step can leverage advanced machine learning algorithms to identify special features of interest for SSA. As an example, the baseline HyTI mission will derive volcanic sulfur dioxide concentrations using a Partial Least Squares Regression-based technique to allow us to convert L1 (radiance) to L2 (SO2, in ppm.m; LST in K) using ~150 operations per pixel (rather than performing a full radiative transfer inversion).

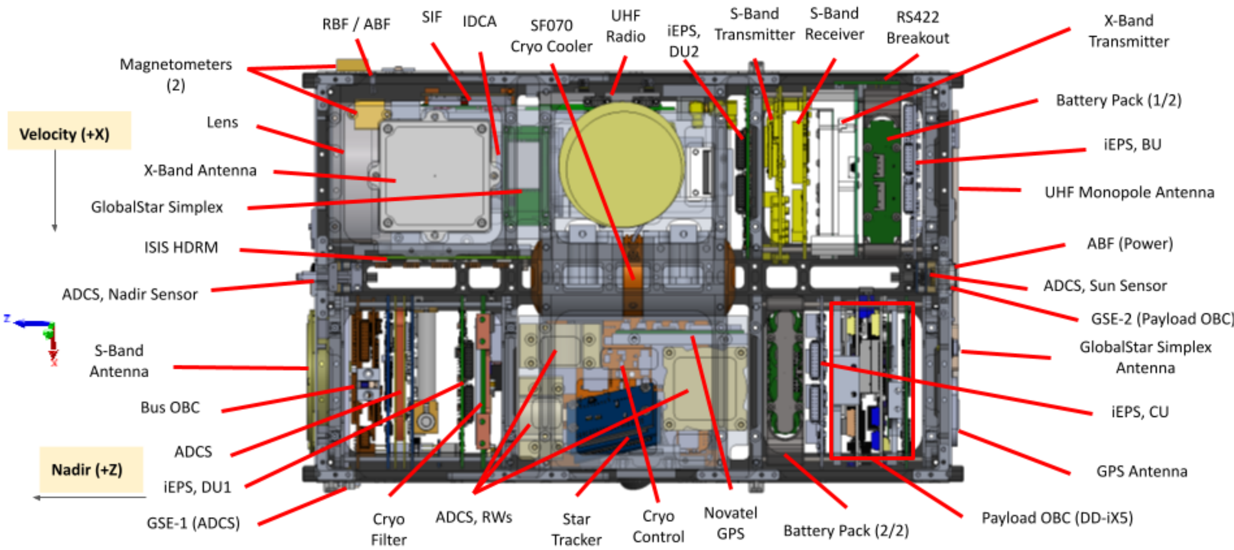

Fig. 5. HyTI subsystems configuration. 'Top' perspective view from the +Y face.

Fig. 5 shows a rendering of the HyTI spacecraft subsystems. The Hawaiʻi Space Flight Laboratory at the University of Hawaiʻi at Mānoa is the lead system integrator of the bus and mission operations. JPL is a Co-Prime on this mission, responsible for integrating the focal plane array (FPA) technology into the HyTI camera payload. West Coast Solutions is the lead on the Cryocooler System Engineering and consulting; AIM provided the SF070 cryocooler, and Creare/West Coast Solutions provided the Cryocooler Control Electronics, including a cryocooler Active Ripple Filter to reduce the large current oscillations on the spacecraft electrical bus. HyTI will use a 6U bus with most subsystems provided by Innovative Solutions in Space (ISISPACE), such as the EPS, the S-band radio (up/downlink), the structure, and solar panels. CubeSpace delivered the ADCS subsystem, and Syrlinks provided the X-band radio.

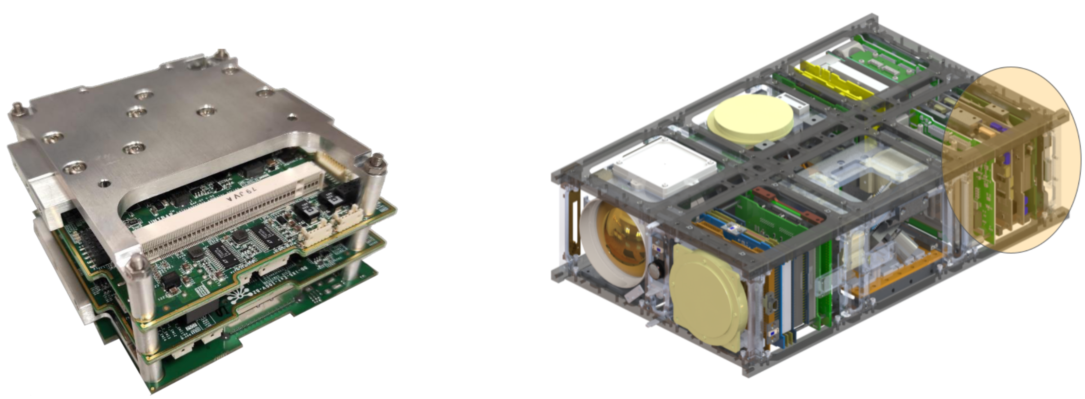

Fig. 6. (Left) SpaceCloud iX5-100 radiation-tolerant cloud computing solution.
(Right) iX5 location in the HyTI 6U volume.

The payload system includes the camera, cryocooler, cryo electronics, and payload computer and uses 3.5U of the 6U available in the CubeSat. American Infrared Solutions integrated the camera that includes the integrated dewar controller assembly (IDCA), the multielement refractive lens (provided by New England Optical Systems / recently acquired by FLIR), and the Fabry-Perot interferometer provided by LightMachinery. Unibap provided the SpaceCloud iX5-100 (DD-iX5) onboard payload computer. Fig. 6 shows a picture of the SpaceCloud iX5-100 cloud computing solution with a sample flight chassis.

4. DATA ACQUISITION AND PROCESSING

The HyTI data acquisition system requires a complex interaction between the payload software processes and the payload hardware, requiring a large amount of data collection and a significant amount of onboard data processing for incoming data at ~45MB/sec. For a typical target data take, it is necessary to:

- Prepare the spacecraft ahead of target acquisition for an appropriate attitude pointing for imaging operations.
- Prepare the instrument by cooling the FPA to ~68 K with the SF070 cryocooler. This needs to happen approximately 10 minutes before imaging operations.
- Maintain the cryocooler at the target temperature during image acquisition, start the camera for image acquisition, monitor the system, and cease operations to protect the detector if an anomaly is detected.
- Measure the temperature of the lens system and set the appropriate motorized focus position.
- Maintain the spacecraft at the appropriate attitude pointing and stability to comply with attitude drift requirements, make position and attitude information available to the data acquisition process.
- Collect L0 of data at a rate of ~45 MB/sec and store data for later processing.
- Embed geolocation and relevant telemetry as part of the L1 data package.
- Software to command the camera, acquiring frames that are then interpolated both spatially and interferometrically. This data can either be written to disk for later processing or sent directly to a data reduction process. This process is also responsible for controlling power to the focus system and the camera and collecting information from the ADCS and the Cryocooler. This is achieved through inter-process communication with their relevant threads.
- A user process reduces the data, first converting from interferogram space to spectral space and then performing intensity calibrations. This process makes extensive use of calculations on both the CPU and GPU cores.
- A user process that queues any desired files for transfer to the ground using the Communications thread.

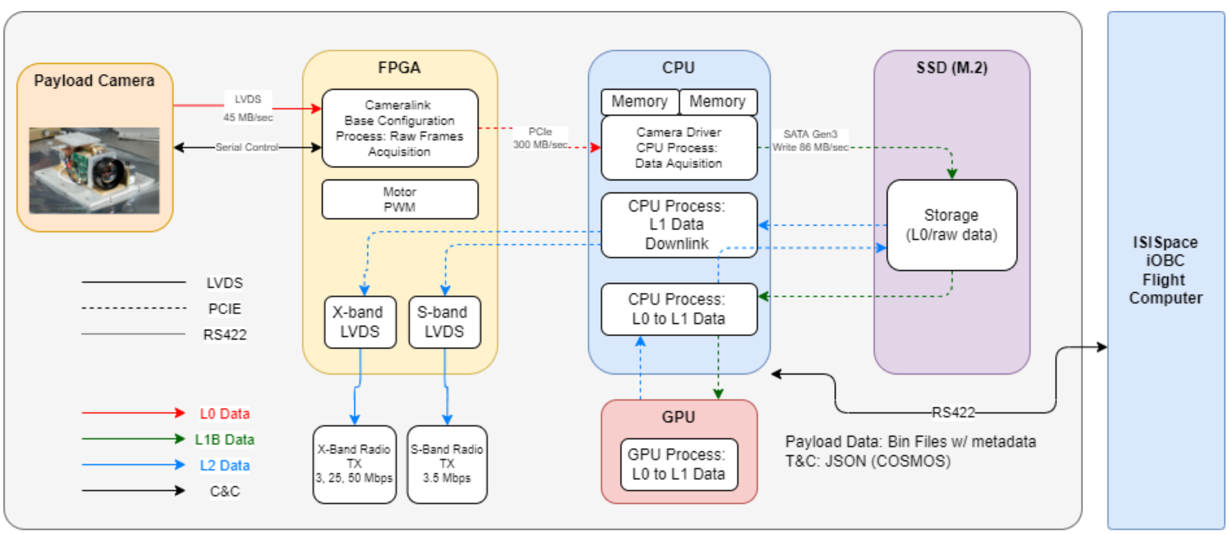

Fig. 7. HyTI Data Processing Flow Diagram on Unibap iX5. The FPGA, CPU, GPU and SSDs are actively used throughout the process

The HyTI data acquisition process makes full use of a combination of system and user-level multi-threaded programs, working in concert. The software processing requires multiple CPU cores and GPU cores for fast data processing for the L0 date. The L0 data is acquired with a coordination of various electrical interfaces from the iX5 computer such as Digital I/O, LVDS, RS422 Serial, I2C, and PCI Express interfaces. This level of interaction and multi-tasking would not be possible without using a fully implemented Linux system with a CPU/GPU architecture. Fig. 7 shows the data flow from the payload camera to the FPGA, to the CPU, SSD storage, and into the radios for data downlink.

The complex, multi-threaded specifications of the iX5 makes it particularly suited to process the hyperspectral image cubes. The FPGA is matched for high-speed interfaces such as the Camera Link. However, access to this link would have been challenging without the straightforward use of existing video libraries in the Unix kernel that allowed this data to be captured like any standard video stream. High-speed control of the S-Band and X-Band radios was also implemented through the Microsemi SmartFusion FPGA, with access being made transparent through Linux kernel devices. The FPGA also controls the PWM controller for the focus motor and the Hall Effect sensor to report the lens position. Access to these functions is available through the Linux kernel on the iX5.

The HSFL Comprehensive Open-architecture Solution for Mission Operations Systems (COSMOS) is a NASA funded middleware software [7] that integrates the low-level hardware drivers with the higher-level multithreaded payload and mission processes. COSMOS was also designed to operate flight payloads and orchestrate multiple satellites, such as swarms or constellations [8]. The hardware libraries for serial, I2C, and digital devices provided by COSMOS enables the embedded control of these various hardware subsystems. COSMOS agents [9] are the higher-level inter-process communications processes that enable the sharing of telemetry and commands between the different mission level programs [12-14]. The COSMOS processes manage the L0 to L1 data processing in the CPU and GPU. The onboard processing flow to process the data cubes is summarized in the steps defined in Table 1. Using a combination of CPU and GPU, the full processing stack has been implemented for a simulated 7-minute data set. The data processing is implemented in the iX5 heterogeneous compute architecture and we have been able to process the data reliably with a 1:1 data processing ratio (1 sec of data takes 1 sec to process).

Table 1. Data processing steps on HYTI
(CPU computation represented in brown cells, GPU computation is represented in blue)

Data Processing Steps	**Algorithm Steps**
1. L0 data acquisition and pre-processing (CPU)	• L0 data from IDCA to CameraLink to RAM • Dark subtraction • Replace bad pixels • 2 Bytes × 320 columns × 512 rows × 139 frames/s • Resulting data volume is ~93 GiB/day
2. Co-register L0 frames, recover interference record, store result (CPU)	• RAM to disk • Reorder data into interferometrically stacked HyTI Image Tiles (HITs) of coregistered data, resampled to 60 m postings • 2 bytes × 320 columns × 667 rows × 512 planes per HIT • Resulting data volume is ~86 GiB/day

3. Generate interferogram and transform (GPU)	• Disk to RAM
	• Generate interferogram for each pixel
	    ○ Cubic spline interpolation
	    ○ Zero mean subtraction
	    ○ Triangular apodization
	    ○ Discrete cosine transform
	• 2 bytes × 320 columns × 667 rows × 25 spectral channels per HIT

4. Radiometric calibration (GPU)	• RAM to disk • Multiply and add each spectrum by column specific transfer function • 2 bytes × 320 columns × 667 rows × 25 spectral channels per HIT
5. L1 storage (CPU)	• Store HITs for subsequent downlink • ~4.2GiB per day

6. Downlink (CPU)	• Downlink accumulated tiles • ~1.7 GiB per day (2.5:1 lossless compression)

5. iX5 SpaceCloud and Containerization

The SpaceCloud framework is riding on top of a tailored Ubuntu Linux distribution. Hence, most x86-64 "PC" compatible software may be used. Fig. 8 illustrates the SpaceCloud software stack with standard Linux compatible libraries and specific ones. An example of a particular software package is L3Harris Geospatial's ENVI®/IDL® geospatial software suite. This is not always available, but it was included for demonstration on the D-Orbit Wild Ride SCV-003 mission [10]. The HyTI data processing described in section 4 is bundled in a containerized package with the SpaceCloud framework. The process involves the exchange of raw frames from the Camera link driver converting L0 data and the production of compressed data files, the resulting output of the containerized process with L1 data. Other containers can then utilize the L1 data and process it into L2 data according to the mission needs. Once the L2 data files are exported to disk, any other process can transfer the files to the radios or another flight computer, depending on the mission needs.

The processing steps in Table 2 can be reconstructed into SpaceCloud applications for simple reusability. This is also the case of the COSMOS framework which can run a separate SpaceCloud container. If this software packaging change is performed, the same software containers can be run on other SpaceCloud framework compatible satellites, such as D-Orbit ION SCV-003 launched in June 2021 and ION SCV-004 launched in January 2022.

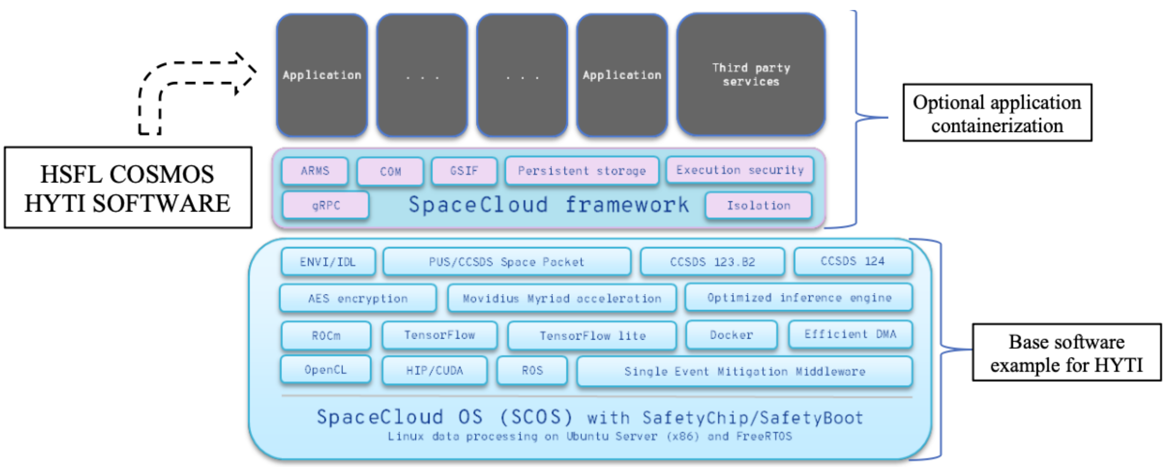

Fig. 8. Illustration of an expanded HYTI software stack with SpaceCloud science application containerization.

6. HyTI SENSOR FOR SSA

The HyTI LWIR sensor can be used as complementary assets for SSA by combining information from existing optical SSA telescopes on the ground and in orbit. Multi-band photometry using distinct channels in the visible and IR part of the spectrum can be used to distinguish similar objects and perform non-resolved object characterization (NROC). The HyTI detector focuses on the acquisition of 25 bands in the long wave infrared part of the spectrum and can be combined with other sensors to provide a wideband hyperspectral system [11] enabling a more complete signature from different targets and possibly identify systems that appear small on the detector (less than one pixel). Fig. 9 shows an example of a potential target RSO identified by a space surveillance satellite. This RSO identification can be complemented with the HyTI instrument tracking the same object. Spectral information can be objetained for the single pixel show in the image for as long as the duration of the tracking is, providing insight into the operation of the satellite over time.

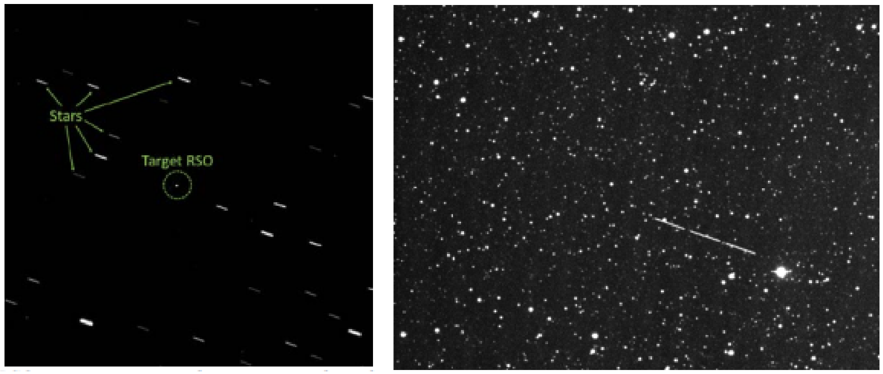

Figure 9. Example of a target resident space object being tracked by Sapphire, a Canadian space surveillance satellite. Image credit by Saphhire.

A limited number of infrared sensors have been built for SSA applications. HyTI would add to this capability in the 8 to 10 micron spectrum enabling night operations and thermal characterization for space based targets. Sensors in the LWIR have the best ability to distinguish unique chemical and material spectral properties of targets: the identification of thermal properties of targets and identification of gaseous plumes indicating thrusting capabilities given that emitted thermal signatures are a function of the target's temperature and material properties. HyTI is a passive optical system capturing the reflected sunlight and thermal emissions from targets and enables the characterization of surface material, thermal properties, propellants, and gaseous emissions both when targets are in the sunlit part of the orbit or in shadow.

A HyTI-SSA type satellite would have to follow a specific motion to acquire the spectral information of the target. The surveying mode will rotate the spacecraft around the Y axis at 1-2 deg/sec for automatic identification of unknown targets. Once the target is identified via onboard machine learning algorithm HyTI would change to target tracking mode to characterize the target. This mode will follow a particular object in space for a specified duration of time requiring the spacecraft to move the sensor FOV in a continuous motion for proper spectral characterization of the target.

The other relevant technology for SSA is the payload computer. The HyTI iX5 payload onboard processing provides the reduction in latency that is critical to SSA applications. The iX5 receives data directly from the LWIR FPA sensor and processes the data in near real-time on board of the CubeSat. This technology enables near real-time SSA target identification and characterization and therefore it can enable quick response to potential threats. The iX5 heterogeneous computer can deploy state of the art classification algorithms based on machine learning technologies because of the high throughput multicore CPU and GPU, this includes neural networks trained over time for space object classification. A traditional operation for SSA capabilities includes scheduling and planning the target observation many days or hours in advance, then downlinking the collected data from the server to the ground for post processing and finally target identification and characterization. The iX5 computer architecture enables the on board target identification significantly reducing the latency of target identification. This process can be automated and improved with machine learning algorithms processing L1 data produced by the LWIR sensor. The SpaceCloud iX5 architecture is designed to containerize and deploy machine learning algorithms leveraging the CPU and the GPU in a less than 30 W of power.

The following table (Table 2) identifies some of the basic mission parameters for a future HyTI-SSA type mission in comparison with the original HyTI mission.

Table 2 - HyTI mission parameters for a SSA type mission

Parameters	**HyTI**	**HyTI-SSA**
Orbit	400 km, circular	500 km, SSO
Detector size	640 x 512 pixels,	1024 x 1280, FLIR 1308
Payload computer	Unibap iX5	Unibap iX10
Sensor duty cycle	< 10%	> 90%

L0 data / day	~100 GB	~5 TB
L1 data / day	~ 5GB	~ 250 GB
L2 data / day (target identified)	< 100 MB	< 100 MB

7. CONCLUSION

The HyTI (Hyperspectral Thermal Imager) mission will demonstrate how high spectral and spatial long-wave infrared image data can be acquired and processed in-orbit on a 6U CubeSat platform. Using the onboard heterogeneous SpaceCloud computing hardware with the Unibap iX5 architecture, the mission will use a spatially modulated interferometric imaging technique to produce Spectro radiometrically calibrated image cubes, with 25 channels between 8-10.7 µm, at a ground sample distance of ~60 m for a 400 km distance. The HyTI performance model indicates narrow band NEΔTs of <0.3 K. Processing the large amount of data produced daily (in the order of ~100 GB) is only made possible with the iX5 heterogeneous solution with the combination of FPGA, CPU, GPU, and optional Neural Network Accelerators/Vision Processing Units and SSD storage.

Space-based situational awareness is a growing field for space security and monitoring of space assets and liabilities. We propose a Hyperspectral Thermal Imager mission for SSA using real-time on-board processing of targets of interest. Emerging machine learning algorithms combined with powerful computer architectures in space will enable new SSA applications not previously possible, such as on-orbit detection of critically small objects, tracking and motion prediction of fast-moving objects, on-board intelligent automated missions operations for strategic pointing, and the incorporation of visual odometry for more accurate state estimation. Multiagent systems and satellite swarms are expected to enhance future SSA applications and high throughput computing architectures such as the Unibap iX5 computer in combination with powerful sensors such as HyTI will enable powerful SSA applications.

8. ACKNOWLEDGEMENTS

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