I-SPI: INTELLIGENT SENSING AND PERCEPTION IN INFRARED.

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Introduction: With increasing interest in returning to the Moon for scientific exploration and human settlement, it is critical that we answer key science questions about the nature of lunar volatiles and water ice in cold traps. To address these priorities, Mission Control is leading a world-class team of scientists and engineers to develop a novel AI-integrated infrared imaging instrument: Intelligent Sensing and Perception in Infrared (I-SPI). I-SPI is the first lunar surface science instrument capable of detecting and mapping both cold traps and water ice, from 5 m or more, without an active lighting source. I-SPI includes two key components, an infrared imaging system called Thermal Infrared Emission Spectroscopy Cameras (TIES-Cam) and an Advanced Data Processor (ADP). These are described herein and illustrated in Figure 1. I-SPI is a versatile instrument which can be added to landers or rovers and offers benefits in rover navigation in poor lighting conditions, in addition to addressing several science themes.

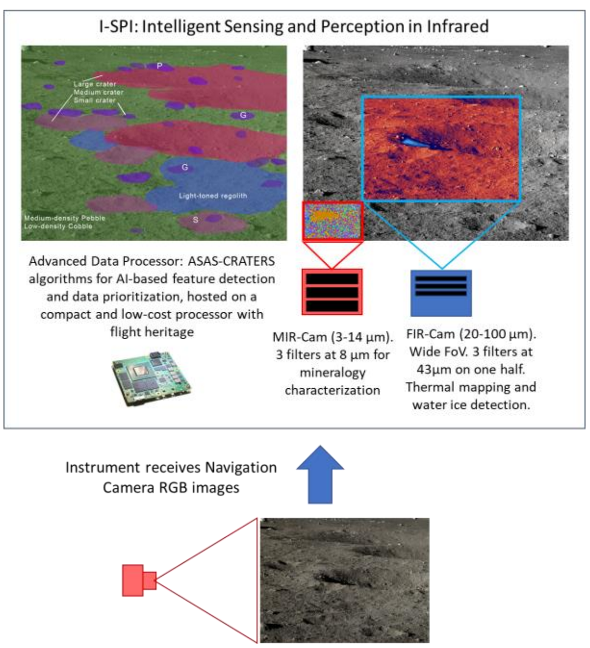

Figure 1:Depiction of I-SPI subsystems, including the TIES-Cam infrared cameras and the Advanced Data Processor for AI-based decision making.

Scientific Rationale: An unprecedented number of missions will soon land on the lunar surface to address a wide range of science and exploration goals. Surface volatiles may be irreversibly altered by the many surface missions this decade [1]; therefore, it is vital that early missions focus on surface volatiles, including fundamental scientific research to characterize the relationship between thermal regimes and volatiles, and to thereby gain a surface-scale understanding of water implantation and trapping on the Moon. A detailed characterization of the lunar surface, particularly polar regions, and specifically detailing of the relationships between craters of varying shapes and sizes, Permanently Shadowed Regions (PSRs), cold traps, and the presence of volatiles is important to answering many science questions, for commercially driven resource prospecting, and for vehicle navigation.

Instrument Overview:

Thermal Infrared Imaging System. TIES-Cam measures thermal infrared emission in the 2.9-100 µm range for mapping surface temperature, identifying water ice volatiles, and characterizing surface mineralogy. Thermal and volatile measurements will answer key questions about cold traps in permanently shadowed regions within craters at the poles, including in micro cold traps [2]. Measurements of surface temperature and thermal inertia will inform thermophysical surface properties and correlations between crater thermophysical properties and the presence of water ice. TIES-Cam will also characterize surface mineralogy to place findings into context, and to provide ground-truth for orbital datasets.

Designing optics to meet measurement needs across the 2.9-100 µm range in one camera is challenging. Thus, TIES-Cam consists of two different cameras that use the same sensor but with different optics. The first is sensitive to far infrared radiance in the 20-100 µm range, labelled Far Infrared Camera (FIR-Cam), which corresponds to 30-140K thermal emission peaks (higher surface temperatures will still be measurable when using a 20-100 µm band). The second, labeled Mid Infrared Camera (MIR-Cam), is sensitive to the mid-wave and long-wave infrared radiance in the 3-14 µm range and can be used to characterize the Christiansen feature at 8µm. Each will have 3-4 butcher-block spectral filters placed directly in front of the FPA (Focal Plane Array), whose transmission wavelength bands are designed for water ice detection and mineralogy characterization.

Advanced Data Processor. I-SPI represents a new wave of AI-integrated smart sensors and instruments that will unlock greater science return in future space exploration missions using Mission Control's core technologies. The ADP features the ASAS-CRATERS (Autonomous Soil Assessment System for Contextualizing Rocks Anomalies and Terrains in Exploratory Robotic Science) suite of science autonomy applications [3]. Its functionality is twofold: 1) to intelligently classify geological features from the rover's NavCam images, and 2) to use the classified features to intelligently make science-driven decisions on targeting and data downlink based on a pre-defined scheme. This ensures that the most scientifically relevant data is captured and downlinked to maximize the scientific return of TIES-Cam – which is of particular importance during tightly constrained micro-rover missions. Once downlinked, the international, distributed I-SPI science team will leverage core Mission Control Software to conduct their operations.

Scientific Investigation: The goals that I-SPI will address fall into five Science Themes:

Science Theme	Science Goals
Temperature	SG-1: Map thermal properties and gradients of the lunar surface at small scales
	SG-2: Characterize temporal variation of thermal properties at the lunar surface
Volatile Detection	SG-3: Characterize volatile cold-trap potential at small scales
Mineralogy	SG-4: Characterize composition of the lunar surface
Trafficability and Navigation	SG-5: Understand rover trafficability at the lunar surface
	SG-6: Understand the potential for surface navigation using thermal infrared imaging
Science Operations	SG-7: Understand the value of the ADP in streamlining science operations

Novel Features: I-SPI builds on Canadian expertise in thermal infrared spectroscopy and artificial intelligence and is a technological innovation for lunar science and prospecting. It will be the first lunar surface science instrument capable of detecting both cold traps and water ice from a stand-off distance of 5m or more, without an active lighting source. Integrated with novel capabilities in AI-based perception and decision-making, including the first demonstration of deep learning on a planetary rover, I-SPI represents a paradigm shift in science instrument development. Additionally, I-SPI will be the first to investigate the feasibility of rover navigation using low-power thermal infrared imaging alone; a beneficial strategy for navigation under poor lighting conditions.

Autonomous Operations Modes on Rovers: I-SPI will be used in two mobility-based operations modes (Fig. 2) that leverage the ADP's intelligent feature detection capabilities in making decisions autonomously to downlink science data or target the cameras for imaging, with a goal of maximizing science return under tight operations constraints. The first, Prospecting Mode, is characterized by continuous imaging when there is sufficient power and onboard storage to do so. In the second, Autonomous Targeting Mode, TIES-Cam is only triggered when key features are identified by the ADP, useful in scenarios where power/storage constraints are greater. Like the AEGIS system pioneered for Mars rovers [4], we intend to use strategies such as key target signatures, novelty detection, and representative sampling.

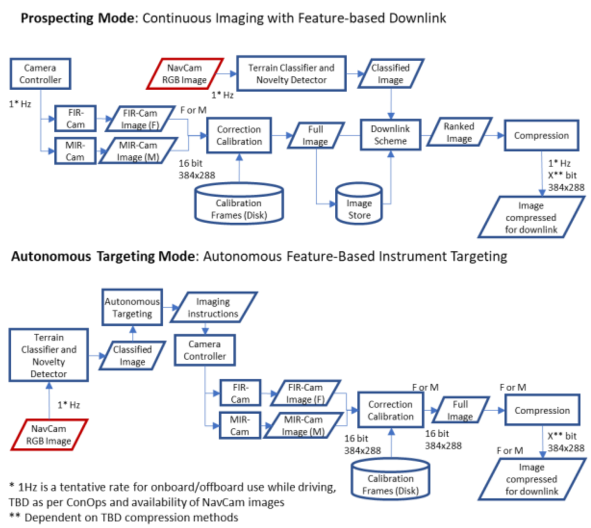

Figure 2: Mobility-based operations modes enabled by the ADP to prioritize TIES-Cam data for downlink.

I-SPI Team: The I-SPI Team is led by Canadian space exploration and robotics company Mission Control, and includes Institut National d'Optique (INO), Canada's largest center of expertise in optics and photonics. I-SPI development is guided by science team members from the University of Winnipeg, York University, Concordia University, Texas A&M University, and Natural History Museum of London.

Next Steps: I-SPI is under Phase 0 development and is targeted for deployment on multiple micro-rover missions, including the Canadian micro-rover mission slated to fly to the Lunar south pole in 2024. An early version of the autonomy-enabling ADP subsystem, currently at TRL 5, will be demonstrated on a commercial lunar mission in 2022.

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References: [1] Prem, P. et al. (2020) *Decadal Survey* [2] Hayne, P.O. et al. (2020) *Nat Astron* [3] Raimalwala, K. et al. (2020) LSSW, LPICo 2241. [4] Castano R. et al. (2007) *JFR* 24.