DEVELOPMENT OF AN INTEGRATED VISION SYSTEM FOR THE PRECURSOR TO HUMAN AND SCIENTIFIC ROVER (PHASR) AS A POTENTIAL CANADIAN CONTRIBUTION TO THE PROPOSED HERACLES MISSION. M. Bourassa[1,2,3], G. R. Osinski[1,2], M. Cross[2,3], P. Hill[1,2], D. King[1,2], Z. Morse[1,2], E. Pilles[1,2], G. Tolometti[1,2], L. L. Tornabene[1,2], and M. Zanetti[1,2]. University of Western Ontario, London, Ontario, Canada ([1]Department of Earth Sciences, [2]Centre for Planetary Science and Exploration (CPSX), [3]Department of Electrical and Computer Engineering). Email: mbouras@uwo.ca, gosinski@uwo.ca.

Introduction: There is an increased interest in the exploration of the Moon by the world's space agencies, preparing for the return of humans to the lunar surface. This new exploration is anticipated to be enabled by the deployment of the Lunar Gateway, a small space station that would orbit near the Moon. The Gateway will enable opportunities to test technologies needed for future lunar exploration. One proposed initiative to test these technologies is Human Enabled Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES), an international mission being developed by the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA) and the Canadian Space Agency (CSA). A component of HERACLES is the Precursor to Human and Scientific Rover (PHASR). PHASR would demonstrate technology necessary for future human lunar missions and perform robotic lunar sample return via the Lunar Gateway. The rover would tentatively land in Schrödinger Basin and collect samples over a 70-day period.

To prepare for future international science discussions for HERACLES and PHASR, CSA awarded a contract to perform a Science Maturation Study (SMS) to our team at the University of Western Ontario (PI: Osinski; see [1]). This study involved maturing science requirements for PHASR to support the development of the Canadian rover design and payload accommodation, and developing an overall rover science investigation (science goals/objectives, instrument payload, and traverse plan) as input to the international HERACLES effort [1]. The study also involved recommending an instrument that could be developed and operated by a Canadian team that CSA could contribute to PHASR. Our team has proposed an Integrated Vision System (IVS) which combines a science colour camera, a LiDAR, and a spectral imager. The IVS has been listed in the 2017 Topical Teams Reports on Planetary Exploration as a key tool for the characterization of planetary surfaces and aid in understanding of geologic surface processes [2].

Concept: The IVS will integrate three types of vision systems into a unified instrument which would enable rapid fusion of the necessary data products to support the science team to make near real-time decisions for a sample return mission. It also facilitates data synthesis which allows for rapid science (progression from observations to results). The IVS would be mounted on the mast of the rover on a pan/tilt unit to enable collection of measurements in 360° in azimuth and ±80º in elevation. The science camera is high definition colour camera with a built-in spectral filter wheel. This would enable capturing detailed images of the lunar surface as well as providing spectral data in the UV-VIS-NIR range to enable mineralogical interpretation. The science camera is modelled after the capabilities of instruments such as Mastcam (Mars Science Laboratory [3]) and PanCam (ExoMars [4]). The LiDAR system will capture the topography of the surrounding lunar surface in order to create a digital terrain model (DTM). This can be used to assess the morphology of the basin and create texture maps. The imaging spectrometer is proposed to be a multispectral imager in the 800 nm to 2500 nm (NIR) range. This would enable the identification of abundant lunar minerals such as olivine, various pyroxenes, plagioclase, etc. Once the data from each component has been collected and processed, the high-definition colour and calculated spectral parameter images can be draped over the 3D DTM facilitate a geologic map. Altogether, the IVS components will be used to identify potential sampling targets that may require further measurements from other instruments and provide geologic context for the samples.

In addition to performing critical observational tasks as part of the science surrounding the sample return mission, the IVS may also be used as an engineering instrument supporting rover navigation. With its LiDAR and high definition camera, the IVS can be integrated into localization and control functions to drive the rover as well as to guide the robotic arm of the rover for contact measurements and sample collection precision. Furthermore, as the LiDAR provides an artificial illumination source, its implementation as a navigation tool would allow the rover to safely traverse into shadowed regions on the lunar surface and collect samples. This would also extend the science capabilities in shadowed regions. Intensity measurements collected by the LiDAR in shadowed regions could be compared to the equivalent wavelength intensities with the data collected by the spectral imager in shadow-adjacent illuminated areas.

Our development of the science investigation for PHASR involved choosing additional instruments that could help to achieve the proposed mission science objectives [1]. In addition to IVS, these instruments are: a mast-mounted combined Raman/LIBS/Zoom

Camera (c.f., Supercam [5]), a body-mounted radiation detector and thermopile, and an arm-mounted microscopic imager and in-situ geochemistry spectrometer. The concept of the IVS was conceived specifically for its potential synergy with the Raman/LIBS/Zoom Camera. These two stand-off instruments would operate in tandem to enable effectual target down-selection in order to select the best lunar samples to return to Earth.

The anticipated operational procedure of the IVS is as follows: when the rover arrives at a new site of interest, it begins a site survey of all three subsystems. First, panoramic colour and spectral images from the science camera are collected. Next the spectral data from the imaging spectrometer is collected while the science team in mission control discuss the panoramic data to begin selecting targets for further analysis. Finally, the LiDAR gets collected to map out the locations of the targets while the science team refines their target selection choices with the acquired spectral data. Once the LiDAR scan is finished and the data is fused together, the science team can direct the rover to collect target data from the LIBS/Raman/Zoom Camera. The combination of these measurements is then used to select targets for contact analysis and eventually sampling.

Science Objectives: The mission goals for PHASR in our study were classified into four broad themes: lunar chronology, impact cratering, volcanics, and preparing for human lunar exploration. The science objectives for the IVS were thus selected such that they complemented the mission goals/objectives. Objective 1 is to support selection of return samples by providing the context needed decision-making in mission control. Objective 2 is to characterize the mineralogic diversity of the traverse area. Objective 3 is to ground-truth orbital datasets (e.g. Clementine, SELENE, or Chandrayaan-1). Objective 4 is to create an outcrop-scale geological map including the creation of a terrain map to aid with potential follow-up human landings to the site. Additional operational rationale for the implementation of the IVS instrument, aside from the conducting navigation and science in parallel, is its potential for implementation of an autonomous scene classifier such as AEGIS [6]. The development of an algorithm to segment, classify, and collection further data using the two stand-off systems adds significant capability to the IVS.

Descoped and Augmented Versions: The concept of IVS described herein represents a “baseline” version of the instrument. As part of the CSA PHASR study, a science plan for the future development of the instrument was required. This plan included providing “descoped” and “augmented” versions of the IVS to examine the sensitivity of the system to key changes. Options for descope include: elimination of the filter wheels on the science camera (i.e., using only three channels instead of multispectral), reducing the spectral range of the imaging spectrometer, and shortening the range of the LiDAR system. Augmented versions of the IVS included: expanding the spectral range of the imaging spectrometer, adding an additional imaging spectrometer in the thermal-IR range (to enable the characterization of the Christiansen feature, similar to Diviner on the Lunar Reconnaissance Orbiter) [7], and adding an additional science camera (for stereo-vision and to supplement the LiDAR system).

Future Work: Completing the PHASR science maturation study for CSA involved the creation of a science development plan. This plan detailed the critical activities required for the IVS science team to be ready for deployment in the mid- to late-2020s as part of PHASR. Some near term-goals (Phase 0/A) include finalizing the selection of the spectral bands for both the science camera and the spectral imager using a similar methodology to Cousins et al. [8], development of an IVS breadboard system, and performing subsequent laboratory and field testing. Longer-term goals (Phase B/C/D) involve performing science testing and validation, and the development of the data management and processing systems.

Conclusions: The inclusion of the IVS instrument onboard PHASR (or a similar rover) would present Canada the opportunity to contribute a flagship instrument to a lunar mission that would be integral to its operation and success. The development of the IVS and its corresponding science team over the next decade would involve collaboration between scientists and engineers from across the country. Its operation on the Moon would generate remarkable images and models that could be a source of pride for all Canadians and the science measurements collected by the IVS would provide unparalleled data of the Moon and the returned samples.

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