SAMCAM FOR THE ESA PROSPECT LUNAR VOLATILES PROSPECTING PACKAGE; AND A NEW FAMILY OF MINIATURE 3D MULTISPECTRAL CAMERAS FOR SPACE EXPLORATION

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Introduction: SamCam (Sample Camera) is an innovative camera being developed for planetary exploration. It employs light-field (plenoptic) imaging technology: in addition to capturing the intensity of light, the incoming direction of the photons are also recorded. This enables the computation of the distance from the camera of features within images. Hence the camera produces a metrically calibrated and accurate 3D image from each exposure of a single sensor. Advantages include: 3D from a single camera with 'point cloud' data products; smaller, lighter and more rigid than a typical stereo-pair and less prone to occlusions and specular reflections; faster optics promoting less motion blur and increased sensitivity; and increased depth-of-field removing the need for mechanical focusing stages. SamCam is being developed for the European Space Agency's (ESA) ProSPA [1] instrument for volatiles prospecting on the Luna-27 mission.

ProSPA is part of ESA's PROSPECT [2] package to support international lunar surface exploration missions such as Luna-27. PROSPECT comprises a drilling element – ProSEED – and a Sample Processing and Analysis element – the ProSPA analytical 'lab'.

ProSEED drills to a depth up to ~1 m and then deploys two tools at the drill tip to collect regolith samples. One tool samples for Russian instruments on the lander; the second is a corer which acquires ~60 mm^3 of regolith for delivery to ProSPA. Following sampling, the drill is withdrawn from the surface and translated to the ProSPA Solids Inlet System (SIS) shown in Figure 1. The drill and corer are aligned with a Sample Delivery Station and a piston discharges the sample directly into one of 25 Sample Ovens on a Carousel, which then rotates to place the sample under SamCam.

SamCam Objectives: SamCam has several objectives. Firstly, it should obtain positive confirmation of the successful delivery of sample into the oven. Secondly, the sample images provide geologic context for the subsequent thermochemical analysis by evolved gas analysis and mass spectrometry. Thirdly, SamCam should obtain images that enable estimation of the amount of sample within the oven. A core objective of PROSPECT is to quantify the concentration of volatiles and potential resources within lunar regolith. Hence in addition to calibration of the mass spectrometer it is necessary to know the sample size giving rise to that signal. Errors in sample volume estimation will directly translate into error in volatiles concentration. The target error is to estimate sample volume to better than ±20%. Additionally, if information can be deduced from images about likely sample density, then this enables better estimation of volatiles yields per unit mass of regolith. Finally, SamCam is required to obtain images of the upper sealing surface of the Sample Oven in order to check for presence of particulate contamination arising from the landing event, or from the sample transfer process, which might adversely affect attempts to seal the oven prior to heating it to evolve gases for transfer to ProSPA lab for analysis.

Figure. 1: Solids Inlet System model including SamCam Prototype

SamCam Design: The SamCam Prototype and schematic can be seen in Figure 2. Narrowband LEDs (451, 595, 730, 850, 940 and 970 nm, all TBC) are illuminated in-turn and diffused and focused in a coaxial fashion (not shown) through the primary lens into the target Sample Oven. Reflected light from the Sample Oven and sample is collected by the Primary Lens and refocused onto the CMOS Sensor plane through the Lenslet Array. Raw images read out through the Camera Electronics comprise multiple sub-images of the Sample Oven scene that originate from sub-apertures of the Primary Lens. These sub-images contain localized redundancy of scene information, as the sub-apertures are physically offset throughout the Primary Lens. Computer Vision techniques allow features to be matched and either triangulated to provide depth information, or warp images with projective distortion and superimpose to increase resolution and signal-to-noise, as can be seen in Figure 4. SamCam's multiple sub-images provide multiple pairings for triangulation and in multiple orientations (compared to that of a traditional stereo-pair camera), to reduce the triangulation error and the number of failed matches that may arise from occlusion or specular reflection.

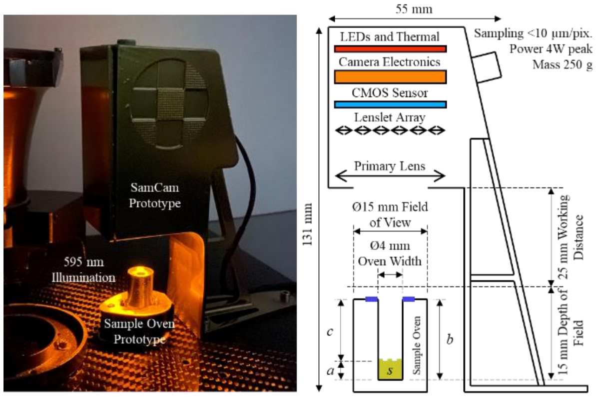

Figure. 2: SamCam and Sample Oven prototypes (Left) schematic and basic geometry (Right). The Sample Oven filled depth (a) is equal to the known 13 mm empty depth of the oven (b) minus the measured depth (c) between a plane fitted to the top of the oven and a plane fitted to the top of the sample (s)

Test Campaign and Results: Figure 3 shows a series of 2D example images with depth markers overlaid as a Sample Oven is filled with JSC-1A. The accuracy of the volume calculation is limited by the non-homogeneity of the filling analog particle shape and size distribution and how the analog is delivered to the Sample Oven. To enable study of this, the ESA Sample Analogue Curation Facility has provided anorthosite samples of the following composition per gram to relate packing density to the 3D-model of the visible sample for different filling depths: 0 to 25 µm (30 to 35%), 25 to 63 µm (15%), 63 to 125 µm (12 to 17%), 125 to 250 µm (12 to 15%) and >250 µm (20 to 25%). We will present the latest results of using SamCam to estimate sample volume and mass.

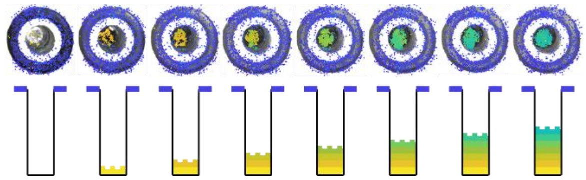

Figure. 3: SamCam depth map filling examples in the Parula colormap. Dark blue markers are at the top of the oven and as the Sample Oven is filled from left to right, the markers on the upper surface of the JSC-1A transition from yellow to green to light blue

Future plans and other applications: SamCam Flight Model will be developed by late 2021. The program has been de-risked through TRL raising activities funded by UK Space Agency [3], including breadboarding and extensive environmental testing.

The multispectral 3D image data cube can be further tailored to specific space applications. A SamCam prototype recorded 3D video of particles moving under microgravity on a sounding rocket [4]. The ability to track and predict the motion of an object in 3D space has wider applications from Guidance, Navigation and Control of vehicles in space to the optimization of robotic motion systems (*e.g.* control of robotic arm/manipulator). Such applications would be enhanced by rapid on-board image processing. We are therefore deploying our algorithms to embedded GPU, enabling rapid and autonomous range-finding and enhancement of resolution and dynamic range. These are being demonstrated for the LUVMI-X Moon rover [5] through the Navigation Camera 'NavCam' and closely related Surface terrain Camera 'SurfCam', (Figure 4) and 3D/360 degree panoramic camera. Miniaturization of the latter allows for imaging down-borehole within an instrumented lunar drill [6].

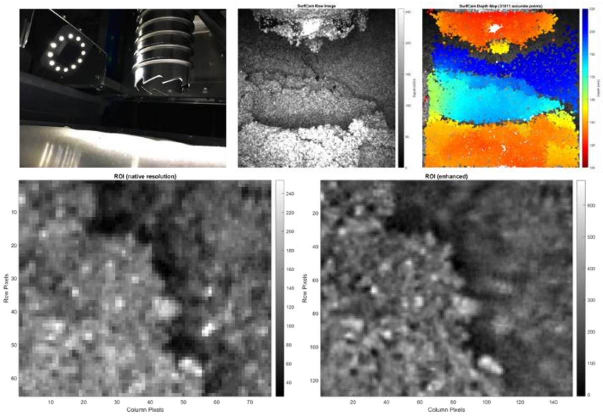

Figure. 4: LUVMI-X Surface Camera and drill test images (Top). Resolution and dynamic range enhancement (Bottom).

Conclusion: SamCam is a compact and versatile 3D multispectral imager. A large depth of field has been achieved in a compact design with no moving parts and sample volume can be estimated to better than ±10%. The optical system can be readily tailored for many space and terrestrial applications requiring high precision quantitative 3D performance within a compact, low mass and rugged camera.

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References: [1] Barber, S. *et al.* (2017) LPSC 2171. [2] Sefton-Nash, E. *et al.* (2018) LPSC 2740. [3] https://www.gov.uk/government/case-studies/light-field-photography. [4] Miles, D. *et al.* (2017) Introduction to the Water Recovery X-ray Rocket. SPIE 10397. [5] Gancet, J. *et. al.* (2019) LUVMI project results 70th IAC. [6] Barber, S. *et. al.* (2020) LPSC.