Lunar PanCam: Adapting ExoMars PanCam for the ESA Lunar Lander

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A scientific camera system would provide valuable geological context from the surface for lunar lander missions. Here, we describe the PanCam instrument from the ESA ExoMars rover and its possible adaptation for the proposed ESA lunar lander. The scientific objectives of the ESA ExoMars rover are designed to answer several key questions in the search for life on Mars. The ExoMars PanCam instrument will set the geological and morphological context for that mission. We describe the PanCam scientific objectives in geology, and atmospheric science, and 3D vision objectives. We also describe the design of PanCam, which includes a stereo pair of Wide Angle Cameras (WACs), each of which has a filter wheel, and a High Resolution Camera for close up investigations. The cameras are housed in an optical bench (OB) and electrical interface is provided via the PanCam Interface Unit (PIU). Additional hardware items include a PanCam Calibration Target (PCT). We also briefly discuss some PanCam testing during field trials. In addition, we examine how such a ‘Lunar PanCam’ could be adapted for use on the Lunar surface on the proposed ESA lunar lander.

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1. Introduction

As discussed elsewhere in this volume, there is renewed international interest in the Moon as a target of scientific investigation (see the reviews by Jaumann et al., in this issue, Crawford et al., this issue). Robotic lunar landers will form a key part in the next phase of lunar exploration, and such landers will require high-performance scientific camera systems. The functions of such camera systems include (a) setting the context for all the other measurements, including morphological and geological context, (b) providing complementary data for use with those of other instruments, and (c) pursuing scientific objectives defined by the camera investigators. The Lunar Lander being studied by the European Space Agency (ESA) is no exception to this, and a multispectral camera is part of the model payload under study (Carpenter et al., this issue). In this paper, we discuss the science objectives for PanCam for ExoMars and how these would be modified for use on the Moon. We also present a summary of the current design of the ExoMars PanCam instrument, which has evolved significantly (e.g. Coates et al., 2011) since the initial design (Griffiths et al., 2006) which was partly based on the Beagle 2 Stereo Camera System (Griffiths et al., 2005) and partly on the proposed Netlander Panoramic Camera (Jaumann et al., 2000); we discuss how ExoMars PanCam could be modified for deployment on the lunar lander.

2. PanCam science objectives for Mars

The overall goals of the ExoMars 2018 rover (Vago et al., 2006; Vago, 2010) are to search for signs of past and present life on Mars, and to characterise the water/geochemical environment as a function of depth in the shallow subsurface. The key new aspect of the mission as a whole is the retrieval and analysis of samples from up to 2 m under the oxidised surface of Mars. The strategy of the mission is:

1. To land at, or to be able to reach, a location possessing high exobiological interest for past or present life signatures, i.e., the Rover must have access to the appropriate geological environment.
2. To collect scientific samples from different sites, using a rover carrying a drill capable of reaching well into the subsurface and into surface rocky outcrops.
3. At each site, to conduct an integral set of measurements at multiple scales: beginning with a panoramic assessment of the geological environment, progressing to smaller-scale investigations on surface outcrops, and culminating with the collection of well-selected subsurface (or surface) samples to be studied in the Rover’s analytical laboratory.

The PanCam instrument plays a key role in the mission by contributing to item 3 above. The main objectives of the ExoMars rover PanCam instrument are to:

1. Provide context information for the rover and its environment, including digital elevation models and their proper visualisation.
2. Geologically investigate and map the rover sites including drilling locations.
3. Study the properties of the atmosphere and variable phenomena, including water and dust content of the atmosphere.
4. Locate the landing site and the rover position with respect to local references, by comparison and data fusion with data from orbiters.
5. Support rover track planning.
6. Image the acquired sample.

The PanCam design for Mars (total mass 1.75 kg) includes the PanCam layout (MSSL) as shown in Table 1. The PanCam mechanical design is illustrated in Fig. 1. The optical bench is located on a rover-supplied pan-tilt mechanism at the top of the rover mast, at a height of ~1.7 m above the surface.

A summary of the main characteristics of the WACs and HRC is shown in Table 1. Each of the WACs includes 11 filters comprising R,G and B colour bands, a geological filter set (optimised for use on Mars by Cousins et al. (2010, in press)), and atmospheric filters to analyse the water and dust content in the Mars atmosphere. The filter wheel and WAC camera system is illustrated in Fig. 2. The HRC hardware is produced by Kayser-Threde, Munich and DLR Institute for Planetary Research, Berlin, Germany.

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The PanCam design for Mars (total mass 1.75 kg) includes the following major items:

(a) **Wide Angle Camera (WAC) pair**, for multi-spectral stereoscopic panoramic imaging, using a miniaturised filter wheel. The WAC camera units themselves are provided by RUAG and Space-X, Switzerland, and the filter wheels and drives are produced by Mullard Space Science Laboratory, University College London (MSSL-UCL).

(b) **High Resolution Camera (HRC)** for high resolution colour images.

(c) **Pancam Interface Unit (PIU)** to provide a single electronic interface. The PIU is provided by MSSL-UCL.

(d) **PanCam Optical Bench (OB)** to house PanCam and provide planetary and dust protection. The OB is provided by MSSL-UCL.

The PIU is the main interface between the ExoMars rover and the PanCam subsystems, and uses an FPGA implementation. The final system component is the Optical Bench, which provides a planetary protection barrier to the external environment (including HEPA filters), as well as mechanical positioning of the PanCam components. A view of the prototype is shown in Fig. 4.

In addition to the major four PanCam optical bench mounted components outlined above, two additional hardware components are part of the PanCam design to improve the scientific return and provide useful engineering data, namely the calibration target and the rover inspection mirror, both provided by Aberystwyth University.

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Table 1: Main characteristics of ExoMars PanCam cameras.

<table>
<thead>
<tr>
<th></th>
<th>WACs (x2)</th>
<th>HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FoV (°)</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>Pixels</td>
<td>1024 × 1024</td>
<td>1024 × 1024</td>
</tr>
<tr>
<td>Filter type</td>
<td>Multispectral RGB</td>
<td>On chip</td>
</tr>
<tr>
<td>Filter number</td>
<td>11 per ‘eye’</td>
<td>3</td>
</tr>
<tr>
<td>FOV (μrad/pixel)</td>
<td>580</td>
<td>83</td>
</tr>
<tr>
<td>Pixel scale (2 m)</td>
<td>1.19 mm</td>
<td>0.17 mm</td>
</tr>
<tr>
<td>Focus</td>
<td>Fixed (1.0 m–∞)</td>
<td>Mechanical autofocus (0.98 m–∞)</td>
</tr>
</tbody>
</table>

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The PanCam calibration target (PCT) is implemented using coloured glass elements similar to ‘stained glass’ (see prototype in Fig. 5; ‘shadow posts’ will be added for relief). A calibration target is located on the rover deck.

In addition to the PanCam hardware components mentioned above, the ExoMars PanCam team includes a 3D vision team which provides key software and calibration support for the PanCam team.

The radiometric and colourimetric data flow and operations scenario as envisaged by the 3D vision team, for 3D vision (Paar et al., 2009) and for colour image processing (Barnes et al., 2011) is illustrated in Fig. 6a and b. Some of the procedures have been tested in the field particularly during the Arctic Mars Analogue Svalbard Expeditions (AMASE) expeditions, as discussed in the next section.

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4. Science with a lunar surface camera

Multi-spectral imagery within the visible range, such as will be covered by PanCam, has long been recognised to be a powerful method of distinguishing between major lunar mineralogies and rock types (e.g. Pieters, 1993). Implementation of the method on the Clementine spacecraft, which orbited the Moon for two months in 1994 (Nozette, 1994), demonstrated that such multi-spectral observations were able to accurately determine Fe and Ti elemental abundances within an imaged area, along with the relative abundances of key lunar minerals (e.g. orthopyroxene, clinopyroxene, olivine, plagioclase, and opaque minerals such as ilmenite e.g. Lucey et al., 2000; Staid and Pieters, 2000; Pieters et al., 2001; Spudis et al., 2002; Lucey, 2004). However, whereas Clementine had a spatial resolution of 100 m/pixel, a PanCam-like instrument on the lunar surface would have a resolution of about 6 mm per pixel at a distance of 10 m (Table 1), making it possible to identify small-scale geological heterogeneities local to the landing site. In part for these reasons, a PanCam follow-on instrument, with
modifications to make it suitable for deployment on the Moon, was proposed as the context imager for the proposed MoonRise sample return mission (Jolliff et al., 2010), and breadboarded as part of the MoonRise phase A study (unfortunately, MoonRise was ultimately not selected by NASA).

For the ESA lunar lander, we will build on the ExoMars PanCam heritage, and on studies formed in the context of MoonRise, to study the implementation of a powerful scientific camera for the Lunar Lander.

Given the proposed south polar landing site of ESA's Lunar Lander, the use of Lunar PanCam to explore the geological context of the rim of Shackleton Crater is of particular interest. Shackleton lies within the topographic rim of the South Pole-Aitken basin (Spudis et al., 2008), and so materials excavated from deep within the Moon (i.e. lower crust or mantle) may be exposed in Shackleton ejecta. These include orthopyroxene- and/or olivine-rich lithologies derived from the lower crust and mantle, respectively. Based on Clementine multispectral data (e.g. Pieters et al., 2001; Spudis et al., 2002; Lucey, 2004), it is known that multi-spectral imaging within the wavelength range of PanCam is able to discriminate between these mineralogies. Lunar PanCam will therefore be able to address the extent to which these materials are exposed on the rim of Shackleton and available for study by contact instruments and/or later rover or sample return missions. In addition, the recent discovery of hydrated minerals in the regolith at high lunar latitudes (Pieters et al., 2009) is of great scientific interest (e.g. Anand, 2010). Although the dominant spectral signatures of these minerals is in the near infrared, we propose to conduct studies to determine if the PanCam filter set might be optimised in such a way as to detect them, following the methodology described by Cousins et al. (2010, in press).

A PanCam-type multi-spectral imager on the Moon would also be able to search for non-lunar lithologies exposed in the surficial regolith. These might include meteoritic fragments, including samples of the giant impactors responsible for lunar basin formation (small fragments of which have recently been identified in Apollo regolith breccias; Joy et al., 2012), and samples of the early Earth blasted off the Earth's surface by giant impacts early in our planet's history (e.g. Armstrong et al., 2002; Gutiérrez et al., 2002). Such materials would be of great scientific interest, and likely to be spectrally distinct from native lunar materials (see discussion in Crawford et al., 2008). As for the identification of hydrated minerals discussed above, it is our intention to conduct a detailed study of filter wavelengths and band-widths in order to optimise the sensitivity of a lunar PanCam to the detection of such extra-lunar materials, while retaining sensitivity to known lunar lithologies. Finally we note that while static-based imaging systems, such as envisaged for ESA's Lunar Lander, may be able to identify such materials in the immediate locality of the landing site, in the longer term it is clear that a rover-based mobile system would be preferable. Given its ExoMars heritage, PanCam would of course be ideally suited to such an application.

In addition to studies of the local geology, and the provision of lander context including digital elevation models, Lunar PanCam will also study dust levitation effects on the Moon, a topic of high interest for science and exploration (e.g. Grün, et al., 2011; Pines, et al., 2011). This will be a complex and interesting problem given the topology near the South pole. We anticipate providing complementary images which will be of high interest in relation to data from the proposed plasma instruments on ESA's Lunar Lander and other proposed lunar surface missions.

5. Adapting ExoMars PanCam for the moon

The Lunar Lander is anticipated to include a boom and a Pan-Tilt mechanism on the static lander, in order to provide wide panoramic views. A study of the detailed adaptations of ExoMars PanCam has recently been started for ESA. In the study, considerations for adapting PanCam for the Moon are planned including:

- The requirements for the boom and Pan-Tilt mechanism on the static lander will be studied.
- The overall ExoMars PanCam design compatibility for the lunar lander will be studied.
- The OB would provide dust protection, as at Mars.
- The PCT is necessary, but no RIM necessary on the static lander.
- The design will be adapted and environmental tests will be performed for the lower temperatures, larger differences between light and shade and deeper thermal cycling, expected for the Lunar Lander environment.
- Radiation studies will be pursued.
- Micrometeorite impact studies will be made.

In summary, a suitably modified PanCam would provide important measurements on the lunar surface, setting the context for and highly complementary with other measurements on the ESA lunar lander. Beyond the lunar lander, similar multispectral imaging systems also have great potential on future lunar rovers, where they will help identify interesting lunar (and possibly extra-lunar) materials for detailed investigation and/or sample return.

6. PanCam field trials

A number of ExoMars-related field trials and tests have been performed in the last few years (see Fig. 7), including participation in recent Arctic Mars Analogue Svalbard Expeditions (AMASE) 2008–11.
(see Steele et al., 2010, Schmitz et al., 2009). For these tests, a representative PanCam simulator was used, provided by Aberystwyth University. This simulator includes representative (though not the final) filter wavelengths from which spectral information may be used to study mineralogy (Cousins et al., 2012b). These campaigns have been used, in combination with teams from other ExoMars instruments, to develop working procedures representative of a mission to Mars, as well as to test instrument performance, develop calibration techniques and pursue scientific investigations of particular areas. These included e.g., the Bockfjord Volcanic Complex (BVC), and the Nordaustlandet/Palander Icecap. Scientific data from these trials will be discussed elsewhere.

Some representative data from the AMASE expedition in 2009 are shown in Fig. 8 (detailed scientific analysis will be presented in additional papers. Other PanCam ground tests have included ‘blind’ geological identifications performed in the AU Mars analogue facility, and tests in a quarry in Hertfordshire with the Astrium UK ‘Bridget’ prototype rover.

7. Conclusions

A modified version of ExoMars PanCam was proposed as the Surface Camera Package for the ESA lunar lander in response to the 2009 ESA RFI. Clearly, ExoMars PanCam heritage provides robust Technology Readiness Level (TRL) for refight on the ESA Lunar Lander.

The ExoMars PanCam overall design provides both broad and detailed context for the lander payload, with additional scientific objectives in the area of dust levitation studies. The powerful scientific performance, particularly the complementary performance of the WACs and HRC, will be essential in support of the Lunar Lander mission.

The required hardware and testing modifications for the Lunar environment (e.g. thermal, micrometeoroid and illumination) will be further iterated including the NASA MoonRise studies with additional thermal and other data.

We anticipate commencing further studies of Lunar PanCam and the required modifications in the near future.

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