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The Beagle 2 Camera Heritage for Pasteur

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Introduction and Scope

The Pasteur payload on the ESA ExoMars rover [Vago et al., 2002] is designed to look for evidence of extant or extinct life either on or up to ∼2 m below the surface of Mars. A UK, German, Austrian, Swiss, Italian and French team has proposed a panoramic camera design for Pasteur which will provide visual imaging of the rovers surroundings and perform (in conjunction with an infrared imaging spectrometer) remote detection of potential sample sites.

Together with the Mars Netlander panoramic camera [Jaumann et al., 2003] the Beagle 2 stereo camera (SCS, [Griffiths et al., 2003]) is regarded to be one of two major predecessors of the Pasteur panoramic camera system. We report on important SCS development results, and how they can be exploited for Pasteur.

Pasteur Camera System Objectives

The scientific goals and operational requirements of a Pasteur panoramic camera system and possible dedicated navigation and safety sensors can be summarized as follows:

- Support of Pasteur payload science (e.g., determination of objects to be investigated in situ by other instruments; monitoring of drilling/coring activities).
- Localization of landing site (stellar navigation) and subsequent rover positions (visual navigation), and determination of rover orientation/tilt.
- Geological characterization (using narrow band geology filters) and cartography

of the local environments (local Digital Terrain Models or DTMs).

- Study of atmospheric properties and variable phenomena near the Martian surface (e.g. aerosol opacity, water vapour column density, clouds, surface frosts, dust devils).
- Geodetic studies (observations of Sun, bright stars, Phobos).
- The Pasteur panoramic camera system also provides a movable platform for small science and/or operational sensors (e.g. environmental sensors & the WISDOM ground penetrating radar magnetic antenna).

The Beagle 2 Stereo Camera

The Stereo Cameras were part of Beagle 2's highly integrated instrument complex known as the PAW, or position adjustable workbench (Sims et al., 2003). The PAW provided mounting points for the twin camera/filter wheel units, or "eyes" such that the stereo baseline was 209 mm with a toe-in (or "cross eye" effect) fixed at 3.7˚ per "eye". A 0.7 m long robot arm orientated the cameras to point in any required direction from within the 0.7 m radius hemisphere above the lander base.

The SCS (Griffiths et al. 2005) had been designed and developed by UCL's Mullard Space Science Laboratory (MSSL). Each SCS eye consisted of a Space-X 1024 x 1024 pixel CCD micro-camera (Josset and Beauvivre, 2003) (and 48˚ optics) and a MSSL filter wheel with twelve interference-coated filters. All the optics and filters were composed of anti-reflection coated radiation hard BK7 silica glass. The 10 mm (usable) diameter filters were mounted in a 59 mm diameter titanium filter wheel and enclosed by an aluminium housing and lid. A 15 mm optical window in the lid allowed light to pass through to the filter wheel, which was rotated by a stepper motor and gear wheel assembly. A stainless steel "wiper blade" attached to the central gear shaft was provided to remove dust from the optical window. The Flight Model (FM) SCS total system mass of 360 g compared very favourably with previous planetary cameras (Bell et al., 2003 and Smith et al., 1997), as did the 520 cm^3 volume envelope and 1.8 W average power consumption.

Due to the depth of focus available with the camera optics, two working distances were required: The 48˚ optics were optimised for viewing high priority objects within reach of the lander's robot arm (i.e. best focus between 0.6 and 1.2 m). To view objects at greater distances four filters with a lenticular cross-section were used to provide the necessary optical accommodation. When using these four filters the best focus range was between 1.2 m and infinity. Additionally the R1 filter position contained a "close-up" lens (or CUL) to provide a magnified view of rock surface textures (similar to that provided by a geologist's hand lens). The CUL gave 60-micron per pixel resolution at a 9 cm working distance, intermediate resolution between the 300 micron per pixel standard SCS resolution and the 4 micron per pixel microscope resolution (Thomas et al., 2004).

After an image had been acquired, it was (optionally) compressed by the lander software using a lossy wavelet-encoding scheme (Rueffer & Borrmann, 2003). Additionally, the lander software provided an auto exposure function and allowed the images to be binned (up to 32:1) or a sub frame extracted before transmission to Earth.

Learning from Beagle 2 design, preparation and operations

The following major sources of Beagle 2 camera system experience can be used for the Pasteur panoramic camera:

- **HW Layout & engineering:** The baseline Pasteur wide-angle cameras (WAC) borrow heavily from the Beagle 2 camera design reusing the Space-X micro-camera modules and filter wheel/housings. However, a new optics design is required to meet the 65º field-of-view currently specified by ESA. The Pan-and-Tilt mechanism, other internal & external harnesses as well as a data processing unit (DPU) is heavily dependent on the Pasteur specific requirements and therefore will go through a complete redesign. The Pasteur high resolution camera (HRC) is considered to use heritage from the Mars Netlander panoramic camera.

- **Selection of optimum filter combination** w.r.t the scientific objectives (although this is an issue highly suffering from missing confirmation due to the Beagle 2 loss): The optimum filter combination will be derived from the results of Beagle 2 pre-flight testing and future testing to determine the best wavelength choices to support Pasteur's goals of identifying biogenic signatures on Mars.

- **Calibration:** The Beagle 2 robotic arm (RA) and the PAW went through a complete geometric calibration including RA dynamics and SCS hand-eye calibration [Barnes et al., 2003]. Viewing of precisely known targets on the Beagle 2 frame should enable an on-site check and refinement. On a rover such as used for Pasteur this should be extended to a full geometric calibration of all instruments w.r.t the camera to ensure precise operations planning and monitoring, in particular instruments directly placed on the WAC support and other optical and/or pointing sensors. The procedure for Beagle 2 can be re-used without major changes. For a refinement of the camera interior orientation direct star observations can be used [Klaus et al., 2004]. Radiometric calibration is required to determine the sensitivity (i.e. responsivity) of the system and allow the removal of CCD/optics artefacts from the returned images. The methods used for Beagle 2 are again directly applicable.

- **Test procedures** under limited resources: The Pasteur camera system requires a full radiometric and geometric calibration to adequately achieve its science and engineering goals on Mars. Building on the lessons of Beagle 2 Assembly Integration and Verification, close liaison will be required between the instrument scientists, ESA and the industrial contractors building the FM. In particular it could be shown in end-to-end tests that a proper head-eye calibration between robotic support (robot arm) and camera using the final FM components could save in-flight resources (images to be taken for calibration during the mission).

- **Surface mapping**: The ground segment of Beagle 2 image data processing provided a complete framework of surface mapping (textured DTM generation [Paar 1999]), embedding the lander Virtual Reality (VR) model and its moving parts into the 3d map. This was also extended to micro – structure provided by CUL – stereo. Various error sources (mechanical, data transmission, varying illumination conditions, complete failure of one camera etc.) were considered. All these operations will be performed in close alliance with the know-how from Beagle 2 and other past Mars lander missions [Oberst et al., 1998; Xu, 2004] as well as the navigation camera operations and data.

- **Landing site & Rover localization:** Using cameras as star sensors for lander position and orientation determination was proposed and simulated for Beagle 2 [Trautner et al., 2004]. Combined with horizon panoramas [Oberst et al., 1999], descent imagery [Li et al., 2004] and accurate calibration of the cameras and pointing devices, the ExoMars Rover and its lander will be equipped with a stable localization package.

- **Close – up imagery & microscope incl. 3D**: The motivation for 3D close-up imaging is to provide extra information about rock texture, morphology and grain size to enable better visual identification. This information is, in conjunction with the HRC, also needed to determine the best areas to image at higher resolution (i.e. a microscope) or to sample with contact instruments (e.g. spectrometers) and sampling devices (e.g. drill or rock corer-grinder). Various tests were performed with the Beagle 2 instrumentation, including the effects of corer and grinder actions on the interpretation of the images.

- **Panorama Mosaiking:** A high resolution panorama of the environment is major source to find potentially interesting regions in the Rover's vicinity.

Panorama generation and interpretation is tightly coupled with sensor calibration, photogrammetry for DTM generation and Rover localization. For Beagle 2 two stages of panoramic imaging (panoramic mirror & mosaic) were implemented and tested, both are available to Pasteur.

- **Other sensing strategies**: Beagle 2 considered the generation of stereo DTMs using the ordinary stereo pair configuration, as well as wider baseline stereo using different positions of the robot arm to gain accuracy at long distances. The full geometric instrument VR model would allow the use of imaging the ExoMars rover deck and lander hardware (before & after egress) for evaluation of structural integrity and dust level, as well as imaging the wheels and tracks or trenches left behind for in-mission re-calibration of the manoeuvre commanding. After proper radiometric calibration also solar imaging (to measure absorption due to water vapour and suspended aerosols) could be performed as support for the environmental sensor package.

Conclusions

The Beagle 2 camera system offers some solutions and concepts that can be re-used and/or extended to the Pasteur camera system. The lessons learned and the existing components (hardware, operations and software) will act as a valuable starting point for the development of the Pasteur scientific camera system.

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