Synopsis of *Phoenix Robot Arm Camera*

Original authors: H.U. Keller, W. Goetz, H. Hartwig, S.F. Hviid, R. Kramm, W.J. Markiewicz, R. Reynolds, C. Shinohara, P. Smith, R. Tanner, P. Woida, R. Woida, B.J. Box, and M.T. Lemmo

Published in the Journal of Geophysical Research, Vol. 113, 2008

Snyposis written by: Kevin Newman
OPTI 521
Date: November 18, 2013

1. Introduction

The Phoenix spacecraft was launched in August 2007, and landed in the north polar region of Mars in May 2008. The soil at the landing site was expected to contain water ice at shallow depths below the surface. The Robotic Arm Camera (RAC) was designed to take close-up images of the Martian surface, and microscopic images of samples collected in the Robotic Arm (RA) scoop. The RAC was based on a camera designed for the Mars Polar Lander and Mars Surveyor Lander missions [1]. The RAC was built and tested by the Max Planck Institute for Solar System Research in collaboration with the Lunar and Planetary Laboratory at the University of Arizona.

This synopsis outlines the paper *Phoenix Robotic Arm Camera* by H.U. Keller et. al. [2] with emphasis on the opto-mechanical design and special environmental considerations for the RAC.

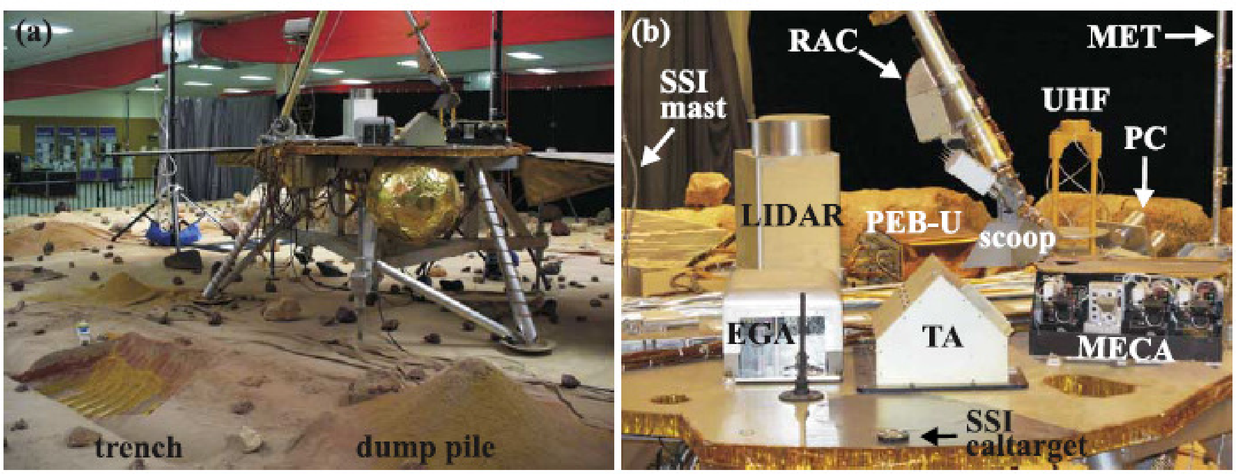

Figure 1: The engineering model of the Phoenix Lander located at a testing center in Tucson (a) and the RAC surrounded by other instruments of the lander (b).

2. Science Objectives

The science objectives for the RAC are to characterize soil material color, grain size (down to 23 microns/pixel), texture, and porosity. Images can also be taken of the Lander surroundings and of object as close as 11mm from the camera window. At the Mars landing site, the RAC will be used to:

1) Characterize a soil patch prior to digging.
2) Characterize scoop-soil interactions in terms of physical properties such as cohesion and soil strength.
3) Characterize trench walls by searching for fine-scale soil/ice layering and monitor possible temporal changes due to sublimation of water ice away from a newly excavated surface.
4) Characterize soil samples in the scoop prior to delivery to an analyzing instrument.
5) Characterize the surface below the lander and estimate the penetration depth of the foot pads.
6) Provide a Digital Terrain Model of the working area.
7) Monitor the horizon and search for dust devils and provide "one shot" overview images of the brightness gradient of the Martian sky.

The main sub-systems of the RAC include the optical bench/frame, the Sensor Head Board with CCD detector, a double Gauss lens with lens cell, a lens focusing mechanism with stepper motor and reference switch, a protective dust cover with mechanism and stepper motor, upper and lower lamp assemblies, two temperature sensors, and a protective shell.

3. Camera Optics

The camera optics, illumination system, and flight software were designed by a team at the Lunar and Planetary Laboratory at the University of Arizona. The RAC includes a movable variable-focus objective ranging from 1:1 macro mode to infinity. The RAC is mounted at the end of the RA, and may utilize all degrees of freedom of the RA to adjust pointing and orientation. The Robotic Arm is described in more detail in Bonitz et al [3]. Red, blue, and green LEDs are included as light sources for the RAC. The camera can take composite color images by illuminating the object with one color at a time.

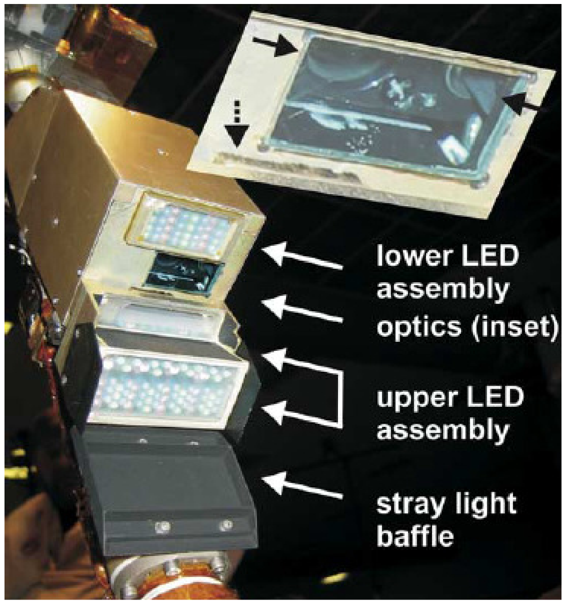

Figure 2: Engineering model of the RAC mounted to the Robotic Arm.

The volume of the RAC is 78 x 62 x 61 mm^3 with a total mass of 415g, and is designed to operate in the temperature range between 160° to 320° K. The size of the RAC was determined by the available CCD detector. The optics consist of a double Gauss system imaging onto a 512 x 256 pixel CCD detector with a 54° x 27° FOV at infinite conjugate. The focus is adjusted by moving the lens system with respect to the CCD. The minimum object distance is 11mm from the front window of the camera, and the f/# of the system varies from f/23 to f/11. At the highest resolution (shortest object distance), each pixel covers 23 microns of the object. A protective window in front of the objective blocks infrared light longer than 700nm. A movable sapphire cover also protects the camera system by blocking dust and debris while the camera is not in use.

4. Optomechanics

The optomechanical layout, shown in Figure 3, consists of a 12.5mm EFL double Gauss lens stopped down to an f/11.2 focal ratio. A titanium lens cell was used to provide a close match in thermal expansion and allow operation over a wide temperature range. Focusing of the lens is necessary to achieve a large dynamic range. The lens is mounted to a translation stage which moves along the optical axis. A ball bearing mechanism carefully designed to avoid over-constraint allows a total travel distance of 13.0mm in step increments of 41.67 microns.

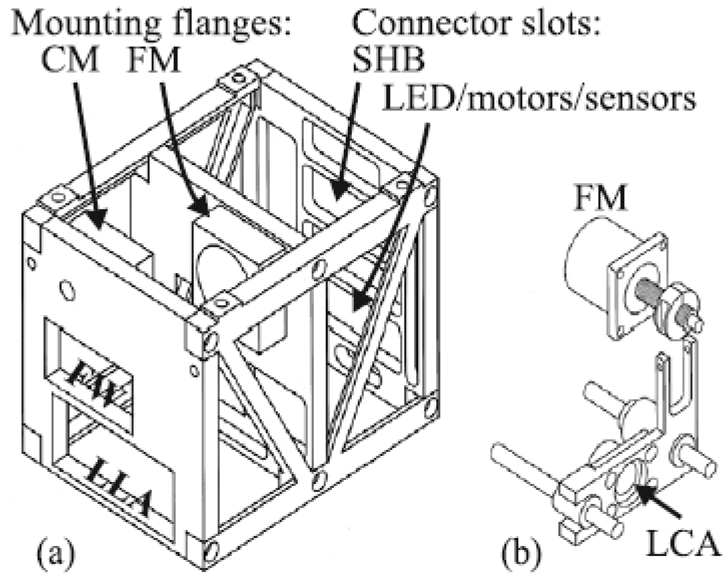

Figure 3: Optomechanical layout of the RAC. (a) The RAC frame and optical bench, including mounting slots for the front window (FW) and lower lamp assembly (LLA). The frame houses the CCD, cover motor (CM), focus motor (FM), and lens cell assembly (LCA). (b) The focusing mechanism.

There are several measures taken to protect the optical assembly from environmental conditions. The optical assembly is protected by a cover mechanism that consists of a sapphire window to protect the filter window from scratches caused by flying dust and frost deposition. Small conductive carbon fibre brushes located inside the cover slot remove particles from the filter window. Temperature sensors are bonded to the drive motors to prevent overheating. The optical assembly is enclosed in an aluminum shell, and the edges of the shell parts are sealed adhesive tape to prevent dust from entering the enclosure. Pressure equalization between the optical cavity and the surrounding environment is achieved with a pair of sintered stainless stell filter disks.

5. Testing

Prior to launch, the entire RAC system is calibrated to characterize the illumination system, the radiometric performance, flat fielding, account for distortion, and determine properties of the CCD. The fully-integrated system was tested in a Mars-like environment on Devon Island [4].

6. Conclusion

The RAC was designed as a long dynamic range camera for the Phoenix Mars Lander. In addition to taking close-up images of the contents of the robotic arm scoop to characterize its contents, the RAC also served as a camera to take images of the lander surrounding area and horizon. The optical design of the camera was relatively simple, but the mechanics surrounding the camera became quite complex when considering environmental issues of operating remotely on Mars. Overall, the RAC proved to be a valuable tool for the Phoenix instrument suite and a compliment to the other imaging devices.

7. References

[1] Keller, H. U., et al. (2001), The MVACS Robotic Arm Camera, *J. Geophys. Res.*, 106

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[3] Bonitz, R. G., et al. (2008), NASA Mars 2007 Phoenix Lander Robotic Arm and Icy Soil Acquisition Device, *J. Geophys. Res.*, 113

[4] Bos, B. J. (2002), Design, calibration, and operation of Mars Lander Cameras, Ph.D. thesis, Univ. of Ariz, Tucson