Forward-looking Infrared Cameras: A Potential Crew Tool for Geological Site Assessments

William L. Stefanov, *Johnson Space Center*
Cynthia A. Evans, *Johnson Space Center*
Kei Shimizu, *Brown University*

Plans for future crewed missions to the lunar or Martian surface, or near-Earth objects such as asteroids or comets, will include field traverses to assess site geological character and potential geohazards, and to identify potential in-situ resources. While much of this information—e.g., mineralogy, chemical composition, and surface particle size distributions—can be obtained from multispectral or hyperspectral instruments located on orbiters, the very high spatial resolution of field validation data obtainable by crews "on the ground" is desirable prior to establishment of site infrastructure and habitats.

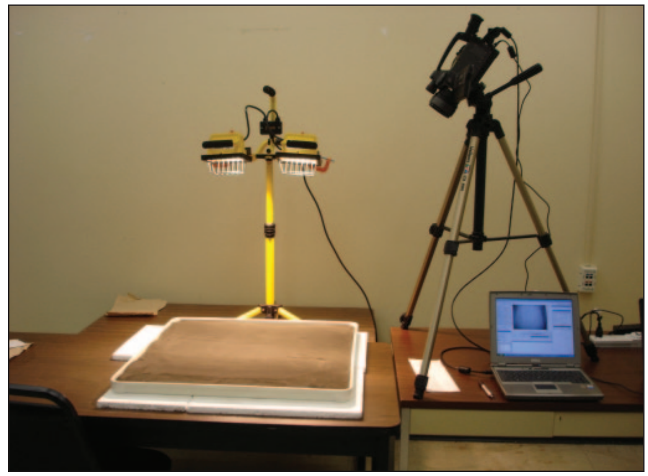

Fig. 1. *Typical forward-looking infrared experimental setup.*

A handheld forward-looking infrared (FLIR) camera was investigated as a field assessment tool for rapid estimation of rock abundance and discrimination of geological materials using both laboratory and field analog site approaches. NASA selected the FLIR Systems, Inc. (headquartered in Wilsonville, Oregon) FLIR SC660 640 x 480 pixel array, uncooled microbolometer thermal infrared camera, as it includes a co-registered digital camera for simultaneous acquisition of visible wavelength (red, green, and blue bands) data. A typical experimental setup of the camera in the laboratory is shown in figure 1.

The camera signatures and thermal response of a laboratory analog of a lunar mare surface were characterized. The analog surface used lunar soil simulant, basalt "gravel" (including vesicular scoria and dense lava fragments), and included depressions to represent impact craters. Figure 2 (left) shows the visible wavelength (true color) image of the laboratory lunar analog surface; the lunar soil simulant substrate is gray, basalt scoria is red to pink, and lava fragments are gray to black. A diurnal cycle was simulated with two 500-watt halogen lamps to illuminate and heat the analog surface over periods ranging from 1 to 8 hours (sunrise, lunar "day"), followed by lamp switch-off and 3 to 16 hours of darkness (sunset, lunar "night"). The percent area of basalt gravel, number of impact craters, and illumination angle were also varied over different data collection runs.

The FLIR camera recorded thermal infrared and co-registered visible wavelength imagery at 1-minute intervals during each data collection run. This allowed the team to observe qualitative variations in apparent thermal inertia—generally speaking, a measure of how quickly a given material heats up and subsequently cools down—related to the different analog materials, particle sizes, and illumination conditions, and provided confidence that the team could obtain similar data in the field. Figure 2 (right) shows a false-color thermal infrared image of the analog surface during heating. Relatively hot, low apparent thermal inertial surfaces appear bright yellow and cooler; high apparent thermal inertial surfaces appear dark orange to violet.

NASA conducted a field assessment with the FLIR camera at Colton Crater—located north of Flagstaff, Arizona—

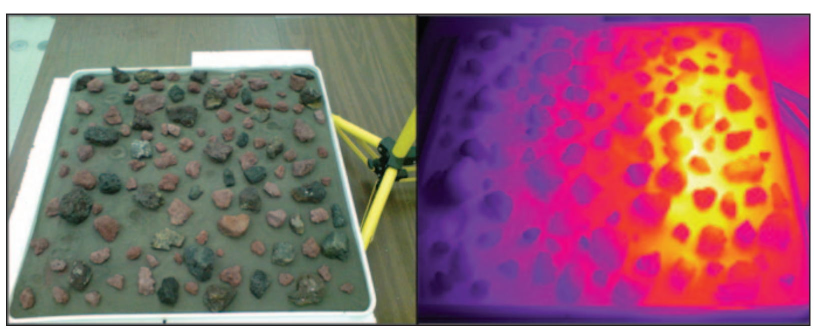

Fig. 2. *Visible image compared to simultaneous thermal infrared image in laboratory environment.*

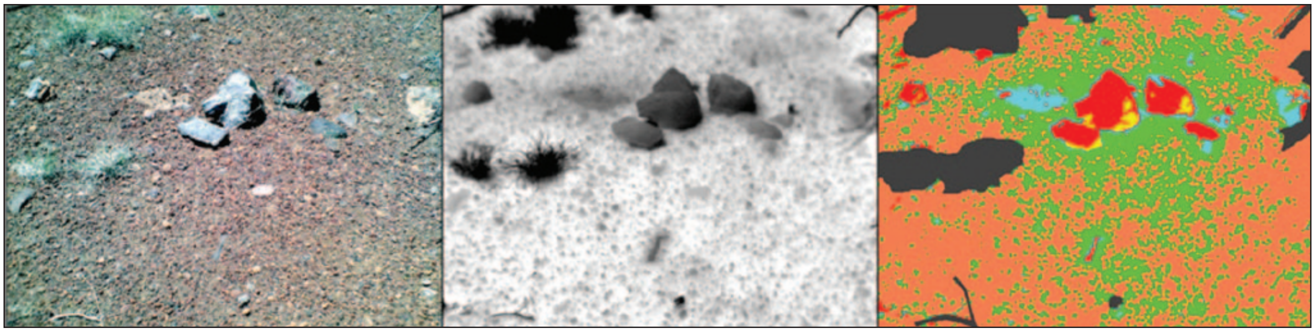

Fig. 3. *Forward-looking infrared field data comparison.*

following initial trials at Johnson Space Center's Planetary Analog Test Site or "rock yard." While this crater was formed from explosive volcanic processes rather than a meteor impact, its basaltic character, geomorphology, and ease of access made it an ideal lunar (and Martian) analog site for the study. Data collection occurred at, or shortly following, sunrise at several sites around and within the crater during the field assessment to maximize apparent thermal inertia contrast between different materials and surfaces—e.g., fine sediments on the crater floor and basaltic gravels and boulders; basaltic agglutinate (hot spatter deposits subsequently welded together) outcrop and surrounding soil, etc. The field data collection methodology was informed by the results of the laboratory analog study, resulting in approximately 4-hour collection runs with thermal infrared and visible imagery collected at 5-minute intervals.

Scientists then performed principal component analysis to extract the most correlated information from the field data, and to reduce noise. By applying both unsupervised and supervised image classification algorithms to the visible wavelength data, thermal infrared data, and fused visible + thermal infrared data, the team assessed the performance of these relatively simple classification approaches for different geological materials and surfaces in the field to simulate "on the fly" operations by crew members—i.e., without significant science backroom support and analysis.

Figure 3 illustrates imagery obtained in the field at Colton Crater. The left image shows a visible wavelength (true color) image and the center image shows the corresponding thermal infrared image. Relatively hot surfaces (indicating low apparent thermal inertia) are bright, and relatively cool surfaces (indicating high apparent thermal inertia) are dark in the center image. The right image shows a supervised classification of fused visible and thermal infrared data: red—basalt boulders; pink—basalt gravel; yellow—shadows; green—basalt agglutinate; blue—high albedo (high reflectance) materials; gray—masked vegetation, not classified.

The team anticipated mixed results from these initial tests. Performance with regard to discrimination of different types of geological materials at Colton Crater was generally poor, with a large variance in overall accuracy obtained using both unsupervised and supervised approaches (35% to 80%); the range of variance for individual class accuracy was similar. This is largely a result of the relatively limited spectral sampling obtained by the FLIR camera—red, green, and blue visible wavelengths, and a single broad thermal infrared band. In contrast, the classified FLIR camera data performed satisfactorily for determination of rock abundance compared with visual estimation in the field. These results suggest that current FLIR cameras would be a useful addition to a crew "tool kit" for geohazard and site suitability assessment, and suggest that further development of multispectral, microbolometer-based thermal infrared and visible wavelength imagers would produce a highly useful tool for crew field geology activities.