ASSESSMENT OF A HANDHELD FORWARD LOOKING INFRARED (FLIR) CAMERA AS A POTENTIAL LUNAR FIELD GEOLOGY TOOL. K. Shimizu[1],W.L. Stefanov[2], C.A. Evans[2] [1]Department of Geosciences, Stony Brook University, Stony Brook, NY 11794 (keshimiz@ic.sunysb.edu), [2]Astromaterials Research and Exploration Science Directorate, NASA Johnson Space Center, Houston, TX 77058 (william.l.stefanov@nasa.gov; cindy.evans-1@nasa.gov).

Introduction: NASA currently plans to construct a lunar outpost by 2024. Such an effort will require astronaut and robotic tools for rapid surface assessment relevant to base construction and field activities particularly mapping of rock and regolith abundance at the field scale.

Thermophysical measurements of surface materials have been used to map rock abundance on both the lunar surface and Mars, taking advantage of the differences in thermal inertia resulting from particle size variations in similar rock and soil compositions. [1, 2] By recording the temperature of materials on the lunar surface at appropriate times to maximize thermal contrast in differing particle sizes, it should be possible to rapidly map the geological environment at a site.

FLIR cameras record surface temperature in both still and video formats, with certain models able to simultaneously take visible image data. Fusion of the thermal infrared (TIR) and visible (VIS) wavelength data provides the potential to develop classification algorithms for dust/regolith/rock abundance characterization.

There have been extensive TIR studies done on Earth, Moon, and Mars from orbit, however there are few high resolution field studies using FLIR cameras. [3-5] Most of these field studies have focused on the use of diurnal thermal inertia measurements to obtain particle size and compositional information, but such an approach during lunar field operations is impractical due to the length of the lunar diurnal cycle.

The primary goal of this study is to assess the usefulness of FLIR cameras in determining rock abundance for geologic hazard assessment, and to develop data collection procedures appropriate to lunar surface sorties. FLIR camera data were collected from two Lunar/Martian analog field sites: the "rock yard" at Johnson Space Center (JSC) in Houston, TX; and Colton Crater, a basaltic maar crater in the San Francisco volcanic field north of Flagstaff, AZ. We report results for two sub-sites; a basaltic boulder field at the JSC rock yard (JSC-S1), and a similar surface on the rim of Colton Crater (CC-S1).

Methodology: The instrument used for field data collection is a 640x480 pixel microbolometer thermal infrared camera model P660 manufactured by FLIR systems. This camera is also equipped with a coregistered 3 megapixel visible wavelength (RGB) digital camera. The camera was mounted on a stable tripod on the ground at each site location. Environmental conditions, camera angle from horizontal, height above the ground, and distance to the target surface was recorded.

Simultaneous visible and TIR images were acquired for each site at 5 minute intervals ranging from local dawn until noon. This time interval was chosen because the predawn-to-midday variations of surface temperature can be interpreted in terms of apparent thermal inertia of materials in the scene. [2] The appropriateness of morning data collection was also indicated by observations of apparent thermal inertia during timed illumination of simulated lunar surfaces under laboratory conditions performed at JSC. [6]

The visible (VIS) and TIR data were fused together as a stacked 4–band image within the ENVI software environment following coregistration of the two datasets. Principle component (PC) analysis was performed for the VIS and stacked (VIS+TIR) images in order to obtain the most correlated data and reduce the noise, and to assess the benefit of using PC analysis results for classification.

Image sets for the field sites were classified using unsupervised K-means and supervised maximum likelihood classification methods. [7, 8] While classifications using different numbers of classes for each site were performed, we report only the 5-class results here as representing the limits of the approach for the FLIR data. The accuracy of classification results were assessed using 20 reference points for each class selected by a stratified random approach. The "true" class identity of each reference point was determined using the visible data for each site. Error matrices were then constructed for the field site classifications using the appropriate reference dataset.

Discussion: In terms of overall differentiation of rocks and regolith both classification methods (raw data and PC data) perform well. However, classification of materials of different compositions of rock or soil is less effective. At JSC-S1 sub-pixel mixing in the VIS data of high albedo granitic gravel (white feldspar and gray quartz) with shadows resulted in effectively gray pixels that were confused with, and misclassified as, underlying fine soil. Thermal variations in the TIR confirmed this misclassification. Since the reference dataset was constructed using the VIS image, the classification accuracy was low for the fused VIS+TIR data as well, despite a seemingly high qualitative accuracy of soil classification.

	Rock Basalt	Gravel	Shadow	Welded Material	High Albedo Material
VIS OA = 87	90/90	79/95	100/ 100	87/65	81/85
VIS PC OA = 87	90/90	79/95	100/ 100	87/65	81/85
TIR OA = 35	25/50	46/ 31	40/100	13/22	43/24
VIS+TIR OA = 55	35/100	79/ 59	65/100	13/50	67/32
VIS+TIR PC OA = 55	35/100	79/59	65/100	13/50	67/32

Table 1. Accuracy assessment results for CC-S1 supervised classifications. Raw data were classified as recorded by the FLIR camera; PC indicates that principle components of the raw data were used for classification. Individual class results are reported as producer/user accuracy. OA is overall accuracy. All values are percentage correct.

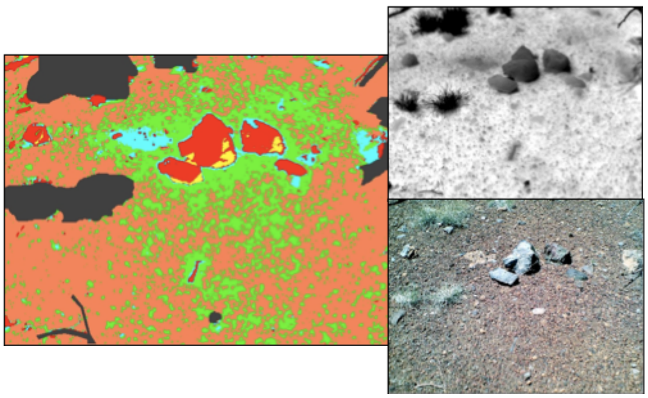

Figure 1. Result of maximum likelihood classification using VIS+TIR base data for CC-S1. Red – Rock Basalt; Pink – Gravel; Yellow – Shadow; Green – Welded Material; Blue – High Albedo Material. Gray regions are masked vegetation. The TIR (upper right) and VIS (lower right) data are provided for comparison.

Both unsupervised and supervised classifications for JSC-S1 differentiated between basaltic boulders and other classes well using the VIS data. This is due to high color contrast between black basalt and light-colored gravels and soil. User accuracy of supervised TIR and VIS+TIR classifications are relatively high (87% - 100%) in discriminating basaltic boulders from other materials at the site, suggesting that this classification approach would be useful in exploration of lunar sites with significant color contrast.

In contrast to JSC-S1, the primary variation at CC-S1 (Fig. 1) was due to particle size and is perhaps more representative of a lunar surface. This is the only site where the accuracy of unsupervised classification based on the TIR data alone was higher than that based on the VIS or VIS+TIR. The cause of this high accuracy is to some extent due to the high contrast in the thermal data between basaltic boulders, gravel, and associated soil, but also because of the method of accuracy assessment. Basaltic gravels have the same albedo as basalt boulders but lower thermal inertia, thus they have higher temperature during morning heating. This resulted in the opposite accuracy of basalt rock classification in the supervised runs, as a reference dataset based on visible information only was used.

The FLIR camera has only four bands and the spectral quality of these bands is not ideal. The visible camera bands likely have significant bandpass overlap (based on other off the shelf digital cameras), and the thermal information is broadband (7.5-13 microns). A multispectral VIS/TIR instrument with narrower bandwidths would undoubtedly improve the capacity for fine discrimination of materials. More sophisticated classification methods may help alleviate some of the limitations of the current FLIR instrument. For example, classification results can be segmented to exclude well-classified results and reduce variability for further iterative classification of other classes. Decision trees could also be used by incorporating data such as textural analysis of visual data using co-occurrence measures, digital elevation data, or geologic maps [8].

Conclusion: Our initial assessment indicates that while current FLIR microbolometer cameras show strong potential in obtaining useful information for lunar field studies and hazard assessment - rock abundance determination in particular - compositional discrimination of materials is problematic. The best overall accuracy of classification was higher than 80%, however individual class accuracies were highly variable and generally lower. Unsupervised classifications performed fairly well, but operationally this would require data transmission to a "back room" for analysis. In order to improve the potential for this class of instrument 1) more complex classification methods should be explored, 2) true coregistration of the visible and thermal data streams is necessary, and 3) an increase in the number of thermal bands, and use of narrow bandwidth visible data would improve material discrimination capability.

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