Processing the Viking Lander Camera Data

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Over 1000 camera events were returned from the two Viking landers during the Primary Mission. A system was devised for processing camera data as they were received, in real time, from the Deep Space Network. This system provided a flexible choice of parameters for three computer-enhanced versions of the data for display or hard-copy generation. Software systems allowed all but 0.3% of the imagery scan lines received on earth to be placed correctly in the camera data record. A second-order processing system was developed which allowed extensive interactive image processing including computer-assisted photogrammetry, a variety of geometric and photometric transformations, mosaicking, and color balancing using six different filtered images of a common scene. These results have been completely cataloged and documented to produce an Experiment Data Record.

INTRODUCTION

During the nominal Viking mission the two landers acquired 1025 different camera events: 451 from the VL-1 site in Chryse Planitia and 574 from the VL-2 site in Utopia Planitia. Details of image acquisition, on-board data tape storage, and transmission to earth are presented elsewhere [Huck et al., 1975]. Table 1 summarizes the camera events. For many camera events, multiple replays from the lander or orbiter tape recorders were received and later merged. Figure 1 illustrates the frequency of imaging data acquired as a function of day of mission; Figure 2 diagrams the ground system flow of camera data and the processing at the Jet Propulsion Laboratory's Viking Mission Control and Computing Center (VMCC) and Image Processing Laboratory (IPL).

Each 3413-bit camera scan line, acquired as the facsimile camera mirror scans upward, is returned to earth as a 'frame' of data. Each data frame starts with a 31-bit pseudo-noise word followed by a 5-bit instrument identification (ID) word, which are used to synchronize the beginning of each imaging line and to identify the source of data as the camera, respectively. The remainder of each imaging frame contains 512 6-bit picture elements as well as engineering data bits.

As lander telemetry is received in near real time at the Deep Space Network (DSN) from the tracking stations, it is relayed to the VMCC for processing. By means of the pseudo-noise and instrument ID words, imaging frames are decoded by the Telemetry Processor Program (TLMP). Imaging data are then passed via in-core transfer to the first-order image-processing program, described below, which resides in the same IBM 360/75 computer and which operates as part of the same real time task as the program TLMP. Imaging is the only lander science experiment allowed to process data in real time. Optionally, the System Data Record (SDR) produced by TLMP (see the appendix, glossary of acronyms) may be accessed at a later time from tape by the first-order imaging program.

After the decoding by TLMP the actual reduction of imaging data is divided into two parts: a real time first-order processing system (Fovlip) for rapid display of the data and production of hard-copy products and a second-order processing system at the Image Processing Laboratory that made available a wider range of analytical techniques and which produced the final versions of the digital data. The preparation of the raw data sets for the latter activity was called Experiment Data Record (EDR) generation and involved the use of both processing facilities. The EDR, in turn, was used to generate the final photoproducts, which are the Team Data Record (TDR).

FOVLP (REAL TIME FIRST-ORDER PROCESSING)

The first-order Viking Lander image-processing software consists of a number of distinct subprograms, each of which performs a single function on a complete lander picture. The subprograms are of three types: those which perform input processing of data, those which create enhanced versions of the images, and those which format the raw and enhanced images for volatile displays and tape output.

When receipt of an incoming real time image is completed, up to three enhanced versions can be created and stored on a data base for later display or hard-copy generation. Each version is the result of one to five serially applied enhancement subprograms. Fovlip has the capability for either operator-directed enhancement processing or automatic processing of incoming images using a library of 100 predetermined enhancement sequences.

Within Fovlip, enhancement processing subprograms consist of despiking (Adespike), contrast stretching (Aconalt), box filtering (Ahipass), and radiometric corrections (Aradcam). Adespike is used to remove random noise. The digital value of each picture element is compared to its adjacent neighbors in the vertical and horizontal directions and, depending upon user-specified tolerances, may be replaced by the average of its neighbors. Aconalt allows considerable freedom to map input pixel values to output values. This mapping can be specified directly by the creation by the user of a look-up table with an arbitrary set of values, or Aconalt can calculate the table automatically by specifying the input and output values of two different brightness levels with other values linearly interpolated or extrapolated. Optionally, one can define a linear stretch so that a specified percentage of the input images pixel values are above and below specified DN values. A table can be generated from a cumulative distribution function, in which case the relative frequencies of different DN levels are examined, more frequently occurring levels being more highly stretched. Ahipass uses a box filter algorithm to boost high spatial frequencies in an image. Aradcam corrects video data for errors in relative and absolute radiometry due to known distortion introduced by the camera by using tables of correction factors based on preflight and inflight calibration.
data. It calculates and presents to the user values of radiance associated with pixel digital values of 0-63.

In addition to providing real time display of processed images, Fovlip produces a digital tape of the processed data which is sent to the Mission and Test Imaging System (MTIS), where a Dicomcathode-ray tube (CRT) scanning device produces master negatives. This in turn is delivered to the Mission and Test Photographic System (MTPS) to produce photcopies for general distribution. The copies were generally available within 24 hours of the receipt of data. A digital facsimile printing device (Digifax) provides prompt prints of Fovlip-processed data within minutes of data receipt. The MTIS product is a negative transparency on a 5-inch-wide roll of film generated by the Dicomcathode raster of 4096 x 4096 elements. Each lander camera pixel is reproduced on film by using a 6 x 6 array of recorder elements giving a crisp square just barely perceptible to the unaided eye but permitting the user to establish precise line and sample values. Figure 3 illustrates a processed version of the first 312 lines of the first lander camera image received from Mars. The annotation, histograms, and marginal scales of the MTIS photoproduct provided the information needed for analysis of these data. Fovlip also produces digital tapes of the raw images which are forwarded to IPL as input to the second-order image-processing system.

EDR Generation

In addition to the real time data stream a second stream, referred to as the Data Record Stream, has the objective of providing the best possible data on a somewhat slower time line. It takes data from the Deep Space Station selected as having the best data and records the data on a tape called the Network Data List. A list is created of all missing telemetry frames along with a System Performance Record. These two are used to generate a request to a second station, which also received similar data; the data from the second source are merged with the data in hand to create an Intermediate Data Record, which, after being read into TLMP, yields the Intermediate System Data Record (ISDR).

One problem encountered late during simulation testing was the severity of the effects of data corruption (noisy data) on telemetry processing. Single bit errors in the 5-bit instrument ID words or 8-bit frame count indicators associated with each 3413-bit scan line resulted in the loss of the entire line. Additionally, bit errors in the pseudonoise word used for frame synchronization resulted in the inability of TLMP to identify imaging frames for Fovlip properly. For a bit error rate of 3/1000, 4% of all imaging lines were lost; for a rate of 20/1000, over half of all lines were lost. Since the latter bit error rate was typical of real time imaging and since despiking can produce

### Table 1: Summary of Camera Events

<table>
<thead>
<tr>
<th>Camera Events</th>
<th>VL-1</th>
<th></th>
<th>VL-2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Extended</td>
<td>Primary</td>
<td>Extended</td>
</tr>
<tr>
<td></td>
<td>CE's</td>
<td>Lines x 10^3</td>
<td>CE's</td>
<td>Lines x 10^3</td>
</tr>
<tr>
<td>By Event Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Resolution</td>
<td>0.04</td>
<td>188</td>
<td>175.6</td>
<td>0.04</td>
</tr>
<tr>
<td>Survey (2)</td>
<td>0.12</td>
<td>44</td>
<td>17.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Color (3)</td>
<td>0.12</td>
<td>74</td>
<td>41.9</td>
<td>0.12</td>
</tr>
<tr>
<td>IR (3)</td>
<td>0.12</td>
<td>48</td>
<td>24.6</td>
<td>0.12</td>
</tr>
<tr>
<td>Color/IR Singlets (4)</td>
<td>0.12</td>
<td>33</td>
<td>16.2</td>
<td>0.12</td>
</tr>
<tr>
<td>Sun (5)</td>
<td>0.12</td>
<td>20</td>
<td>3.9</td>
<td>0.12</td>
</tr>
<tr>
<td>Calibration</td>
<td>0.12</td>
<td>25</td>
<td>1.5</td>
<td>0.12</td>
</tr>
<tr>
<td>Scan Ver. (6)</td>
<td>0.12</td>
<td>19</td>
<td>0.8</td>
<td>0.12</td>
</tr>
<tr>
<td>Total</td>
<td>0.12</td>
<td>574</td>
<td>181</td>
<td>0.12</td>
</tr>
</tbody>
</table>

(1) Extended mission refers to the period from conjunction to March 1, 1977.
(2) Five survey CE's were recorded at 0.04° step size, see note (7) below.
(3) The line totals for color and IR triplet CE's are given in the number of "single diode" lines scanned.
(4) Many of these color and IR singlet mode, CE's were recorded at 0.04° step size, see note (7) below.
(5) Only two of the Sun CE's were recorded at 0.12° step size, all others were recorded at 0.04° (nonnominal) see note (7).
(6) The scan verification CE's are images of a light source in the camera post assembly using an HR diode at 0.12° step size.
(7) High resolution diodes sampled at 0.12° step size results in a 5.6° camera elevation pointing shift. Low-resolution diodes sampled at 0.04° step size results in a 5.6° elevation pointing shift.
(8) The camera can rescan at the stop azimuth of a camera event in both real-time and recorded modes. In recorded images rescan was done in 14 CE's which were entirely rescanned lines using color mode at the slow (250 bps) scan rate. Many other recorded images had small amounts (<15 lines) of rescans resulting from a strategy related to tape recorder performance.
useful results for such a bit error rate, a determined effort was made to recover all such corrupted data. The program RESTIMG (Restore Imaging Data) corrected the problems listed above. Since the techniques required for successful data recovery are not feasible for real time telemetry processing, the input for program RESTIMG was either an SDR or an ISDR tape, and the output was a similarly formatted tape suitable for input to Fovlip. By means of RESTIMG, several hundred degrees of real time imaging, as well as hundreds of missing lines within images, were recovered and became part of the EDR.

Of approximately 723,000 imagery scan lines commanded from earth associated with 1036 camera events during the Primary Mission, all but about 9000 were received from 1025 camera events and form part of the Lander Camera Experiment Data Record of this part of the mission. Three camera events from Viking Lander 1 were not received owing to shortened real time relay communication links, and eight were lost owing to a direct communication link problem late in the operation of Viking Lander 2, accounting for 6886 of the missing lines.

At this point, many images still contained bit errors. In some cases, multiple data transmission provided the opportunity to select pixels from two or more transmissions and remove this source of bit error noise. Programs Despike and VL MERGE, operating at IPL, were used for this function. One of the playbacks is despiked, and, rather than replace the pixels by an average of neighboring pixels, they are replaced by the value of the corresponding pixels in the second playback. Figure 4 illustrates the results of this processing, which produced, as the EDR, an ordered, cataloged, verified digital record of the imagery data received from Mars. This will be the basis of the Experiment Data Record Picture Catalog to be published.

SECOND-ORDER IMAGE-PROCESSING SYSTEM

The Image Processing Laboratory provided computer resources required to support both batch and interactive image processing. Non-real time processing of imagery in support of science objectives had been performed by the Jet Propulsion Laboratory (JPL) Image Processing Laboratory on prior missions [Rindfleisch et al., 1971; Green et al., 1975; Levinthal et al., 1973; Soha et al., 1975]. The Viking requirements represented an increased emphasis on flexible, adaptive, and interactive image processing in comparison to previous missions, a new requirement for color processing, and a considerably greater throughput capacity.

In order to meet the above demands of the Viking Lander mission the computer facilities at IPL were substantially upgraded. The IBM 360/44 central processing unit (CPU), used on prior missions [Levinthal et al., 1973], was replaced with an IBM 360/65 CPU, and 800 Mbyte of on-line disk storage was added to the configuration. A Digital Equipment Corporation PDP 11/40 minicomputer was interfaced to a channel on the 360/65 and was used to support a variety of interactive terminals and image display systems [Jepsen, 1976]. The available terminals included both dial-up terminals and direct line Imlac CRT terminals. The image display systems include a Ramtek GX-100B system (black-and-white system with graphics overlay and track ball/cursor unit with resolution of $640 \times 512$ picture elements), a Comtal 8003 system (a system that displays either three separate black-and-white images or a single color image, with track ball/cursor unit with resolution of $512 \times 512$ picture elements), and a Comtal 1024 system (a black-and-white system with graphics overlay and track ball/cursor unit with resolution of $1024 \times 1024$ picture elements). The overall configuration of the IPL computer facility is shown in Figure 1 of Ruiz et al. [1977]. The details of the hardware and software design of the interactive terminal and display system controlled by the PDP 11/40 are described by Jepsen [1976].

A specially designed video system supports stereo viewing and computer-assisted stereo mapping. It was developed at Stanford University to interface to the Ramtek GX-100B system at IPL for use with the application program Ranger. The details of its design and functioning are described by Liebes and Schwartz [1977].

The IBM 360/65 operates under the IBM OS/MVT operating system, and the Time Sharing Option (TSO) is used to support interactive applications. The PDP 11/40 operating system is Comtex, and all terminals and image display systems emulate standard IBM-supported devices when controlled via the Comtex system.

The Image Processing Laboratory began development for Viking operations with a large inheritance of existing applications software that had been successfully utilized to support previous JPL flight projects. The major developments required for Viking support included the following classes of software: (1) an executive system for control of interactive image-proc-
Fig. 2. Flow chart indicating the steps involved in the generation of the lander camera data base and lander image processing. The dashed path indicates the flow of the non-real time data prior to their merging with the real time data stream. The data base is generated on the Disk System, from which it is accessed for the subsequent processing steps.
processing sequences, (2) an automated method for cataloging auxiliary data relating to each camera event, the sequence of programs used to process a particular camera event, and the numerical parameters used, (3) a capability for interrogating the results of the cataloging, and (4) new applications programs required to accommodate the unique features of the Viking Lander facsimile camera and particular mission objectives.

The new software executive developed for interactive processing, Libexec, represents an outgrowth of the Vicar image-processing system used at JPL for 9 years in batch-processing applications. The existing Vicar system, operational on the 360/44 computer, was modified to operate under the OS/MVT operating system and to incorporate the automated cataloging functions of Libexec. The Mark IV data base management system (acquired from Informatics Inc.) was used to maintain and search the picture catalogs created under Libexec and Vicar. An interactive software package, OQL, was also acquired from Informatics Inc. which enables interactive interrogation of the picture catalogs by using the TSO.

An extensive set of applications programs were developed to support second-order Viking Lander image-processing activities. Software development began during lander camera calibration and system test activities. Several programs were written to evaluate lander camera radiometric response and geometric distortion characteristics by using test data recorded by the camera manufacturer (Itek Corporation) and system level calibration data acquired with the cameras mounted on the flight spacecraft prior to launch. Additional programs were written to generate camera calibration data regarding camera performance characteristics. These data were later used by a variety of programs to support flight science analysis.

Although the Viking Lander cameras are less susceptible to the types of distortions returned by vidicon systems utilized on
previous missions, it is still necessary to remove the small amounts of radiometric and geometric distortions for many applications. The program Geocam removed camera system induced geometric distortion from the imagery, and the program Radcam converted raw camera output into standard radiometric units.

Several other geometric transformations were required for lander applications. Because the facsimile camera samples at uniform intervals in solid angle space, objects in the scene appear in the image with their true shapes distorted. The Geotran program reprojected lander images so that shape distortion was removed and objects would appear as if they were acquired by a film plane camera. The same program was used to project images so that hard-copy imagery could be mosaicicked on a cylindrical surface for viewing with correct shape representation. Geotran could also provide an overhead view of a scene imaged with the lander camera by using topographic information as input.

After the spacecraft landed, it was apparent from the shape of the horizons that the landers were tilted (this was a much larger effect for the second lander than for the first). By means of horizon information a geometric transformation was performed that removed the scene distortion caused by the tilt of the landers.

A series of programs (CLRBALVL and GREFIX) were written to color-balance imagery from sets of six images of the scene: three in visible color and three in infrared. The programs accounted for the quantitative radiometric performance of the camera systems and for the fact that the three visible color diodes also responded to some extent to infrared wavelengths. An additional correction was required to remove nonlinearities in the color film and print paper. The details of the spectrophotometric analysis are described by Huck et al. [1977].

Another major activity within IPL was the production of computer-generated mosaics of the high-resolution imagery recorded over several months. Several mosaics were constructed by using imagery from both cameras on both landers.
Fig. 5. Portion of the same image as is shown in Figure 4 (11A077/011). The data have been subjected to a linear contrast stretch to maximize the Martian surface detail. This is an example of the output of the TDR processing (version A, see text).
Each mosaic is an ensemble of images taken at about the same
time of day: 0700 and 1400 for Viking Lander 1 and 0700,
1200, and 1730 for Viking Lander 2.

**Film Recording for Second-Order Processing**

Four film recorders were used in recording second-order
versions of the lander imagery onto film. Two 70-mm black-
and-white film recorders utilizing a flying spot cathode-ray
tube to expose imagery onto film spot by spot were employed.

An Optronics black-and-white recorder was used for playback
whenever large format and/or high geometric precision
was required. This recorder records onto 8 × 10 inch sheet film
and was used for mosaics and stereo pair production.

The Viking Ground Reconstruction Equipment (GRE) re-
corder was used for both black-and-white and color imagery.
This recorder was developed by the Itek Corporation. By
means of a laser as the light source, three spectral lines are
separated, individually modulated, and then recombined to
produce a single beam for color recording. For black-and-
white recording, only the green band is used.

**TDR Processing**

The EDR (described earlier) was the data used to generate
the final photoproducts, which are the Team Data Record and
which are furnished to others through the National Space
Science Data Center (NSSDC). Different IPL software pro-
grams were used to produce computer-processed versions of
the raw data, appropriate to the peculiarities of each camera
event. After much experimentation, three enhancement al-
gorithms were chosen that provided images suitable for the
detailed geological interpretation of lander images. Version A
consists of a simple linear contrast stretch, chosen for each
image to maximize Martian surface detail. Version B is a
logarithmic contrast stretch (\(DN_{out} = A + B \log DN_{in}\)) which
'extends' the darker levels more than the lighter, the result
being more representative of one's visual impression of the
scene than a linear contrast stretch. Version C is a con-
volutional filter algorithm which applies a truncated modula-
tion transfer function correction followed by a linear contrast
stretch identical to that used in version A. Program MASKVL
generated the scales, annotation, histograms, and appropriate
format for the GRE. The GRE was used with an 8-mil spot
to produce the negatives. For camera events of more than
900 lines the image was broken into multiple overlapping
negatives. These negatives were used, at MTSP, to produce
a master positive from which all the photoproducts for final
distribution were derived. Figure 5 illustrates these products.

**Data Cataloging and Management**

The inventory of camera events and the experiment parame-
ters associated with them were cataloged and managed with
the Mark IV system described above.

The system has three major inputs. A summary of the com-
manded images was accumulated from the Lander Sequencing
Software (LEQ). This summary provided Fovlip and IPL
with an expected camera event list from which control infor-
mation could be generated for processing the images. A record
of the first-order image processing was acquired via an inter-
face with Fovlip. It provided a list of the transmitted images,
the engineering parameters, and the first-order photoproducts.
A second-order image-processing record was received from the
Vicar/IPL system supplying tape storage information, proc-
essing parameters, and photoproduct identifiers.

The major catalogs generated are as follows: (1) a complete
description of all camera events comprising the EDR sorted by
camera event number, (2) camera events sorted by type (see
Table 1), (3) high-resolution events sorted by time of day on
Mars, and (4) events sorted by elevation pointing angle and
starting azimuth.

For the Primary Mission the above listings together with an
offset reproduction of each camera event suitable for identi-
fication purposes will be published as the Viking Lander Cam-
era System Experiment Data Record Picture Catalogue and
will be available through the Langley Research Center, Hamp-
ton, Virginia 23665, or the NSSDC, Code 601, Goddard Space
Flight Center, Greenbelt, Maryland 20771 (NASA document
RP-1007).

**Appendix: Glossary of Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digifax</td>
<td>Digital Facsimile Printing Device</td>
</tr>
<tr>
<td>DSN</td>
<td>Deep Space Network</td>
</tr>
<tr>
<td>EDR</td>
<td>Experimental Data Record</td>
</tr>
<tr>
<td>Fovlip</td>
<td>First-Order Viking Lander Image Processing</td>
</tr>
<tr>
<td>GRE</td>
<td>Ground Reconstruction Equipment</td>
</tr>
<tr>
<td>IPL</td>
<td>Image Processing Laboratory</td>
</tr>
<tr>
<td>ISDR</td>
<td>Intermediate System Data Record</td>
</tr>
<tr>
<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
</tr>
<tr>
<td>LSEQ</td>
<td>Lander Sequencing Software</td>
</tr>
<tr>
<td>MTIS</td>
<td>Mission and Test Imaging System</td>
</tr>
<tr>
<td>MTPS</td>
<td>Mission and Test Photographic System</td>
</tr>
<tr>
<td>NSSDC</td>
<td>National Space Science Data Center</td>
</tr>
<tr>
<td>RESTIMG</td>
<td>Restore Image Data</td>
</tr>
<tr>
<td>SDR</td>
<td>System Data Record</td>
</tr>
<tr>
<td>TDR</td>
<td>Team Data Record</td>
</tr>
<tr>
<td>TLMP</td>
<td>Telemetry Processing Program</td>
</tr>
<tr>
<td>VMCC</td>
<td>Viking Mission Control and Computing Center</td>
</tr>
</tbody>
</table>

**Acknowledgments.** The first-order processing system (Fovlip) was
written by L. G. Green, H. F. Lesh, and E. Morita at JPL. Many
individuals at the JPL Image Processing Laboratory developed and
implemented the second-order image-processing programs and capa-
bilities. The following identifies areas of major responsibilities: Li-
hexec; Michael Girard; library and catalog programs, Michael Martin,
Edward Y. S. Lee, and Ted Sepplauski; calibration and distortion
removal, Michael Wolf; ranging, Arnold Schwartz; color reconstruc-
tion, William Benton; mosaic production, Joseph Berry and Steven
Albers; data logging and graphics, Rodger Philips; TDR formatting
and production, Susan LaVoie and Deborah Spurlock; PDP 11/40
software, Paul Jepsen; IPL facility upgrade, Joel Seidman; and IPL
management and administration, Don Lynn. The Viking Image Pro-
cessing System, as a whole, was under the management responsibil-
y, at JPL, of Kermit Watkins of the Viking Project Office and the direc-
tion of Elliott Levinthal and Sidney Liebes, representing the
Lander Imaging Team. This paper presents the results of one phase of
the tasks carried out at the Jet Propulsion Laboratory, California
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Department, Stanford University, under contract NAS-1-9682; and by
the Department of Geological Sciences, Brown University, under con-
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nautics and Space Administration.

**References**

Green, W. B., P. L. Jepsen, J. F. Kreuzer, R. M. Ruiz, A. A. Schwartz,
and J. B. Seidman, Removal of instrument signature from Mariner

Huck, F. O., H. F. McCall, W. R. Patterson, and G. R. Taylor, The

Huck, F. O., D. J. Jobson, S. K. Park, S. D. Wall, R. E. Arvidson,
W. R. Patterson, and W. D. Benton, Spectrophotometric and
color estimates of the Viking lander sites, *J. Geophys. Res.*, 82,
this issue, 1977.

Jepsen, P. L., The software/hardware interface for interactive image

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