planning in response to information on local conditions observed by the rovers and in response to deviations of rovers from planned paths.

Once a rover reached a target, it would acquire close-up images and possibly other sensory information about the target. Features would be extracted from the image data and from any other sensory data to characterize the site. Then the rover would be commanded to move on to the next target. The exploratory process as described thus far would be repeated by each rover until all targets in the terrain area of interest had been examined. A partly functional model of such a system operates in a 4-by-5-ft (1.22-by-1.52-m) test bed that simulates terrain.

The test bed is strewn with variously colored and shaped blocks to simulate targets and obstacles. An overhead view is provided by a camera on a mast above the center of the test bed. Miniature rovers equipped with cameras maneuver on the simulated terrain. At the time of reporting the information for this article, efforts to develop a more fully functional model for testing advanced hardware and software designs were under way.

This work was done by Wolfgang Fink, Tien-Hsin Chao, Jay Hanan, and Mark Tarbell of Caltech, and James M. Dohm of the University of Arizona for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-40428, volume and number of this NASA Tech Briefs *issue, and the page number.*

A 640 × 512-Pixel Portable Long-Wavelength Infrared Camera

This hand-held camera shows promise for imaging at high thermal resolution.

NASA's Jet Propulsion Laboratory, Pasadena, California

This **Image Was Generated From One Frame** of video readout, at frame rate of 30 Hz, from the camera described in the text.

A portable long-wavelength infrared electronic camera having a cutoff wavelength of 9 µm has been built around an image sensor in the form of a 640 × 512-pixel array of Al$_x$Ga$_{1-x}$As/GaAs quantum-well infrared photodetectors (QWIPs). This camera is an intermediate product of a continuing program to develop high-resolution, high-sensitivity infrared cameras.

Major features of the design and fabrication of the camera are the following:

- The QWIPs are of the bound-to-quasi-bound type, for which the thermionic component of dark current is less than for other types. [This concept was discussed in more detail in "Bound-to-Quasi-Bound Quantum-Well Infrared Photodetectors" (NPO-19633), *NASA Tech Briefs*, Vol. 22, No. 9 (September 1998), page 54.]
- The basic multiple-quantum-well (MQW) structure of the QWIP array in the present camera is a stack of about 50 identical quantum-well bilayers. Each bilayer comprises (1) a 45-Å-thick well layer of GaAs n-doped at a density ≈5 × 10^{17} cm^3 and (2) a 500-Å-thick barrier layer of Al$_{0.3}$Ga$_{0.7}$As.
- The MQW structure is sandwiched between 0.5-µm-thick top and bottom contact layers of GaAs doped similarly to the well layers.
- All of the aforementioned layers were fabricated on a semi-insulating GaAs substrate by molecular-beam epitaxy. A 300-Å-thick Al$_{0.3}$Ga$_{0.7}$As stop-etch layer was grown on top of the top contact layer. A 0.7-µm-thick GaAs cap layer was grown on top of the stop-etch layer. A cross-grating structure for coupling light into the QWIPs was fabricated in the cap layer by photolithography and dry chemical etching. [The cross-grating-coupler concept was described in "Cross-Grating Coupling for Focal-Plane Arrays of QWIPs" (NPO-19657), *NASA Tech Briefs*, Vol. 22, No. 1 (January 1998), page 6a.]
- The array of 640 × 512 photodetectors, with a pitch of 25 µm and a pixel size of 23 × 23 µm^2, was then formed by wet chemical etching through the MQW layers into the bottom contact layer. The cross gratings on the tops of the detectors thus formed were covered with Au/Ge and Au for ohmic contact and reflection.
- Indium bumps were evaporated onto the top (Au/Ge)/Au layers, then the bumps were used to bond (hybridize) the array to a silicon-based complementary metal oxide semiconductor (CMOS) integrated-circuit 640 × 512 readout multiplexer.

As described thus far, with the exception of the sizes and numbers of pixels, the QWIP-array/readout-multiplexer is nearly identical to that of the prior camera. An important difference is that in the present camera, the readout multiplexer is part of a commercial infrared-camera body that includes two "back-end" video-signal-processing circuits and a germanium lens of 100-mm focal length and 5.5° field of view. The lens is designed to be transparent in the wavelength range of 7 to 14 µm (compatible with a nominal QWIP operational wavelength of 8.5 µm). The digital acquisition resolution of the camera circuitry is 14 bits, so that the instantaneous dynamic range of the camera is 16,384. However, the dynamic range of the QWIPs is 85 dB.

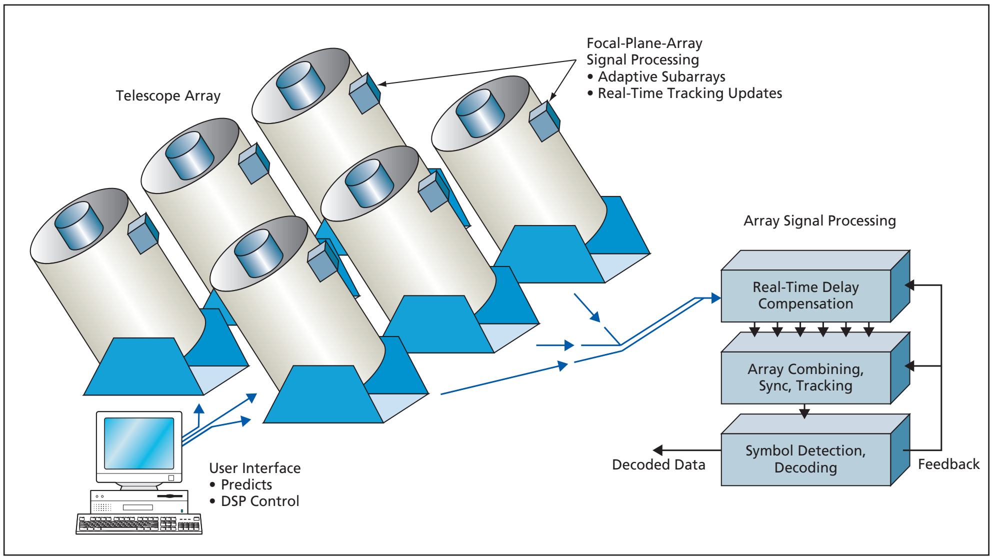
The camera has been demonstrated to produce excellent video imagery (see figure). Whereas prior infrared cameras based on detectors of different types have been limited to thermal resolutions in excess of 30 mK, this camera is expected to exhibit significantly finer thermal resolution: On the basis of single-pixel test data, a noise equivalent differential temperature of 8 mK is expected in operation at a temperature at 65 K with *f*/2 (focal length ÷ aperture diameter = 2) optics and a background temperature of 300 K. The array of photodetectors has exhibited background-limited performance at an operating temperature of 72 K using the same optics and background conditions. Optimization of operating conditions (including frame rate, integration time, and QWIP bias voltage) is expected to lead to even better performance.

This work was done by Sarath Gunapala, Sumith Bandara, John Liu, and Sir B. Rafol of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30624

An Array of Optical Receivers for Deep-Space Communications

This array would be considerably simpler and less expensive to implement.

NASA's Jet Propulsion Laboratory, Pasadena, California



A **Conceptual Block Diagram of the Optical-Array Receiver** identifies key receiver functions.

An array of small optical receivers is proposed as an alternative to a single large optical receiver for high-data-rate communications in NASA's Deep Space Network (DSN). Because the telescope for a single receiver capable of satisfying DSN requirements must be greater than 10 m in diameter, the design, building, and testing of the telescope would be very difficult and expensive. The proposed array would utilize commercially available telescopes of 1-m or smaller diameter and, therefore, could be developed and verified with considerably less difficulty and expense.

The essential difference between a single-aperture optical-communications receiver and an optical-array receiver is that a single-aperture receiver focuses all of the light energy it collects onto the surface of an optical detector, whereas an array receiver focuses portions of the total collected energy onto separate detectors, optically detects each fractional energy component, then combines the electrical signal from the array of detector outputs to form the observable, or "decision statistic," used to decode the transmitted data.

A conceptual block diagram identifying the key components of the optical-array receiver suitable for deep-space telemetry reception is shown in the figure. The most conspicuous feature of the receiver is the large number of small- to medium-size telescopes, with individual apertures and number of telescopes selected to make up the desired total collecting area. This array of telescopes is envisioned to be fully computer-controlled via the user interface and prediction-driven to achieve rough pointing and tracking of the desired spacecraft. Fine-pointing and tracking functions then take over to keep each telescope pointed toward the source, despite imperfect pointing predictions, telescope-drive errors, and vibration caused by wind.

The turbulence-degraded image of the laser source in each telescope would be sensed by a focal-plane photodetector array, the outputs of which would then be digitized. The digitized array outputs would be synchronized and combined by field-programmable gate-array circuits that would execute digital-signal-processing algorithms, for both the individual telescopes and the entire array. Symbol detection and decoding operations would then be carried out on the synchronized and combined array signal. Receiver parameters would be controlled adaptively at each telescope to accommodate changing atmospheric conditions, thus optimizing the performance of the optical-array receiver in real time.

This work was done by Victor Vilnrotter, Chi-Wung Lau, Meera Srinivasan, Kenneth Andrews, and Ryan Mukai of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1). NPO-40190*