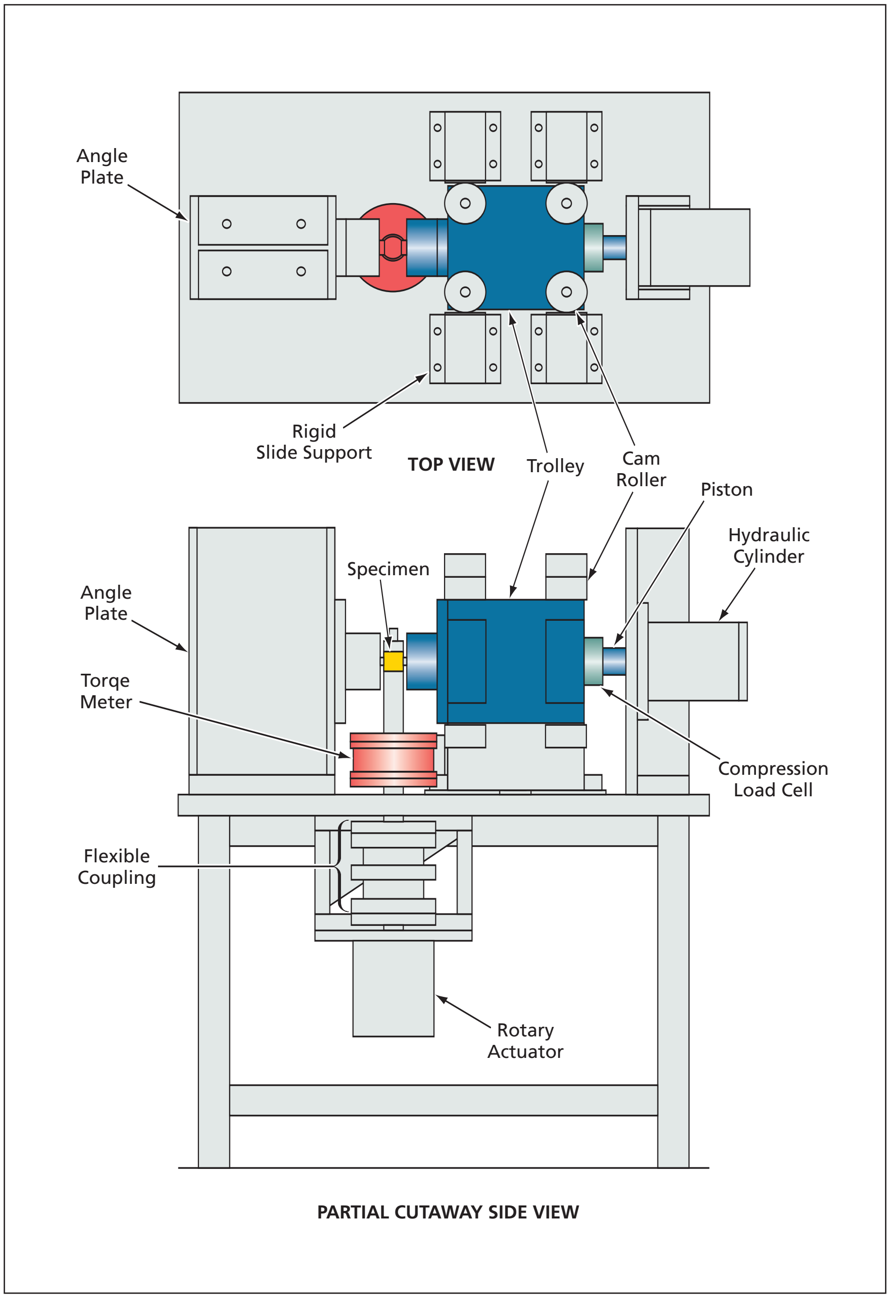


Figure 1. This **Monoball-Bearing-Testing** apparatus subjects a specimen to oscillating rotation at a controlled frequency and amplitude and to a controlled load perpendicular to the axis of rotation.

The apparatus includes a data-acquisition-and-control system (see Figure 2), based on a personal computer and a microprocessor, that controls a test from beginning to end and calculates, displays, and stores test information. An operator enters test instructions into the personal computer, which runs software that translates the instructions into commands. The microprocessor transmits the commands to electronic servocontrollers. Once the operator has initiated a test by entering the instructions, no further intervention by the operator is necessary to ensure successful completion of the test.

The servocontrollers control servovalves that, in turn, control pressures and flows of hydraulic fluids in the hydraulic rotary actuator and the load-applying hydraulic cylinder. Digital signals generated by sensors are fed back to the microprocessor; analog signals from sensors and actuators are fed back to the computer via a fast analog-to-digital converter, and the computer relays these signals to the microprocessor if so required by the test instructions.

The signals from the compression load cell, the torque meter, and the angular-position sensor are used by the control system as both control feedback signals and data. The apparatus measures the applied load, the resisting torque, and the angle of rotation, and the computer calculates the number of cycles and the coefficient of friction in real time. The data are also stored for postprocessing.

This work was done by Phillip B. Hall of **Marshall Space Flight Center** *and Howard L. Novak of USBI/USA Co. Further information is contained in a TSP (see page 1).*

This invention has been patented by NASA (U.S. Patent No. 6,886,392). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31706-1.

High-Speed Laser Scanner Maps a Surface in Three Dimensions

Surface flaws can be scanned automatically and displayed in real time.

Ames Research Center, Moffett Field, California

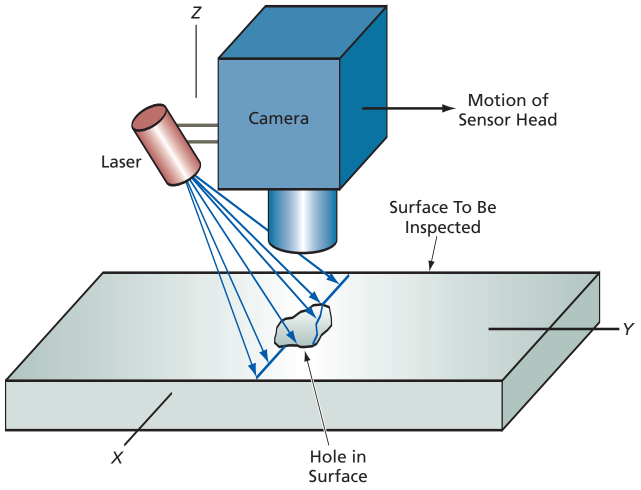
A scanning optoelectronic instrument generates the digital equivalent of a three-dimensional (X,Y,Z) map of a surface that spans an area with resolution on the order of 0.005 in. (≈0.125mm). Originally intended for characterizing surface flaws (e.g., pits) on space-shuttle thermal-insulation tiles, the instrument could just as well be used for similar purposes in other settings in which there are requirements to inspect the surfaces of many objects. While many commercial instruments can perform this surface-inspection function, the present instrument offers a unique combination of capabilities not available in commercial instruments.

This instrument utilizes a laser triangulation method that has been described previously in *NASA Tech Briefs* in connection with simpler related instruments used for different purposes. The instrument includes a sensor head comprising a monochrome electronic camera and two lasers. The camera is a high-resolution unit with digital output. The sensor head is mounted on a computer-controlled, servomotor-actuated translation stage at a fixed height above the nominal X,Y plane. Scanning is effected by using the translation stage to position the sensor head repeatedly at small, equal increments of Y until the entire surface has been traversed in the Y dimension.

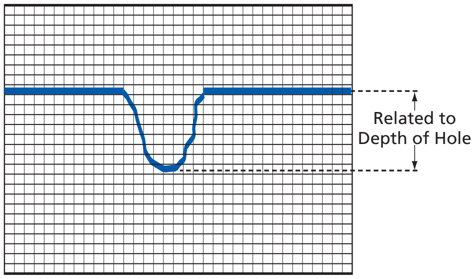
Figure 1 depicts the basic optical layout for the laser triangulation. The camera is aimed downward (in the –Z direction). Each laser is equipped with optics to project an X-oriented line onto the nominal X,Y plane at a nominal Y position, and is tilted at a known angle of incidence. At each incremental position along the scan, the camera records the image of the laser-illuminated line on the surface. The camera is oriented so that pixel rows are X-oriented and pixel columns are Y-oriented.

The X coordinate of each surface point in the image of the line is obtained by direct correspondence between X and the pixel-column number. Any deviation of the laser-illuminated line from its nominal Y position (and, hence, its nominal pixel-row number) indicates a deviation of the surface from the nominal X,Y plane. The image is digitized and the depth (Z) of the surface at each point along the line is calculated from the Y (pixel-row) deviation by use of a standard triangulation equation. The Y position of each point along the line is obtained from a combination of (1) the known Y position along the scan, (2) the aforementioned Y deviation of the illuminated line, and (3) another standard triangulation equation to correct for the effect of Z on the apparent Y position. The process as described thus far is repeated at each increment of position along the scan. The data collected at all the increments of position are assembled to produce a three-dimensional (3D) map of the surface.

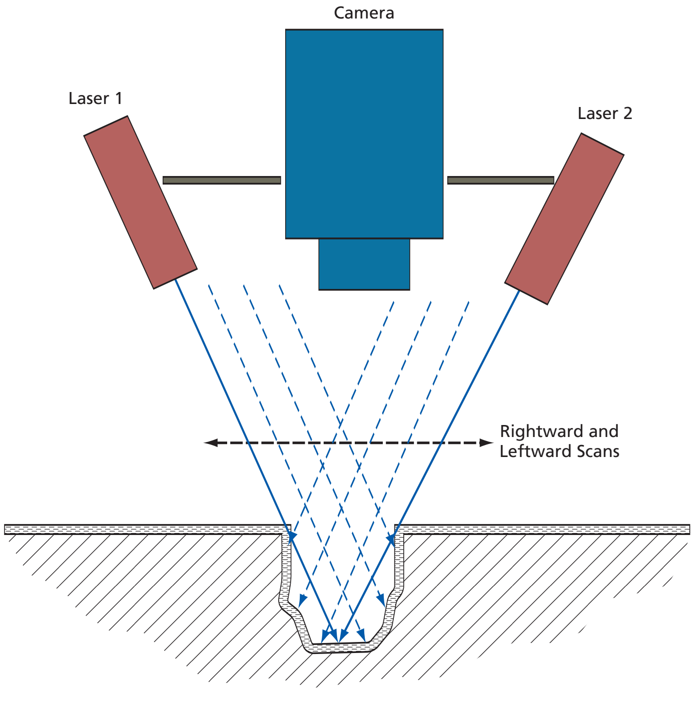
Two lasers are used (but not simultaneously) in conjunction with a dual-scan scheme to overcome shadowing at overhangs, edges of steep holes, and the like. As depicted in the lower part of Figure 1, a surface is scanned twice: from left to right and from right to left. During the scan toward the right, the left laser is used; during the scan toward the left, the right laser is used. Both lasers illuminate common areas (typically, a central area at the bottom of a hole), and each laser illuminates an edge area that may be shaded from the other laser. Surface points in the hole that may be shaded from the left laser during the rightward scan are illuminated by the right laser during the leftward scan, and vice versa.



OPTICAL LAYOUT
(FOR CLARITY, SECOND LASER OMITTED FROM THIS VIEW)



TYPICAL CAMERA IMAGE OF LASER-ILLUMINATED LINE THAT PASSES THROUGH HOLE



DUAL SCAN

Figure 1. The **Camera Observes the Line of Light** projected on the surface of a plate by a tilted laser. Any deviation of the line from its nominal position is indicative of a hole or bump on the surface.

Figure 2 is a block diagram of the electronic system of the instrument. The system includes an onboard processor, plus an external personal computer (PC) for further processing of the acquired data and displaying resulting depth maps. The processor is capable of generating 3D data in real time, eliminating the need for both onboard memory and post-processing to generate 3D data. The 3D data output of the onboard processor is sent to the PC via a high-speed serial data-communication link. By reducing the computational burden on the PC, onboard preprocessing enables the PC to create and display 3D images in real time during scanning.

This work was done by Joseph Lavelle and Stefan Schuet of **Ames Research Center**. *Further information is contained in a TSP (see page 1).*

This invention is owned by NASA and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-14652-1.

Electro-Optical Imaging Fourier-Transform Spectrometer

Size, weight, and vibration are reduced by eliminating moving parts.

NASA's Jet Propulsion Laboratory, Pasadena, California

An electro-optical (E-O) imaging Fourier-transform spectrometer (IFTS), now under development, is a prototype of improved imaging spectrometers to be used for hyperspectral imaging, especially in the infrared spectral region. Unlike both imaging and non-imaging traditional Fourier-transform spectrometers, the E-O IFTS does not contain any moving parts. Elimination of the moving parts and the associated actuator mechanisms and supporting structures would increase reliability while enabling reductions in size and mass, relative to traditional Fourier-transform spectrometers that offer equivalent capabilities. Elimination of moving parts would also eliminate the vibrations caused by the motions of those parts.

Figure 1 schematically depicts a traditional Fourier-transform spectrometer, wherein a critical time delay is varied by translating one the mirrors of a Michelson interferometer. The time-dependent optical output is a periodic representation of the input spectrum. Data characterizing the input spectrum are generated through fast-Fourier-transform (FFT) post-processing of the output in conjunction with the varying time delay.

In the E-O IFTS, the Michelson interferometer optics and the bulky, slow translation mechanism are replaced with a solid-state time-delay/interferometer assembly. Included in the assembly (see Figure 2) are an input polarizer, an input passive quarter-wave plate (phase shifter), a series of N liquid-crystal-based electro-optical achromatic half-wave switches (S_1, S_2, . . . S_N) interspersed with a series of ($N + 1$) passive birefringent wave retarders (Γ_1, Γ_2, . . . Γ_N), and an output polarizer.

The assembly can be regarded as consisting largely of a series of overlapping building blocks, each consisting of two of the passive wave retarders and the achromatic half-wave switch between them. By electro-optically rotating the orientation of the switch to an angle of either 0° or 45° with respect to the input polarization, one can cause the total retardation of the waves passing through the unit to be either the difference or the sum, respectively, of the retardations introduced by the individual retarders. Each retarder following the first one is made twice as thick as (to introduce twice the retardation of) the one preceding it. Hence, by means of binary actuation of the switches among all combinations of sums and differences, it is possible to obtain 2^N different retardation values in increments of the smallest such value and thereby to obtain an arithmetic progression of small time-delay steps.

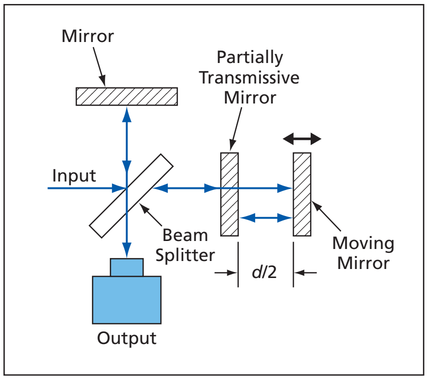


Figure 1. A **Traditional Fourier-Transform Spectrometer** includes a Michelson interferometer in which a time delay d/c (where c is the speed of light) is varied by varying the distance $d/2$ between two mirrors.

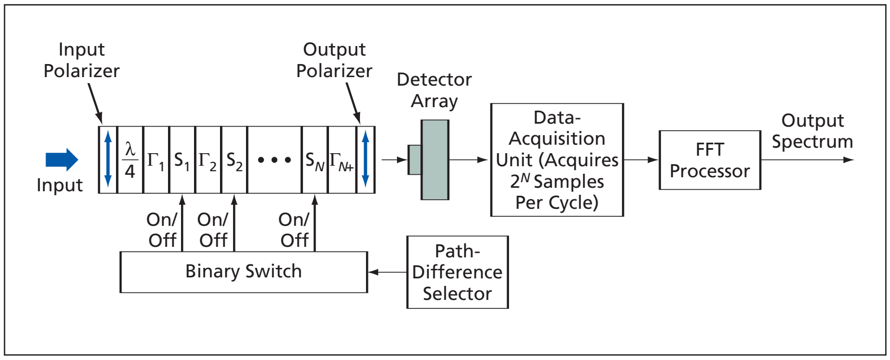


Figure 2. The **E-O IFTS** is built around a solid-state time-delay/interferometer assembly that contains no moving parts.

This work was done by Tien-Hsin Chao and Hanying Zhou of Caltech 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-42371, volume and number of this NASA Tech Briefs *issue, and the page number.*