targets, all of which are corner-cube retroreflectors. The targets are covered with filters that pass the 850-nm light and block the 800-nm light. The short-range targets are positioned around, and are smaller than, the long-range targets. The short-range targets are equipped with plano-concave lenses; this is necessary to make these targets visible to the camera over a range of angles at distances <1.5 m.

The operating cycle begins with the firing of the 800-nm lasers and capturing the resulting frame of video data; this frame represents a background image because the target filters block the returns from the targets at the 800-nm wavelength. Then the 850-nm lasers are fired to capture another frame of video data; this frame represents an image that contains the target spots because target filters allow reflection at the 850-nm wavelength. Because the camera operates at a standard 30-Hz video frame rate, the time between frames is short enough to reduce motion-induced noise to an acceptably low level.

To remove the background (and thereby obtain target-image data alone), the DSP subtracts the first frame of video data from the second, and then subtracts a threshold from the resulting frame. Then the DSP processes the image data to group the illuminated pixels into spots and recognizes the targets by associating the patterns of spots with the known target patterns. The number of targets and their positions in the assembly are designed so that the relative positions and orientations of the sensor head and the target assembly can be computed by iterative numerical solution of the equations that relate the camera/sensor-head geometry to the positions of the target spots in the video image.

This work was done by Richard T. Howard, Thomas C. Bryan, and Michael L. Book of **Marshall Space Flight Center** *and John L. Jackson of Micro Craft, Inc. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. MFS-31283*

Hybrid Piezoelectric/Fiber-Optic Sensor Sheets

Multiple sensors of different types could be installed on or in structures.

Marshall Space Flight Center, Alabama

Hybrid piezoelectric/fiber-optic (HyPFO) sensor sheets are undergoing development. They are intended for use in nondestructive evaluation and long-term monitoring of the integrity of diverse structures, including aerospace, aeronautical, automotive, and large stationary ones. It is anticipated that the further development and subsequent commercialization of the HyPFO sensor systems will lead to economic benefits in the form of increased safety, reduction of life-cycle costs through real-time structural monitoring, increased structural reliability, reduction of maintenance costs, and increased readiness for service.

The concept of a HyPFO sensor sheet is a generalization of the concept of a SMART Layer™, which is a patented device that comprises a thin dielectric film containing an embedded network of distributed piezoelectric actuator/sensors. Such a device can be mounted on the surface of a metallic structure or embedded inside a composite-material structure during fabrication of the structure. There is has been substantial interest in incorporating sensors other than piezoelectric ones into SMART Layer™ networks: in particular, because of the popularity of the use of fiber-optic sensors for monitoring the "health" of structures in recent years, it was decided to incorporate fiber-optic sensors, giving rise to the concept of HyPFO devices.

The development of HyPFO devices has included the development of novel techniques to incorporate fiber-optic sensors into SMART Layer™ devices, as well as the development of ancillary optoelectronic hardware and software. The advantages expected to be afforded by HyPFO sensor sheets include the following:

- It would not be necessary to install each fiber-optic or piezoelectric sensor individually on a structure. Sensors would be embedded in thin, flexible films that could easily be mounted on structures in minimal amounts of installation time.
- Because piezoelectric and fiber-optic transducers exploit different signal-transmission mechanisms, interference between piezoelectric and fiber-optic transducers is expected to be minimal.
- Multiple measurements could be performed. For example, fiber-optic sensors could be used to measure temperatures, piezoelectric transducers could be used to measure concentrations of hydrogen, and sensors of both types could be used to monitor acoustic emissions.

This work was done by Mark Lin and Xinlin Qing of Acellent Technologies, Inc., for **Marshall Space Flight Center**. *For further information, contact the company at info@acellent.com.*
MFS-31846

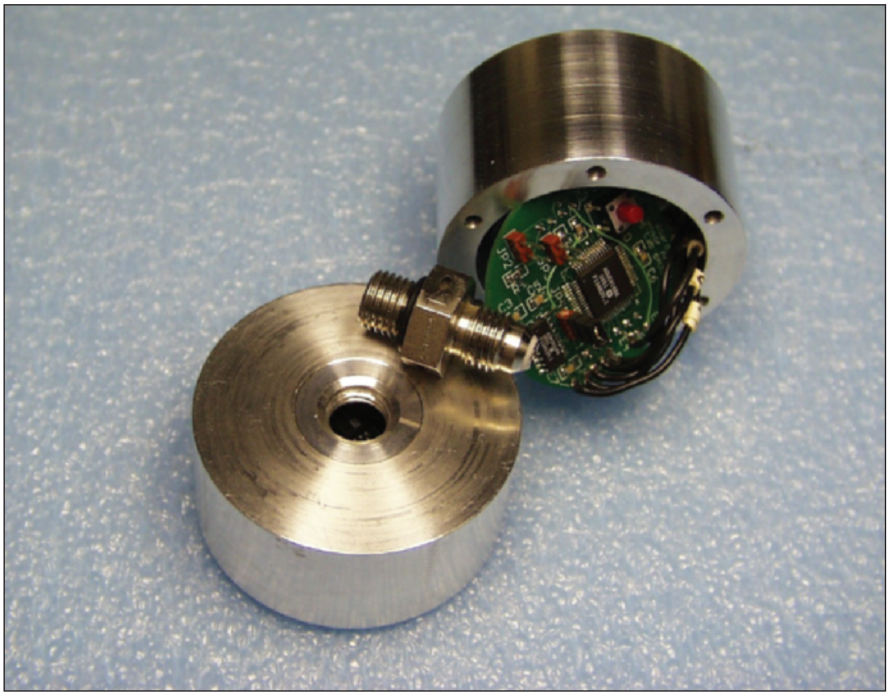
Multisensor Arrays for Greater Reliability and Accuracy

Calibrations and replacements are needed less frequently than they are for single sensors.

John F. Kennedy Space Center, Florida

Arrays of multiple, nominally identical sensors with sensor-output-processing electronic hardware and software are being developed in order to obtain accuracy, reliability, and lifetime greater than those of single sensors. The conceptual basis of this development lies in the statistical behavior of multiple sensors and a multisensor-array (MSA) algorithm that exploits that behavior. In addition, advances in microelectromechanical systems (MEMS) and integrated circuits are exploited. A typical sensor unit according to this concept includes multiple MEMS sensors and sensor-readout circuitry fabricated together on a single chip and packaged compactly with a microprocessor that performs several functions, including execution of the MSA algorithm.

In the MSA algorithm, the readings from all the sensors in an array at a given



A **Compact Unit Containing Eight Pressure Sensors,** a microprocessor, and other circuitry generates not only a pressure reading of greater than usual precision, but also an assessment of its own reliability and remaining lifetime.

instant of time are compared and the reliability of each sensor is quantified. This comparison of readings and quantification of reliabilities involves the calculation of the ratio between every sensor reading and every other sensor reading, plus calculation of the sum of all such ratios. Then one output reading for the given instant of time is computed as a weighted average of the readings of all the sensors. In this computation, the weight for each sensor is the aforementioned value used to quantify its reliability.

In an optional variant of the MSA algorithm that can be implemented easily, a running sum of the reliability value for each sensor at previous time steps as well as at the present time step is used as the weight of the sensor in calculating the weighted average at the present time step. In this variant, the weight of a sensor that continually fails gradually decreases, so that eventually, its influence over the output reading becomes minimal: In effect, the sensor system "learns" which sensors to trust and which not to trust.

The MSA algorithm incorporates a criterion for deciding whether there remain enough sensor readings that approximate each other sufficiently closely to constitute a majority for the purpose of quantifying reliability. This criterion is, simply, that if there do not exist at least three sensors having weights greater than a prescribed minimum acceptable value, then the array as a whole is deemed to have failed.

Monte Carlo simulations of the MSA algorithm on a computational model of a representative multisensor array have demonstrated that a sensor package equipped to implement the MSA algorithm can monitor its own health and estimate its remaining lifetime. In addition, the simulations showed that the array can have a lifetime up to three times that of a single sensor and the errors in the readings delivered by the MSA algorithm are characterized by error bands smaller than those of a single sensor. As a consequential further benefit, calibrations and replacements are needed less frequently than they are in the cases of single sensors.

The figure shows a prototype sensor MSA unit that includes eight surface-mount pressure transducers and an eight-channel multiplexer circuit on a circular circuit board potted with epoxy in a chamber in a sealed aluminum housing. The housing is fitted with a threaded port that gives access to the chamber. A microprocessor and its supporting electronic circuitry are on a separate board that is plugged into the sensor board. The supporting circuitry comprises almost all of the peripheral circuitry needed to complete the functionality of the sensor package, including a self-calibrating 16-bit analog-to-digital converter, a bandgap voltage reference, ample program flash memory, a nonvolatile data memory, and a serial port for communications.

Upon receiving a command to take a measurement, the microprocessor cycles through the multiplexer to measure the voltage from each pressure transducer. It then converts each transducer voltage to a pressure reading via a linear calibration, using unique calibration coefficients for each transducer. The calibration coefficients are stored in the nonvolatile memory and can be easily updated by means of a simple download routine. The pressure readings are entered into the MSA algorithm.

This work was done by Christopher Immer, Anthony Eckhoff, John Lane, Jose Perotti, John Randazzo, Norman Blalock, and Jeff Rees of Dynacs, Inc. for **Kennedy Space Center**.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Technology Programs and Commercialization Office, Kennedy Space Center, (321) 867-8130. Refer to KSC-12221/359.

Integrated-Optic Oxygen Sensors

Lyndon B. Johnson Space Center, Houston, Texas

Compact optical oxygen sensors with self-calibration capabilities are undergoing development. A sensor of this type features a single-chip, integrated-optic design implemented by photolithographic fabrication of optical waveguides in a photosensitive porous glass. The porosity serves as both a matrix for retention of an oxygen-sensitive fluorescent indicator chemical and a medium for diffusion of oxygen to the chemical from the ambient air to be monitored. Each sensor includes at least one such waveguide exposed to the atmosphere and at least one covered with metal for isolation from the atmosphere. The covered one serves as a reference channel. In operation, the concentration of oxy-