and there has been no wear since the prior measurement, then the present temperature can be determined from the present resonance frequency.

The lower part of the figure depicts another sensor of the present type, containing multiple sets of interdigitated electrodes embedded parallel to the wearing surface in a configuration such that the number of electrode pairs, and thus the capacitance, decreases with the depth of wear. Optionally, one or more of the sets of interdigitated electrodes can be embedded along with a temperature-sensitive dielectric material to obtain a temperature-measurement capability.

This work was done by Stanley E. Woodard of Langley Research Center and Bryant D. Taylor of Swales Aerospace. Further information is contained in a TSP (see page 1). LAR-16591-1

Processing Nanostructured Sensors Using Microfabrication Techniques

Nanostructured sensors have uses in safety, environmental monitoring, fire detection, and security.

John H. Glenn Research Center, Cleveland, Ohio

Standard microfabrication techniques can be implemented and scaled to help assemble nanoscale microsensors. Currently nanostructures are often deposited onto materials primarily by adding them to a solution, then applying the solution in a thin film. This results in random placement of the nanostructures with no controlled order, and no way to accurately reproduce the placement. This method changes the means by which microsensors with nanostructures are fabricated. The fundamental advantage to this approach is that it enables standard microfabrication techniques to be applied in the repeated manufacture of nanostructured sensors on a microplatform.

The fundamental steps are first to define a standard metal electrode pattern of interdigitated fingers with parallel fingers that are saw-toothed. Nanostructures are then added to a standard photoresist to form a dilute solution. The photoresist solution is then applied to the microstructure. Before the solution solidifies, alternating electric fields are applied across the electrodes in order to align the nanostructures on the wafer. Once this photoresist later dries into a film and is processssed, a second layer of metal is deposited on top of the first layer. The effect is to remove photoresist from the metal fingers, but leave the nanostructures that bridge the fingers to be held in place by the top metal layer. Longer nanostructures, which are already aligned across the fingers, will be held in place by the top metal.

This buries the contacts of the nanostructures that are bridging the fingers between two layers of metal. The result is a microsensor fabricated using microfabrication techniques with aligned nanostructures bridging the electrodes and buried electrical contacts.

Possible applications include emissions monitoring, leak detection, engine monitoring, security, fire detection, extra-vehicular-activity (EVA) applications, personal health monitoring, and environmental monitoring. Because this process is compatible with low temperatures and thin-film supports, it can be used in thin films for conductive coatings requiring electrical connections.

A proof-of-concept of this approach was demonstrated using alumina as the substrate, metals such as platinum as the bottom electrode and titanium as the top metal layer, and both multiwalled carbon nanotubes and metal oxide nanowires as the nanostructured material.

This work was done by Gary W. Hunter, Randall L. VanderWal, Laura J. Evans, and Jennifer C. Xu of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18418-1.

Optical Pointing Sensor

The sensor can be used as a digitizer of physical objects to extract shape data.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The optical pointing sensor provides a means of directly measuring the relative positions of JPL's Formation Control Testbed (FCT) vehicles without communication. This innovation is a steerable infrared (IR) rangefinder that gives measurements in terms of range and bearing to a passive retroreflector. Due to its reduced range of motion, the range and bearing measurements are on the order of 10 times better than those of the existing sensor system.

The retroreflector is placed on one robot, and the rangefinder and steering optics are on another robot. The measurements are available on the rangefinder-mounted robot, giving it relative position knowledge to the retroreflector.

The system is composed of an HeNe pointing laser, a SICK IR laser rangefinder, a two-axis fast steering mirror, a shear sensor, and a far-field retroreflector (see figure). The pointing laser is injected into the optical path using a beam splitter and bounces off the steering mirror toward the retroreflector. If the retroreflector is hit by the pointing laser, the beam is returned with the exact opposite direction. When the beam impact with the retroreflector is non-central,
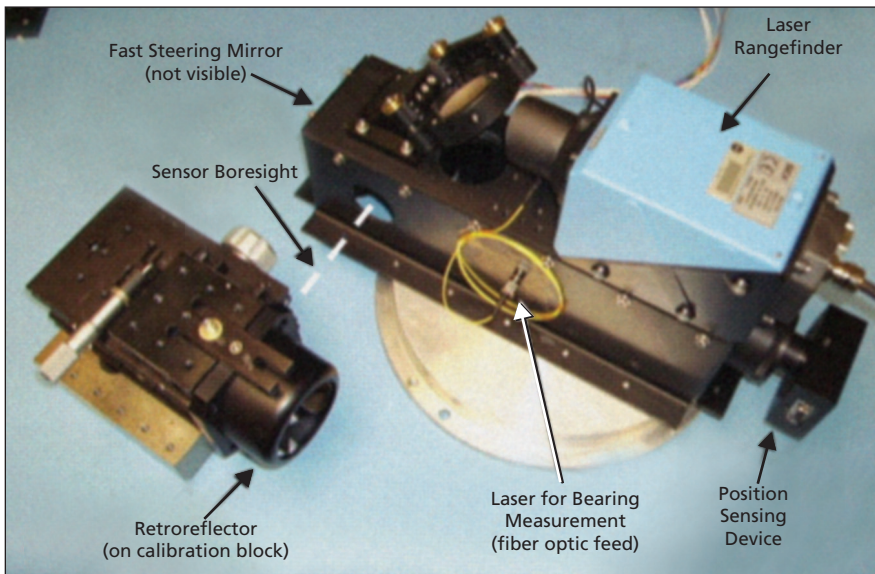
The **Formation Control Testbed Optical Pointing Loop** hardware is shown. The sensor system is composed of a laser rangefinder, fast steering mirror, back-end shear sensor, and a large-aperture, open-face retro target.

the return will be separated (sheared) from the outgoing beam by twice the distance between the impact point and the center of the retroreflector. Provided that shear amount is small enough, the return will hit the aperture of the steering mirror and go back through the beam splitter and be imaged on the back end of the scanner with the shear sensor. A telescope placed in front of the shear sensor serves to compress the image of the return beam to the size of the detector.

To acquire the retroreflector within the field of view of the shear sensor, the system operates by first performing an open loop search for the retroreflector target. Once a return from the retroreflector optic is detected, a servo loop is closed with the fast steering mirror and shear sensor to center the laser beam on the vertex of the retroreflector. Once locked, any motion of the retroreflector will be tracked by keeping the servo error small. Once in track mode, the IR rangefinder can be used to give range measurements. Bearing measurements are available from a local sensor used by the steering mirror.

In comparison to flash LIDAR systems, this work represents a system with much less complexity and a lower cost. The rangefinder used by the sensor system is a low-cost COTS (commercial off-the-shelf) unit. The camera in a flash LIDAR system is replaced with a much lower cost, two-dimensional shear sensor that reports only the center of light of the image. This sensor serves as both a detector for determining whether or not the retroreflector is hit by the pointing laser and as a feedback sensor for the tracking system when the retroreflector is moving.

Radio-Frequency Tank Eigenmode Sensor for Propellant Quantity Gauging

This sensor has applications in cryogenic liquid storage tanks.

John H. Glenn Research Center, Cleveland, Ohio

Although there are several methods for determining liquid level in a tank, there are no proven methods to quickly gauge the amount of propellant in a tank while it is in low gravity or under low-settling thrust conditions where propellant sloshing is an issue. Having the ability to quickly and accurately gauge propellant tanks in low-gravity is an enabling technology that would allow a spacecraft crew or mission control to always know the amount of propellant onboard, thus increasing the chances for a successful mission.

The Radio Frequency Mass Gauge (RFMG) technique measures the electromagnetic eigenmodes, or natural resonant frequencies, of a tank containing a dielectric fluid. The essential hardware components consist of an RF network analyzer that measures the reflected power from an antenna probe mounted internal to the tank. At a resonant frequency, there is a drop in the reflected power, and these inverted peaks in the reflected power spectrum are identified as the tank eigenmode frequencies using a peak-detection software algorithm. This information is passed to a pattern-matching algorithm, which compares the measured eigenmode frequencies with a database of simulated eigenmode frequencies at various fill levels. A best match between the simulated and measured frequency values occurs at some fill level, which is then reported as the gauged fill level.

The database of simulated eigenmode frequencies is created by using RF simulation software to calculate the tank eigenmodes at various fill levels. The input to the simulations consists of a fairly high-fidelity tank model with proper dimensions and including internal tank hardware, the dielectric properties of the fluid, and a defined liquid/vapor interface. Because of small discrepancies between the model and actual hardware, the measured empty tank spectra and simulations are used to create a set of correction factors for each mode (typically in the range of 0.999–1.001), which effectively accounts for the small discrepancies. These correction factors are multiplied to the modes at all fill levels. By comparing several measured modes with the simulations, it is possible to accurately gauge the amount of propellant in the tank.

An advantage of the RFMG approach of applying computer simulations and a pattern-matching algorithm is that the