

Figure 2. **Eight Linear Magnetic Actuators**, partly similar to traditional voice-coil actuators, apply forces to the star-simulator table to control its position and attitude in all six degrees of freedom. The actuators are represented by the cylinders labeled C0 through C7.

mercial system) and it can be constructed at relatively low cost.

The drive system includes eight magnetic linear actuators — two more than the minimum of six needed for the six

degrees of freedom. Each actuator partly resembles a traditional voice-coil actuator in that it includes a permanent magnet, upon which an axial force is exerted by a nominally concen-

tric electromagnet coil. The force exerted by each actuator depends on the current applied to its coil and typically lies in the range of  $\pm 10$  N (for some degrees of freedom, the typical range is  $\pm 40$  N). Unlike a traditional voice-coil actuator, which cannot withstand a lateral displacement of more than 0.1 mm without breakage, each of these magnetic actuators can withstand a displacement of  $\pm 5$  mm in any direction without breakage. The electromagnet coils are wound on aluminum forms that contain water cooling channels to remove excess heat from the coils when necessary. The motions of the permanent magnets in the aluminum forms also provide eddy-current damping of rapid motions (e.g., vibrations) of the table.

*This work was done by Yekta Gursel and Elizabeth McKenney of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30805*

## Improved Position Sensor for Feedback Control of Levitation

In this application, an incandescent light bulb is preferable to a laser.

Marshall Space Flight Center, Alabama

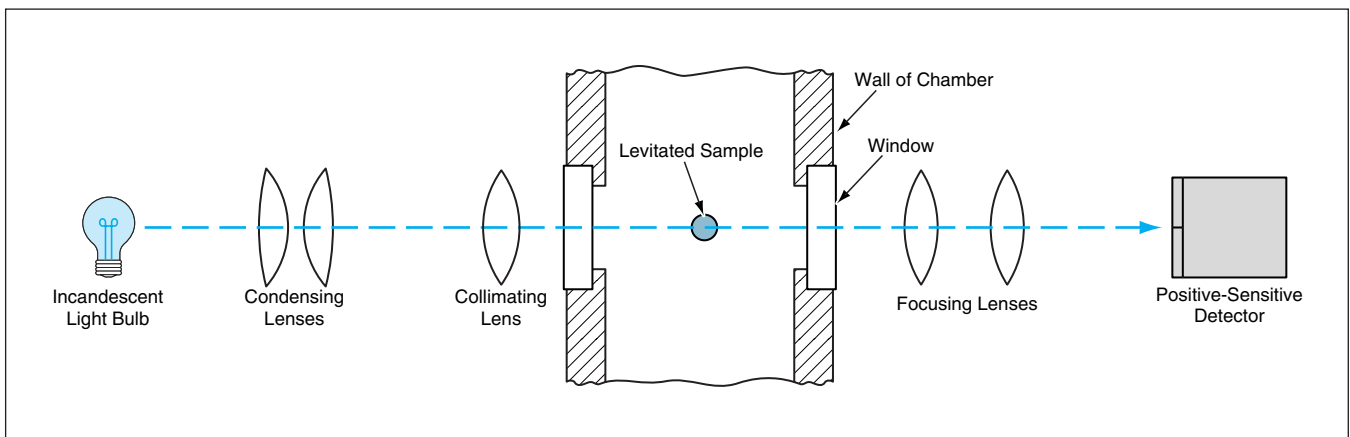
An improved optoelectronic apparatus has been developed to provide the position feedback needed for controlling the levitation subsystem of a containerless-processing system. As explained below, the advantage of this apparatus over prior optoelectronic apparatuses that have served this purpose stems from the use of an incandescent lamp, instead of a laser, to illuminate the levitated object.

In containerless processing, a small object to be processed is levitated (e.g.,

by use of a microwave, low-frequency electromagnetic, electrostatic, or acoustic field) so that it is not in contact with the wall of the processing chamber or with any other solid object during processing. In the case of electrostatic or low-frequency electromagnetic levitation, real-time measurement of the displacement of the levitated object along the vertical axis (and, in some cases, along one or two horizontal axes)

is needed for feedback control of the levitating field.

In a typical prior position-measuring optoelectronic apparatus for levitation control, a laser beam is aimed through the nominal levitation position to a position-sensitive photodetector, so that the levitated object casts a shadow on the detector face. The output of the position-sensitive detector circuitry is a voltage proportional to the displacement of the shadow from a nominal



An **Incandescent Light Bulb** and some lenses are used to illuminate a levitated object in a processing chamber so that the object casts a shadow on a position-sensitive detector.

central position and, hence, to the displacement of the levitated object from the nominal levitation position. The main shortcomings of such an apparatus are associated with the laser: Lasers tend to be expensive, and laser beams are often characterized by poor spatial distribution (speckle) and by poor short-term spatial and temporal stability.

The basic principle of operation of the improved optoelectronic position-measuring apparatus is the same as that of the prior apparatus described above,

except that the laser is replaced with an incandescent light bulb and associated optics (see figure). Unlike the light from a laser, the light from an incandescent lamp is not subject to mode shifts and, hence, is spatially and temporally stable in the short term. The spatial distribution of light is better for the intended application because there is no speckle and the illumination is approximately constant across the levitation region. Unlike the light from a laser, the light from an incandescent lamp varies smoothly with applied

power and is thus more easily controllable. Finally, a light bulb is easily replaceable and costs much less than does a laser.

*This work was done by Robert Hyers, Larry Savage, and Jan Rogers of Marshall Space Flight Center.*

*This invention is owned by NASA, and a patent application has been filed. For further information, contact Benita Hayes, MSFC Commercialization Assistance Lead, at [benita.c.hayes@nasa.gov](mailto:benita.c.hayes@nasa.gov). Refer to MFS-31535.*

## Compact Tactile Sensors for Robot Fingers

Simple, rugged, compact sensors measure spatial distributions of contact forces.

*Lyndon B. Johnson Space Center, Houston, Texas*

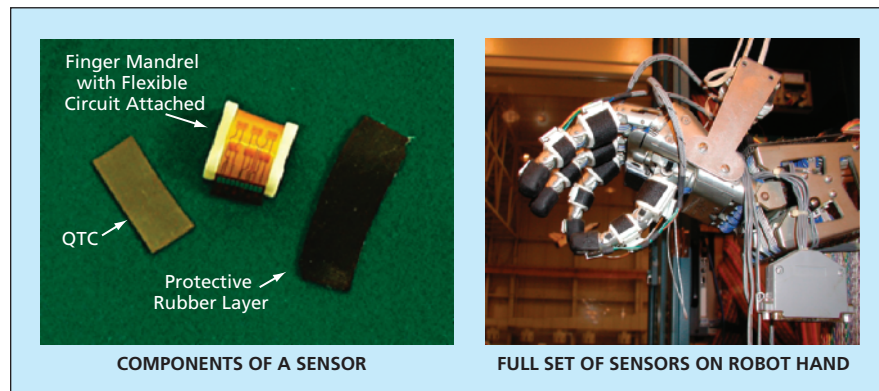
Compact transducer arrays that measure spatial distributions of force or pressure have been demonstrated as prototypes of tactile sensors to be mounted on fingers and palms of dexterous robot hands. The pressure- or force-distribution feedback provided by these sensors is essential for the further development and implementation of robot-control capabilities for humanlike grasping and manipulation.

Each sensor (see figure) includes a hard mandrel designed to fit over a finger segment or a palm. A flexible circuit that includes an array of electrodes is attached to the mandrel and is overlaid with a force-sensitive rubber denoted quantum-tunneling composite (QTC). A protective layer of non-sensory rubber is placed over the QTC.

Each electrode defines a tactile sensor point denoted a tactel in analogy to a

pixel (picture element) in an image-detecting array of photodetectors. In addition to the electrodes, the sensor includes a ground conductor common to all the elements of the array. The local electrical resistivity of the QTC changes in response to local pressure. By use of simple electronic circuits (e.g., resistive voltage dividers), the local changes of resistance in the tactels are converted to voltages. The voltages can be read by use of external analog-to-digital converter circuitry, then processed into forces or pressures on the tactels. Hence, the processed sensor output indicates the spatial distribution of force or pressure at the spatial resolution of the tactels.

*This work was done by Toby B. Martin of Johnson Space Center; David Lussey of Peratech, Ltd.; Frank Gaudiano, Aaron Hulse, Myron A. Diftler, and Dagoberto Rodriguez of Lockheed Martin Corp.; Paul Biel-ski of Titan Systems Corp.; and Melisa Butzer of Oceaneering Space Systems. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23608/93*



A Sensor for a Finger includes a hard mandrel that fits over the finger and that supports a flexible circuit overlaid by a QTC overlaid by protective rubber.

## Improved Ion-Channel Biosensors

Improvements include greater stability and greater signal-to-noise ratios.

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

An effort is underway to develop improved biosensors of a type based on ion channels in biomimetic membranes. These sensors are microfabricated from silicon and other materials compatible

with silicon. As described below, these sensors offer a number of advantages over prior sensors of this type.

To place these advantages in context, it is first necessary to present some back-

ground information on prior sensors of this type:

- Ion channels of the type in question are very sensitive to a wide variety of ligands, to which they respond by gen-