Tactile Robotic Topographical Mapping Without Force or Contact Sensors

A "tap test" yields data on a succession of surface points.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of topographical mapping of a local solid surface within the range of motion of a robot arm is based on detection of contact between the surface and the end effector (the fixture or tool at the tip of the robot arm). The method was conceived to enable mapping of local terrain by an exploratory robot on a remote planet, without need to incorporate delicate contact switches, force sensors, a vision system, or other additional, costly hardware. The method could also be used on Earth for determining the size and shape of an unknown surface in the vicinity of a robot, perhaps in an unanticipated situation in which other means of mapping (e.g., stereoscopic imaging or laser scanning with triangulation) are not available.

The method uses control software modified to utilize the inherent capability of the robotic control system to measure the joint positions, the rates of change of the joint positions, and the electrical current demanded by the robotic arm joint actuators. The system utilizes these coordinate data and the known robot-arm kinematics to compute the position and velocity of the end effector, move the end effector along a specified trajectory, place the end effector at a specified location, and measure the electrical currents in the joint actuators. Since the joint actuator current is approximately proportional to the actuator forces and torques, a sudden rise in joint current, combined with a slowing of the joint, is a possible indication of actuator stall and surface contact. Hence, even though the robotic arm is not equipped with contact sensors, it is possible to sense contact (albeit with reduced sensitivity) as the end effector becomes stalled against a surface that one seeks to measure.

The control software algorithm is specified to move the end effector along a succession of different trajectories ending at different positions (to perform a "tap test") to measure locations of stalls of the end effector against the surface of interest, thereby acquiring the coarse topographical data on the surface. In the original application, the topographical data were used to determine safe areas for robotic excavation and sampling of soil.

This work was done by Kevin Burke, Joseph Melko, Joel Krajewski, and Ian Cady of Caltech for NASA's Jet Propulsion Laboratory.

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-43922.

Thin-Film Magnetic-Field-Response Fluid-Level Sensor for Non-Viscous Fluids

This sensor would be inexpensive and easy to fabricate.

Langley Research Center, Hampton, Virginia

An innovative method has been developed for acquiring fluid-level measurements. This method eliminates the need for the fluid-level sensor to have a physical connection to a power source or to data acquisition equipment. The complete system consists of a lightweight, thin-film magnetic-field-response fluid-level sensor (see Figure 1) and a magnetic field response recorder that was described in "Magnetic-Field-Response Measurement-Acquisition System" (LAR-16908-1), *NASA Tech Briefs*, Vol. 30, No. 6 (June 2006), page 28.

The sensor circuit is a capacitor connected to an inductor. The response recorder powers the sensor using a series of oscillating magnetic fields. Once electrically active, the sensor responds with its own harmonic magnetic field. The sensor will oscillate at its resonant electrical frequency, which is dependent upon the capacitance and inductance values of the circuit.

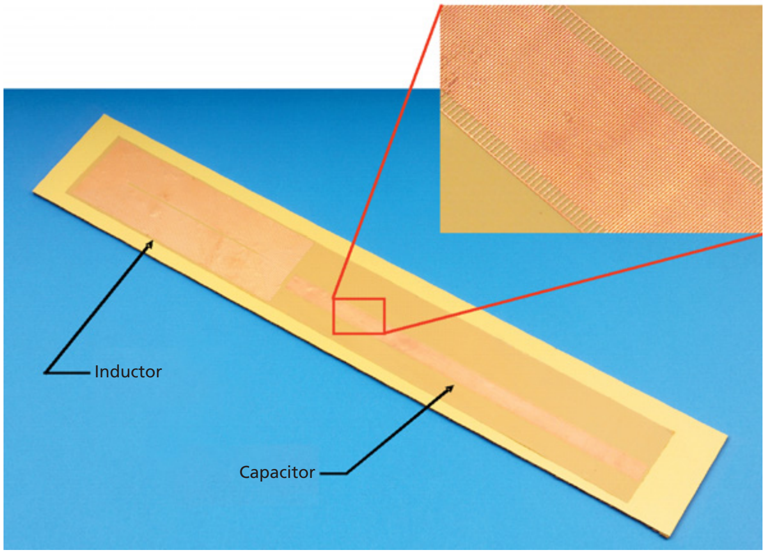

Figure 1: Thin-film magnetic field response **Fluid-Level Sensor** is a capacitor connected to an inductor to form a resonant circuit.

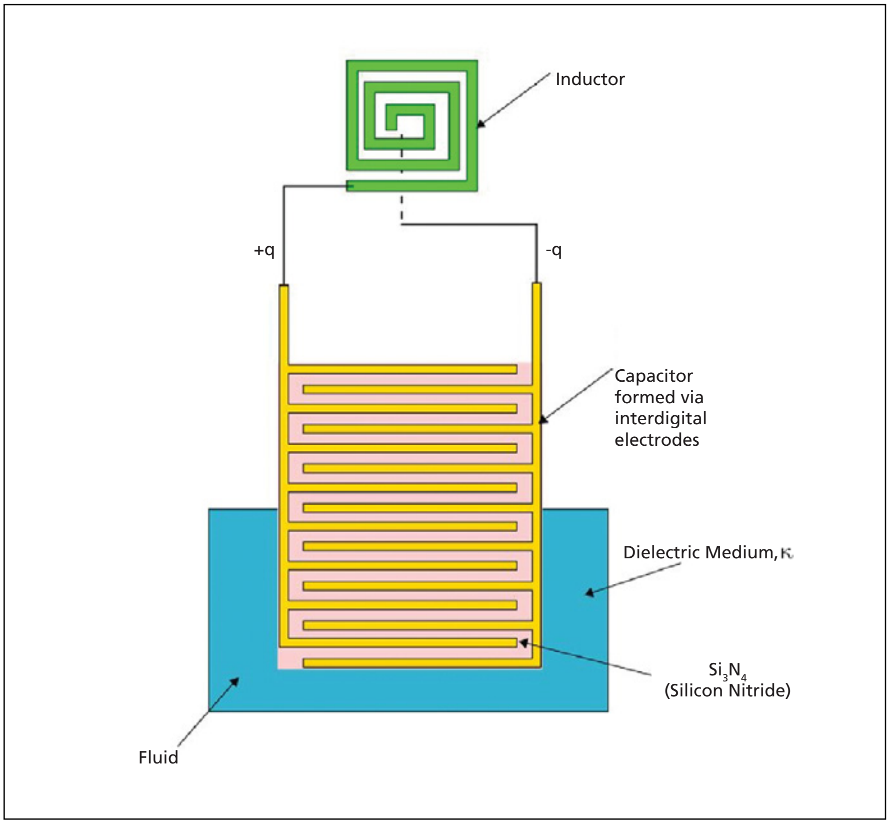

Figure 2: **Part of Capacitance** (fluid sensor) is immersed in fluid.

The capacitance value of the sensor increases as the amount of fluid that the sensor is exposed to increases. When the energy is in the inductor, the harmonic magnetic field produced can be interrogated. The response recorder interrogates the sensor response and correlates the response frequency to fluid level.

A thin layer of silicon nitride film is deposited on interdigital electrodes as shown in Figure 2 to electrically insulate the sensor's capacitor. Silicon nitride also can be placed on the inductor. The fluid-level sensor uses interdigital electrodes for the capacitor that are electrically connected in parallel to a spiral trace inductor. The advantage of this design is that the entire sensor can be embodied as a thin film, and can be directly deposited to the inner wall of a nonconductive container for measuring non-viscous fluids.

In Figure 2, a fluid having dielectric constant, κ, is in contact with m pairs of electrodes (e.g., placed in a fluid such that m electrode pairs are submersed). Each electrode pair has a capacitance of C_{free} when not immersed in the fluid and $C_{immersed} = \kappa C_{free}$. The advantage of this method is that it serves as a lightweight, thin-film method of measuring fluids that are non-viscous. Another advantage is that the level measurements are discretized. The sensor capacitance, $C(m)$, for a sensor having n electrode pairs increases as the number of electrode pairs, m, in contact with the dielectric increases.

$$\begin{aligned} C(m) &= (n-m)C_{free} + mC_{immersed} \\ &= (n-m+\kappa m)C_{free} \\ &= [n+m(\kappa-1)]C_{free} \end{aligned}$$

When the electrodes are electrically connected to an inductor, a resonant circuit is formed having the resonant frequency of

$$\omega = \frac{1}{2\pi\sqrt{[n+m(\kappa-1)]LC_{free}}}$$

The sensor response frequency ranges from its maximum value when the capacitor is not immersed ($m = 0$)

$$\omega_{\max} = \frac{1}{2\pi\sqrt{nLC_{free}}}$$

to its minimum when the capacitor is completely immersed ($m = n$).

$$\omega_{\min} = \frac{1}{2\pi\sqrt{m\kappa LC_{free}}}$$

This work was done by Stanley E. Woodard, Qamar A. Shams, and Robert L. Fox of Langley Research Center and Mr. Bryant D. Taylor of SWALES Aerospace. For more information, contact the Langley Innovative Partnerships Office at (757) 864-8881. Refer to LAR-16614-1.

Progress in Development of Improved Ion-Channel Biosensors

Improvements in design and fabrication have been made since a previous report.

NASA's Jet Propulsion Laboratory, Pasadena, California

Further improvements have recently been made in the development of the devices described in "Improved Ion-Channel Biosensors" (NPO-30710), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 30. As discussed in more detail in that article, these sensors offer advantages of greater stability, greater lifetime, and individual electrical addressability, relative to prior ion-channel biosensors.

In order to give meaning to a brief description of the recent improvements, it is necessary to recapitulate a substantial portion of the text of the cited previous article. The figure depicts one sensor that incorporates the recent improvements, and can be helpful in understanding the recapitulated text, which follows:

These sensors are microfabricated from silicon and other materials compatible with silicon. Typically, the sensors are fabricated in arrays in silicon wafers on glass plates. Each sensor in the array can be individually electrically addressed, without interference with its neighbors. Each sensor includes a well covered by a thin layer of silicon nitride, in which is made a pinhole for the formation of a lipid bilayer membrane. In one stage of fabrication, the lower half of the well is