Compact Tactile Sensors for Robot Fingers

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

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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 Bieliski 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

Improved Ion-Channel Biosensors

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

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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 background 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-
erating specific electrical signals. Consequently, such ion channels would be ideal bases for biosensors if they could be constructed in arrays and made stable and electrically addressable.

- Unfortunately, such ion channels function only within biological or biomimetic membranes, the life spans of which, heretofore, have usually been no more than several hours. In addition, their small signals (currents of 1 to 10 pA) make it necessary to mount them on platforms along with, and coupled to, low-noise, highly-amplifying electronic circuits. These characteristics have posed difficulties that have limited the commercial development of ion-channel biosensors.

- Heretofore, the standard design of one commercial product line of ion-channel recording devices has provided for lipid-bilayer recording chambers. Such chambers are suitable for short-term (1 to 2 hours) recording only and are not constructed in arrays. Another commercial product line of ion-channel biosensors offers the stability needed for longer-term recording, but operation is limited to DC capacitive measurements.

The figure presents top and bottom views of a prototype array of four of the developmental sensors fabricated in a silicon wafer on a glass plate. 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 lipid bilayer membrane. In one stage of fabrication, the lower half of the well is filled with agarose, which is allowed to harden. Then the upper half of the well is filled with a liquid electrolyte (which thereafter remains liquid) and a lipid bilayer is painted over the pinhole. The liquid contains a protein that forms an ion-channel on top of the hardened agarose. The combination of enclosure in the well and support by the hardened agarose provides the stability needed to keep the membrane functional for times as long as days or even weeks.

An electrode above the well, another electrode below the well, and all the materials between the electrodes together constitute a capacitor. What is measured is the capacitive transient current in response to an applied voltage pulse. One notable feature of this sensor, in comparison with prior such sensors, is a relatively thick dielectric layer between the top of the well and the top electrode. This layer greatly reduces the capacitance of an aperture across which the ion channels are formed, thereby increasing the signal-to-noise ratio. The use of a relatively large aperture with agarose support makes it possible to form many ion channels instead of only one, thereby further increasing the signal-to-noise ratio and effectively increasing the size of the available ionic reservoir. The relatively large reservoir makes it possible to measure AC rather than DC.

This work was done by Jay Nadeau, Victor White, Dennis Dougherty, and Joshua Maurer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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