Electronics/Computers

"Virtual Feel" Capaciflectors

Increases in capacitance with deviations from desired central positions would be exploited.

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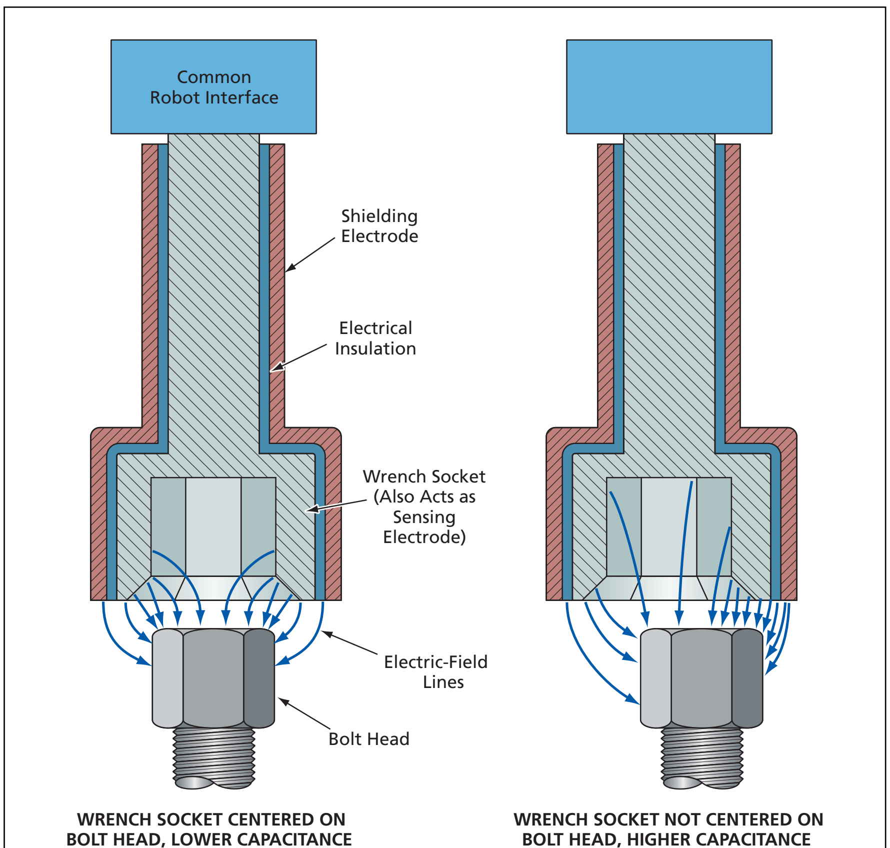
The term "virtual feel" denotes a type of capaciflector (an advanced capacitive proximity sensor) and a methodology for designing and using a sensor of this type to guide a robot in manipulating a tool (e.g., a wrench socket) into alignment with a mating fastener (e.g., a bolt head) or other electrically conductive object. Unlike robotic vision, capacitive proximity sensing does not require a clear line of sight to the mating fastener. On the contrary, capacitive proximity sensing affords the greatest position-measuring sensitivity in the situation in which it is most needed — when the tool is so close to the fastener as to prevent viewing.

Capaciflectors, other capacitive proximity sensors, and related developments have been described in numerous previous *NASA Tech Briefs* articles. Of those articles, the one most relevant to the present innovation was "Guiding Robots With The Help of Capaciflectors" (GSC-13614), *NASA Tech Briefs*, Vol. 21, No. 3 (March 1997), page 44. Like other capacitive proximity sensors, a capaciflector includes at least one sensing electrode, excited with an alternating voltage, that puts out a signal indicative of the capacitance between that electrode and a proximal object.

As described in the cited previous article, a robotic manipulator would be tipped with a tool instrumented with a capaciflector that would include an array of sensing electrodes that would be somewhat complex because it would be designed to enable three-dimensional proximity sensing. The outputs of the sensing electrodes would be converted to DC, digitized, then fed to a digital processor. In the processor, the variation of sensed capacitances with relative position and orientation of the capaciflector and a sensed object would be used to generate data equivalent to a fictitious force field that could be a source of signals to control the motion of the robotic manipulator in the vicinity of the object. Thus, collisions could be avoided and the manipulator could be guided into proximity and alignment with the intended object without making premature contact with the object. The initial approach would typically involve a raster scan of the manipulator while capaciflector outputs were processed to determine positions of closest approach in scan planes that were progressively brought closer to the object, without bringing them so close as to risk collision. This scan would yield data on the approximate position and orientation of the object relative to the manipulator. Following the scan, the capaciflector outputs would be processed and used for guidance as the manipulator was dithered into soft contact with the object.

The "virtual feel" capaciflector methodology also involves digitization and processing of capacitance readings as functions of relative position and orientation to obtain data equivalent to a fictitious force field that, in this case, is regarded as providing a quasi-tactile sense of imminent contact. However, a "virtual feel" capaciflector would be electronically and mechanically simpler because it would typically include only two electrodes: a sensing electrode and a shielding electrode. Moreover, the tool could serve as the sensing electrode. For example, if the tool were a wrench socket to be mated with a bolt head, then the wrench socket would be the sensing electrode (see figure). The sides of the wrench socket would be covered with a layer of electrically insulating material that would, in turn, be covered by a metallic outer shell that would serve as the shielding electrode. The capaciflector output would in-



A **Wrench Socket** would double as the sensing electrode of a capaciflector. The capacitance between the bolt head and the wrench socket would be measured as the socket was dithered, in order to derive information needed to keep the socket centered on and clocked to the bolt head in preparation for mating.

dicate the capacitance between the wrench socket and the bolt head.

The algorithm processing the digitized capaciflector readings would exploit the fact that for any fixed position of the wrench socket along the central axis of the bolt head, the capacitance would reach a minimum when the axis of the wrench socket coincided with the axis of the bolt head and the wrench socket was clocked (rotated about its axis) to the angular position for mating with the bolt head: any lateral (horizontal in the figure) translation or any rotation of the wrench socket away from the central position and the mating orientation would cause an increase in capacitance. Hence, for a given fixed position along the center line of the bolt, the information needed to correct any deviation of the wrench socket from the central position and the mating orientation could be obtained by taking capacitance measurements during a sequence of controlled dithers of the position and orientation along and about the various coordinate axes. This is analogous to the feel a skilled craftsman instinctively uses, except it is noncontact, hence, "virtual feel."

This work was done by John M. Vranish of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
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FETs Based on Doped Polyaniline/Polyethylene Oxide Fibers

Advantages include tailorability of electronic properties and low power demands.

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A family of experimental highly miniaturized field-effect transistors (FETs) is based on exploitation of the electrical properties of nanofibers of polyaniline/polyethylene oxide (PANi/PEO) doped with camphorsulfonic acid. These polymer-based FETs have the potential for becoming building blocks of relatively inexpensive, low-voltage, high-speed logic circuits that could supplant complementary metal oxide/semiconductor (CMOS) logic circuits.

The development of these polymer-based FETs offers advantages over the competing development of FETs based on carbon nanotubes. Whereas it is difficult to control the molecular structures and, hence, the electrical properties of carbon nanotubes, it is easy to tailor the electrical properties of these polymer-based FETs, throughout the range from insulating through semiconducting to metallic, through choices of doping levels and chemical manipulation of polymer side chains. A further advantage of doped PANi/PEO nanofibers is that they can be made to draw very small currents and operate at low voltage levels, and thus are promising for applications in which there are requirements to use many FETs to obtain large computational capabilities while minimizing power demands.

Fabrication of an experimental FET in this family begins with the preparation of a substrate as follows: A layer of silicon dioxide between 50 and 200 nm thick is deposited on a highly doped (resistivity ≈0.01 Ω·cm) silicon substrate, then gold electrodes/contact stripes are deposited on the oxide. Next, one or more fibers of camphorsulphonic acid-doped PANi/PEO having diameters of the order of 100 nm are electrospun onto the substrate so as to span the gap between the gold electrodes (see Figure 1).

Figure 2 depicts measured current-versus-voltage characteristics of the device of Figure 1, showing that saturation channel currents occur at source-to-drain potentials that are surprisingly low, relative to those of CMOS FETs. The hole mobility in the depletion regime in this transistor was found to be 1.4×10^{-4} $cm^2/(V{\cdot}s)$, while the one-dimensional charge density at zero gate bias was esti-

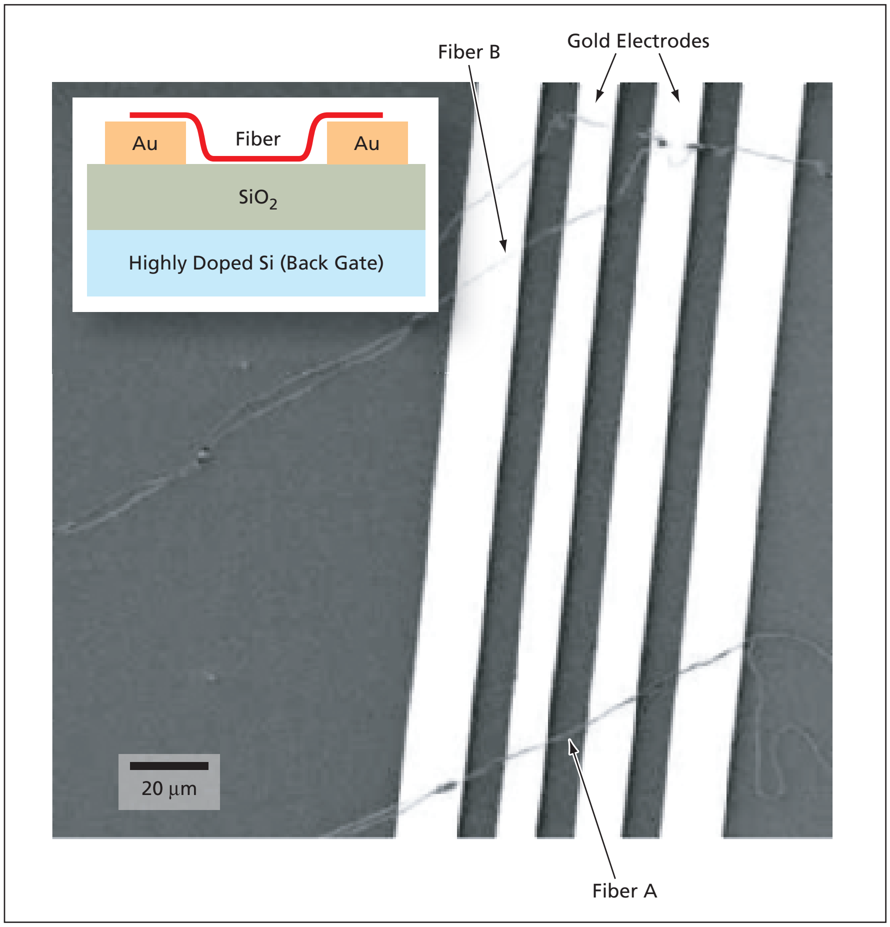

Figure 1. **Fibers of Doped PANi/PEO** are electrospun across the gap between source and drain gold electrodes on a prepared substrate to form an FET. The inset presents a simplified cross section showing one fiber. The rest of the picture is a scanning electron micrograph, wherein fiber A (12 µm long, 300 nm in diameter) and fiber B (18 µm long, 120 nm in diameter) in contact with the two inner gold electrodes are parts of an experimental FET.