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Biomimetic Tactile Sensor

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I. INTRODUCTION

The performance of prosthetic hands and robotic manipulators is severely limited by their having little or no tactile information compared to the human hand. Technologies such as MEMS, microfluidics, and nanoparticles have been used to produce arrays of force sensors, but these are generally not robust enough to mount on curved, deformable finger pads or to use in environments that include dust, fluids, sharp edges and wide temperature swings. Furthermore, it is not clear how the prosthetic controller will use the tactile information, so it is difficult to generate specifications for these sensors.

Our tactile sensor is shaped like the fingertip and consists of a rigid central core surrounded by fluid and covered by a silicone elastomeric "skin" (Fig. 1). The skin is resistant to wear and possesses texture and tackiness similar to the properties that facilitate grip by biological fingertips. External forces deform the skin and weakly conductive fluid, causing changes in the electrical resistances measured by an array of electrode contacts distributed over the curved surfaces of the core. Applying an alternating current to each contact and measuring the resulting voltage drop with respect to a reference contact can measure the impedance of each volume conductive path.

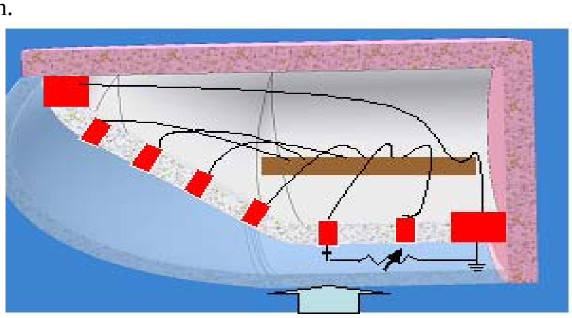

Figure1: Mechanical drawing of the biomimetic tactile sensor showing a rigid core shaped like the distal phalanx (white) with an internal, sealed compartment for electronics (brown) connected to sensing electrodes (red) in contact with a weakly conductive fluid under a viscoelastic skin (light blue).

II. DESIGN AND DEVELOPMENT

The sensitivity of the sensor depends complexly on the size of the electrode contacts, the conductivity of the fluid, and the viscoelastic properties of the combined system of skin and pressurized fluid. Lower viscosity provides higher sensitivity and frequency response. Lower conductivity provides higher sensitivity because the electrode impedance consists of two components in series: the metal-electrolyte interface, which is essentially a constant capacitance, and the volume-conductance of the surrounding fluid, which provides the variable resistance to be measured [1]. Presently the fluid is a blend of glycol, water, sodium chloride and ethyl alcohol. Salt water acts as the conductor, glycol is a hygroscopic agent to preclude water loss by diffusion through the silicone elastomer and ethyl alcohol lowers the viscosity.

Attaching the skin to the dorsum in the manner of a fingernail and positioning sensor electrodes on the curved surface of the core adjacent to this restriction causes these lateral-facing electrodes to respond selectively to tangential forces applied at the fingertip. Such forces cause sliding of the skin over the core, constricting the fluid on one side of this "nail bed" and bulging it on the other, similar to a biological fingertip. The number and distribution of electrodes required to sample these phenomena efficiently remain to be determined. The strategy of dip-coating elastomeric skin onto the rigid core offers the advantage of easy repair of the most vulnerable part of any finger. It should be possible to replace the skin without affecting the sensing electrodes or their supporting electronic circuitry within the rigid core.

The detection circuit (Fig. 2) is driven with a 20 kHz, 5VAC voltage in series with R1, which acts as a current source over the lower impedance range of the sensor. Based on the dynamic range of sensor impedances measured, an 80K resistor was chosen for R1. The envelope magnitude of the sinusoidal signal is demodulated by the diode and low-pass filter R2-C2 to provide Vout. The signal generator is operated with a +0.3VDC bias to help bias the diode at low values of sensor impedance. C1is a blocking capacitor that removes any DC bias from the sensor electrodes to prevent corrosion and electrolysis. The time constant of the filter was chosen to be 100ms, based on physiological experiments that showed that the loading phase of a grip was never shorter than about 200ms [2]. At the same time, such a low cut-off frequency significantly reduces the level of noise and improves accuracy of readings; if the sensor needs to detect higher frequency vibration, active filtering is likely to be required. The resistor R3 serves to discharge the capacitor C2 when the diode is not conducting. In an array of such electrodes, most of the circuitry can be electronically multiplexed among rather than duplicated for each electrode.

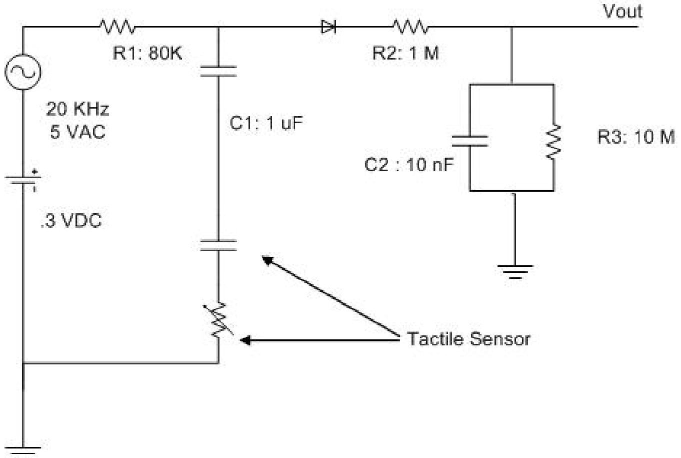

Figure 2: A circuit diagram of a single sensor channel.

III. INITIAL RESULTS

Shown below is the first prototype (Fig. 3); it contains four gold working electrodes and a wrap-around copper ground electrode. The gold electrodes were cut from wire with an outside diameter of .025 inches, whereas the copper electrode is a wire with an outside diameter of .016 inches. Initial data were gathered using a .1 mm thick latex coating around the sensor core; it has been removed for illustrative purposes. The ionic fluid used to fill the unit was 2mL of standard saline solution diluted in distilled water as 1:4. In this case, 2mL was used to adequately inflate the "skin" away from the core such that the dynamic range of the sensor was accessible.

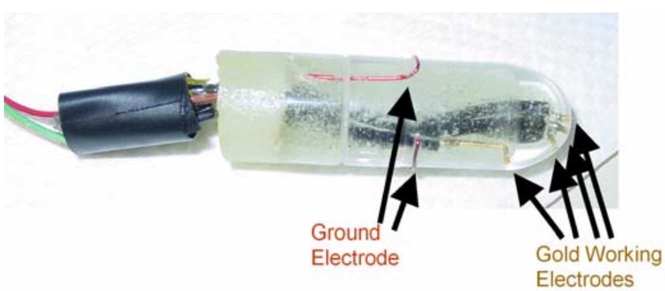

Figure 3: Initial Sensor Prototype Core

The prototype sensor was rolled over an Inastomer pressure sensitive resistor while monitoring the output of two of the electrodes on an oscilloscope (Fig 4).

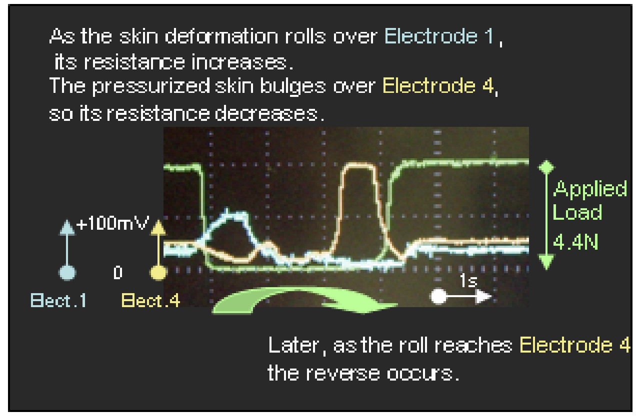

Figure 4: Initial Prototype Sensor Output

The biomimetic fingertip described in this report will not by itself solve any of the above problems of object manipulation and identification. It does provide a mechanically robust and informatically rich set of sensors that bears some resemblance to the biological tactile sensors. Most of the tools and tasks of an industrial world were designed by humans to be performed by human hands. This motivates the strategy of biomimetic design for robotic and prosthetic hands intended to function in this world.

ACKNOWLEDGEMENTS

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