Thick film force and slip sensors for a prosthetic hand

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Summary: *In an attempt to improve the functionality of a prosthetic hand device, a new fingertip has been developed that incorporates sensors to measure temperature and grip force, and to detect the onset of object slip from the hand. The sensors have been implemented using thick film printing technology and exploit the piezoresistive characteristics of commercially available screen printing resistive pastes and the piezoelectric properties of proprietary lead-zirconate-titanate (PZT) formulated pastes. This paper describes the design and production of these different types of sensor and presents some results from initial investigations.*

Keywords: *piezoelectric, piezoresistance, prosthesis*

1 Introduction

A problem with the majority of prosthetic hands is the lack of any form of feedback control system, meaning that the operator has no sense of what they are holding within the hand beyond that which can be visually assessed. This has the obvious disadvantage that the prosthetic device could be damaged if, for example, an object that is too hot or too cold were to be grasped. Moreover, a lack of knowledge of the forces imparted by the hand during a grip posture may also result in damage to the grasped object, or at the very least, to the establishment of an insecure grip with the possible consequence of slip occurring.

To address these problems, a new force sensitive fingertip has been designed that incorporates a number of thick film force sensors as well as rudimentary temperature sensing. Two different types of force sensor have been included: a static force sensor to measure and monitor the absolute forces exerted by the fingers during a grip posture, and a dynamic force sensor, operating as a vibration sensor, to detect the onset of slip.

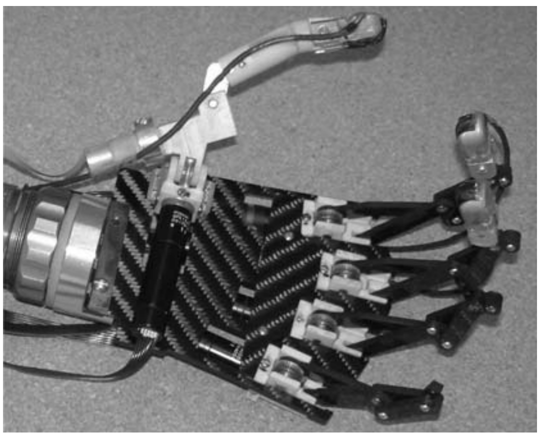

Fig. 1: The Southampton-Remedi prosthetic hand [1].

The fingertips are bolted to the distal ends of the digits of a myoelectrically controlled prosthetic hand, designed at the University of Southampton and described elsewhere [1] (Fig. 1). Each fingertip forms a simple mechanical cantilever structure. As the hand closes around an object during operation, the fingertip cantilevers are bent against their supports, creating a change in the surface strain of the fingertip. Since the strain produced is directly proportional to the magnitude of the force bending the fingertip, the latter may be measured with a suitably positioned strain sensor.

2 Fingertip design

The force sensitive fingertip is constructed from 2.0 mm thick, type 430S17 stainless steel, with overall dimensions of 26.0 x 17.0 mm as shown in Fig. 2. The absolute force sensor is based upon the piezoresistive properties of commercial thick film resistor pastes, which exhibit relatively large changes in resistance with strain compared to other strain sensing systems [2, 3]. Three resistors are included in this design, each of the same nominal dimensions and orientated upon the fingertip surface such that they respond to the longitudinal component of the strain along the length of the cantilever. Each resistor is positioned a different distance from the end of the fingertip, and therefore each will experience a different magnitude of strain when a force acts upon the fingertip. By measuring the changes in resistance of each thick film resistor it is possible to determine a position independent value for the force. The dimensions of the fingertip allow forces of up to 100N to be measured without exceeding the elastic limit of any of the materials used.

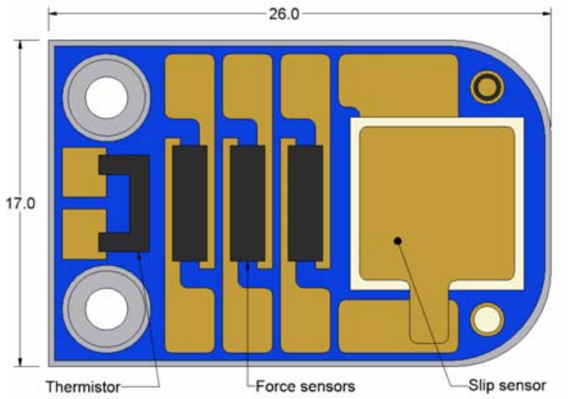

Fig. 2: Dimensions of finger tip cantilever (mm) showing the location of the various sensors.

The slip sensor utilizes the piezoelectric properties of lead-zirconate-titanate (PZT), which has been rendered into a suitable format in our laboratories for thick film screen printing [4]. The PZT layer is printed between two gold electrodes in a sandwich structure as shown in Fig. 2. After printing and curing, the PZT layer must be polled in an electric field to enhance the piezoelectric properties. Values for the d_{33} piezoelectric coefficient as high as 70 pCN^{-1} have been achieved by varying the paste processing and polling parameters.

The slip sensor operates as a simple vibration sensor, producing a charge that is proportional to the level of vibration on the surface of the cantilever. When an object is gripped by the prosthetic hand, any movement by the object that could indicate the beginning of slip will produce a vibration in the cantilevers that is promptly detected by the PZT sensors and readily converted to a measurable voltage through the use of a charge amplifier.

A simple thermistor temperature sensor has also been printed upon the fingertip, located between the two mounting holes. The temperature sensor is used to indicate if an object being gripped is either too hot or too cold for the prosthetic device, as well as providing temperature compensation for the force and slip sensors.

3 Results

Fig. 3 shows the normalised change in resistance for the three resistors printed upon a single fingertip cantilever device when subjected to forces in the range 0 to 10 N. Here, forces were applied by suspending masses of known value from the tip of the cantilever. Measurements of resistance were taken as the masses were both placed on the fingertip and as they were removed. The figure clearly shows that the resistors exhibit a linear change in resistance with the applied force, and that the sensitivity of the measurement is a function of the distance between the resistor and the location of the force (R3 nearest the tip).

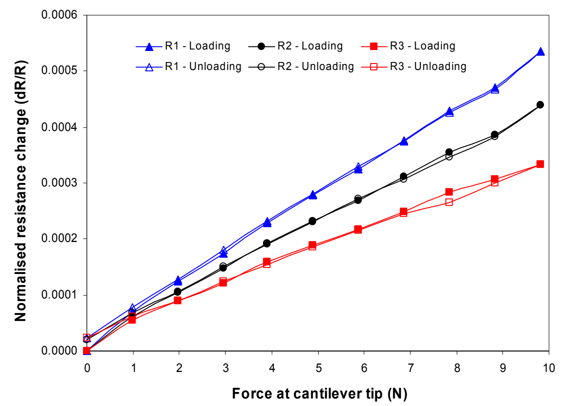

Fig. 3: Normalised change in resistance for the three force sensors as a function of fingertip force.

Fig. 4 shows an example response from the PZT slip sensor. This signal was obtained by dropping a small 100g object onto the surface of an inclined cantilever and then allowing the object to roll across the surface of the cantilever. The figure clearly shows the moment of impact between the object and the fingertip as well as an acoustic signal as the object rolls over the PZT sensor, simulating the onset of slip.

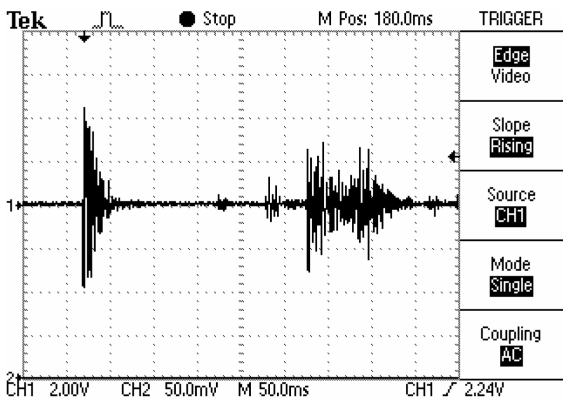

Fig. 4: Example response from PZT slip sensor.

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