ESTIMATION OF CURVATURE FEATURE USING A BIOMIMETIC TACTILE SENSOR

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INTRODUCTION

Human's sense of touch is rich in the amount of information it can acquire simultaneously. Unlike vision, haptic sensing can extract information about many attributes of an object: shape, mass, volume, rigidity, texture, and temperature etc. A variety of technologies have been used in tactile sensors, but commercially available tactile sensors tend to be limited to relatively coarse arrays of normal force sensors based on compression of elastic materials. In fact, most of the commercially available robotic and prosthetic hands are not supplied with any tactile sensing.

Many technologies are difficult to apply to the curved, deformable "skin" that facilitates grip and few are able to resist damage in the electromechanically hostile environments in which hands are often used (moisture, grit, sharp edges, etc). One promising new candidate is the BioTac®, a biomimetically designed, multimodal array that provides most of the dynamic range of human tactile sensing for location, magnitude and vector direction of contact forces, micro-vibrations associated with slip and textures, and thermal flux resulting from contact with objects that differ in thermal effusivity(Figure.1), [1, 2, 3].

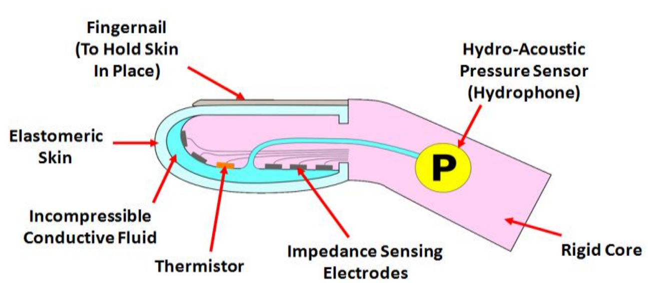

Figure 1: Schematic diagram of the BioTAC® biomimetic tactile sensor.

The mechanism of implementing these sensing modalities are: measurement of normal and shear forces detected by changes in impedance between electrodes as fluid pathways deform, detection of slip-related microvibration which propagate through the skin and sluid and are detected by the hydro-acoustic pressure sensor, and thermal properties as detected by a thermistor capable of detecting heat flow between the preheated core and contacted objects.

Phillips and Johnson [4] showed that SA-I mechanoreceptors embedded in the skin of fingertips are particularly sensitive to spatial details for example: points edges, corners and different radius of curvatures. Psychological experiments also show that human are able to differentiate several forms of spatial pattern independent of contact force [5, 6]. To replicate this dedicated spatial feature extraction scheme, we designed a novel algorithm to facilitate the radius of curvature estimation on a BioTac® sensor.

Just like human fingers, the most sensitive region of our tactile sensors is located on the tip. We used the impedance signals from this cluster of four electrodes (*E7, E8, E9, and E10*) (Figure. 2) to characterize the spatial features from contacted object.

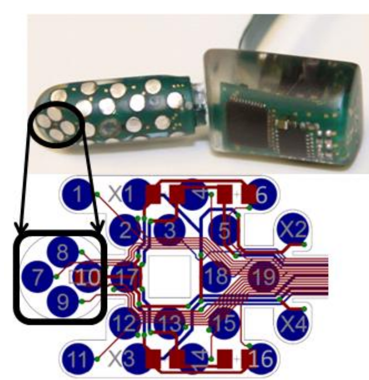

Figure 2: Electrodes array distribution of the tactile sensor corresponding to different spatial features.

MODELS

In this work, we used a BioTAC® fingertip tactile sensor to probe an object. The radius of curvature is estimated from the deformation pattern detected by the pair of electrodes (E7/E10 or E8/E9 in Figure 2) at the contact surface. The fingertip of BioTac® sensor is modeled as one quarter of a circle, which has a radius of *R*. The probed object is assumed rigid, frictionless, and circular with unknown radius *r*. The radius of the object can then be estimated from the measureable deformation at the BioTac® sensor. The indentation distance of deformation is define as *d* and tangential contact points are *A* and *C*. The angle between *OA* and *OC* is *θ*, where *O* is the origin of the fingertip, (Figure. 3).

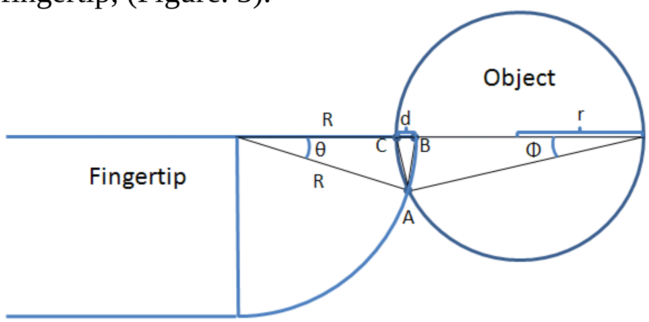

Figure 3: Schematic of mathematical model for radius of curvature estimation in the plane space.

We begin with deriving the geometric properties of the deformation at the BioTac® fingertip.

$$|AB| = 2R\sin\frac{\theta}{2} \quad (1)$$

$$|BC| = d \quad (2)$$

$$|AC| = d^2 + 4R(R-d)\sin^2\frac{\theta}{2} \quad (3)$$

$$\cos\angle ACB = \frac{d-2R\sin^2\frac{\theta}{2}}{\sqrt{d^2+4R(R-d)\sin^2\frac{\theta}{2}}} \quad (4)$$

$$\cos\angle ACB = \frac{|AC|}{2r} \quad (5)$$

The analytical solution for estimating the unknown object's radius of curvature is obtained.

$$r = \frac{d^2+4R(R-d)\sin^2\frac{\theta}{2}}{2(d-2R\sin^2\frac{\theta}{2})} \quad (6)$$

RESULTS

The analytical solution indicates that estimating radius *r* depends on three variables: *R and θ* are initially designed in the BioTac® tactile sensor, indentation *d* is measured by the distributed electrode array (Figure. 2). We have tested various radii of curvature by our designed estimation model, and the results are depicted in Figure 4.

The parameter *θ* defines the effective contact area between the sensor and object; it is designed and built in BioTac®. We could predict the radius of curvature by only measuring the indentation distance *d*. initial contact point of the fingertip is labeled by red line in the left circle, and the dotted lines are estimated radius for various objects.

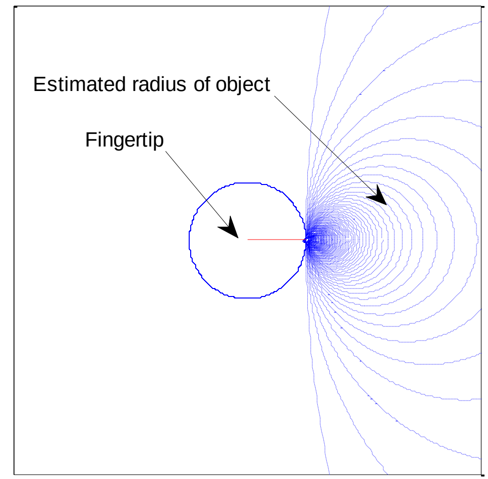

Figure 4: Simulation results for radius estimation.

DISCUSSION AND FUTURE WORK

Human fingers tend to have the best discrimination for the objects with similar radius as the fingertip. The developed BioTac® sensor along with the estimation algorithm provides us a platform to further analysis of the sensitivity of human fingertip.

Biological tactile sensors in the skin of fingertip are relatively noisy. Thus, we plan to implement a probabilistic model, Gaussian Mixture Model (GMM) [7], to account for the noise in this proposed estimation model. We have found that GMM model is effective at extracting three dimensional force vectors [3]. Some other important spatial features (edges, corners, etc.) have also been successfully characterized on the GMM model.

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