# Tactile Sensing,Perception and Modeling

The tactile (touch) sensory modality is important in order for biological and or robotic system to make a physical contact with objects and environment as they manipulate objects or move around. Tactile sensing plays a fundamental role in providing :

1. Action-related information including mobility on confound environments
2. Control parameters in manipulation and grasping
3. Delivering contact parameters such as force vector which an classify surface as degree of hardness (normal and shear),soft contact with deformation, texture and slip, and temperature.

There are many physical principles that can and have been used to implement tactile sensors.

Based on the review from [7] Dahiya et al.[2013] we list below:

Transduction Medium Sensor material Sensor Structure

Resistive Conductive Polymer Composites Microelectromems systems

Capacitive Carbon nano tubes Plastic MEMS

Optical Force sensing resistors Silicon transistors

Magnetic Conductive Gels Extended Gate Transistor

Ultrasonic Conductive Fibers and Yarns Organic Field Effect transistor

Piezoelectric Piezo/pyroelectric Flexible printed Circuit board

Electrorheological Electro-Optic materials mechanical Switches

Similar table but different is in [3] the handbook on robotics.

Table 20.1: Tactile sensor modalities and common transduction types.

Sensor and Sensor Type Modality and Attributes Advantages and disadvantages

Normal Pressure

Piezoresistive Array

•Array of piezoresistive junctions Simple signal conditioning Temperature sensitive

•Embedded in a elastomeric skin Simple design Frail

•Cast or screen printed Suitable for mass production Signal drift and hysteresis

Capacitive Array

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Array of capacitive junctions Good sensitivity Complex circuitry

Row and column electrodes separated by elastomeric dielectric Moderate hysteresis, depending on construction

Piezoresistive MEMS Array

Silicon micro-machined array

with doped silicon strain gauged Suitable for mass production Frail

Optical

•Combined tracking of optical No interconnects to break

markers with a constitutive model Requires PC for computing applied forces

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Skin deformation

Optical

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Fluid-filled elastomeric membrane Compliant membrane Complex computations

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Tracking of optical markers in- No electrical interconnects Hard to customize sensor

scribed on membrane coupled with

energy minimization algorithm to be damaged

Magnetic

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Array of hall effect sensors Complex computations Hard to customize sensor

Resistive Tomography

Array of conductive rubber traces Robust construction Ill-posed inverse problems

as electrodes

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Piezoresistive (Curvature)

•Employs an array of strain gauges Directly measures curvature Frailty of electrical inter-

Connects

Hysteresis

Dynamic Tactile Sensing

Piezoelectric (stress rate)

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PVDF embedded in elastomeric

Skin High bandwidth Frailty of electrical junction

Skin Acceleration

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Commercial accelerometer affixed

to robot skin Simple No spatially distributed

Sensed vibrations tend

To be dominated by structural

resonant frequency

Since our task of control of a soft manipulator system that can change its volume/shape based on the environment, the corresponding tactile system must have the following properties:

1. We need to understand /model the sensor performance ,i.e. its sensitivity, ability to measure various contact parameters
2. Understand physical aspects ,i.e. conformability, stretchability, spatial distribution and optimal placement of sensors
3. Data processing and hardware issues: data acquisition, signal conditioning, communication, power.
4. Algorithms and software :processing tactile data distributed in 3D space, sensor representation, deciphering tactile information;
5. Engineering issues, that is integration of sensing structure with the rest of the system, maintenance and reliability.

We will begin with the models of the sensor. This very much depends on the Sensor material and how tactile sensor is constructed ,which principle transduction it is used.

In order to demonstrate the basic parameters that we need to model tactile sensors I took the results from the paper: [6]Maximilain Karl and al.: ML-based tactile sensor calibration: universal approach,in arXiv:1606.06588v1 [cs.RO] 21 June 2016, where they compare two different tactile sensors one installed in BioTac and the other on iCub. The BioTac consists of a rigid core surrounded by an elastic skin which is filled with a conductive fluid. iCub has an solid support covered by a flexible printed circuit (PCB). The PCB is surrounded by a conductive silicon sheet which form s the second terminal of the sensor. He pictures below describe the construction of both sensors.

The tactile sensors in BioTac record impedance values across their electrodes (see Fig1.) while those in iCub record capacitance values and their change by the way of change in the thickness of silicon rubber interface,see Figure 2.





As seen from table 1, while iCub only returns the tactile information from 12 taxels. The BioTac returns pressure and temperature both in DC and instantaneous AC ,in addition to 19 taxels.

Below I display an optically based tactile sensor taken from reference [1].



Another material principle is used in a Flexible Piezoelectric tactile sensor based on polyvinylidene (PVDF) is from paper by Ping Yu et all, published in MDPI Journal ,Sensors 2016,16,819. The Figure 1 below illustrates the diagram of the three axis tactile array, arranged in 3x2 matrix. In Figure 1c shows the 5 layers ,PDMS bump layer Fig 1d, an upper aluminum (Al) electrode layer, a PVDF film layer, a lower Al layer and a PDMS substrate layer. The PVDF film is sandwiched between four square-shaped upper electrodes and one square-shaped lower electrode, thus forming a piezoelectric capacitors.

In Figure 2. Shows the principle fo sensning. The applied three axis force applied on the bump is decomposed in normal force (F[z]) and shear forces (Fx],F[y]},shown in Figure 2a. Under normal force compnent the bump is compressed and the four piezoelectri capacitors are subjected to the same compressive stress(P[11},P[12],P[21],P[22]).y the piezoelectric effcet of the PVDF film, charges (Q[11],Q[12],Q[21]Q[22]) with the same amplitude and polarity(negative) will be geneated on the upper electrodes of the four piezoelectric capacitors , and symmetricall positive charges will be on lower electrodes.Under the shear force components, the bump deforms and generates and generates a torque at the fixed end .The two piezoelectric capacitors on the left side a subjected to tensile stress, whereas other two on the right side are subject tocompressive stressas shown in Figure 2c,d.

Thus F[z] can be caluclated by taking average of Q[11],Q[12]Q[21]Q[22}, while F[x] and F[y] are calculated from differences among Q[11],Q[12]Q[21] and Q[22].



Figure 1.

Figure 2.

As one can see the model of tactile sensor very much depend on the principles of the construction of the sensor.

There are some common characteristics of the parameterization the tactile devices such as The external Load (Vector of forces in 3D), the vector of position of contact in 3D.If the sensor is attached to a manipulator then the proper transformation (rotation and translation) must be performed as shown in [5].If we consider reference sensing module s[i] then orientation and translation of each sensing module with respect to the load cell is a matrix multiplication from one frame to the other. This is independent what the transduction principle is. On the other hand if the sensor transduction is optical as oppose to resistive or capacitive then electrical fields direction must be considered. In order to measure deformation one needs to detect change in position/displacement. It can be executed via vision ad or some other position encoding device.

In summary as well known the tactile sensing measures the pressure (the hardness of material, typically normal force), the tangential/shear forces (slip, surface texture) the contact position. The calibration consists of performing the above mentioned values of each of those parameters and their range.

The challenges in selecting the “RIGHT” tactile/force sensor of course will depend on the task and application. The recent developments suggest that the field is aiming for deformable, stretchable substrates including flexible printed circuit boards, towards arrays of sensors (provides robustness in measurement but also more demand on processing)rather than single sensor and embedded electronics so that the communication with the actuators that must respond to the sensing does not have delays.

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