EECS C106B / 206B Robotic Manipulation and Interaction **Spring 2022**

Lecture 22: (Soft Robotics, Part II)

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22.1 Key Takeways and Open Research Area

Design and function are closely connected, and the possibilities are endless

We can be inspired by the biology and design (biomimetics) the soft robotic towards or beyond biology.

Soft robotics should evolve with materials science and chemistry

There are new modules including flexible electronics, chemical or pneumatic circuits to replace the traditional electronics.

Softer is not always better

22.2 Tactile Sensors

22.2.1 Definition

Tactile sensors are devices measuring information arising from physical interaction with its environment. Tactile sensors are generally modeled by the biological sense of touch or contact which is capable of detecting stimuli. It measures the force from the contact or geometry of the object and the two kinds of information can be transformed into each other.

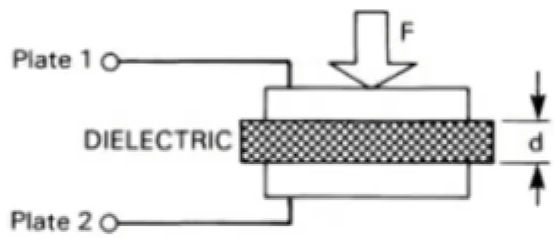
Notably, the sensor only measuring the temperature is not rigorously defined as tactile sensor since the temperature can be conveyed and detected without touch directly.

22.2.2 Non-optical Sensors

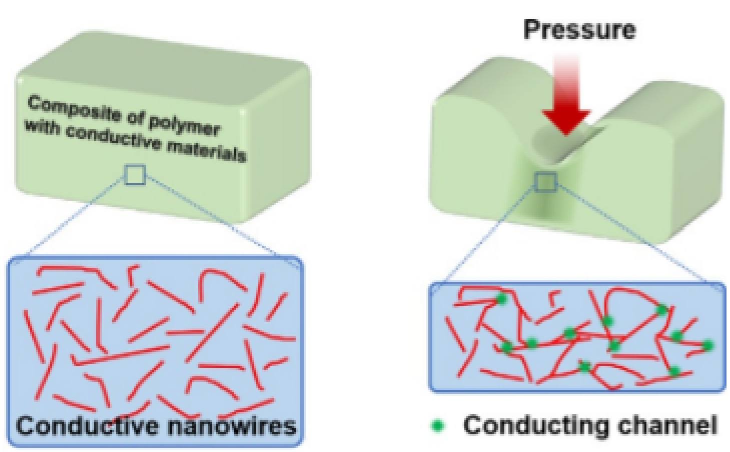
Non-optical sensors use electronic components instead of cameras, and were the among the earliest of tactile sensors. Generally, these are implemented with an array of sensing tactile elements. The most common transducers are capacitive, piezoresistive, and strain gauges. The advantages and disadvantages of them are shown in following table.

Name	Advantages	Disadvantages
Capacitive sensors	Excellent sensitivity	Stay capacitance
	Good spatial resolution	Noise susceptible
	Large dynamic range	Complexity of measurement electronics
Piezoresistive sensors	Fast dectecting	Low frequency response
	High spatial resolution	Suffers from hysteresis
	Resistant to noise	Higher power consumption
Strain-based transducers	Wide sensing range	Non-linear and suffers from hysteresis
	Sensitivity	Requires calibration
	Low cost	Susceptible to temperature and humidity changes
	Established product	

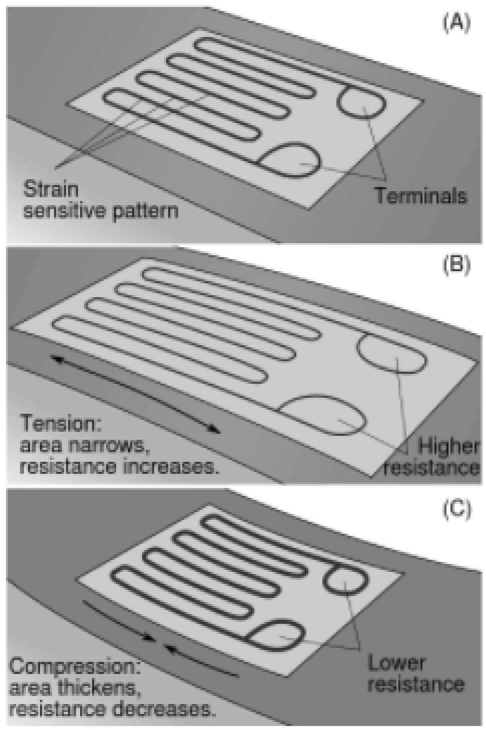
Capacitive Sensors Capacitive sensors work by way of capacitance: $C = \frac{\varepsilon A}{d}$ where ε is electric permittivity of the material, A is the area of the plate, and d is the distance between the plates. The plate is generally flexible, such that distance between plates can decrease and therefore capacitance can decrease. This decrease in capacitance can then be picked up by other circuitry.



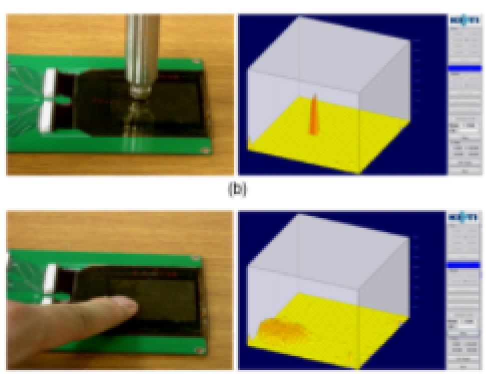
Piezoresistive Sensors In piezoresistive sensors, various conductive materials are dispersed throughout a material. Thus, when pressure is applied, these conductive components are brought into contact with one another leading due differences in resistance which can, again, be picked up by additional downstream circuitry.

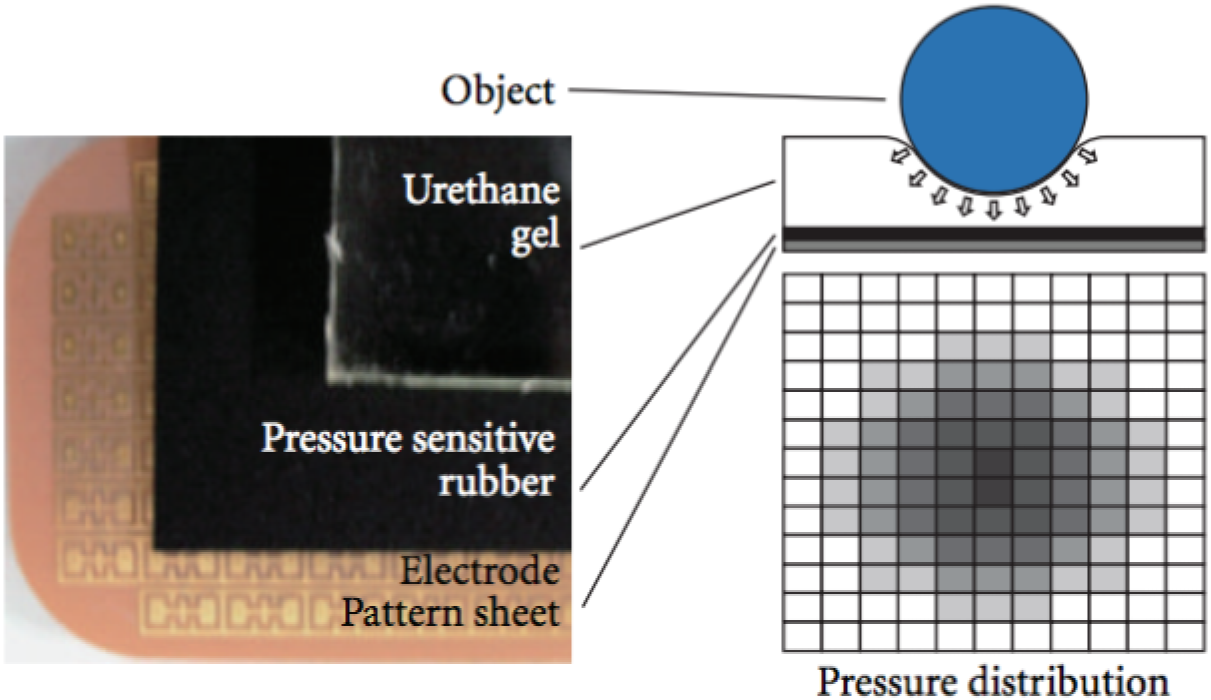


Strain-based transducers Strain-based transducers are traditionally implemented via metal strain gauges. With tension and compression, the resistance of the material changes as shown below. Notably, these are typically used when you know the direction of deformation, as tension in the correct direction leads to higher resistance, while compression leads to decreased resistance.



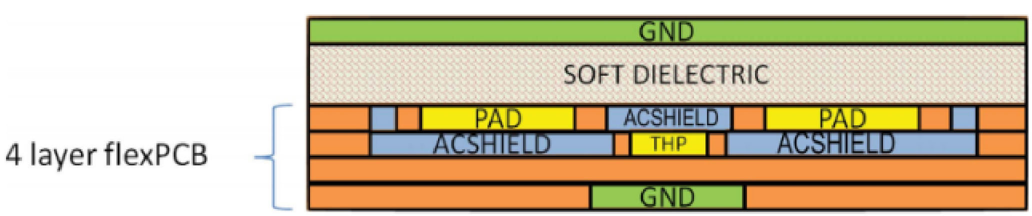
Each of these three sensors can be combined in arrays for more dimensionality. In these cases, the elements are called "tactels" (short for tactile elements). With only one tactel, one can only give apoint force, but given an array of tactels, one can determine an entire force distribution, and therefore geometry.





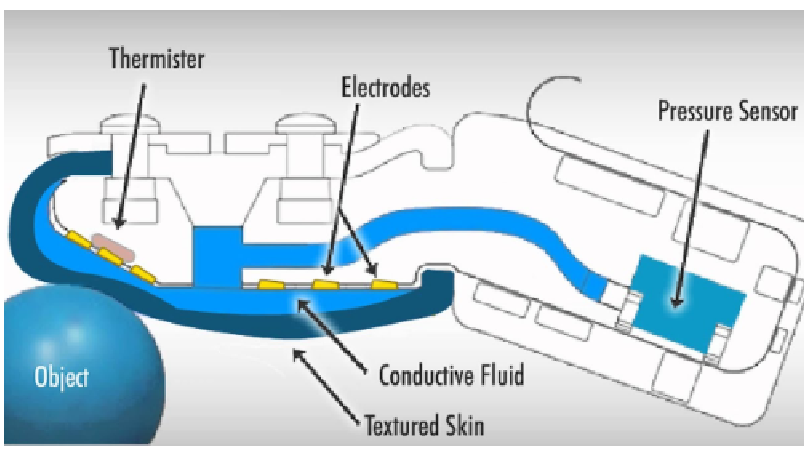
Below are some of the applications of non-optical sensors in robotic systems.

Capacitive tactile skin Capacitive technology makes sensors small and sensitive. The capacitive tacile skin system is used to cover various humanoid robots, where the tactiles are covered by 3D frabic and the sensors embed the transducers for thermal compensation of the pressure measurements from the external force. The following figure shows the vertical structure of the capacitive tactile skin. The yellow pads can detect the pressure through upper layers.

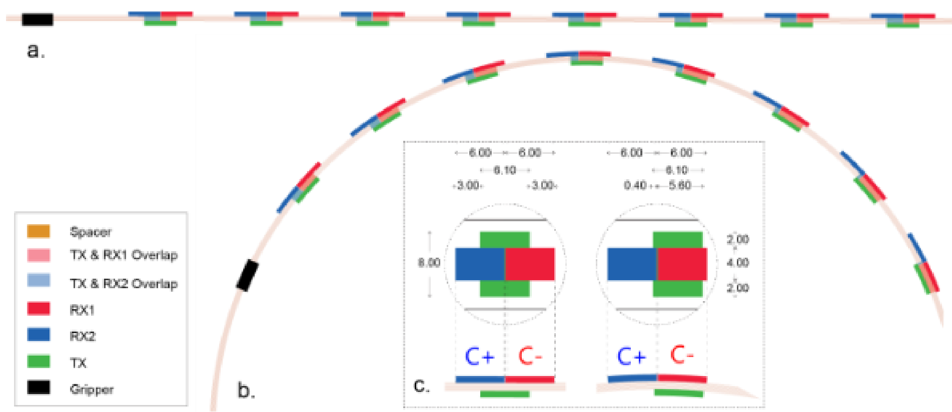


Piezoresistive tactile skin The piezoresistive tactile skin is used to cover humanoid robots with more physical movement challenges likes nurse care. The tactile sensors cover all arm except the joints to detect the small force which is difficult for force sensors to detect.

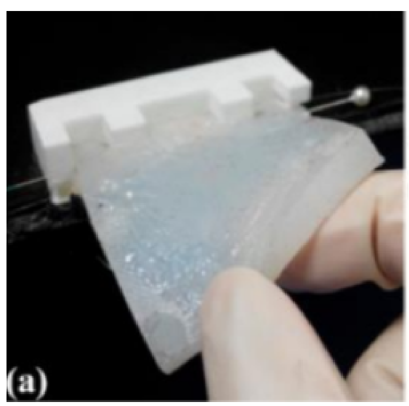
Biotac: distributed impedance sensors The tactile sensors usually provide low-density contact information including contact location and force. The contact forces distort the skin and the conductive liquid inside shown in figure below. To estimate tactile features and analyze the BioTac signals, a simulated information were generated by FEM to confirm the parameters; the neural networks are trained to learn the experimental information such as contact location and high-dimensional force distributions.



Capacitive self-shape sensing The capacitive self-shape sensor uses a series of flexible materials joined together to form complex curves. It can be used to measure curvature by relative shift of two parallel capacitive strips.



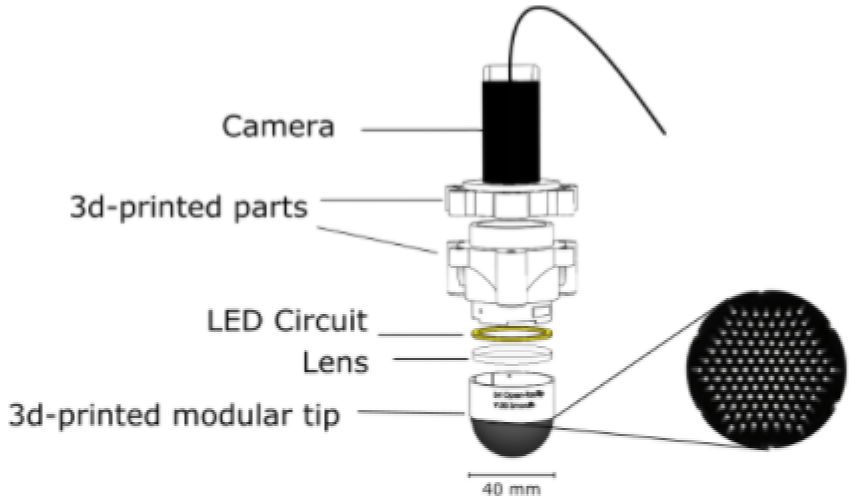
Fiber bragg grating self-shape sensing Fiber bragg grating self-shape sensors can reconstruct its surface shape to detect in real time. The fiber is embedded into the elastomeric substrate to reconstruct the surface morphology. FEM design the sensor parameters with embedded fiber bragg grating and the machine learning enables more robust shape reconstruction.

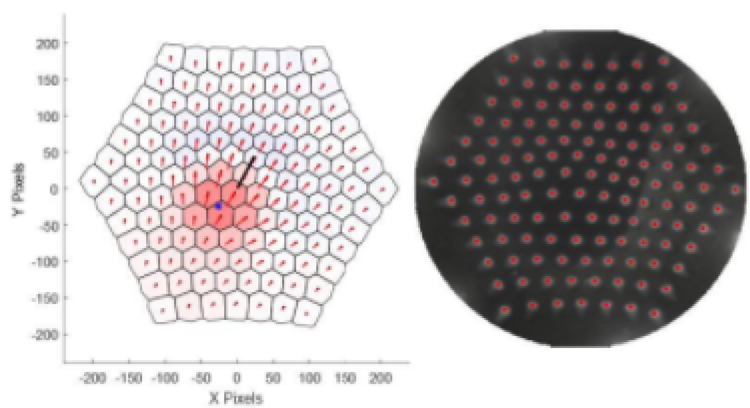


22.2.3 Optical Sensors

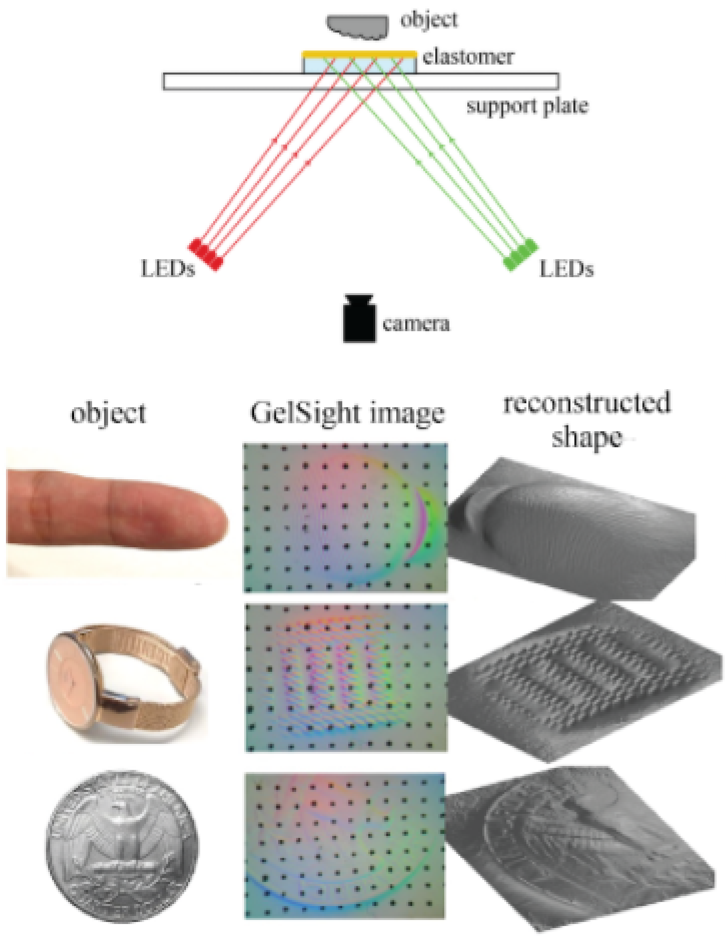
As the name suggests, optical sensors use a camera as the transducer. As cameras have become increasingly smaller, the viability of optical sensors has increased. The main benefit to using a camera as transducer is that excessive embedded electronics are no longer needed.

TacTip One such example of an optical sensor is the TacTip. The TacTip works by a camera detecting deformations in the tip of the device. By using deep learning, the different variations of deformations can be mapped to different poses of the TacTip in reference to an object.

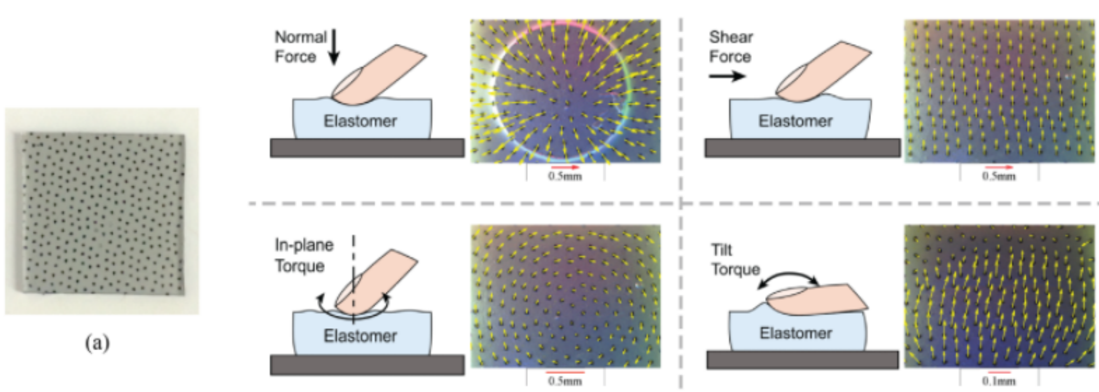




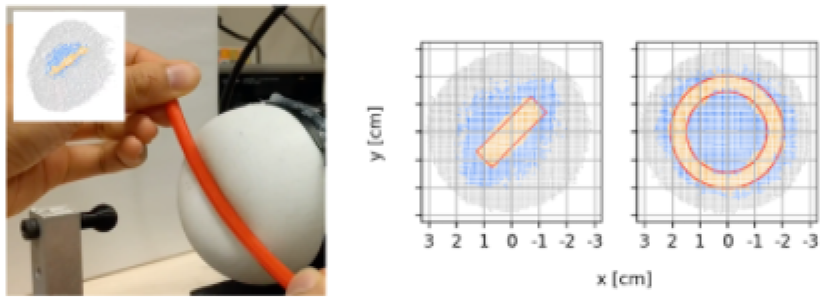
GelSight GelSight is another such example of an optical sensor that can be used to determine object geometry. When an object deforms the reflective coating on the elastomer (image below), the reflection due to deformation is picked up by the camera. This can then be used to reconstruct the geometry of the pressed object via an analytical photometric stereo algorithm. Although the applications are virtually infinite, the example provided was using the sensors to follow a wire and then plug it into a device, a task that requires precise sensing.

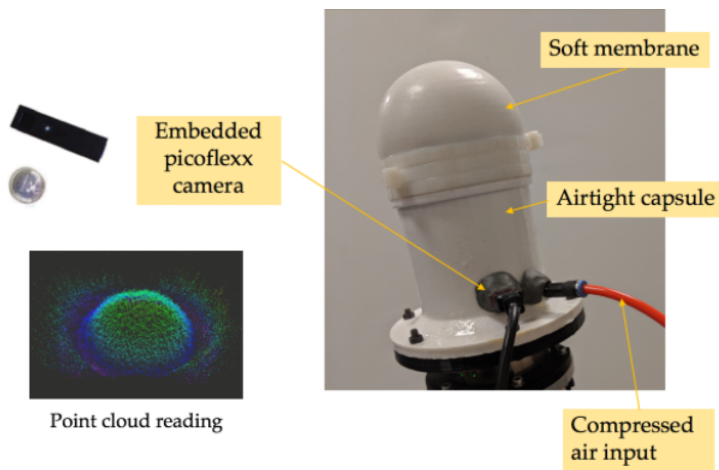


Below are a few images showing the GelSight more closely with examples of shear force, normal force, in-plane torque, and tilt torque.



Depth Camera-Based Sensor Professor Huang's recent work involved the depth camera-based sensor, another optical sensor. By using a soft membrane and a camera that detects depth, the object's shape can be inferred.





Using this, edges, surfaces, and contours can be followed by a robot. The example provided was wiping marker off of a plastic mannequin's back. This form of sensing is accurate enough that it can be done to wipe pepper off of a human, and not cause them harm.

22.2.4 Soft Sensing Takeaways

As technology evolves, so will soft sensing

Examples include: MEMS, flexible PCBs, tiny cameras, etc.

Soft sensing is task dependent

Carefully consider the problem to determine what kind of sensing to use.

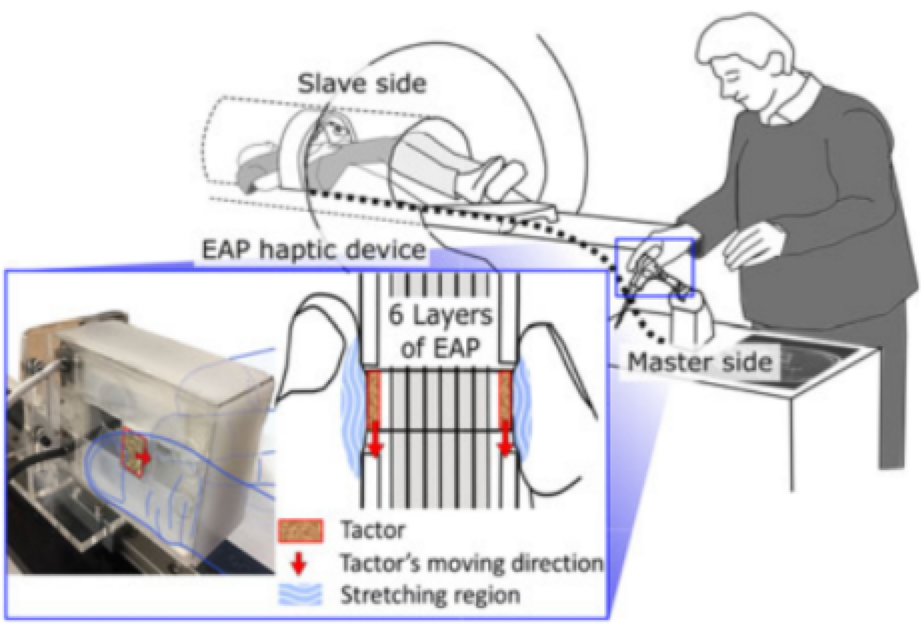
Consider hybrid sensing subsystems

Depending on the task, the accuracy of the sensing can lead to difference mixes in strategies of sensing

22.3 Haptic Devices

Haptic devices are devices that allow users to touch, feel, and manipulate three-dimensional objects in virtual environments and tele-operated systems. It could be thought of as the opposite of what was covered to this point; instead of sensing material properties, we're recreating them.

Besides the obvious application of VR controllers/gloves exhibiting haptic feedback, there is also medical applications. One such example being a haptic tool that simulates how it feels to puncture skin for training.



Another example provided was a haptic array that mimics tissue in a human, so that doctors not on site could feel and diagnose someone thousands of miles away.

22.3.1 Additional Related Papers

[1] "Soft tactile sensing skins for robotics", Roberts 2021

[2] "Elastomeric haptic devices for virtual and augmented reality", Bai 2021

[3] "Recent advances in tactile sensing technology", Park 2018

[4] "Novel Tactile Sensor Technology and Smart Tactile Sensing Systems: A Review', Zou 2017

[5] "A review of tactile sensing technologies with applications in biomedical engineering", Tiwana 2012