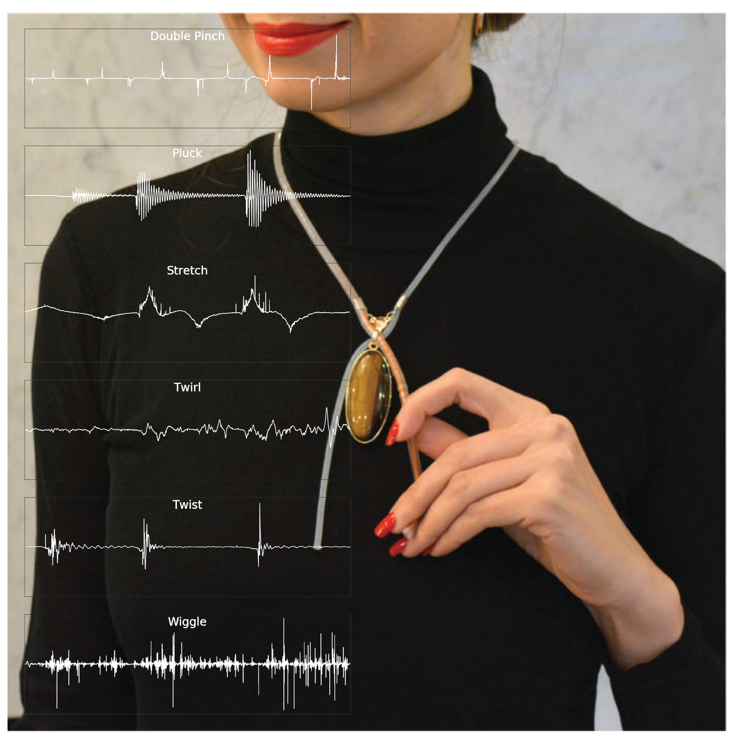
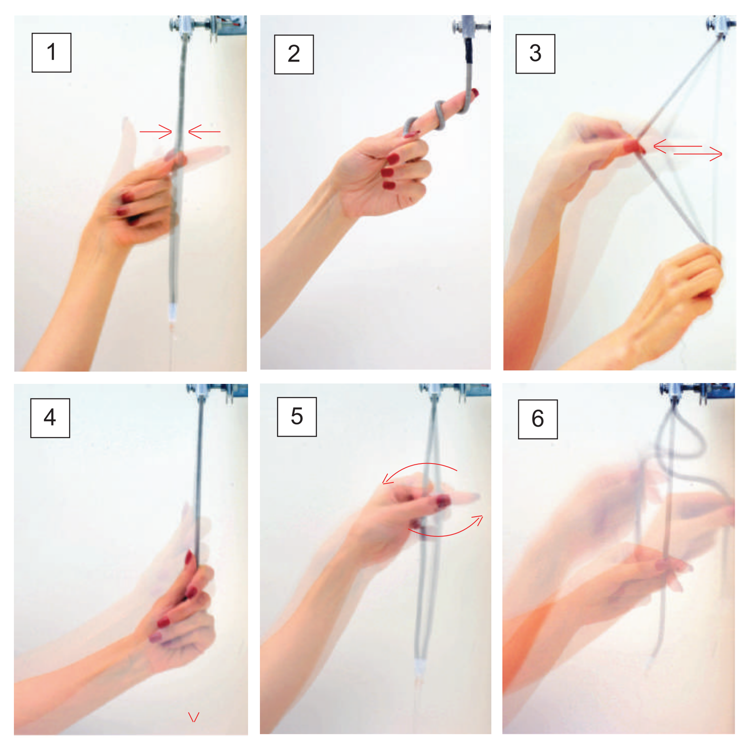
Serpentine:

Gesture Recognition using a Self-Powered Stretchable and Squeezable Cord-shape Force Sensor based on Triboelectric Nanogenerators



What is Serpentine?

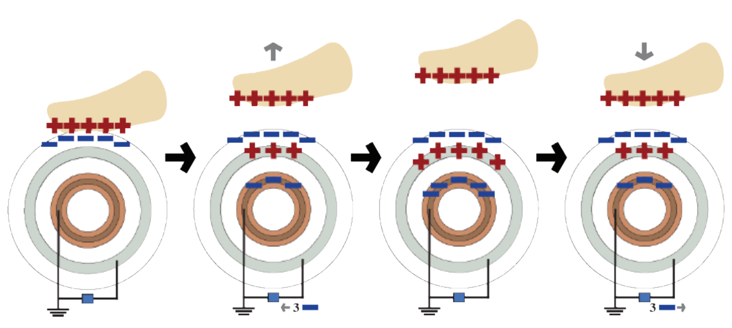
Serpentine is a self-powered sensor that is reversibly deformable cord capable of sensing a variety of natural human input. It's material properties and structure allow it to be flexible, twistable, stretchable and squeezable, enabling a broad variety of expressive input modalities. The sensor operates using the principle of Triboelectric Nanogenerators, which allows it to sense mechanical deformation without an external power source. The affordances of the cord suggest six natural interactions.Serpentine demonstrates the novel ability to simultaneously recognize these inputs through a single physical interface.



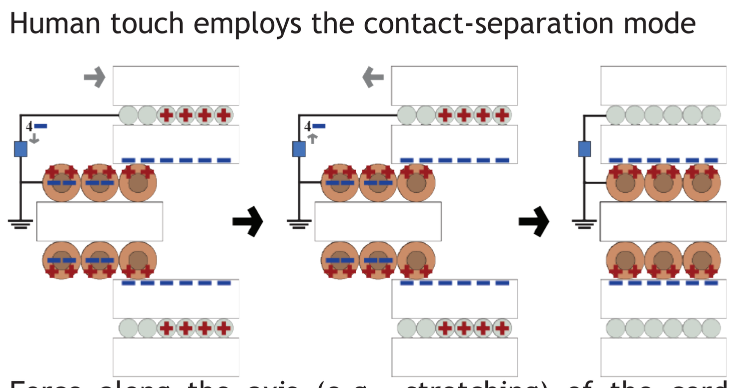
Gestures & Applications

Gestures identified by serpentine are multiple expressive one-handed and two-handed interactions. We evaluated Serpentine for six specific gestures, which have been inspired by affordances of a flexible cord in everyday situations. Smart necklace is among many applications for Serpentine. Gestures are as following:

- Double Pinch - as in pinching a piece of clay
- Twirl - like the twirling of hair
- Pluck - like plucking a harp string or bow
- Stretch - like stretching an elastic band
- Twist - like rolling a cord between fingers
- Wiggle - like ringing a bell using a rope



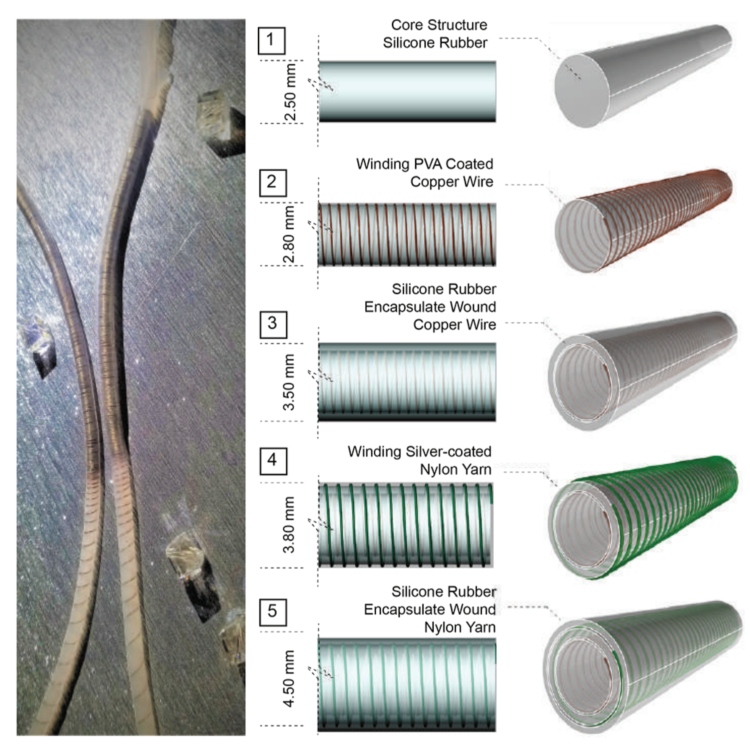
Human touch employs the contact-separation mode



Force along the axis (e.g., stretching) of the cord induces a lateral sliding mode TENG

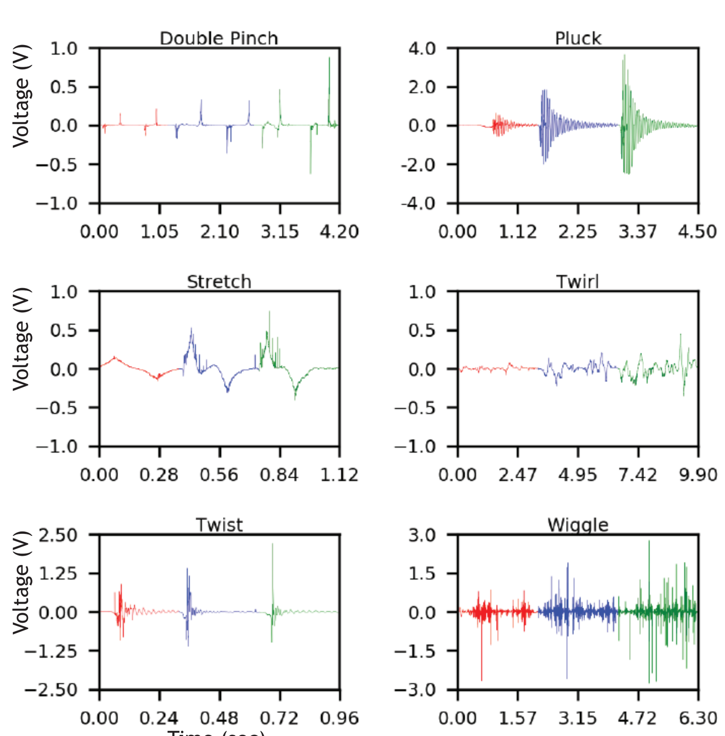
Sensing Mechanism:
Triboelectric Nanogenerators

Serpentine is a self-powered sensor; it harvests energy to perform its sensing operation. Triboelectrification occurs as a result of charge transfer between two materials of different electronegativity. When two materials come in contact, the triboelectrification creates a buildup of charges between the layers, resulting in electrostatic induction, or a charge flow. Charge redistribution is observed as a electrical current. Thus, relative movement of charged dielectric layers and the subsequent charge redistribution generates electrical power. We show that this harvested electrical signal is indicative of the way the Serpentine cord has been manipulated.



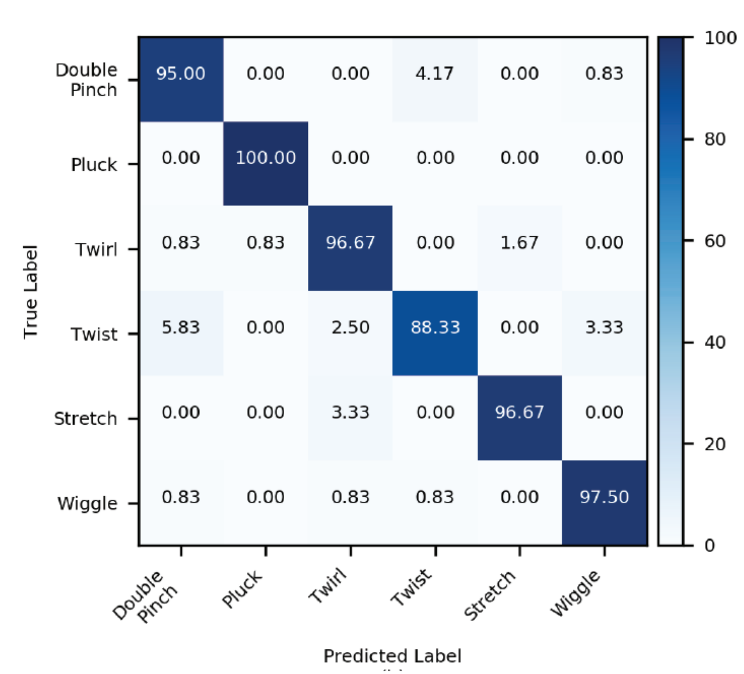
Design Parameters and Material Choice

Silicone Rubber Substrate:
The main substrate for Serpentine is the silicone rubber solution, which makes up three layers of the sensor. It acts as a dielectric with a highly negative triboelectric polarity, meaning it helps to increase the magnitude of the self-powered current resulting from mechanical deformation. Second, its elastic properties support repeatedly squishing and stretching.
Electrode Coils:
Two conductive threads; copper and silver-coated nylon, coiled around the silicone provide both mechanical strength as well as being electrodes to support charge flow.



Signal Intensities and Gesture Expressiveness

The Serpentine sensor generates electrical signal proportional to net applied force on the sensor at any time. This means that along with a distinct temporal shape for the signal, the output signal ay also differs in amplitude information between two different examples of the same class of interaction (i.e., a harder Pinch results in a higher amplitude of electrical signal detected). As figure shows the different signals generated for increasing intensities of the same gesture. This aspect of the sensor can allow for more expressive inputs. For example, stronger pluck gesture can result more intense impact on the actuation of longer throwing.



Results:
Quantitative Analysis

The real-time gesture detection accuracy of the system across 12 participants and 6 gestures was 95.7% (sd=4.10%) for user-dependent model and 92.17% (sd=5.35%) for user-independent model.

Note on Classification:
We use a Random Forest machine learning classifier to recognize the gestures. The used features include spectral features, statistical features, frequency domain features, Discrete Wavelet Transform and gradient of the signal. Since the length of the segmented data varies with each gesture type and user, we further calculate statistical features on the previously calculated feature vector to get a new feature vector of fixed length.

What if Single Form-factor of Serpentine acts as an Antenna to harvest Power and Transmit Data, besides Inherently being a Triboelectric Nanogenerator.

Believing the idea of "less is more", we will study how single form-factor of serpentine can act as a hybrid system including Triboelectric Nanogenerator and Radio Frequency (RF) power harvester and transmitter. Accordingly, such simple, unique and novel structural design - helical structure of electrode coils embedded in stretchable and squeezable silicone - seems promising in affordance of a fully self-powered workflow for sensing, communication and potentially computation and actuation in the future.
Moreover, although, in current status, the energy generated from this sensor may not be sufficient for complex computation tasks, it can be used to relay the data wirelessly to a more complex system, thus producing a battery free input device. One way to achieve this is through analog backscatter. The sensor's energy can be used to do an amplitude modulation of a reflected or backscattered RF signal that is incident on the antenna.

Research Team:
Fereshteh Shahmiri, Chaoyu Chen, Anandghan Waghmare, Dingtian Zhang, Shivan Mittal, Steven Zhang, Yi-Cheng Wang

Advised by:
Dr. Gregory Abowd, Dr. Thad Starner, Dr. Z. L. Wang

Georgia Institute of Technology
School of Interactive Computing - Mobile & Ubiquitous Computing Lab
School of Material Science & Engineering - Nanoscience Research Group