Ultrahigh-Performance Soft Tactile Sensors using Flexible Coils

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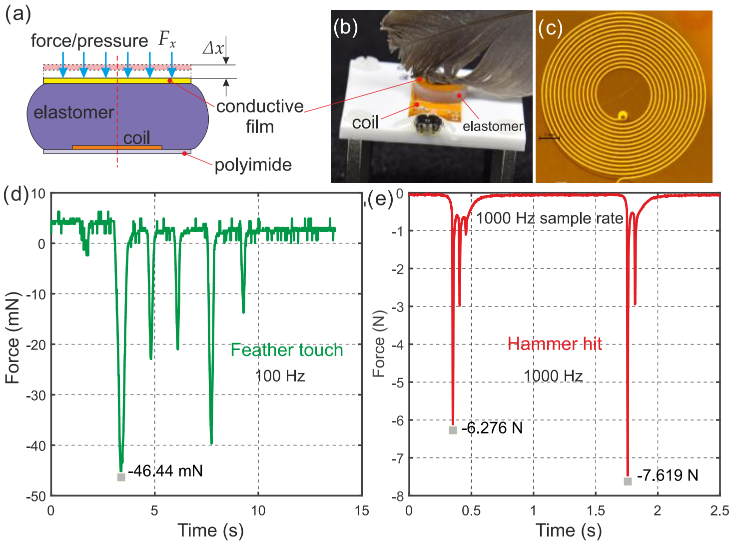
Tactile sensors are becoming increasingly ubiquitous and valuable components in today's technology. They are instrumental in enabling robotic systems to perform tasks such as interacting safely and effectively with humans and the environment. Equally they offer significant potential for use in modern healthcare systems, including prosthetics, wearable electronics, health monitoring devices and smart surgical instruments. Compared to the auditory and visual senses, replicating the sense of touch provided by human skin remains challenging, requiring both high compliance (mechanically conform during interaction with objects) and high performance (high resolution, accuracy, and bandwidth). To be effectively applied in real-world environments, tactile sensors should also be durable and robust to survive repeated physical interaction. Furthermore, to emulate human skin requires coverage of large areas with multiple sensing nodes, sensors meeting these criteria are typically expensive, difficult to fabricate and challenging to integrate into other systems. In the past two decades, new transducers and materials, novel structures/composites, and new fabrication techniques have been explored to address these challenges and thus develop low-cost, high performance, durable tactile sensors. Here, we present a new sensing system-Inductive Tactile Sensors (ITSs), which offers a new direction with the potential to address many of the above challenges.



As shown in Figure (a), an ITS comprises three layers, a flexible polyimide substrate with printed coil (the sensing device), a top conductive film (the sensing target), and a middle elastomer layer. When the sensor is deformed, the AC magnetic field coupling between the coil and the conductive film changes, leading to variation in the inductance of the coupled coil-target pair. By measuring the inductance variation of the sensing coil, the force applied can thus be inferred. Figure (b&c) shows a sensor prototype with a circular elastomer layer (12 mm diameter, 2 mm thick, Ecoflex 00-20) combined with a double-layer sensing coil (14 turns per layer, 100 µm trace, 100 µm space), with a diameter of 8 mm. The prototype has a nominal unloaded inductance of 4.47 µH (at 5 MHz) and a measurement resolution of 2.14×10^{-5} µH (100 Hz bandwidth) using a digital to inductance converter (LDC1614, Texas Instruments, USA). The characterised prototype results in a force measurement range over 15 N, with a resolution of 0.57 mN (equivalent to 5 Pa, less than 0.004% of the measurement range). The sensor is extremely sensitive, high speed (up to 4 kHz), durable, robust, and has a large dynamic range due to the high resolution of inductance measurement. Consequently, the sensor is capable of measuring both small forces (e.g. 46 mN when gently touched by a feather, figure d) and large impact forces (e.g. 7.6 N during a hammer strike, equivalent to 67 kPa pressure, see figure e).

In conclusion, ITSs represent a new type of high-performance soft tactile sensors, which are low cost, highly sensitive, high speed, deformable, durable, and insensitive to environmental contaminants. The measurement range and resolution can be readily adjusted by using different elastomer materials, geometries or structures, and the size of the sensing node can scale from 2 mm to 20 mm+. In our ongoing work, a 4×4 array and tri-axis ITS will be developed and evaluated. In the near future, new materials (e.g. conductive ink, metal liquids) and advanced fabrication techniques can be used to improve the flexibility, stretchability, and/or durability to suit different applications.

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