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Recent advances in wearable tactile sensors: Materials, sensing mechanisms, and device performance

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ABSTRACT

Tactile sensors, most commonly referred as strain and pressure sensors, can collect mechanical property data of the human body and local environment, to provide valuable insights into the human health status or artificial intelligence systems. The introduction of a high level of wearability (bendability and stretchability) to tactile sensors can dramatically enhance their interfaces with the contact objects, providing chronically reliable functions. Therefore, the developed wearable tactile sensors are capable of conformably covering arbitrary curved surface over their stiff counterparts without incurring damage, emerging as a promising development direction toward the Internet of Things (IoT) applications. Fundamental parameters of the wearable tactile sensors such as sensitivity and stretchability have experienced unprecedented advancement, owing to the progress of device fabrication techniques and material structural engineering. Moreover, novel smart materials and mechanically durable sensor design concepts endow these sensors with multi-functionality integration (*e.g.*, simultaneous force, temperature and humidity detection, simultaneous pressure and strain discrimination) and stirring properties (*e.g.*, biocompatibility, biodegradability, self-healing, self-powering and visualization), further broadening the application scope of current wearable tactile sensors. Besides, it is desirable that a tactile sensor is compatible with a printing process that presents a new era of feasible wearable technology due to its large-area and high-throughput production capability. In addition to the development of sensors, packaging, and integration of the rest of the tactile device system (data memory, signal conversion, power supply, wireless transmission, feedback actuator, *etc.*) to build a wearable platform also emerge as major research frontiers in recent years. This review attempts to summarize the current state-of-the-art wearable tactile sensors concerning basic concepts, functional materials, sensing mechanism, promising applications, performance optimization strategies, multifunctional sensing, and system integration. Finally, the discussion will be presented regarding potential challenges, pathways, and opportunities.

Contents

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1. Introduction

Tactile sensing which provides measurement information of given properties of an object or event through physical contact is ubiquitous in human activities. Indeed, human interact with the world using tactile sensing every day *via* the largest sensory organ, the skin. In general, there are seven types of sensory receptors in human skin, including pain receptors, cold receptors, warm receptors and four mechanoreceptors that measure innocuous mechanical stimuli [1]. Owing to these receptors embedded in the skin, human tactile sensing conveys perceptible information about material and surface properties especially the contact force and thermal properties, which helps human survive, explore, and respond to the external world [2,3].

Researchers have been pursuing the development of tactile sensing technology that can mimic the properties of human skin for decades. Since the 1980s, tactile sensing has evolved as a research field which integrates highly diversified researchers and practitioners with interdisciplinary expertise, such as electronics, mechanics, material sciences, measurement methods, system engineering, robotics, and bioengineering. However, tactile sensing developed slowly compared with vision sensing, which can be attributed to the following challenges. First, tactile sensors need to be wearable and incorporated into surfaces of adequate shapes with compatible, durable, and abrasion resistant. Therefore, the typically used brittle materials in the semiconductor industry (*e.g.*, Si) are impracticable. Second, tactile sensing requires a sophisticated sensing system which is capable of differentiating multiple environmental stimuli (mechanics, temperature, humidity, *etc.*) as well as various mechanical components, such as normal pressure, lateral strain, shear, flexion, torsion, and vibration.

Despite these challenges, a continuous evolution of new tactile sensing devices [4–6] with wearable capabilities has been taking place throughout the years, motivated by the fast emerging ability