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Research Article

BIOCOMPATIBLE AND SOFT CONDUCTIVE COMPOSITE FOR ELECTRO TACTILE-BASED AR/VR HAPTIC INTERFACE

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Abstract

Virtual reality (VR) and augmented reality (AR) systems have expanded virtual or augmented reality experiences beyond sensation of ear and eye. These kinds of systems detect user inputs and provide haptic, audio, and visual feedback to blend interactive virtual environments with the real word for the vivid reality experience. One promising technology is electro-tactile stimulation, which uses electrical stimulus for activating afferent nerves or mechanoreceptor. The main purpose of haptic technology involves the development of wearable system that could provide myriads of sensation to the skin through not only fingertips, but also to all regions of the body with high conformal contact. To provide the wearing comfort with haptic devices, skin-like technologies that impose negligible physical burden on the user should be used. In this review, we highlight the biological background of sensation of human and suggest the future direction in electro-tactile technology for haptic system by using biocompatible and soft composite conductors. Firstly, we will examine the conductive polymer called "Poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS)" that shows exceptional electrical and mechanical property in terms of deformability and conductivity for developing the low-impedance, skin-like haptic interfaces. Besides, we address the strategy to impart skin-like property as well as low impedance using hydrogel polymer which is desirable for future opportunities toward seamless integration of the virtual and real world

Keywords: Hydrogel, PEDOT:PSS, Haptic, Electrotacile, Modulus.

INTRODUCTION

The feelings and experiences that were previously out of reach owing to physical restrictions, financial restraints, or technological limits can be considerably expanded by the use of virtual environments realized with advanced systems. For example, simulations generated with computers have provided low-cost and effective solutions to complex and repetitive tasks such as surgical training and physical therapy (Joda *et al.,* 2019). Approaches to integrating virtual worlds with reality can be achieved by two categories: virtual reality (VR) and augmented reality (AR). Augmented reality (AR) is a technology that enriches the perception of human and provides a live view of the real world with digital information, aiming to expand it by adding images, sound, video and other virtual details. The purpose of AR is to augment the environment and let virtual elements interact with real objects to create intended meanings. In AR, informative virtual environments coexist with the real ones by providing additional information about the real world. Most often, no specialized equipment is required to create an AR; instead, commonplace technologies, primarily smartphone cameras, are used to produce AR. Based on their geometric relationships, virtual three-dimensional (3D) items and surroundings are superimposed on actual things via augmented reality (AR) systems in real time. The goal of VR is to give the impression that the user is completely immersed in a life-size 3D digital environment. VR systems typically use computer vision and cutting-edge graphics that add depth and reconstruct the scale and distance between static two-dimensional (2D) pictures in order to create 3D visuals and films, many of which replicate the real or imagined world. All of this works together to replicate a real-world setting and give the impression that you are a part of the particular computer-generated digital environment you are experiencing.
However, the AR/VR devices provide the only two kinds of sensory information: Visual and hearing. To make more vivid experiences, we could use the tactile information, which provide the sense of touch, pressure, vibration and pain. One of the promising strategies is an electrical stimulation, which stimulate the nerves located under the skin. This technology has shown the new class of AR/VR system in terms of low power consumption, light weight and easy fabrication. Although these advantages, it is challenging to make electrio-tacile based AR/VR system due to lack of biocompatible and soft conductor. In order to create electrically and mechanically reliable interfaces that allow for the recording or stimulation of the neural-interface and skin, bioelectronic materials for haptic systems have been studied for a long time (Athukorala *et al.,* 2021). Current skin-haptic interfaces must be converted into a low-impedance technology that uses softer, more biocompatible electrodes in place of stiff metallic ones in order to perform these duties. This requires material research. In order to match the mechanical and electrical properties of wearable technology with those of skin, advancements in electrode topologies are therefore required. As a result, a number of ideas and methods from flexible and wearable electronics have been used to the development of haptic interfaces that mimic the skin. Conductive polymers (CPs) such as PEDOT:PSS (poly(3,4-ethylenedioxythiophene) polystyrene sulfonate), Polyaniline (PANI), Polypyrrole (PPy), which have both mechanical flexibility and high conductivity, have been addressed for promising materials for wearable electronics. These characteristics result from their backbones' conjugated nature and the subsequent manifestation of the polaron and bipolaron structures, which stand in for singly and

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doubly charged quasiparticles, respectively. Additionally, CPs have outstanding qualities that can enhance the electrode/tissue interaction. Wearable conductors fabricated with CPs have extremely lower impedance than inorganic electrodes such as Au, Ag, Ni and Cu due to their combined ionic-electronic conductivity (Yang *et al.,* 2020). In addition, CP-based conductor couldminimize the mechanical mismatch between conductor/skin interface, allowingdurableand functional skin interface (Fan *et al.,* 2019). The curvilinear region of any body parts is in conformal contact with the thin, flexible electrodes when CP is coated on thin, flexible films of polyimide or parylene. However, it is still challenging to achieve both superior electrical performance and skin-like modulus simultaneously due to relatively high modulus of polyimide or parylene compared to that of skin. Hydrogel has been studied for bioinspired materials because of its high stretchability and low modulus characteristics. For this reason, researchers have used hydrogel as bio-interface materials (Lu *et al.,* 2019). According to Lim et al., a skin-device interface made of characteristics resembling tissue can be created by utilizing an ultrathin functionalized hydrogel. They demonstrated the wearable bioelectronic device can build a stationary quasi-solid yet moistened contact with human skin using a functionalized hydrogel film made of poly(acrylamide) (PAAm). (Lim *et al.,* 2021). However, intrinsic conductivity of hydrogel is too low to operate the entire wearable electronic system. We have conducted a thorough analysis of biocompatible functional materials for skin-like haptic interfaces in this study. We have outlined the benefits of using hydrogel to reduce the modulus of polymeric materials and conventional PEDOT: PSS polymeric material as a low impedance electrical stimulator to reduce mechanical stress on skin. We grouped the three materials as follows for the sake of this review.

PEDOT: PSS as flexible and conductive polymer

Fundamental nature of PEDOT:PSS: Due to its high conductivity, outstanding optical transparency, superior physical and chemical stability, and ease of doping and solution processing, PEDOT:PSS is the most widely used conductive polymer. Based on the aforementioned benefits, PEDOT:PSS has been widely utilized in a variety of energy conversion and storage, as well as biosensor, devices. The process used to create PEDOT:PSS PEDOT:PSS is crucial because it adds new qualities that influence how it is used. Four conductive polymers polyacetylene (PA), polyaniline (PANi), polypyrrole (PPy), and polythiophene (PTh) have so far been reported and the subject of in-depth research. Although conductive polymers exhibit reasonable flexibility and conductivity, their low stability due to the doping state and insufficient conductivity half-life provide a significant barrier to their commercialization. Among conductive polymers, PEDOT:PSS has drawn most of the attention in both academic and industrial fields due to its relatively high conductivity and remarkable stability in ambient conditions, as well as its potential to be applied to transparent electronics. Since it directly affects how conductive polymers are used, conductivity is a crucial parameter. Meanwhile, PEDOT's crystallinity and doping, which are directly related to the various synthesis techniques, are what are primarily responsible for the enhancement in conductivity. Since there are numerous oxidants and additives used during the difficult polymerization of PEDOT, even the smallest adjustment could have a significant impact on the final product's characteristics. The chemical structure of PEDOT:PSS consists of two parts: PEDOT as positive charge ionomer, which imparts electrical conductivity and PSS as negative charge ionomer, which acts as insulator as shown in Figure 1. To improve the electrical property, we could remove the PSS part by using acid treatment, however, It could make aggregation of PSS parts, which reduces the flexibility. From the understanding of PEDOT:PSS, mechanical, electrical properties could be tuned for high performance flexible electronics.

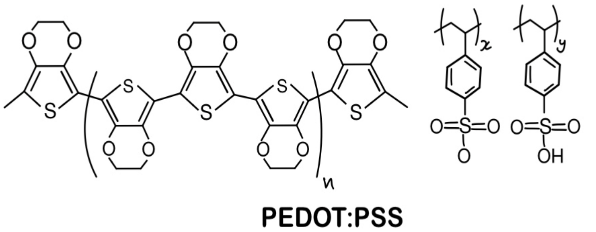

Figure 1. Chemical structure of PEDOT:PSS

Biocompatibility of PEDOT:PSS: In general, the word "biocompatibility" refers to a biomaterial's capacity to support high-quality, compatiblr interfaces between biotic and abiotic interactions as well as its absence of cytotoxicity in the environment in which it is applied. The study of biocompatibility in biomaterials is crucial, particularly in the area of human-friendly electronic devices like wearable haptic devices, which call for in vitro tests to determine the material's local and systemic effects on the entire body. Due to its well-known biocompatibility, PEDOT:PSS is a potential material for biomaterials when compared to other metallic materials. The low biocompatibility of PSS and the lack of functionality of PEDOT, however, limit the two components. Innovative poly(dioxythiophene) polymers with various functional groups have been designed to address this problem and increase biocompatibility. The use of biomolecules as dopants has been shown to improve biocompatibility and decrease cytotoxicity. Consequently, using biopolymers could be a solution to get around PEDOT's drawbacks. PSS dispersions for a haptic interface that mimics skin. Electropolymerization of EDOT in the presence of biomolecules is the process used to create PEDOT doped with biopolymers (heparin, hyaluronic acid, fibrinogen, gellan gum, carboxymethyl cellulose, xanthan gum, pectin and gellan gum) (Thaning *et al.,* 2010). Functionalized PEDOT exhibits non-toxicity and has the ability to act as the skin's electrode interface (Asplund *et al.,* 2009). Different water-based PEDOT:biopolymer dispersions have recently been created by several groups utilizing chemical polymerization, which was inspired by this method. Using this technique, we could create haptic systems that are comfortable for people to use on their bodies and are made of biocompatible PEDOT electrodes.

Hydrogel as low modulus matrix

Chemical structure of hydrogel: Hydrogels are soft materials that are often made of cross-linked, three-dimensional, insoluble polymer networks that can hold a lot of water inside their network (Figure 2).Cross-links are typically created by chemical or physical interactions between these polymer networks. While normal chemical cross-linked hydrogels are commonly created by temperature, light, or radiation-driven free radical polymerization, physically cross-linked hydrogels are created via non-covalent bonding interaction at the molecular level (Yuk *et al.,* 2016).

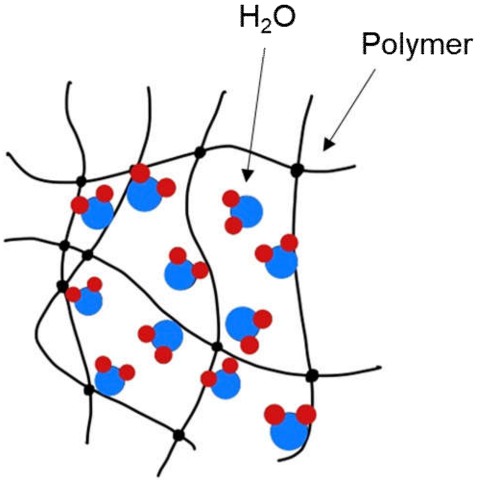

Figure 2. Schematic showing structure of hydrogel

Systems made on polymer hydrogels have had significant uses in modern industries and daily life. However, multiple networks are frequently constructed for the construction of the tough hydrogels, for example the double network hydrogel, due to the poor mechanical properties of a single chemical cross-linked network. In addition, it has been demonstrated that combining a chemical and physical network can be used to create high strength hydrogels. Due to its well-designed flexibility, hardness, and strength, as well as its capacity to respond in a different way to environmental stimuli. The best materials for replicating the chemical, physical, and mechanical qualities of natural extracellular matrix are believed to be hydrogels (ECM). Due to potential application for tissue organs, cell scaffolds, and implantable artificial muscles, hydrogels are extensively studied and created. For many implanted biomaterials techniques, the development of functional hydrogels is essential

Ionic conduction mechanism: Water molecules are bonded with hydrophilic polymer chain using hydrogen bonding. In general, hydrogel has porous structure, which is formed when all the water evaporates in hydrogel. It has its intrinsic conductivity called an “ionic conductivity”. However, it has low electrical performance due to low ionic conductivity of water molecules. An ideal method to improve the conductivity is to add some ions to hydrogel, including Na+, K+, Cl-. All these ions could perfectly be ionized in hydrogel, providing electrical path in the medium. As the number of ions increases in the solution, it becomes more conductive because the conductivity is determined by the number of carriers. Sweat is also known as perspiration and consists of water with tiny amounts of other chemicals like ammonia, urea, salts, and sugar. These biomolecules could impart ionic conductivity to hydrogel by penetrating into the polymer structure. For this reason, hydrogel is promising candidate for wearable electronics.

PEDOT/Hydrogel conductive composite

Due to their great mechanical compliance (100 kPa), which is unusual even in the context of the field of stretchable electronics, conductive hydrogels have drawn interest for biointegrated applications. Due to the majority of the substance content being water, a conductible hydrogel enables high deformability and a low modulus. In particular, conductive hydrogels have been used for tissue engineering and neural interfaces to reduce the impedance of electrodes. It has been proposed that several methods could be used to create nanostructured conductive hydrogels. The first, and most popular procedure, entails crosslinking the hydrogel before drying it out and re-swelling it in a solution containing the conjugated polymer monomer. Combining the two materials involves the aqueous blending of PEDOT monomers and the Hydrogel solution. The hydrogel, swelled in water, is mixed with the PEDOT monomer. After solidification process, the PEDOT:PSS/Hydrogel composite film is fabricated (Figure 3). By combining the PEDOT:PSS with soft hydrogels, we could realize highly biocompatible, soft conductive electrodes for wearable electrotactile-based haptic interfaces.

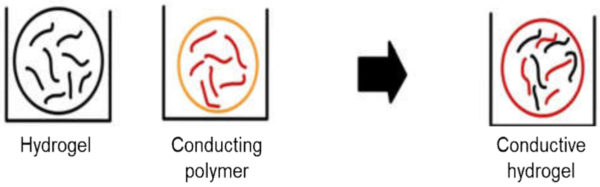

Figure 3. Schematic showing PEDOT/Hydrogel

Conclusion

Many different areas of research, including materials, electronics, and mechanics, have been investigated in relation to wearable haptic devices. By utilizing the sensory feedback of the haptic system, our experience could be extended to include all of our body in addition to the visual and auditory senses. Many researchers have searched for materials with strong conductivity and high deformability to deliver the entire haptic experience. We review the two promising candidates for electric tactile-based haptic system. 1) PEDOT:PSS and 2) Hydrogel. When compared to other organic materials, PEDOT performs reasonably well against air and moisture. It is also chemically and thermally stable. Additionally, the inherent flexibility of haptic systems enables the creation of wearable versions of them. Long utilized in biomedical applications, hydrogel is a cross-linked polymeric network having a significant amount of water contained inside the porous structure. The hydrogel's ability to be easily shaped and organized into different shapes gives the polymeric network solidifying capabilities, while the water content allows for liquid-like properties. PEDOT:PSS/Hydrogel composite, a mixture of above two materials, is a new kinds of material that provide synergistic effect of both materials. In the haptic electronic system, hydrogel imparts mechanical softness and PEDOT:PSS improves the electrical performance of entire composites and forms stable interfaces between skin and devices. With this material strategy, we could make a next generation wearable haptic AR/VR interfaces for vivid and immersive experience.

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