Resistive Flexible Pressure Sensors and Their Applications

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Abstract. Resistive flexible sensors are widely used in many fields. Especially now, resistive flexible sensors are making great contributions to the development of wearable sensors and artificial intelligence. Therefore, the current situation in this article studies the resistive flexible sensor. This article will first introduce the background of the research, and then elaborate on sensing mechanism, the sensing improvement strategy, materials of dielectric composite, and had a great discussion in detail. The research significance of this article is to provide ideas and some summaries of the current situation for future research accuracy. Therefore, the research in this paper will be of great value to the application and research of wearable and more accurate treatment and diagnosis of future patients with the help of resistive flexible sensors. It is worth mentioning that the working principle and The sensitivity improvement strategy of this kind of sensor are introduced in detail in the following paper, and the physical and chemical properties of the raw materials of the flexible sensor are well analyzed, and then in-depth discussion is carried out. It provides some feasible ideas for improving performance.

Keywords: Resistive, Flexible Sensors, Bio-sensors.

1. Introduction

In recent years, the demand for wearable and sensitive sensors in human medicine, as well as bionic robots and artificial intelligence for flexible human-imitation sensors has greatly increased. For human medicine, the hottest topics in recent years are electronic skin and wearable devices that continuously monitor physical activity and physiological signals. To make the function of flexible and portable e-skin like that of human skin, we need to improve the tactile perception of e-skin. Naturally, the development of flexible pressure sensors with high sensitivity is required. Over the past few years, numerous reports on flexible pressure sensors have been published, along with numerous studies on enhancing sensor performance, particularly sensitivity [1]. In addition, a lot of research has looked at self-healing materials, multifunctional detection, etc. In recent years, there has been a great deal of interest in flexible and wearable sensors that can monitor human health and activity. Commercially available wearable devices like the apple watch and fit bit wrist band can measure physical activity and physiological signals for audiological signals. The pressure sensor, which monitors the signal fluctuation in addition to mechanical deformation or situational factors, is a crucial instrument for applications in soft robotics, synthetic electronic skin, human-machine interface, and other. Recently, there has been a surge in curiosity about the usage of robots extending far beyond repetitive and constricted operations of the industrial environment to more sophisticated operations for interacting with humans in both the research and applied technology domains. For jobs like physical handling and scanning, as well as for safe operations and human interactions, significant breakthroughs are needed in this field.

Numerous developments in miniaturized electronics, the widespread use of smartphones and other connected devices, rising demand from customers who are far more health concerned, and rising patient demand from doctors are all major contributors to the spectacular expansion of wearable sensors. There is an unmet need for access to high-quality healthcare data, driving affordability and ergonomics. But we need more information in the patient's body, and that information needs to be continuously monitored. At least part of the reason is that most of what has been found in wearable devices so far, we have found that there are still problems of insufficient sensitivity and low comfort for human wearing. According to the characteristics of the resistance strain sensor through body-signal transduction and the flexible sensor, we find some feasible schemes [2].

Therefore, in the following article, we first briefly introduce the principle of the sensor mechanism according to the basic formula of resistivity [3], and then put forward some methods to improve the sensitivity according to the advantages of high accuracy, easy-to-wear, and high utilization of this type of sensor, mainly using microstructure, and the integrated discussion is carried out by discussing the materials selected by the sensor. We discussed ways to improve sensitivity and illustrate it with two examples. The first example quickly shows how to easily create a flexible array of very sensitive pressure sensors, a stretchable pressure sensor array is suggested for wearable and artificial electronic skin devices. The total resistance of the sensor decreases as the contact resistance decreases with straight up-and-down applied pressure. The second example shows that compared with the traditional resistance pressure sensor through the combination of a compressible micro pyramid structure with a high-tensile electrode, this type of sensor has higher eye pressure sensitivity, thus proving that our conclusion also provides ideas for subsequent discussion.

2. Resistive flexible pressure sensor

2.1. Sensing mechanism

Sensors with flexible materials produce deformation when subjected to pressure and are converted to electrical signals based on that deformation. Flexibility and volatility make flexible pressure sensors better compatible with the human body than high-pressure sensors. Having a good wear capability while ensuring pressure detection, they can deform with the human body. At the same time, due to their small size and flexibility, flexible pressure sensors can easily set up large-scale sensor networks and detect the pressure distribution of the human body.

The principle of this kind of sensor can be well explained according to the definition of resistance:

$$R = \rho \frac{L}{S}$$

Where R stands for resistance, ρ stands for resistivity, and S stands for the cross-sectional area of the conductor.

According to the definition of resistance, when the pressure sensor is affected by external pressure, the sensor deforms, and the length of the sensor L and cross-sectional area S will change, so the resistance changes.

The contact resistance between the material and the electrode and the resistance change caused by the change of its internal structure. Under the influence of external pressure, the contact resistance between the material and the electrode changes, and more contact points are formed between the structure or the fiber structure inside, resulting in lower resistance. If the resistive flexible sensor is made up of different materials, the change of spacing between conductive materials will also cause a change of resistance. Based on the ability for liquids and gases to flow through why something works or happens the way it does and the current tunnel effect, the distance between the conductive material and the polymer with low (ability to let electricity flow) changes due to the external pressure, and the conductive material is in the polymer, in this way a conductive network is formed, resulting in a drop in resistance [4].

2.2. The sensitivity improvement strategy

The sensitivity improvement strategy of resistive flexible pressure sensors is very similar to that of capacitive ones. Through the design of microstructure, the sensitivity of resistive flexible pressure sensors can be greatly improved by making the flexible substrates or conductive materials form spherical or columnar structures. Although resistive flexible pressure sensors have the advantages of simple structure, easy preparation, and easy collection of electrical signals, there is a large hysteresis, and the array of resistive flexible pressure sensors can only be achieved by increasing the number of sensors, low efficiency, and limited by the volume of a single sensor, the spatial resolution is limited, it is difficult to realize the pressure distribution at small intervals.

For instance, a facile fabrication of a stretchable high-sensitivity pressure sensor array was reported [4]. Through experiments on the proposed pressure sensor, a flexible pressure sensor for an array of portable electronics and fabricated skin. The overall resistance of the sensor diminishes when pressure is exerted from top to bottom as the contact resistance does. The polyaniline nanofibers' roughness raises the sensor's sensitivity. So, because contact resistance reduces with increasing pressure on the sensor, more current flows through the thinner gold layer than through other thin film resistors.

The researchers developed a resistive pressure sensor based on a high-stretch electrode, giving the sensor a higher extended pressure sensitivity of 10.3 kPa^{-1} [5]. It's the highest value ever recorded, but the sensor stretched only 40%. Such excellent stretchability and sensitivity result in the sensor being able to respond with high accuracy and speed at low pressures. At the same time, due to its self-powered system, gives it good operability as a wearable sensor. Several existing stretchable electrodes were tested as counter electrodes and the tensile properties of these fabrics were tested, leading to the conclusion that the surface structure of the counter electrode also influences the pressure sensitivity. It is worth mentioning that the working principle and the sensitivity improvement strategy of this kind of sensor are introduced in detail in the following paper, and the physical and chemical properties of the raw materials of the flexible sensor are well analyzed, and then the in-depth discussion is carried out. It provides some feasible ideas for improving performance.

2.3. Materials of dielectric composite

Carbon atoms are used to make carbon nanotube-based conductive polymeric composites. It has strong mechanical compliance and great electrical conductivity. polydimethylsiloxane (PDMS) is a silicon rubber with exceptional extensibility, transparency, and stability. A mixture of carbon nanotube material and PDMS material is soft, and it is as stretchable as human skin. It has not only excellent flexibility but also high durability and detectability after modifying its structure [6]. Due to its good property, carbon nanotube–polydimethylsiloxane became a basic element of the sensor. This highly compressible integrated system can reliably power low-power electronic devices because it is composed of a piezoresistive sensor and a compressible supercapacitor. The great feature of the material allows it to be stuck on skins and cloths. Thus, it can have multiple functions and it can detect multiple values. It can be used in the detection of real-time health monitoring because of its advantages.

The sensor is made of nitrocellulose paper coated with silver nanowires [6]. The sensor has a high sensing range even if it is in a bent situation. People can stick this sensor on their skin for the purpose of detecting physiological signals. The advantages of the sensor can be shown by its low cost, fast preparation speed, and easy incineration.

Graphene-based polymeric materials are formed utilizing graphene, which is a single layer of hexagonally organized carbon atoms. Because of its high piezoresistive capability, this material can be used to create sensors for sensing delicate and intense human activities. A highly viscous weakly cross-linked polymer matrix will improve the fluidity of the graphene filler, resulting in ultra-high sensitivity. The biological degradability of this substance is its most significant advantage. Sometimes the piezoelectrical sensors need to be inserted into the organs. Thus, it needs to avoid invasive removal surgery as possible. As a result, Graphene-based polymeric composites are a good choice of material for some specific sensors.

Monolithic conductive foam is one type of conductive foam-based sensor [7]. This type of foam has a relatively lightweight and higher surface area than other kinds of materials. This kind of material shows great resilience of elasticity. The integrated high-conductivity internal graphene tablet ensures the sensitivity of the foam structure. Unfortunately, the rigid and brittle feature made by the bunching of carbon nanotubes and graphene sheets in porous structures restricted the use of this material.

Conductive composite foam is another type of conductive foam-based sensor. This kind of material is composed of polymer and conductive filler. It is usually made by "cast-etching" and "freeze-drying" methods [8]. Sugar and starch are widely used materials in these methods. The fully embedded carbon nanotubes are partially exposed to porous surfaces, causing changes in the conductive path when composite materials are deformed. The resulting nano-porous composite foam shows high-pressure resistance sensing performance.

Conductive material-coated foam is another type of conductive foam-based sensor. It is a material that decorates the pore surface of a ready-made template with conductive material by coating techniques. The solution dip coating method is widely used in manufacturing conductive material coating foam because of its features of speed and extensibility. The carbon black coated PDMS foam, which is statistically light, shows high piezoresistive sensitivity, reproducibility, and mechanical durability.

Porous fibers, piezoresistive materials made of conductive fibers, can provide sensors with a highly flexible and stretchable behavior due to their structure. The three-dimensional fiber structure provides this material great flexibility, longer durability, and higher sensitivity through its capability of compressive deformation.

3. Discussion

The sensors with flexible material can generate electrical signals when the user put pressure on the sensor. The advantages of its flexibility and portability enable this material to be used on various circumstances and devices to approach different goals.

The principle of this kind of sensor can be well explained according to the definition of resistance.

Although the flexible pressure sensors have the features such as its great flexibility and portability, it still need improvements to perfect its functions. The fist method of the improvement of the sensor is to use a different kind of material for increasing the sensibility and accuracy of the sensor [9]. The spherical or columnar structures and materials such as polyaniline nanofibers and Au-coated polydimethylsiloxane micropillars can be used for making improvements for the sensor. By using these kinds of materials, the sensor can possess a high sensitivity and its advantages of simple structure, easy preparation, and easy collection of electrical signals is so it can be used in wearable and artificial electronic skin devices. Another possible way of improvement to the senor is the use of polyurethane composite polymer material which is a kind of highly stretchable electrode. The advantage of this material is that it pressure-sensitivity and feature of elongation is much better than the typical sensors. These sensor advancements allow this sensor module to be the first capacitive sensor that can quantify the main elements of the human pulse waveform non-invasively [10]. The feature of higher sensitivity under the low-pressure circumstances is the most reason of this usage of this sensor. One other methos of improvement is the counter electrodes. It has effects to the pressure sensitivity although the improvement is not significantly great. And the sensitivity became low when the counter electrode is replaced by a 70-nm-thick gold film evaporated on a polished silicon wafer.

Because of the exceptional productivity, flexible pressure sensors have a promising future. The invention and production of high-performance piezoresistive sensors with the requisite high sensitivity and ductility have made remarkable progress. By the increase of the requirements, the function of real-time health monitoring became important. Under this circumstance, carbon nanotube-based conductive polymeric composites just fit its requirement. The advantages of low battery requirement and wide versatility, makes it to be able to monitor different values.

Piezoresistive 3D monolithic conductive sponges is another possible sensor for the future. Its flexibility creates itself a powerful potential for being used in wearable devices. The use of the material provides itself a high-pressure sensibility and high flexibility.

Following the examples of possible materials and sensors, one can clearly demonstrate that the search for new functional materials and the development of novel integration techniques for flexible pressure sensors will be an important research area for scientists. This type of sensors is an indispensable part of future wearable electronic products with intelligent human-machine interface. Environment with large pressure such as underwater will be a good place for the application of these sensors due to their high-pressure resistance.

An important possible method could be used to the pressure sensor is that people can improve the manufacturing process of the flexible pressure sensor. Using effective easy-approachable material is a great way of decreeing the cost of manufacturing the flexible pressure sensor in the meantime of approaching a goal of high quality, although some technology could not be used when people are using this way to decrease the cost.

Implementing flexible and scalable piezoresistive sensors into practical wearable sensing devices presents numerous obstacles. The fundamental drawback of piezoresistive sensors is that they require power. To control the process of sensing the resistor signal, piezoresistive sensors require an external power source. As a result, integrating piezoresistive sensors with energy generation and storage devices is fraught with difficulties.

4. Conclusion

The flexible pressure sensor used the theory of the conversion from deformation created by pressure to electronic signals. The high flexibility and sensitivity are the main reasons of why people are favoring the flexible pressure sensor. The flexible pressure sensor is a great field for modern biomedical engineering. In the recent days, there are varieties of new technologies and new products made by the scientists. The new technologies each process different kinds of advantages and great features, which showed people that the flexible pressure sensor unquestionably has a bright future and a huge potential. Although scientists created great flexible pressure sensors, they are still working for getting a better product. There are few major subjects that people are working on in the field of flexible pressure sensor, which are the better accuracy of the sensor, the greater durability of the sensor, the cheaper price of the material, and the easier way of manufacturing. Materials of dielectric composites is one of the points that the scientists are focusing on. Materials such as carbon nanotube-based conductive polymeric composites, all paper-based flexible and wearable piezoresistive pressure sensor, graphene-based polymeric composites, Monolithic conductive foam, conductive composite foam, conductive material-coated foam, and porous fibers are examples of the progress people made on the material of the field of flexible pressure sensors. The future of the flexible pressure sensors is considerable which scientists could make the sensor cheap and wearable so that not only for the patients, but also normal people can monitor their biological condition, such as blood pressure, blood glucose level, and heart rate, in their daily life to allow them to do the corresponding measures according to the values monitored by the flexible pressure sensor.

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