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# Electronic Skin Design Methods Applied to Capsule Robot

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***Abstract* - Electronic skin is also widely used in robots, which mainly sense relevant information of the outside world through tactile sensors, so high-performance tactile sensors are important indicators to determine the performance of robots. The tactile perception function of capsule robots plays an increasingly important role, especially in minimally invasive surgery and tumor detection. Electronic skin has also become a research hotspot in the field of capsule robots. Based on the bionic structure and structural design, material selection and experimental results of electronic skin, and by comparing the design and application of electronic skin at home and abroad, this paper proposes a design method of pressure tactile sensation based on graphene three-dimensional array applied to capsule robots, which has the capability of sensing three-dimensional pressure. The design method is expected to be popularized and applied in actual capsule robots, which is beneficial to the application and development of robot tactile sensing technology.**

**Keywords: electronic skin; Capsule robot; Bionic structure; Tactile sensor; Structure design**

## I. INTRODUCTION

Skin is of vital importance to human beings and is a highly sensitive multifunctional sensor for sensing the external environment. Electronic skin is the main research field of human-computer interaction technology and artificial intelligence. Intelligent robots mainly sense external related information through tactile sensors, so high-performance tactile sensors are an important indicator of robot performance. Compared with auditory and visual imitation, developing electronic skin tactile sensors with high sensitivity, high resolution and fast response is a challenge.[1-4] As early as the 1990s, many researchers devoted themselves to the research of sensors with tactile sensation, but the developed devices have low resolution and poor flexibility of materials.[5-7] Until the 1990s, the discovery and application of flexible materials made great breakthroughs in both flexibility and stretch ability of tactile sensors.[8-10]

In order to better simulate the pressure sensing system of human skin, tactile bionic electronic skin should be able to measure the changes of external pressure in different ranges (micro pressure less than 10kPa and medium pressure in the range of 10-100kPa) and has the characteristics of high sensitivity and fast response.Unfortunately, the current limitations of tactile sensors in sensitivity and measurement range affect the performance of tactile bionic electronic skin. For example, Y joo et al.[11] have designed a capacitive pressure sensor that can measure pressure under bending using CNT, silver nanowires and other materials. The sensor has a sensitivity of $9.91kPa^{-1}$ in the range of 0-0.6kPa, and can be easily integrated into a wearable system. However, its measuring range is extremely small, which makes it difficult to measure micro-pressure (<10kPa).The wearable pressure sensor prepared by Pang et al.[12] combining graphene with PDMS with porous network structure has a measurement range of 0-2000 kPa, but the sensitivity of the sensor in the low pressure region is only $0.091kPa^{-1}$, and its response time is 100ms, which is not suitable for use in occasions with high real-time requirements. Wang [13] and others have developed a stretchable polymer transistor array with a transistor density of 347/cm2. Under the condition of stretching to 200%, the charge carrier mobility remains at 0.98 $cm2V^{-1}s^{-1}$Zhou [14] and others have developed a nanofiber fabric sensor using polyvinylidene fluoride functional material coated with 3, 4-ethylenedioxythiophene monomer. The sensor shows high sensitivity (pressure sensitivity is 18.376 $kPa^{-1}$ at about 100 Pa), wide pressure range (0.002~10kPa), and fast response time (15ms). Hua [15] and others have developed a multifunctional sensor, which can sense parameters such as temperature, in-plane strain, humidity, light, magnetic field, pressure and proximity. In addition, it can detect and distinguish 3 or more stimuli, greatly expanding the function of the sensor. However, there are still some problems in the current research. Kim[16] and others have developed a composite film of polydimethylsiloxane (PDMS) and carbon nanotubes. Although high conductivity can be obtained, the high conductivity is opaque due to the need to add carbon nanotubes. Most of the existing tactile sensor arrays focus on pressure detection, while a few can simultaneously detect parameters such as temperature, humidity, tension and pressure. The preparation of electronic skin tactile sensor with high elasticity and high sensitivity involves complicated procedures such as electron beam evaporation, magnetron sputtering, micromachining and the like, and the corresponding equipment is relatively expensive. In addition, the materials needed to develop electronic skin are generally expensive. Considering the cost, this limits the number of



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researchers and the mass production of electronic skin to a certain extent. At present, there is no electronic skin suitable for capsule robots. To sum up, it is of great significance to design a tactile sensor with high sensitivity and tactile electronic skin applied to capsule robots.

Graphene film has become another promising carbon conductive material in polymers due to its excellent electrical properties, high strength elasticity and high stability. Based on this, in order to solve the problem of low sensitivity of tactile sensors, this paper proposes a new electronic skin based on graphene film applied to capsule robots. The sensor has the characteristics of high sensitivity, cross multi-scale measurement range, fast response speed, high stability, etc. The electronic skin designed in this paper has high practical value for the progress and development of artificial intelligence, rehabilitation medicine, capsule robot and other fields.

## II. Analysis of Electronic Skin Design Methods

It can be divided the research situation into two parts: conduction mode and functional materials to discuss and analyze.

Using different conduction methods to convert external stimuli (pressure, strain force, shear force, temperature, humidity, distortion, etc.) into electrical signals is an important step in developing electronic skin systems. Common conduction methods include resistive,[17] capacitive [18] and piezoelectric [19] sensing technologies.

### *A. Resistive type*

Resistive pressure sensor mainly changes the contact resistance between conductive materials and the conductive path in conductive elastic composite materials through the loaded force to achieve the purpose of detecting force. Silicone rubber is usually selected as the flexible matrix for flexible resistive pressure sensor units. Silicone rubber is nontoxic and odorless, resistant to severe cold and high temperature, and has good flexibility, excellent mold release and water repelled. Carbon black and carbon nanobots are usually selected as filling materials.

Stanford University Hoo-ha[20] research group reported a new type of stretchable, transparent and height adjustable resistive pressure sensor on Excommunications. The bottom layer of the pressure sensor is elastic pyramidal micro structure PDMS sprayed with single-wall nanobots, SWNT) layer, and the top layer is PDMS sprayed with single-wall carbon nanobots. Three different pressure sensors, PS-1, PS-10 and PS-30, were fabricated by adjusting the height of SWNT on the micro structure gold tower. This work proves that the threshold value of the resistance switching range can be adjusted by adjusting the height of SWNT on the micro structure pyramid. The research group of Tan[21] in Songhua University reported a resistive pressure sensor based on grapheme. The device structure of the grapheme pressure sensor is shown. The sensing unit of the pressure sensor is a cross-shaped structure, i.e. two V-shaped grapheme films are piled up. The tactile sensor has a sensitivity of 0.96 Pa−1 in the low pressure region less than 50 Pa and a sensitivity of 0.005 Pa−1 in the high pressure region of 50~113 Pa. all sensors show stable conductivity. Moreover, the dynamic pressure test shows that the response time under high pressure can be as high as 0.4 ms Lou[22] research group of Chinese Academy of Sciences reported a grapheme pressure sensor with ultra-sensitive and fast response speed. The height, width and length of the device are 1.3 mm, 0.7 cm and 1.4 cm respectively. The resistive pressure sensor has high pressure sensitivity (15.6 Pa−1), low detection lower limit (1.2 Pa), low working voltage (1 V) and fast response characteristic (5 ms).

### *B. Capacitance*

Capacitance tactile sensor is designed by using the characteristics that the capacitance C formed between two conductive plates is proportional to the plate spacing D, the effective facing area S between plates, and the dielectric constant ε between plates. Capacitance tactile sensors are characterized by high sensitivity, good frequency response and small temperature effect. At the same time, its shortcomings are inevitable. Due to the demand of miniaturization, capacitance tactile sensors usually have small output capacitance, low signal-to-noise ratio and are susceptible to interference from parasitic capacitance. Therefore, such sensors usually require additional signal amplification and signal processing circuits.

Y joo [11] of Seoul national university, south Korea, ET AL. used pressure sensitive transistors made of CNT, silver resonances and other materials to design sensors that can measure pressure under bending conditions. The sensor has a sensitivity of 9.91$kPa^{-1}$ in the range of 0-0.6kPa, has the characteristic of low power consumption, and can be easily integrated into wearable systems.

Wan Sh [23] of Southeast University and others designed a capacitance pressure sensor using grapheme oxide with a sensitivity of 0.81$kPa^{-1}$. It can sense a micro pressure of 0.24 Pa and the dynamic response time can reach 100 ms.

CAI[24] research group of Chinese academy of sciences reported a new capacitance strain sensor based on carbon nanobots (CNT). The structure of the capacitance sensor is similar to that of a parallel plate capacitor, that is, a thin layer of silicone elastomer is sandwiched between two carbon nanobot films (CNT). It reflects that the change of capacitance increases with the increase of stress, and can quantitatively detect the change of capacitance when the stress is 300%. Airy[25] research group of Italian Institute of Technology reported a fully flexible capacitance mistrial force tactile sensor in Advance Materials. The electrode strips on the top layer of the sensor and the 4 electrode strips on the bottom layer form 4 capacitors. By detecting the changes of the 4 capacitors, high sensitivity detection of dimensional force can be realized, and the minimum mass that the sensor can detect is 0.01 g. In the pressure range of 0.5~2.0 Pa (32~130 MN), the sensitivity of the pressure is 0.53 $kPa^{-1}$;In the pressure range of 2.0~4.0 Pa, the pressure sensitivity is 0.30 Pa−1;In the pressure range of 4.0~10.0 Pa, the pressure sensitivity is

0.20 $kPa^{-1}$. The Joo Y[26] research group of Seoul University, South Korea, reported a capacitance electronic skin tactile sensor. The surface and bottom electrodes of the sensor are silver resonances, the dielectric layer is PDMS, and the minimum detectable mass of the object is 0.04 g. The sensitivity of pressure is high: 3.80 Pa−1 in the low pressure region of 45~100 Pa.

### C. Electricity

Piezoelectric tactile sensors are designed using materials with piezoelectric effect. The so-called piezoelectric effect refers to the fact that when external force acts on the dielectric of some ionic crystals, electric charges will be excited on the surface of the materials. When external force is removed, these electric charges will disappear again. Piezoelectric sensors are electromagnet conversion sensors and self-generating sensors. Common piezoelectric materials include No resonances, PVDF, PZT, etc. Piezoelectric tactile sensors have high sensitivity, good dynamic performance, low power consumption or self-power capability. However, the requirements for relevant circuit systems are also very strict and sensitive to temperature.

The Lee M[27] research group of Georgia Institute of Technology reported a self-powered sensor system driven by generator. The system consists of a Kano generator based on No resonances, a rectifying circuit, a capacitor for charge storage, an LED light source and carbon nanobots. No resonances (NW) have not only piezoelectric properties, but also environmental friendliness and bio compatibility. This work proves the feasibility of using self-powered sensor system based on immaterialness to detect toxic pollutants.

Zhou[28] of Georgia Institute of Technology and others designed a flexible and stretchable sensor using No. The GF of the sensor is as high as 1250. At the same time, the sensor also shows the characteristics of high stability and fast response.

To sum up, capacitance tactile sensor has the advantages of high sensitivity and low power consumption, but it is vulnerable to external interference and requires additional protection system and signal processing system. Resistive tactile sensor has the advantages of high sensitivity, simple structure and stable performance, but its measurement resolution is not as good as capacitance. Piezoelectric tactile sensor has the characteristics of good dynamic performance and high sensitivity, but its static performance is poor, which usually requires complex peripheral circuits.

Functional materials used for electronic skin tactile sensors can be divided into carbon-based materials, semiconductor materials and metal materials.

## III. DESIGN OF ELECTRONIC SKIN FOR CAPSULE ROBOT

With the progress of science and technology, capsule robots are becoming more and more miniaturized, lightweight and multifunctional, becoming an important branch in the field of medicine. Compared with traditional endoscope, capsule robot has many advantages. The capsule robot can enter the human body through swallowing, the capsule moves forward along with the peristalsis of the digestive tract, and finally is discharged through the anus, so that dead corners which cannot be reached by the traditional endoscope can be inspected, too much discomfort is not caused to the patient, and some unnecessary risks are avoided; compared with the traditional endoscope, the capsule robot collects more comprehensive information in the inner part of the human body, and assists doctors to carry out more comprehensive and accurate diagnosis on the patient. At present, medical capsule robots cannot realize various functions. One of the reasons is that they cannot directly receive various signals such as pressure through touch, which will lead to complicated operation process and cause greater pain to patients. Therefore, it is of great practical significance to design an electronic skin suitable for capsule robots.

Many receptors composed of different types of neurons are distributed in human skin. Different stimuli make them react differently. Among them, Terkel cells and Ruffian corpuscles mainly feel continuous and low-frequency pressure, such as touching and sliding. Therefore, the flexible electronics skin tactile sensor proposed by us is an imitation of these two tactile sensors.

The electrical signal is transmitted to the measuring system. The whole tactile sensing process is as follows: when external micro-pressure force acts on the upper substrate of the sensor, the force will be transferred to the sensitive layer of the intermediate layer, i.e. the grapheme film, and the micro structure of the grapheme film will change accordingly. The resistance change of the grapheme film is positively related to the pressure, so the tactile sensor can be used for measuring micro-pressure. The structure of the electronic skin applied to the capsule robot is shown in fig. 1.The capsule robot is designed to place 14 pieces of electronic skin, one on each end and 12 pieces of electronic skin on the capsule pillar wall. Due to the small size and length of capsule robots, the design requirements for electronic skin are even more stringent.

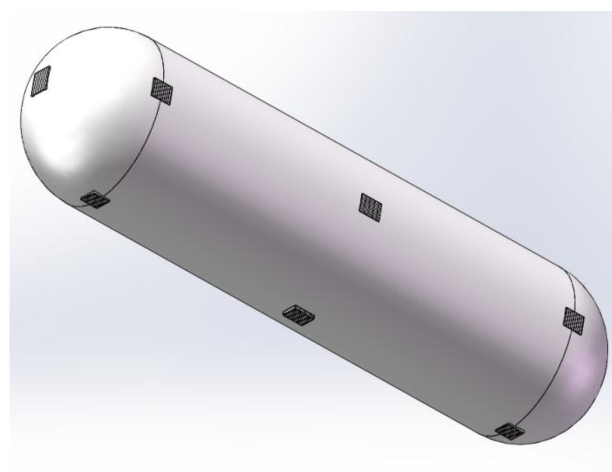

Fig.1 Electronic skin-based capsule robot overall mechanism

### A. Selection of Materials for Tactile Sensors

The selection of tactile sensor materials designed in this paper is divided into three parts, namely the upper protruding substrate material, the middle sensitive layer material and the bottom substrate material.

The upper protruding substrate material is made of flexible materials, common flexible materials such as polyethylene, polyethylene leatherette vinegar, poolside, poly methyl Merthiolate, polypropylene and the like. Compared with PDMS, PDMS not only has the advantages of excellent flexibility, high transparency and the like, but also can easily produce products with different morphology under laboratory conditions and products with different Young's modulus due to the viscous matrix material. Therefore, PDMS is used to fabricate the upper substrate of the tactile sensor in this thesis.

The middle sensitive layer is designed as a grapheme film. grapheme films have excellent conductive properties, good flexibility and high stability. However, in order to enhance the stability and robustness of grapheme films, we need to choose a flexible material as the attachment. PET not only has high film-forming property, but also has excellent properties such as optical transparency, excellent wear resistance, friction resistance and dimensional stability. Therefore, we chose PET film (thickness 50um, hardness 2H) as the adhesion of grapheme film.

The main function of the underlying substrate is to transmit the signals generated by the sensitive layer to the measurement circuit. Therefore, it is necessary to fabricate electrodes and circuits on the underlying substrate. This electrode uses silver electrodes.

### *B. Dimension Design of Tactile Sensor*

The size design of tactile sensor designed in this paper is divided into three parts, namely the upper raised substrate, the middle sensitive layer and the bottom substrate. As shown in fig. 2.

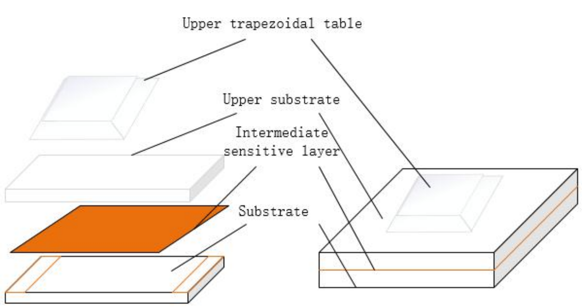


Fig.2 Sensor Explosion Diagram and Sensor Structure Diagram

The structure of the upper substrate is shown in the figure. The main design parameters considered are: trapezoidal table angle θ, upper substrate thickness D (where d1 represents the height of trapezoidal table and d2 represents the thickness of substrate base) and upper bump width L. Since the electronic skin tactile sensor exists in different positions on the capsule robot and the force directions measured at the same time are different, different angles are designed considering the trapezoidal table of the upper substrate of the tactile sensor, which is more conducive to the accuracy of the measured force.

Because the positions of the electronic skin sensors are different, according to the physical characteristics, the trapezoidal table angle of the upper lining convex structure of the electronic skin sensors at the two ends of the capsule robot is 60 degrees. However, the trapezoidal table angle of the upper lining convex mechanism of the electronic skin tactile sensor of the capsule robot column wall is 45 degrees.

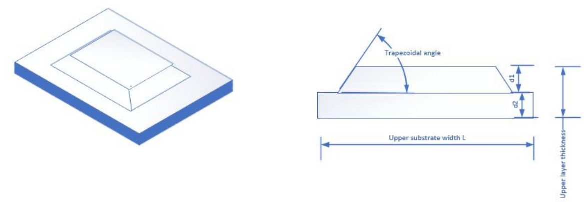


Fig.3 Raised isometric side view and front view

The thinner the bulge thickness D is, the better the stress transmission is. This result accords with the actual situation in our life. Considering the actual production conditions, the thickness of the upper substrate is designed to be 0.5mm, i.e. the trapezoidal table thickness d1 is 0.25mm and the substrate base thickness d2 is 0.25mm. The width of the upper substrate is designed according to the size of the intermediate sensitive layer material. Therefore, the upper substrate width L is designed to be 2mm×2mm.

The middle sensitive layer is made of grapheme film. Analysis of the influence of grapheme size on resistive characteristics shows that the smaller the grapheme film is, the better the measurement range of the low pressure region is. The low pressure region range of the 1.5 mm 2 mm grapheme FICA reach 0-3.8 Pa, which is more consistent with the pressure sensing range of the actual skin tactile sensor. Therefore, the size of the middle sensitive layer grapheme film is designed to be 1.5 mm 2 mm in this paper. Considering that the grapheme film needs to be adhered to the electrode, the actual size of the grapheme film required is 2mm.

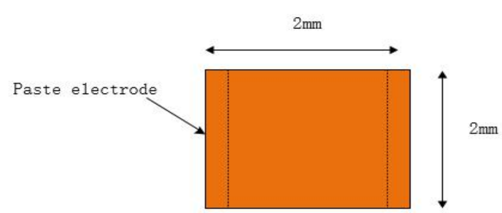


Fig.4 Intermediate sensitive layer

Electrodes need to be made on the underlying substrate, whose function is to output the electrical signals generated by the sensitive layer to the measurement circuit, so corresponding electrodes and leads must be made. As shown in the design drawing of the underlying substrate, in order to fully contact the grapheme film with the electrode, the width of the electrode is designed to be 0.25mm, so the size of the entire substrate is 2mm×2mm.

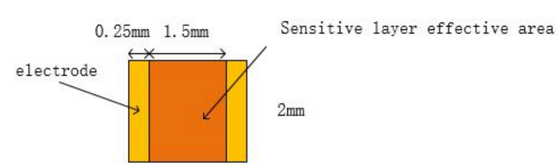


Fig.5 Underlying substrate

## IV. EVALUATION SUMMARY

In summary, this paper summarizes the design methods and materials of electronic skin. The research of electronic skin tactile sensor has made good progress, but there are still many problems, especially there is no electronic skin suitable for capsule robots in the field of electronic skin of capsule robots. Combined with domestic and foreign research, this paper proposes a design method of pressure tactile sensor based on grapheme three-dimensional array application, which is suitable for capsule robots. With the capability of sensing three-dimensional pressure, it can provide a good foundation for tactile target recognition and pathological recognition of capsule robots in the future. The design method is expected to be popularized and applied in actual capsule robots, which is conducive to the application and development of robot tactile sensing technology.

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