

## REVIEW ARTICLE

# Research progress of flexible sensor and its interaction technology in force feedback electronic clothing

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### ABSTRACT

The sense in simulated reality is the key of human-computer interaction technology. Force feedback interaction technology is an important factor to realize simulated force sense in virtual reality. It can truly reproduce the physical information such as the mass, inertia and hardness of things in the virtual world. This paper summarizes the flexible sensors commonly used in force feedback technology and the development and research status of virtual reality wearable electronic clothing equipment based on force feedback technology, summarizes the principles of several force feedback structures, analyzes and compares their characteristics and main application fields. This paper briefly describes the prospect of force feedback technology, summarizes the trend of high-precision, multi-modal and multi-point interaction of force feedback equipment in the future, and puts forward some suggestions on miniaturization, softness and authenticity of force feedback technology in combination with the application characteristics of wearable electronic clothing.

**Keywords:** wearable electronic clothing; force feedback technology; virtual reality; human computer interaction; flexible sensor

## 1. Introduction

Virtual reality technology refers to the technology that simulates the virtual world by computer, and uses interactive equipment to immerse people in the virtual world through intuitive perception (such as hearing, vision, touch, force, etc.). Force sensing technology is a major difficulty in virtual reality interaction technology, and force feedback technology is the decisive factor to realize simulated force sensing. According to the principle, the force feedback system can be divided into bionic manipulator feedback, magnetorheological hydraulic

feedback, aerodynamic feedback, electromagnetic force feedback and exoskeleton force feedback. This paper analyzes the principles of different force feedback systems, and summarizes the current research status, application and development prospect of force feedback technology in wearable electronic clothing, in order to provide new ideas for the research of force feedback technology in wearable electronic clothing.

## 2. Commonly used flexible sensors for force feedback structure

In wearable smart clothing, how to efficiently

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and sensitively convert various external stimuli into electrical signals and measure and transmit them timely and accurately is the key problem of sensor application in force feedback structure. Flexible sensor refers to the sensor made of flexible materials, which has good foldability and changeable structure, and can adapt to the spatial position change of flexible materials such as fabrics. Therefore, flexible sensors are usually used for information measurement and transmission of force feedback structures in wearable devices.

According to the signal conversion mechanism, flexible sensors can be divided into the following five types: piezoresistive sensors, piezoelectric sensors, capacitive sensors, optical fiber sensors and inductive sensors.

## 2.1. Piezoresistive sensor

The piezoresistive sensor acts on the elastic sensor through external force, which changes the resistance of the sensor, and then changes the electrical signal output by the detection circuit to indirectly perceive the change of force. The earliest piezoresistive sensors were made of semiconductor materials silicon and germanium, and later made of conductive elastic composites (such as polymer composite conductive fiber filled with carbon black, composite conductive fiber filled with graphene, etc.). The resistance change of the piezoresistive sensor is directly proportional to the square root of the external force. Therefore, the piezoresistive sensor made of textile composite materials has the advantages of softness, high resolution, simple signal readout mechanism and equipment, easy combination with fabric and so on. It is a common sensor for the force feedback structure of wearable clothing.

**Figure 1** is a knitting flexible sensor. Philips laboratory invented a flexible sensor<sup>[1]</sup> which is made of carbon fiber and elastic fiber by knitting (see **Figure 1 (a)**). The length of the fabric will change with the force, and its equivalent resistance will also change with the elongation of the fabric. Using the “plating structure” in knitting technology, the conductive fibers and tracking materials are ar-

ranged in parallel and formed in the same loop forming system to form interconnected sensors and transmit electrical signals (see **Figure 1 (b)**).



(a) Schematic diagram of knitting structure of fabric elongation sensor.



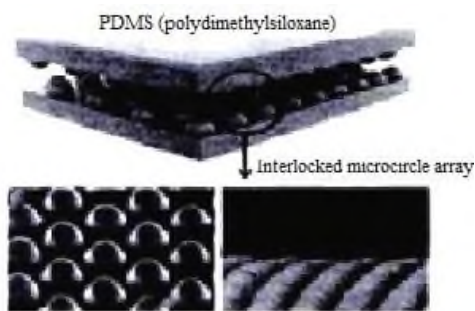
(b) Knitting sensor and conductive tracker.

**Figure 1.** Knitted flexible sensor.

De Rossi et al.<sup>[2]</sup> invented a piezoresistive sensor that combines the polypyrrole part of the sensor with Lycra cloth. When pressure is applied to the sensor, the size of the Lycra fabric will also change, and the resistance of the sensor will decrease due to the increase of the conductive cross-sectional area of the material. However, with the deepening of the experiment, it is found that this type of sensor has many problems, such as long signal transformation time, poor response sensitivity, difficult manufacturing process, rigid cloth and so on.

Carbon black conductive material is a potential sensing material for flexible sensors. Feng et al.<sup>[3]</sup> made a piezoresistive sensor with nano-carbon black/silicone rubber composite on a ceramic substrate with interdigital electrode. The test shows that the sensor has positive piezoresistive effect at 0.1–100 kHz, and the sensor has fast response and recovery performance. However, with the increase of frequency, the polarization intensity of space charge will be reduced and the piezoresistive effect of the sensor will be reduced.

Park et al.<sup>[4]</sup> developed a stretchable electronic skin with multi-directional force sensing capability. The piezoresistive interlocking micro circular array is used in the flexible sensor sensitive to stress direction. Two CNT (carbon nanotube) composite films with micro circular pattern are connected on one side of the pattern to form the interlocking geometry, as shown in **Figure 2**. When stimulated by various mechanical forces such as shearing, bending and torsion, etc. this pressure sensor has high-sensitivity detection ability. Due to the unique geometric structure of the array, it shows different degrees of deformation in different applied force directions, so it can distinguish various mechanical stimuli. The response time of microstructure device is about 18 ms and the recovery time is about 10 ms. It is a piezoresistive sensor with high accuracy and stretchability.



**Figure 2.** Flexible pressure sensor with interlocked micro-circle array.

## 2.2. Piezoelectric sensor

Under the action of external force, the crystal structure of piezoelectric material deforms and produces electric dipole distance, which forms a potential difference at both ends of piezoelectric material. After connecting external circuits, electrical signals can be generated. Piezoelectric sensor is a sensor with piezoelectric effect made of piezoelectric materials. In order to meet the demand of wearable electronic products, some new piezoelectric materials are gradually introduced to replace brittle ceramics and quartz in the existing market, including polyvinylidene fluoride trifluoroethylene copolymer P (VDF-TrFE), lead zirconate titanate (PZT) and zinc oxide (ZnO). Polyvinylidene fluoride trifluoroethylene copolymer flexible P

(VDF-TrFE) has good chemical inertia, simple processing technology and large piezoelectric coefficient. It has become a new piezoelectric material attracting much attention at present.

Shirinov et al.<sup>[5]</sup> used piezoelectric polyvinylidene fluoride (PVDF) as the sensing element to prepare a flexible piezoelectric sensor with an area of 25 mm<sup>2</sup>, which can be used normally between 40–125 °C, with a detection range of 10–2,000 kPa and a response delay time of 1 ms. The pressure sensor has the advantages of simple manufacturing method and low cost.

Drean et al.<sup>[6]</sup> integrate PVDF conductive material into the outer layer of automobile seat and the inner layer foam, and transfer the current change brought by the piezoelectric effect to the amplifier and the impedance phase analyzer. The results show that this change is linear and can be used in the automotive field to detect the pressure applied to the car seat.

Liu et al.<sup>[7]</sup> developed a monitoring system integrating textile materials and piezoelectric materials, which can collect angular acceleration, vertical acceleration and piezoelectric data. The monitoring system can feed back and record the gait stability of people with motor disabilities in real time. The monitoring system embeds piezoelectric sensors, printed circuit boards, microcontrollers and other electronic components into the clothing to collect signals, and transmits the piezoelectric data to the designated location through Bluetooth, so as to identify and distinguish people with movement disorders.

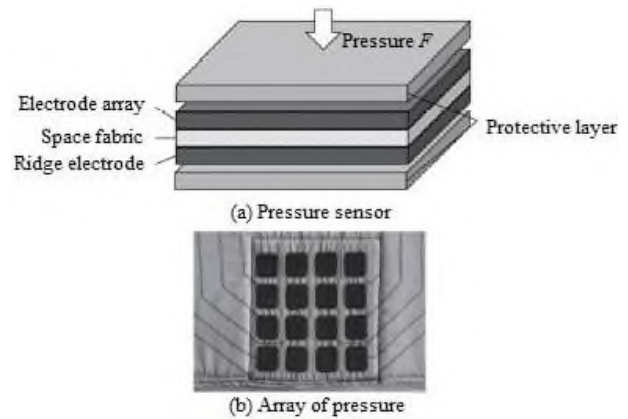
Persano et al.<sup>[8]</sup> developed a fiber array with independent three-dimensional structure by electrospinning using polyvinylidene fluoride-Co-trifluoroethylene. This material has good piezoelectric characteristics, and can sense pressure less than 0.1 Pa, and has high sensitivity. It can be used in micro sensors with high sensitivity requirements, such as sensitive collision detector.

### 2.3. Capacitive sensor

Flexible capacitive sensor generally takes flexible material as capacitor plate and elastic material as spacer, which is equivalent to a device that converts the changes of various forces into capacitance. The flexible capacitive sensor is combined with textiles to make intelligent textiles. It has the characteristics of high sensitivity, high spatial resolution, soft and stretchability of textiles.

Sergio et al.<sup>[9]</sup> designed a capacitive fabric pressure sensor that can be integrated into clothing. The conductive wire matrix ( $16 \times 16$  capacitance matrix formed by warp and weft conductive yarn)) is covered on the elastic foam. When the pressure is applied to the substrate, the foam sandwiched in the middle is extruded and deformed, resulting in the change of the distance between the conductive yarn matrices on both sides, thus causing the capacitance to change. The external circuit can scan the capacitance change of the sensor and draw the signal change curve, and get the fabric pressure change. Due to sandwiching elastic foam in the middle, the sensitivity of the sensor decreases, and the flexibility of the fabric sensor decreases with the sandwich structure, and the comfort of the fabric is also affected.

Meyer et al.<sup>[10]</sup> optimized the model on the basis of reference<sup>[9]</sup>. The structure of the optimized fabric pressure sensor is shown in **Figure 3**. The measurement of the fabric sensor in **Figure 3** is 0–10 N/cm<sup>2</sup>, the average error is less than 3–4%, and it can be integrated into clothing to measure the pressure of the human body. For example, there is a 6mm thick spacer fabric in the middle of the fabric sensor and it is used as a dielectric layer. At this time, the capacitance before applying force to the sensor is 3.5 pF (no load), and the capacitance after applying pressure is 5.8 pF (pressure 5 N/cm<sup>2</sup>). However, due to the friction between the sensing band of the sensor and the human skin during relative movement, the pressure distribution measured when the muscle bends to the front arm is uneven. This kind of fabric pressure sensor can be applied to the situation where high local resolution is required.



**Figure 3.** Structure of textile pressure sensor.

Donselaar et al.<sup>[11]</sup> invented a sandwich structure intelligent pressure pad with insulator wrapped in upper and lower conductive fabric layers. The pressure pad is composed of 64 pressure sensors and supporting test software. It is mainly used to collect the pressure of each part of the baby's limbs on the protective pad in the incubator to ensure the safety of the baby.

### 2.4. Other types of flexible sensors

#### *Optical fiber sensor*

Optical fiber sensor is a kind of sensor that uses the optical transmission characteristics of optical fiber to convert the measured optical signal into optical characteristics (intensity, phase, polarization state, frequency and wavelength). Many scholars at home and abroad weave optical fibers into optical fiber sensors, which can measure signals such as pressure, acceleration, temperature and electric field without affecting the softness and wearability of the fabric itself.

Rothmaier et al.<sup>[12]</sup> woven plastic optical fiber into the elastic knitted fabric by embroidery to make optical fiber pressure sensors, as shown in **Figure 4**. When pressure is applied to the sensor, due to the deformation of the fabric, the intersection position of elastic yarn in the area with optical fiber will change, resulting in the change of transmitted light intensity. Therefore, the change of fabric stress can be detected.





**Figure 4.** Textile sensor with optical fibers inductive sensor.

### **Inductive sensor**

Using the principle of electromagnetic induction, the change of measured non-electric physical quantity is converted into the change of coil self-inductance coefficient or mutual inductance coefficient, and then the measured circuit is converted into voltage or current output. This device is called inductive sensor, which is usually made of textile materials such as conductive fiber or yarn. Compared with ordinary metal coils, this sensor is softer, more comfortable to wear and more suitable for use in combination with textiles. At present, inductive sensors have been used in the fields of sleep quality monitoring and motion capture.

Wijesiriwardana<sup>[13]</sup> integrated elastic Lycra fiber, conductive copper wire and ordinary fiber into the fabric, arranged conductive fibers with different conductive levels in the spiral path to form a coil, and developed a tubular inductive sensor (also known as fabric transducer). When the sensor is worn on the chest, breathing can lead to small fluctuation changes in the chest, so that the inductance of the sensor also changes and is converted into voltage signal output. The monitoring of respiration can be completed by using this principle.

Liu et al.<sup>[14]</sup> embedded the inductive sensor into the fabric and designed a digital rip breathing monitoring belt based on body area network technology to monitor the subjects' daily activities such as sitting, walking, running, 6 h sleep breathing and so on. The results show that the average measurement accuracy of respiratory rate of this product can reach 95%, and can be applied to the collection and analysis of daily physiological signal changes of human body.

## **3. Force feedback technology based on flexible sensor**

### **3.1. Bionic manipulator feedback (piezoresistive force feedback)**

The finger structure of bionic manipulator studied by Lin et al.<sup>[15]</sup> adopts tendon transmission structure. The five finger knuckles are equipped with light-weight pressure sensors. When the bionic manipulator is used to hold the object, the resistance value of the pressure sensor will change, and the pressure is inversely proportional to the resistance value. The pressure value generated by holding the object will be transmitted to the force feedback data glove through the pressure sensor. After receiving the signal, the glove can control the micro electromagnet. The electromagnet will produce attraction. Because the pawl is connected with the electromagnet, the pawl will also approach the ratchet wheel with the electromagnet, so that the ratchet wheel and the pawl can complete the work together.

The force feedback data glove is shown in **Figure 5**. Virtual technologies designed a commercial force feedback data glove “CyberGrasp” (see **Figure 5 (a)**) based on CyberGlove glove<sup>[16]</sup>. It is driven by the force generated by the motor and transmits the force through the steel wire rope, so it can generate up to 16 N force on the finger; however, the glove also has many disadvantages, such as the large mass, and users will feel tired after wearing it for a long time.

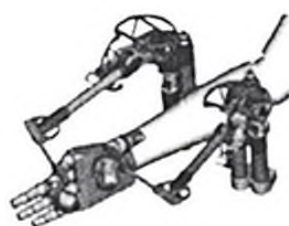
Frisoli et al.<sup>[17]</sup> used brushless DC motor as power source to make a force feedback data glove with human hand tactile interface structure (see **Figure 5 (b)**). The base of the structure is installed on the forearm. Due to the tendon transmission arrangement, the gloves can feed back the movement of the thumb and index finger; however, the whole system is heavy and bulky, and the integration is not high.

The advantages of bionic manipulator are: It can not only grasp objects accurately and stably, but also can replace human hands to do some high-risk

actions; however, it also has the following defects: The mass is large, so it will feel tired to wear it for a long time, and its system takes up a large space larger and less integrated.



(a) CyberGrasp data glove

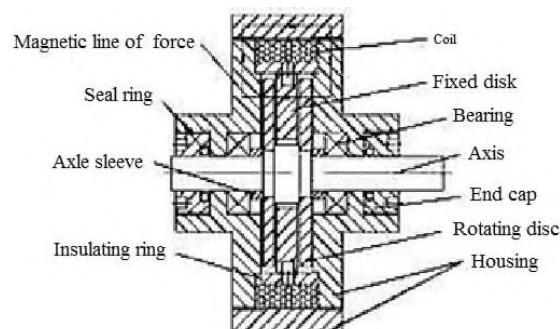


(b) Force feedback data glove based on current liquid

**Figure 5.** Force feedback data gloves.

### 3.2. Magnetorheological fluid feedback

Magnetorheological fluid is composed of magnetic particles, carrier fluid and stabilizer. The fluidity of magnetorheological fluid is related to the existence of additional magnetic field. The existence of additional magnetic field can enhance the fluidity of MR fluid; on the contrary, after the additional magnetic field disappears, the magnetorheological fluid can change from liquid to solid immediately. This process can be realized in only 1 ms and is reversible. Therefore, the state of MR fluid or its viscosity and yield stress can be controlled by changing the magnetic induction intensity. Dai et al.<sup>[18]</sup> proposed a driver, which is realized by the above magnetorheological fluid principle. The driver structure is shown in **Figure 6**. The driver uses the electromagnetic pure iron with high permeability to make the shell, fixed disk and other main parts, and uses the magnetic insulation material to make the magnetic insulation ring and shaft, so as to improve the use efficiency of the magnetic field energy generated by the coil and make it mainly used in the fluid of the working gap of magnetorheological fluid.



**Figure 6.** Crosssection of drive profile.

The performance of magnetorheological fluid will change under electric field, so that it can meet the requirements of flexibility and hard object contact force at the same time in specific environment<sup>[19]</sup>; in addition, if different viscosity and yield stress need to be changed, it can be realized by changing the magnetic induction intensity on the magnetorheological fluid.

A force feedback data glove developed by Southeast University<sup>[20]</sup>, as shown in **Figure 7**. This kind of glove is based on Cyberglove number driven glove. The difference is that it adds electrorheological fluid (ERF). Electrorheological fluid is composed of basic fluid (such as oil) and suspended particles. The size of suspended particles is 0.1–10  $\mu\text{m}$ .



**Figure 7.** Force feedback data glove based on electrorheological fluids.

With the change of electric field, the liquid viscosity changes sharply, the electric field strength increases, the viscosity increases, and the performance of ER fluid finally changes. Under the action of electric field, ER fluid has shear resistance under static state, which is due to the change of mechanical properties of ER fluid, and this force is the source of force in force feedback gloves<sup>[21]</sup>. Compared with most existing force feedback data gloves, the force

feedback structure has the advantages of stability, safety, small friction, large force feedback range, light weight, easy to carry and strong continuous force.

### 3.3. Aerodynamic feedback

Wang et al.<sup>[22]</sup> conducted a more in-depth study on the structure of micro low-friction cylinder, and its structure is shown in **Figure 8**. This structure is an elastic sealing device. The piston is equipped with a one-way sealing ring of nitrile rubber. The sliding resistance is very small, but the resistance will increase with the increase of air pressure.

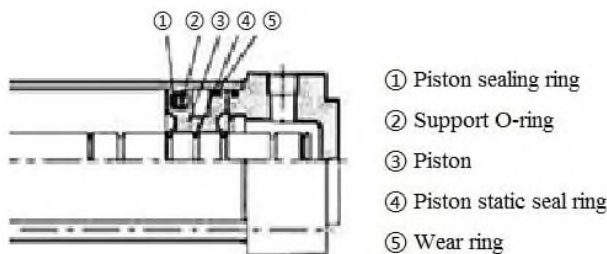


Figure 8. Low friction cylinder structure.

In the above low-friction cylinder experiment, the angle sensor and displacement sensor are used to measure the movement degree of the cylinder and the position change of the piston rod respectively, so that the experimental data can be used to calculate the bending angle of each joint. Once the virtual hand touches the real object, the piston rod will send force to the virtual finger under the condition of air supplied by the cylinder, so that the hand can feel the existence of force and complete the force feedback.

Based on the principle of aerodynamic feedback structure, Rutgers Master Glove<sup>[23]</sup> designed by Rutgers University in the United States can bend, stretch, abduct and retract fingers through the coaxial design of cylinder and spherical joint, as shown in **Figure 9**. The executive structure of the glove is fixed. Users can adjust the Velcro on the glove according to the size of their hands to adjust the size of the glove and achieve the best state. The gloves have the advantages of low friction, simple structure and light weight. The disadvantage is that the movement space of fingers is limited. In terms of the overall performance of gloves, this Rutgers Master Glove is

superior to the CyberGrasp.



Figure 9. Rutgers Master force feedback data glove.

Kopecny<sup>[24]</sup> realizes force sensing through pneumatic muscle. The principle of pneumatic artificial muscle device is that the push and pull force is provided by external compressed air. It is not only light in weight, but also can provide relatively large driving force. One end is fixed on the support and the other end is fixed on the sleeve of the finger. The magnitude of its transverse force can be controlled by the magnitude of pressure.

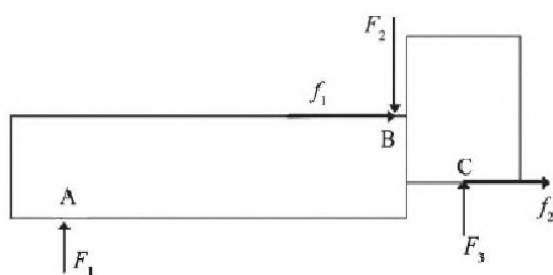
Sun et al.<sup>[25]</sup> developed a force feedback data glove based on pneumatic artificial muscle, but the difference is that it uses a micro low friction cylinder as the source of force and can measure the bending and extension angles of fingers and joints. This kind of gloves has small quality and can provide great tactile force to make the touch more real. The maximum tactile force can reach 30 N.

### 3.4. Electromagnetic force feedback

The principle of force feedback through electromagnet is: When the glove does not receive the signal, because the electromagnet is attached to the finger, it will move with the finger, and the friction resistance is small at this time. When the glove receives the signal, the electromagnet will provide a feedback force and stop moving. The feedback force can be set by adjusting the current.

According to the above principle, two different types of circular tube push-pull electromagnets are used as the braking device. The stress of the elec-

tromagnet is shown in **Figure 10**. Among them, the stop electromagnet can achieve instantaneous braking, and produce resistance to the thrust electromagnet to stop sliding. With the help of the friction between the electromagnet itself and the inner wall of the sleeve to complete the braking, the braking can be completed more efficiently and more energy-saving. At the same time, the stiffness of the device can be enhanced.



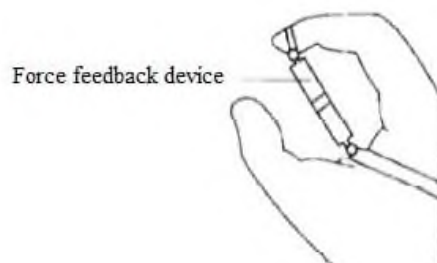
$F_1$  is the positive pressure at point A of the electromagnet that generates the thrust;  
 $F_2$  is the positive pressure at point B of the electromagnet that generates the thrust;  
 $F_3$  is the positive pressure at point B of the electromagnet that generates the thrust;  
 $f_1$  and  $f_2$  are the friction force between the electromagnet and the inner wall of the conduit.

**Figure 10.** Force diagram of electromagnet after tilting.

Asamura et al.<sup>[26]</sup> designed a force tactile system. The system uses the electromagnetic principle to fix four magnets on the user's finger or palm skin respectively, as shown in **Figure 11**. The upper magnet controls the attraction or repulsion of the magnet by opening or closing the electromagnet and controlling the direction of the current, so as to stimulate the skin of the finger or palm. The biggest feature of the system is that the structure is simple and the principle is easy to understand. The final force feedback can be adjusted according to the force of the manipulator, and the adjustment is more convenient.

The point-based finger force feedback system developed by Yuan et al.<sup>[27]</sup> is a force feedback device composed of an outer skeleton driven by a proportional electromagnet. When applying force to the device, it can not only inhibit the joint movement of the hand, but also prevent the virtual hand from embedding into the virtual object. Through the electromagnet to realize the braking, it can brake

immediately while receiving the force. It has the advantages of simple structure and strong controllability. Compared with the traditional mechanical braking device, this feedback system has better control effect.



**Figure 11.** Force feedback diagram.

## 4. Application of intelligent wearable force feedback structure

Intelligent wearable force feedback structure can be applied to all fields of life. For virtual reality system, force sense can significantly enhance the sense of reality of the participants, and improve the execution efficiency and success possibility of task objectives in human-computer interaction. Intelligent wearable force feedback structure is entering various fields such as education, entertainment, tourism, medicine, aerospace and so on.

### 4.1. Application of traditional mechanical force feedback structure

The mechanical force feedback structure has a small range of motion, and the force only acts on the joint position of the finger. After the control device captures the specific movement of the finger, the appropriate force is applied to the finger to imitate the human grasping action. CyberGrasp is a finger type force feedback device driven by a motor and transmitted by a steel wire, which can generate a force of about 12 N<sup>[28]</sup>; its disadvantage is that it has large back impulse and friction, and is not suitable for wearing for a long time. Master-II-ND is a feedback device built in the force feedback structure, which can provide large feedback force. Its disadvantage is to restrict the movement of fingers.



#### **4.2. Application of force feedback structure in education and learning**

In mathematics, physics, architecture and other disciplines, the force feedback structure constructs a real experience from concrete to abstract for teachers and students in the virtual world, which helps to improve the learning efficiency of users. Stanford University and Johns Hopkins University introduced the force feedback technology into the primary dynamic system course of college students to guide students to personally experience mechanical movement, and the teaching effect is quite remarkable<sup>[29]</sup>.

#### **4.3. Application of force feedback structure in health care**

In medical treatment, virtual surgery is a concrete presentation and application example of force feedback interaction technology. This technology constructs virtual surgical objects through three-dimensional modeling technology. Doctors can wear force feedback equipment, simulate real surgical scenes, and practice surgery with virtual objects to improve the success rate of doctors' surgery. In recent years, with the development of force feedback technology, doctors can operate by manipulating virtual force feedback surgical equipment and synchronously reflecting its actions into real surgical equipment by means of signal transmission. This technology has become an important auxiliary prop and real-time recording tool for modern surgery<sup>[30]</sup>. The force feedback surgical equipment can reduce the action of the doctor's hand in the same proportion, and has the correction function. It can filter out the shaking of the hand, so as to eliminate the small errors caused by physical factors, ensure the flexibility and accuracy of the doctor's operation, and improve the accuracy of surgical operation. At the same time, some external frame force feedback equipment can be applied to rehabilitation training and realistic simulation of the disabled and some special patients.

In traditional Chinese medicine, it is often said to "looking, listening, asking and pulse-feeling".

Understanding the specific situation of the patient's pathological part will help doctors better diagnose the patient's condition. Doctors can train their professional ability through the palpation system with force feedback structure and sensors as the main components. The palpation system can reflect the doctor's palpation action on the display screen in real time. The doctor can feel the change of hand force when pressing different examination parts with the help of force feedback equipment, and judge the patient's disease. This kind of training is more real, accurate, simple and efficient. It provides a large number of practical cases for medical staff, saves the training cost and training time to a certain extent, and provides the possibility for doctors to diagnose patients' condition remotely.

#### **4.4. Application of force feedback structure in space technology**

The combination of force feedback and sensing structure with virtual reality technology can be used to simulate the real feeling of human body in the scenes of outer space and deep sea, and study the shape, temperature, hardness and other information of objects that people feel in this scene. Moreover, in the immersive environment, the remote command can be carried out with the human body feeling similar to the real situation, which can greatly improve the safety of scientific research team members in harsh and dangerous situations<sup>[31]</sup>.

#### **4.5. Outlook and prospects**

With the progress and development of visual reproduction technology, the demand of human society for force feedback technology will be more and more complex. High-precision position detection, real multi-simulation state force tactile reproduction system and multi-point interactive force tactile reproduction system will be the main development direction of force feedback technology in the future<sup>[32]</sup>. At the same time, the research on how to reduce the manufacturing cost of wearable electronic clothing equipment will have a great impact on the promotion of virtual reality interaction technology.

## 5. Conclusions

As a key technology in the field of virtual reality, force feedback technology combines visual, auditory, tactile and other senses in the process of virtual reality interaction, making the interaction experience between users and the virtual world more realistic and more engaging. In recent years, interactive devices with force feedback technology as the core are developing rapidly all over the world, and the research on this technology is further deepened in various countries. At present, although force feedback equipment is a key factor affecting the authenticity, experience, timeliness and accuracy of virtual reality interactive system, its development is still restricted by many aspects. In the field of clothing, in the process of combining force feedback technology with intelligent electronic wearable clothing, how to realize the miniaturization, softness and authenticity of equipment is still a problem to be solved.

## Conflict of interest

The authors declare no conflict of interest.

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