The wearable tactile feedback system and its application in the Virtual Reality

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Abstract. Virtual reality provides users with an interactable environment based on the real world. In addition, the users can use wearable devices to detect the environmental conditions and project real-world body movement to the virtual world. The development of Virtual Reality highly depends on the hardware devices. In that way, the wearable tactile feedback system is considered as a reasonable choice. The article will mainly focus on three parts about the feedback system. First, how the system works and what kind of sensors and hardware devices are contained in the system will be discussed. How they are connected will be investigated as well. Secondly, three articles about the researches done by others will be introduced, including the sensors' materials, the system's improvement, and the application and future of the system. Finally, the particular application of the system in Virtual Reality will be presented. The research of passage will be greatly valuable for the further study of the wearable tactile feedback system in Virtual Reality.

Keywords: tactile feedback system, electronic biosensor, electronic skin, virtual reality.

1. Introduction

Tactile, in general, is the human body's reaction with the environment and other humans. The world around us can be more complex than the imagination, so the need for simple and stronger human interaction is rising. The Virtual Reality (VR) can stimulate an environment that is close to the real world. The technology is widely used in the game, medical care, and even some experiment. Users can interact with the 'world' through kinds of devices. So many wearable VR devices are developed by various companies such as the Google Moto 360, the Asus Zen Watch, the Apple Watch, and some coming-soon products [1]. In that way, there is an increasing market need for wearable devices. It is reported that in 2014, the wearable electronics business more than $14 billion, and it is estimated to be over $70 billion by 2024 [1]. The sensors should provide instant and accurate collection of the different environment elements and conversion to electrical signals. It seems that the wearable tactile feedback system can provide a potential choice for developing VR.

The wearable tactile sensory technology is firstly made into our daily life in 1997 by Sony. The invention of PlayStation gaming system uses a simple but effective tactile feedback system. The newly released Apple Version and the mature Apple Watch indicate that the tactile feedback systems are widely investigated and developed. But there are some drawbacks and limitations for the systems and several method or novel technology to improve it. For example, the progression of the material can provide

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better flexibility, thus improving the wearability of the devices. Until now, a general structure of the feedback system is developed, but some questions remain.

This passage will discuss three aspects of the wearable tactile feedback system. In the first part, the system's working principle will be introduced, including what should be contained in the system, what kind of sensors should be used and how they work. The second part will focus on the researches done by others. They are about how to improve the sensors' accuracy and speed, including the materials, the combination of the sensors to a system, and finally the future development and applications of the sensors and the system. Finally, the passage goes to the application of the system in VR. How the features of the system can match the need of the VR and how the signals are detected and processed into the VR feedback to the users.

2. Working principle of wearable tactile sensor and system

2.1. Brief introduction

The tactile sensors are the pressure sensors, which can detect the change of mechanical features such as the strains and the force of the human body and the surroundings [1]. The wearable tactile sensor works through the receptors on the human skin. Like the skin, the sensors detect and measure mechanical and thermal information and environmental stimuli. And the wearable feedback system consists of various components used to get the perception of the contact object. For the stimuli, the mechanical ones are more complicated than the temperature and the humidity. For instance, holding a teacup needs the adaption of the receptors inside the skin of the pressure and the skin-stretch. The vibration signal is produced when a person physically touches the teacup's surface. But because of the surface texture and the object shapes, the stimulations are exactly complex, the parameters of pressure, strain, shear and vibration should all be measured by the sensors.

2.2. Working principle

To implement the wearable tactile sensors, the sensors should be able to offer the quick response. As shown in the Figure.1, there are mainly two ways: skin-based and textile-based. The skin-based sensors are pressed on the human skin or robotic surface to get the periodic and accurate result of the physiology and environment. But detaching the device from the skin will lead to more interference and decrease the accuracy. The textile-based sensor is put on the human skin or inside the fibers like the clothes. It has a self-adapted network configuration to follow the movement of human body and then lead to a smaller strain and higher damage tolerance. As a result, many wearable tactile sensors are made by fibres [2].

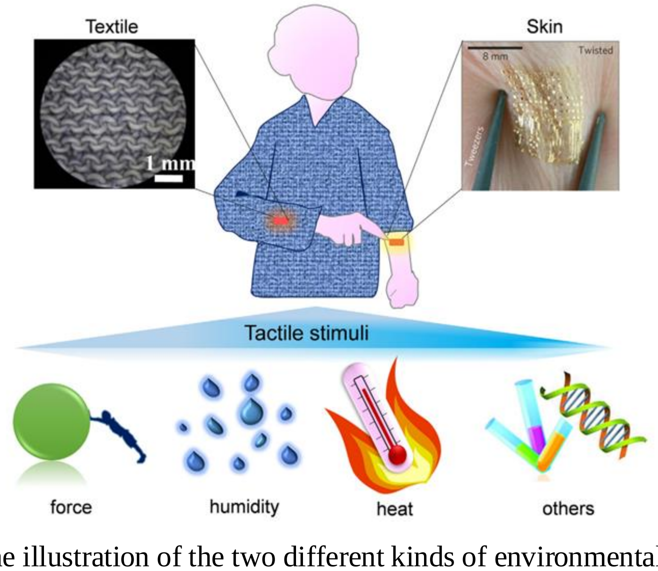

Figure 1. The illustration of the two different kinds of environmental stimuli [2].

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2.3. Key features of the sensors and the system

The wearable tactile sensor system can reach a rapid, accurate and convenient way to perceive the environment around. The system needs to feedback the fast and precise response to the targets and transport the data in a characteristic display method with an operating platform. As illustrated in Figure 2, the sensor system firstly needs several functional electronic components such as data collection and processing, device operation control, smart data display, and self-powered working style. As a result, the system may be broken down into a variety of useful functional modules, including signal detection, signal processing, data analysis, data transmission, and display modules. The temperature, humidity and mechanical stimuli will interact with the sensors and be transformed into the electrical signals. The signals will be converted to digital ones by the signal processing circuit which contains ADC part. Thus, users can see the result of the data on the display device.

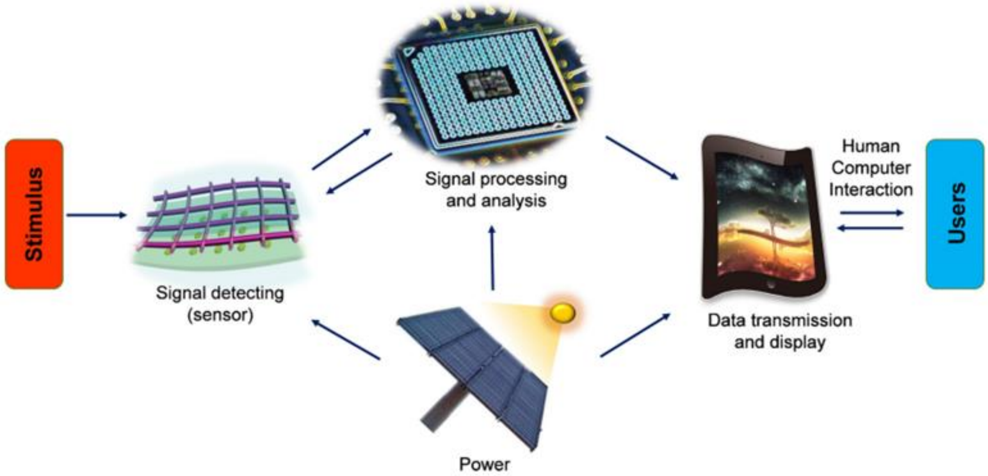

Figure 2. The block diagram of the process of the tactile sensor [3].

Returning to the tactile sensor, the mechanical stimuli contain three elements: touch, movement, and pressure. Touch is detected by the sensors when the distance between the sensor and finger is zero and the force applied is also zero. When the force increases, the pressure is detected. For the movement, multiple sensing points or proximity sensors are needed. Based on the transducer, the sensors are classified as electrical, magnetic, optical, and ultrasonic sensors. The tactile stimuli are converted into different signals, and the electrical ones are most commonly used.

The principle of detection is converting the force and distance of the receptors into electrical signals. The sensors are mainly capacitive touch sensors, resistive touch sensor, and piezoelectric and triboelectric touch sensors. The electrical transduction technology mostly supports these sensors since it has simple sensor fabrication, device operation, and easy of data acquisition and processing. In that way, the cheaper, more effective, and more accurate sensor can be made simply and quickly, leading to rapid development. Also, the electrical signals can be easily processed by the sensor arrays.

A proper hybrid multisensory mechanism should be used to connect the sensors to improve the system's sensitivity. The single-principal sensor does not meet the requirement of malfunctions and cannot detect different parameters [4]. The three-principal integration is the best choice for the wearable tactile feedback system. Various mechanical parameters should be imported to improve the system's acceptability. Different materials such as polymeric materials and nanomaterials, need better performance and adapt to the great pressure and temperature changes.

3. Wearable tactile sensor and system

The wearable tactile system has a great potential in a wide range and still facing challenges now. Meanwhile, much research is done about sensors' materials, applications, and structure and their system.

The wearable tactile system uses the strain sensor to detect the users' movement. Yan T et al. indicates that different materials will greatly impact the sensors' performance. For bettering the flexibility and stability of the sensor, carbon-based nanomaterials such carbon-based nanofibers, carbon nanotubes, graphene, and carbon black nanoparticles may be simply and effectively coupled with polymers. Also, the sensor designed in that material can be produced in many ways, such as filming casting, screw extrusion, and 3D printing. The gauge factor can evaluate the quality of the sensor. There are various ways to combine the materials n polymers such as films, fibres, nanofiber membranes, yarns and fabrics. These sensors work via changing the conductive network between overlapped nanomaterials, tunnelling effect, and crack propagation, are also different compared with traditional semiconductor and metal sensors. Different materials and structures will lead to different performance of the sensors, and the article illustrates different materials and structure and compare their characteristics. The nanomaterials provide excellent sensitivity, static and dynamic stability based on the tunnelling effect and crack propagation. Now, some kinds of satisfying strain sensors are made and used in real-life [4]. The flexible strain sensing technology has great potential in pressure sensing. It is integrated with other sensors and electronic devices to make into wearable devices such as gloves and keen of trousers. They are used to measure the movement and pressure of humans [5]. But there are still some challenges to be faced. Firstly, improving both stretchability and sensitivity remains challenging. The deformation cannot be detected for the circuit part because of the mismatch of the strain and the change in the resistance during loading and unloading. The sensor's stability and sensitivity will be reduced by connecting it to the data processing units. To make further development, more researches on the carbon-based nanomaterial flexible strain sensors.

The system uses the pressure sensor to measure the surrounding objects' touch, pressure and textile. In the journal article called 'Wearable tactile sensor based on flexible microfluidics', the detailed and specific research on the liquid-based thin film microfluidic tactile sensor of high flexibility, robustness and sensitivity. The research is done to overcome the disadvantages that the traditional piezoelectric silicon-based sensor materials are not so flexible, bendable, and lightweight because the photolithographic fabrication methods utilize rigid substrates that limit deformability. The research designed the sensor using the micropatterned silicone elastomer thin film and screen-printed conductive electrodes. Then the model is stimulated, created in SolidWorks, and processed in MATLAB. The sensor works similar to a micropump system, the fluid will be displaced to the end regions under the pressure and the collapses of the microchannel. The pressure is then expressed as the resistance correlated with the silicone elastomer resembling mechanical beam acting on the conductive fluid. To experiment, the load is changing from 2 kPa to 10 kPa. The stress and the channel deformation detect the sensitivity, the pressure range and sensitivity can be altered based on the sensor thickness for different applications. The robustness is tested by extreme deformation such as bending, twisting, and crushing. The reliability is determined by the dynamic load using a linear actuator. The pressure and the temperature are changed to evaluate the reliability [6]. The microfluidic tactile or pressure sensor has excellent flexibility, durability, and sensitivity. It is built of micropatterned silicone elastomer filled with conductive fluid and attached to a polymeric film. And it has a great potential to be used in the wearable tactile sensor system for better overall performance.

All these sensors should be connected to other devices to form a whole system, the data should be processed and the result should be displayed to the user. Zhong W et al. reported the topic focusing on the recent advances of the system: common sensing mechanisms, important performance evaluation parameters, the device design trends and the main applications. Additionally, the transistor and the way the sensors are integrated are explored. Sensor arrays are used to combine the sensors in order to acquire huge amounts of information, acquire information in several modes, and integrate tactile sensors with transistors [7]. The sensor array will enable a large-area sensor while increasing the service lifetime of the sensor. That can lead to a multifunction and large area for the system. The arrays are mostly based on the piezoelectric material arrays on a polydimethylsiloxane substrate, presented in the Figure 3. And the sensor will show high flexibility under continuous stretching, bending, and twisting [8]. The multi-mode tactile sensor can provide real-time feedback on stimuli and complex environmental changes. The

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tactile sensors are commonly connected with transistors to reduce the noise during the processing of the signals and amplify the signals. In that way, the overall performance of the tactile feedback system will be improved. Finally, the systems can be used in various conditions like the human-machine interface, health monitoring, and virtual reality.

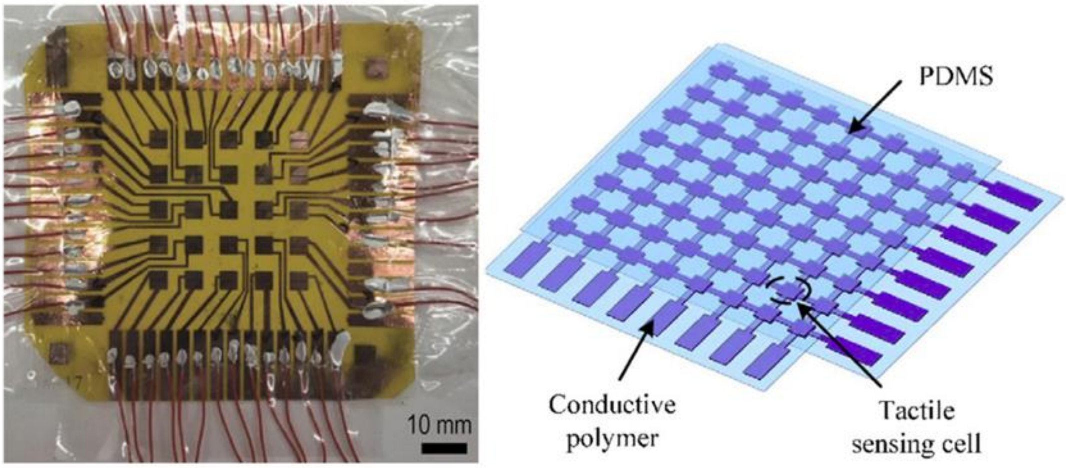

Figure 3. Details the sensor array based on polydimethylsiloxane substrate [9].

4. The applications of the wearable tactile feedback system in virtual reality

In Figure 4, the VR is a technology that can let the user immersed in the 3D environment created by the computer and interact with the computer [10]. The users can have the experience very similar to the real world and using specific devices to interact in the virtual world. The realization of the VR needs both the software and hardware. The VR needs to meet the requirement that the user should firstly see the virtual environment in the first aspect and then see the movement in the real world being converted to the virtual world and having interaction. Thus, the VR system should give the feedback, and the stereo visual perception is insufficient to meet the demands.

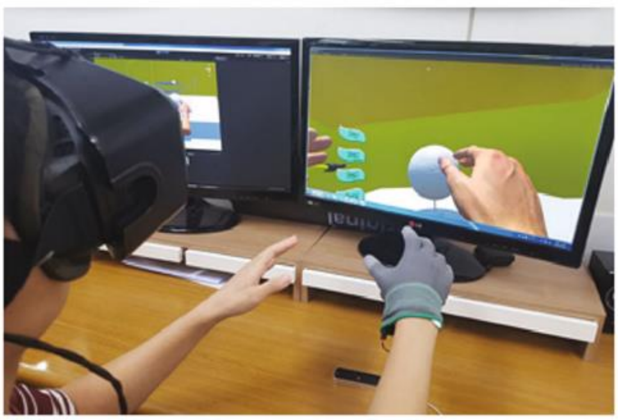

Figure 4. The wearable tactile system(glove) used in the VR [11].

The electro-tactile feedback system can be applied to the VR system because it not only does it overcome the complexity, expensive, and cumbersome of the haptic feedback, but it can also provide a wider range of tactile sensations than the vibrotactile feedback systems because of the wider bandwidth. The overall system should detect the movement of the human using a glove which detecting the finger bending, the acceleration sensor on the headset detects the head angle and the final display, and the arm movement is detected by the human motion detection system [12]. A mirror-reserved image transforms the arm and hand movements into the virtual world. For the software part, the display of the real-time response to the users is needed. The collision detection between the virtual affected arm and the virtual target object was calculated and the feedback of other stimuli should be shown to the user. For the sensors, an accurate measurement will give the users a better experience of the virtual world, the rapid calculation can let the user be more immersed in the virtual system, and thinner equipment will make the user feel better when using the VR system. And these are three important features the system should develop in the future.

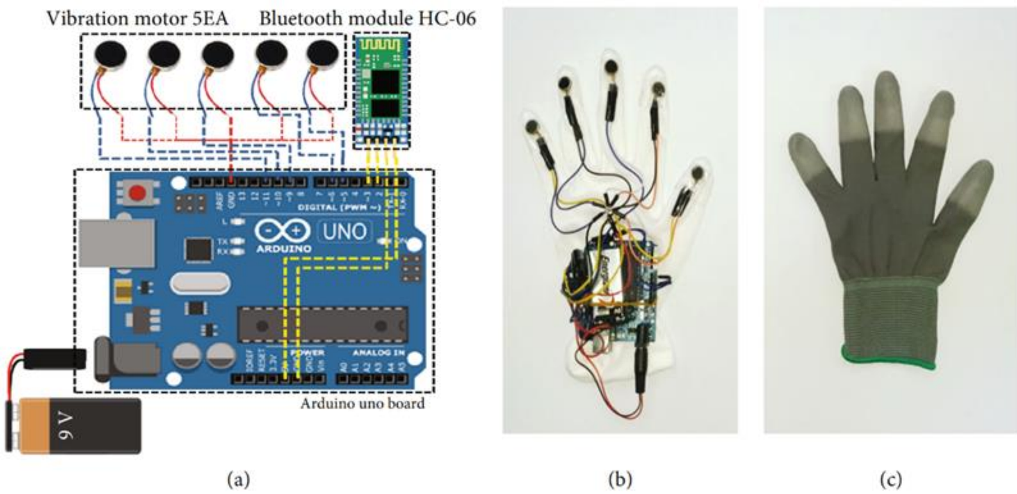

Figure 5. The model and electrical explanation of the wearable tactile device [12].

The wearable tactile sensor system can detect the movement of the human itself and the surrounding conditions, while calculating the parameters rapidly and accurately, as shown in Figue5, the devices are mostly made by the microcontrollers. With the building method of the virtual world, the system can have great potential in a quick, accurate, and comfortable VR system for users.

5. Conclusion

In conclusion, the wearable tactile feedback system contains several sensors which are combined in a certain way to detect different stimuli in the surrounding such as the temperature, moister, intensity of light, and the force and pressure while the movement of human bodies like arms, head, and the fingers. The sensors are divided into two kinds, skin-based and textile-based sensors. They will convert these outside stimuli and the users' movement into electrical signals. The system also contains the hardware components, such as the power supply, result display, the wearable devices, and the signal processing units. The principle of the system is that the environmental conditions including the movements of human body are collected by the sensors and processed by the units, the system will response to the movement of the user and give feedback through the display screen. Since the tactile system is a relatively mature technology, much research has been done in this field. Some important researches are conducted about how to improve the system’s performance, the connection of the whole system, and the details about the working principle of the movement sensors. It can be concluded that the wearable tactile feedback system has a wide range of applications in many fields.

In most cases, electro-tactile sensors are frequently used. The applications in Virtual Reality are becoming developing technology since it has advantages over conventional haptic sensors. The reaction of sensors to the movement and the changes of the environment can be accurate and rapid, the new materials will make the wearable devices lighter and more portable. In that way, the feedback system has great potential for being used in Virtual Reality such as the game or imitating certain statements.

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Overall, the future development of the VR will be supported by the wearable tactile feedback system to a great extent.

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