Review

Flexible and wearable healthcare sensors for visual reality health-monitoring

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Abstract

Visual reality (VR) health-monitoring by flexible electronics provides a new avenue to remote and wearable medicine. The combination of flexible electronics and VR could make smart remote disease diagnosis by real-timely monitoring the physiological signals and remote interaction between patient and physician. Flexible healthcare sensor is the most crucial unit in flexible and wearable health-monitoring system, which has attracted much attention in recent years. The paper briefly reviewed the progress in flexible healthcare sensors and VR healthcare devices. The
flexible healthcare sensor was introduced with the basic flexible materials, manufacturing techniques, and their applications in health-monitoring (such as blood/sweat detections and heart rate tracking). The VR healthcare devices for telemedicine diagnosis have been discussed, and finally the smart remote diagnosis system by flexible and wearable healthcare sensors and VR device was discussed.

**Keywords** flexible electronics; flexible healthcare sensors; visual reality; telemedicine

1 **Introduction**

Nowadays, aging society requires the medical resources and makes it become increasingly shortage. The limited medical resources have been prioritized for the patients who suffering serious disease or urgent needs. Current and traditional medical methods cannot meet the requirement of patients’ needs timely. Flexible and wearable health-monitoring provides an revolutionary technology to traditional diagnosis methods, and put them towards remote, portable, and timely. \([1-4]\) The flexible healthcare sensors are crucial units in wearable health-monitoring system, which could transduce physiological signals of human body to electrical signals for quantitative analysis and evaluation of body condition. Physiological signals could be real-timely collected by flexible healthcare sensors, and transferred to the cloud database by wireless data transmission techniques. Then, those date will be used by physician to evaluate the body conditions with AI deep learning algorithm. \([5-7]\) Visual reality (VR) is a computer simulation system that created a virtual world and provides
an immersive interactive experience. VR was demonstrated potential applications in combination of modern medicine, computer graphics, and computer vision to create a “VR + medical” system that was used by physician to conduct clinical trials.[8-10] As assumes in Figure 1, we believe the combination of VR and flexible healthcare sensors will promote the remote medicine towards smart, accurate, and reliable. The VR device could help physician connect users in a virtual environment, and obtain the physiological signals of patients timely and accurately. Then, the professional medical diagnosis results will be feedback to patients by internet.

There are several review papers that summarized the progress of flexible electronic devices and their applications in health-monitoring.[11-16] However, there lacks the discussion on combination of flexible electronics with VR and artificial intelligence (AI). This review paper briefly summarized the advance in flexible healthcare sensors and VR healthcare devices. The flexible materials and manufacturing techniques for sensors fabrication, and their applications in health-monitoring (such as blood/sweat detections and heart rate tracking) have been introduced. Finally, we briefly discussed the VR devices with flexible and wearable healthcare sensors for smart telemedicine diagnosis system.

2 Flexible healthcare sensors

Currently, various of flexible sensing electronics have been developed for healthcare applications, such as artificial bionic sensors and smart flexible sensors that could be used in monitoring of physiological signals. The key factors in flexible sensing
electronics include materials, manufacturing process, and device configurations, which refer to the interdisciplinary research that combines the field of materials science, device physics, chemistry, electronics and computer science. The characteristics of soft, stretchable and flexible properties enabled those devices could attachable to skin and wearable to any part of the body for healthcare applications. Compared to the conventional rigid and fragile sensors, flexible electronics make those health monitoring applications more comfortable, biocompatible, energy-saving, and portable. In this part, we summarized the materials, and manufacturing techniques for flexible electronics, and reviewed several typical applications in health-monitoring.

2.1 Flexible materials for flexible healthcare sensors

Flexible materials are basic building blocks for flexible healthcare devices. The intrinsic mechanical flexible and stretchable properties could be observed from the polymers and rubbers due to their specific molecular structures. The polymers such as polyimide (PI), polyethylene (PET), polyethylene (PEN) and polydimethylsiloxane (PDMS) were demonstrated are promising materials that could play as substrate for flexible electronics.[17-22] The conducting polymers such as polyaniline (PANI) and poly(3-hexylthiophene) (P3HT) can be employed as channel materials and electrodes for flexible transistor and flexible sensors.[23-25] For example, Stefan C. B. Mannsfeld et al. reported patterned PDMS as dielectric layers of capacitive sensing device, and demonstrated highest sensitivity of 0.55 kPa$^{-1}$ and relaxation times of millisecond.[26] Lijia Pan et al. described a type of conductive and elastic
microstructure polymer consisting hollow-sphere of polypyrrole (PPy).\textsuperscript{[27]} The microstructure polymer has high sensitivity (\(\sim 56.0 \text{ to } 133.1 \text{ kPa}^{-1}\) in 30 Pa range) and excellent stability of sensing features. The intrinsic mechanical properties of polymers make those materials better to traditional rigid inorganic materials in wearable applications due to their good attachable and biocompatible property. In addition, the polymers could be easily for device fabrication with low cost and large scale. However, hysteresis of polymers put the device with long response time, which cast shadow on their applications in high frequency vibration detection.

The rigid materials could turn to flexible materials when their size down to micro- and nano-scale, or constructed them with specific nanostructures. For example, the bulk silicon wafer and glass slides are rigid and easily broken into pieces. If the thickness reduced less than 50 μm, silicon wafer and glass slides could be bend and present mechanical flexibility.\textsuperscript{[28]} The glass fibers with the diameter ranged in microscale have high tensile strength, which could elongated to 3 % without broken.\textsuperscript{[29]} Network structure composed by nanowires and nanotubes have been developed for flexible and transparency conducting films.\textsuperscript{[30, 31]} The most contact points in network are physical stacking that could be welded into chemical bond.\textsuperscript{[32]} Therefore, the network structures shown electrical stability and reliability upon repeated bending, and are promising electrode used in flexible electronics.\textsuperscript{[33]} The chemical bonded contact points in networks decreased the contact resist between the nanowires, and reduced the power consumption in final devices. Low power consumption is one of the important advantages for wearable devices because it will
extend the working times and improve the battery life.

Due to the requirement of electrical conductivity, sensing materials usually consist of inorganic and organic materials which possessing metal and semiconducting properties. For example, carbon nanotubes and graphene were commonly used in the flexible and wearable electronic sensors as electrode due to their tunable electrical conductivity.\[22\] Inorganic semiconductors with strong piezoelectricity such as ZnO have been demonstrated with high performance (high sensitivity and fast response) in the flexible mechanical sensors and shown potential applications in wearable health-monitor.\[34, 35\]

2.2 Micro-manufacturing for flexible healthcare sensor

The micro-manufacturing process is a fundamental step and important driving force for flexible electronics. This process could fabricate the circuit module on flexible substrate, and make the device miniaturized and highly integrated. Typically, there are two main kinds of manufacturing processes: lithography and printing.

Lithography is a widely used technology for fabrication of microelectronic devices due to its precise manufacturing with high resolution. The resolution of this process could reaches to microscale and nanoscale if electron beam and the UV light was used as exposure light. The principle of lithography is based on the photochemical properties of photoresist, where the photoresist will be modified and showed different dissolubility when exposure by UV light. Generally lithography contains light exposure, developing, metal deposition, and lift-off steps. As shows in Figure 2, the photoresist was spin coated (step 1) onto flexible substrate for solid film, exposed
(step 2) by UV light and developed (step 3) to form patterned photoresist. Followed by metal film deposition (step 4) and lift-off (step 5), the conducting electrode patterns could be fabricated onto target flexible substrate. In this lithography process, the sample was heated to the temperature of 100-150°C for solidification of photoresist, and it also needs immersed into polar solvent such as acetone for lift-off. Therefore, the manufacturing on flexible substrate requires the substrate materials should be resist to high temperature and polar solvent. PI, PEN, and PET were the suitable candidates as the substrate materials for flexible electrode. Lithography on elastic PDMS substrate is difficult because the swelling effect of PDMS in acetone solvent and large coefficient of thermal expansion that brings large deviation to patterning of photoresist and alignment. Thermal expansion of PDMS could be decreased by changing the composition of materials. There is a few report on PDMS based flexible lithography device. Because large value of thermal expansion make sure the material is sensitive to temperature, the temperature sensitive phenomenal was used to design the new type of flexible temperature sensors. Beside electrode fabrication, the lithography technology was also employed to fabricate the semiconductor of channel materials with micro-patterns. For example, Yugang Sun and John A. Rogers developed the “top-down” approach in which lithographic patterning and etching techniques create single-crystalline nano-/micro-structures of semiconductors (Figure 4a). However, there are some problems still existing in lithography technology for fabrication of flexible electronics. Thermal expansion of flexible substrate makes resolution of alignment is difficult reaches to nanoscale. For
removing of photoresists, the polar solvent will damage the flexible organic electronic materials, and cast shadow on their electrical properties and performance in final applications.

Beyond lithography, printing technology is an effective, low cost, large scale method for fabrication of the flexible electronic devices and large-area integrated circuits. Another important advantage of printing is that there will avoid the use of polar solvent and complex manufacturing process. The technology could produce the dedicated function circuit by inputting the patterned images which could be revised conveniently. Various and versatile printing inks (such as conducting ink, insulating polymer ink, and semiconducting ink) have been developed for printed electronics like FET devices and sensors.\textsuperscript{[37-40]} Currently, there are several printing methods including inkjet printing, screen printing and aerosol-jet printing have been used to fabricate the electronic devices. Since printing technology can print any inky material to arbitrary target substrate, this technique and printed electronics are compatible and interlinked with flexible and stretchable electronics such as organic electronics, plastic electronics, paper-based electronics, transparency electronics, and wearable electronics. Recent studies have demonstrated the solar cell, touch screen, and healthcare devices by printing.\textsuperscript{[41-43]} For example, the surface gate electrode of traditional crystalline silicon solar cell is prepared by screen-printing with conductive silver paste.\textsuperscript{[44]} Organic and perovskite solar cells could use printing to reduce the cost of manufacturing.\textsuperscript{[45]} With the development of conducting and sensing materials, recently, the printed flexible sensing electronics especially healthcare sensors have
been reported with high sensitivity and multifunctionality. Yuki Yamamoto et al. have reported the use of printing technology to achieve multifunctional, disposable and flexible medical sensors.[46] The low-cost printing process makes the sensor cheap and disposable which avoided medical cross-infection. Multifunctionality of device could be realized by the integration of it with modules of monitoring ECG and body temperature. Recently, Rui Guo et al. achieved a stretchable electronic circuit by rolling and transfer printing of nickel eutectic gallium-indium alloy semi-liquid metal. The paper-based devices have stable electrical performance and high durability after repeating cycles of more than 1000 times, and the stretchable electrodes and strain sensor can be sustain the strain of 100% (Figure 4b). [47] Despite lithography and printing technology are widely used in traditional micro-electronic circuit, the parameters of process on flexible substrate should be further developed and improved. How to balance the thermal expansion and resolution is still a challenge problem.

2.3 Applications in monitoring health-related physiological signals

Wearable technology developed rapidly and wearable products emerged endlessly. Wearable device with flexible healthcare sensors provides a novel and convenient way for health-monitoring, and puts traditional diagnosis method towards portability and remote. With the development of novel flexible and soft materials, flexible healthcare devices performed multifunctionality that could monitor multiple physiological signals simultaneously. Flexible and wearable healthcare devices will be more delicate, low-cost, comfortable and durable. As shows in Figure 3, there are some typical applications of flexible electronics in monitoring health-related physiological
signals.

2.3.1 Blood sensors

Oxygen saturation, pH value, and glucose concentration in blood are crucial physiological signals to indicate the physical conditions. Rapid analysis of these components in the blood plays an important role in clinic operation and available to evaluate the state of health. However, conventional device is cumbersome and uncomfortable. For example, monitoring oxygen saturation always adopts finger clip which limited physical movement. Detection of glucose concentration and pH value requires destroying skin to collect blood. In view of this situation, flexible blood sensors were developed for detection of pH value, glucose and blood oxygen noninvasively. Yasser Khan et al. have invented a kind of blood oxygen sensors which consists of organic electronics printed on flexible plastic and can be used with attached to skin (Figure 5a). The sensor can monitor wound healing in real time. In contrast to traditional oximetry, the technology uses printed light-emitting diodes and photodetectors to alternately form an array of sensors that can detect blood oxygen levels at nine points simultaneously, and can be placed anywhere on the skin. The sensor uses light reflection to detect oxygen saturation instead of transmitted pulse oxygen saturation because the traditional device limited to specific tissues (such as earlobes and fingers) that cannot be transmitted by light. This flexible blood sensors can be real-timely monitor the blood oxygen for patients who suffering the diabetes and respiratory, and report the results timely. Monitoring the blood flow is essential to patients who was under recovery after reconstructive surgeries. Implantable sensors
for detection of blood flow are commonly used in clinical practice, however, the process requires medical staff to fix the device in specifically designed position and brings the risk of infection. Clementine M. Boutry et al. developed a kind of biocompatible and flexible pressure sensors that can measure arterial blood flow in contact and non-contact modes. The flexible device was fabricated by bio-degradable materials based on the configuration of fringe-field capacitor(Figure 5c).\textsuperscript{[49]} The advantages of this flexible sensor are noninvasive, fast response, high stability, good biocompatible, which bring the blood monitoring device towards smart, safety, rapid, and comfortable.

### 2.3.2 Sweat Sensors

Body fluids such as interstitial fluid and sweat carry a great deal of vital information for human body. Sweat is one of the most readily available body fluids, which contains large amounts of inorganic salt (K+, Na+, Cl-) from metabolism of human body and is closely related to the state of body. It has been demonstrated that sodium ions in the blood can be used to detect dehydration, chloride ions to diagnose cystic fibrosis, and glucose to test diabetes. Different types of sensing units were integrated into a substrate according to various components in sweat, and the device was attached to the surface of human skin for physiological analysis. Various kinds of multi-component sweat analysis system have been designed in recent years. For example, Amay J. Bandodkar et al. developed a wireless electronic sensor with a biofuel cell for monitoring lactate, glucose, chloride, pH and sweat rate(Figure 6a).\textsuperscript{[50]} This small and low-cost sensor could provide a continues monitoring of multiple
component in sweat. The variation in sweat composition could be observed at anywhere and anytime. Yongjiu Lei et al. reported a stretchable, wearable, and modular multifunctional biosensors by MXene/Prussian blue (Ti$_3$C$_2$Tx/PB) composite(Figure 6b).\textsuperscript{[51]} The composite can be used for durable and sensitive detection of biomarkers, such as glucose and lactate. Specially, they developed a unique modular design with three interface of solid, liquid and gas that allow the sensor to measure multiple physiochemical signals with high sensitivity (35.3 $\mu$A mM$^{-1}$cm$^{-2}$ for glucose and 11.4 $\mu$A mM$^{-1}$cm$^{-2}$ for lactate), and great repeatability stability. Smith Rachel E. et al. demonstrated a kind of highly conductive and flexible cotton fiber sensor that is biocompatible and antibacterial.\textsuperscript{[52]} The sensor shown high sensitivity and fast detection capability to the sweat pH in the range of 2.0 to 12.0. Recently, Lu Yao et al. prepared intelligent sweat analysis system, which integrated with micro-supercapacitor and self-power module.\textsuperscript{[53]} They demoed the system in detection of accurate sweat signals and remote data sharing, that the signals were sent to individual mobile phone through wireless transmission technology. The method break the limitation of bio-enzyme sensor for measuring temperature and humidity. These devices will promote the remote medicine for pre-diagnosis of disease such as diabetes screening and kidney status detection.

2.3.3 Respiratory and Heart Rate Sensors

There are two ways to measure heart rate: PPG (photoplethysmography) photoelectric volume pulse wave and ECG (electrocardiogram) signal measurement. The method of PPG photoelectric volume wave uses pulsating changes in light
transmittance in the blood to reflect heart rate. However, the accuracy of the method is affected by the influence of irregular exercise and sweat.

The patch ECG signal measurement needs several wired electrodes attached to the chest, ankle and wrist for detection. It is a complex method and restricts physical movement. Conventional ECG signal collection cannot be conducted with a long working time, while flexible and wearable sensors shown high sensitivity, fast response speed, great adhesion, optional stability, good portability and comfort for detection of heart rate. Sungjun Park et al. invented a self-powered ultra-flexible heart rate (HR) sensor by patterned ultra-flexible organic solar cell, which can accurately monitor the heart rate with high signal to noise ratio in real-time(Figure 7a).[54] The OPV and OECTs were integrated on the top of ultrathin polymer substrate. In the manufacturing of OPV, the nanopattern of ZnO maximized the efficiency of OPV and weaken the reflection of incident light so as to the performance of sensor is not affected by the light angle. Meanwhile it also exhibited excellent mechanical stability and durability. Wang Guangming et al. designed a stretchable optical HR sensing patch system with promising performance (Figure 7b).[55] The device has been close contact to skin and obvious HR fluctuation frequency during intensive exercise. However, the resolution of collected original waveform still need to be improved.

Skin-inspired flexible sensors such as electronic skin are designed to mimic the human skin for sensing the pressure, strain, stretch, and temperature. Real-time monitoring the wrist pulse provides a convenient way for detection of HR. There are several research groups have fabricated the electronic skins by organic
semiconductors, inorganic nanowires, carbon nanotubes, graphene, metal nanowires, and microstructure conducting polymers\textsuperscript{[56-60]}. Electronic skin could be attached to wrist for detecting wrist pulse due to its high accuracy, sensitivity and resolution in detection of tiny pressure. In our previous studies, we developed ultra-sensitive pressure sensors by micropatterned PDMS with carbon nanotube films\textsuperscript{[3]}. The device presented high sensitivity and accuracy to the wrist pulse, and capable to distinguish the wrist pulse from persons with different body conditions.

3 VR technology for health-monitoring

The most prominent feature of VR is that it can provide users a sense of immersive. VR combines new applications with multi-field technologies, which changes the service model of the industry and expands the perceptual boundary. Currently, VR shows potential applications in the fields of computer, medical, military, education, aerospace, and entertainment. For example, miniature VR goggle, ear wearing equipment for panoramic sound, lightweight tactile feedback gloves and digital smell interface have been studied and look forward to serving human life in the near future \textsuperscript{[61]}. According to the user experience, there are mainly three types of VR hardware equipment: (i) The PC head-mounted device with high immersion. The shortage of this device is the limited portability and the high system configuration, which makes it more suitable for enterprise user; (ii) the portable and mobile VR, such as Google Cardboard. The advantage of this type of VR including rich VR resources and low cost; (iii) hybrid and integrated VR system. The system integrate processor and screen together for the function of display and calculation.
As shows in Figure 8, new VR applications for healthcare have been designed based on the rapid development of VR technology. There are mainly two themes for VR in the area of medicine: remote disease surveillance, rehabilitation training and physical and mental monitoring.

VR can be used in monitoring health signals by physiological sensors and some immersive virtual scene. VR health monitoring system contains sensor unit for detection of individual physiological signals, VR equipment for visual interaction interface, and software program. Physiological signals varied under different scenes. For example, heart rate and respiratory rate could be increased by exercise. Different states of body condition may reflect by indicators of electrophysiological signals. EEG with different virtual scenes can reflect participants’ concentration, relaxation and mood\textsuperscript{[66]}. If the user equipped with VR headset and EEG monitor to carry out activities, while the system integrated software programs to record the effects of brain waves in real time. The user could freely adjust posture, and the physician could obtain a wide variety of EEG samples. VR enhanced the communication between patient and physician, and enabled the physician comprehensive understanding of patients' information. VR devices provide a way to monitor health signals in different scenarios at anytime and anywhere.

3.2 VR for teletherapy

VR equipment is used for remote diagnosis of disease or rehabilitation by vision therapy VR. Telemedicine surveillance with VR visual scene allows physician to immerse themselves to practice clinic diagnosis and operation. Shahzad Rasool et al.
proposed to use 3D simulation and tactile sense interaction to solve the lack of cases. \[62\]

The virtual lesion modeling scene was used to simulate minimally invasive surgery. \[62\] Alessandro De Mauro et al. have achieved an immersive surgery experience by the combination of tactile force simulator with VR neurosurgical microscopes. Similarly, Pingjun Xia et al. presented a novel and low-cost approach for image-based virtual haptic venipuncture simulation, which used 2D actual photos with tactile feedback and real-time interaction between force feedback and 3D operation screen (Figure 9). \[63\]

VR technology also has been used for treatment of mental illness, such as anxiety disorders, traumatic and stress-related disorders (PTSD), obsessive-compulsive and related disorders (OCD) and schizophrenia spectrum and other psychiatric disorders. During treatment, the system makes use of computer graphics, physiological signal sensor and visual imaging technology which enabled patients to immerse themselves in the scene that provided by VR equipment, to obtain perceptual experience and emotional response.

3.3 Rehabilitation training

VR could help patients on rehabilitation which including stress management, autism relief, and stroke treatment. For example, Wendy Powell et al. demonstrated the potential of VR to ameliorate pain and improve rehabilitation by building a system of gait rehabilitation. \[64\] The VR screen can adjust the patients’ steps signal, then adjust the frequency of the scene switching and audio rhythm, so as to alleviate the pain in the rehabilitation process. Moreover, VR can be integrated with multiple kinds
of sensors for remote medicine. Paul D. Marasco et al. put forward a system of motor control for prosthetic hands by VR. In particular, this study combined the kinesthetic sense, intent and vision to improve the body movement control. These systems help physician and patients to achieve fast remote detection. In brief, they have demonstrated the potential of disease cure and healthcare monitoring. At present, more and more VR products were used in healthcare services. With the development of VR technology and flexible electronics, the medical industry will take on a new look in the near future.

4 Conclusion and outlook.

We presented a comprehensive review on the recent advances of technologies and applications in the field of flexible healthcare sensors and VR healthcare devices. Several flexible functional materials and typical micro-manufacturing technology have been described. Beside sensor units, the flexible and wearable healthcare system also include the power supply unit, integrated circuit for signal process, and wireless communication units for data transferring. Therefore, the key will be investigating on novel materials (e.g. flexible energy materials and soft semiconductors) and advanced manufacturing and integration techniques not only for sensor units, but also for the whole functional units of flexible healthcare system.

Flexible healthcare sensor and VR technology is considered to be a revolutionary techniques for healthcare service such as remote disease diagnosis. The techniques will promote not only the revolution of the next medical instruments towards portable,
wearable, remote, and timely, but also the change of the conventional diagnose method in clinical practice. Recently, wearable health-monitoring was demonstrated by flexible healthcare sensors for telemedicine applications. Health-related physiological signals could be collected by flexible sensors and transmitted to hospital and database for analysis. The physician's role is still crucial and irreplaceable, as patients need physicians' professional medical advice by analyzing physiological signals and referring to the results of algorithm. Typically, physiological signals vary widely from different parts of human body. Patients will obtained various physiological signals when the flexible healthcare sensors were worn to different parts of body, which will makes the diagnosis difficult for physicians. VR technology provides an effective way to connect the physicians and patients. Physicians could use this technology to ask patients to make the correct placed position for flexible and wearable healthcare sensors. VR technology could be used to improve the accuracy of diagnosis by integrity of sensing system which established by the flexible and wearable healthcare devices. Therefore, the combination of flexible and wearable healthcare sensor and VR technology will be a potential disruptive technology for healthcare.

5 Acknowledgement

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References


Figure 1. Compared to time-consuming medicine, convenient medicine could promote the sharing medical resources, make it convenient for patients to access the physician anytime and anywhere and improve the quality and efficiency of diagnosis.
Figure 2. The schematic of lithography: 1) resist coating, 2) UV light exposure, 3) developing, 4) metal film deposition, 5) lift-off.
Figure 4. a) The fabrication of GaAs wires with the method.\textsuperscript{[36]} Copyright 2007, Advanced Materials. b) The printed acceleration sensor and circuit diagram.\textsuperscript{[47]} Copyright 2019, Science China Materials.
**Figure 5.** Blood sensors. a) The new sensors, alternating arrays of printed light-emitting diodes and photodetectors, can detect blood oxygen levels in any part of the body. The sensor uses light-emitting diodes to emit red and near-infrared light, penetrating the skin and detecting the proportion of reflected light.\cite{48} Copyright 2018, Proc Natl Acad Sci U S A. b) A kind of e-skin for monitoring blood pressure and temperature. c) The sensor made of biodegradable materials utilizes edge-field capacitance technology for monitoring arterial blood, and then transmits the data wirelessly.\cite{49} Copyright 2019, Nature Biomedical Engineering.
Figure 6. a) The system of wireless battery-free sweat sensor, the process of detecting during sweating, and the wireless transmitting and analysis interface of sweat composition on the smart phone.\textsuperscript{[50]} Copyright 2019, Science Advances. b) Schematic diagram of the multi-functional sweat sensor. As shown in b), the wearable monitoring film connects to an electrochemical analyzer, and transmits data to smart phone through blue-tooth.\textsuperscript{[51]} Copyright 2019, Small.
Figure 7. a) The size of self-powered wearable electronic sensor and the photography of this sensor attached to the heart of a rat for monitoring heart rate.\cite{ref54} Copyright 2018, Nature. b) The smart analysis system of real-time flexible sensor for monitoring physiological signals during exercise, including , and data collecting from the sensor.\cite{ref55} Copyright 2019, IEEE Transactions on Biomedical Engineering.
Figure 9. The haptics-based Virtual Reality training system for Venepuncture.\textsuperscript{[63]} Copyright 2012, ACM.