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Flexible sensors for mechatronic engineering education

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ABSTRACT

Mechatronics has become an inevitable trend in the development of the industry, manufacturing industry in the rapid development of today has also driven the innovation of technology. In the development process of mechatronics, flexible sensors stand out, flexible sensors have the characteristics of flexibility, and a wider range of applications, which is the frontier direction of contemporary electromechanical development. Mechanical and electronic engineering is for the traditional engineering disciplines, the teaching process of students to accept concepts and other content ability is poor, lack of interest, the need for new solutions to solve problems. And by using flexible sensors in exemplary teaching, electromechanical knowledge can be taught more effectively, which can enhance students' vision, learning ability, indepe, dance, and innovation. In this paper, we outline the principles of flexible sensors, and sensors in electromechanical engineering, the advantages and disadvantages of each type of flsensorsensors, and their broad prospects for electromechanical teaching applications.

1. Introduction

Mechatronics technology is the inevitable result of the development of modern science and technology. When mechanical technology and electronic technology cross, pe, nitrate, and integrate each other, so that mechanical technology and electronic technology are organicallbaseded analyses of system theory, information theory, and control theory, forming today's mechatronics technology [1–3]. With the continuous development of the modernization of industrial production, the integrated application of mechatronics technology is playing an increasingly important role [4–7]. The combination of technologies' technology and intelligent control can combine theory and technology to form a variety of efficient control methods to achieve effective management of systems and equipment, enabling mechatronics systems to play a more active role in CNC, machinery manufacturing, robotic,s, and other fields, thus ensuring the accuracy and efficiency of production and management, reducing human and material costs, and providing strong support for industrial production [8]. Many countries are moving toward becoming a world manufacturing powerhouse, and the research and application of mechatronics will be the cornerstone of future industrial development [9–11]. Based on the shortage of high-level personnel, various institutions around the world have taken up the burden of how cultivating specialized mechatronics personnel [12–17]. To study the principles of mechatronics in depth, develop the technical basis of mechatronics, and accelerate the training of mechatronics specialists, institutions of higher learning around the world have established corresponding specialties to incorporate mechatronics principles, technologies, and design methods into their teaching programs and conduct research [18–20].

The new industrial era (Industry 4.0) is underway and requires professionals with the technical skills of the Industry 4.0 pillars. The concept of mechatronics in Industry 4.0 is constantly reinforced by the industry, and education is changing according to the needs of the industry, which in turn leads to the need for universities to update their curricula to support the professional knowledge and skills required by the changing expectations of the industry. Integrating mechatronics into teaching and learning allows for the development of human resources that are more responsive to industry, and a group of scholars, including Héctor A. Guerrero-Osuna, have proposed a computer vision-based training system for educational mechatronics (EM) based on the concept of "teaching for achievement, task-centered teaching, and learning". The system is

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designed to integrate Industry 4.0 and Industry 4.0. The system aims to integrate Industry 4.0 elements into the curriculum of different bachelor's degree programs such as Mechatronics. The system makes students aware of how to engage and practice what they learn in the classroom, allowing the system to assist in teaching and learning. Inspired by this, we hope to use flexible sensors in mechatronic engineering education to train people to support the various changes in the industry [21–25].

Mechatronics is a discipline that combines machinery, electronics, optics, control, computer, information, and other discipline analyses. How to make students understand the knowledge of electromechanical professional courses more deeply and make the knowledge transfer more concrete becomes a challenge [13,26,27]. The use of flexible sensors for the demonstration teaching of electromechanical courses and the display of flexible sensors in the classroom will improve the teaching effect. First of all, flexible sensors can convert the stimulus of the external environment into electrical signals that can be collected, and they are the "eyes" of industrial production, so they can be used as an example to explain the adaptation of electromechanical expertise to industrial production, which can combine professional knowledge with production practice [28–35]. Furthermore, flexible sensors are the frontier of electromechanical development, and the development direction of flexible sensors perfectly fits the characteristics of the future development of the lelectromechanicalprofession of intelligence, modularity, networking, miniaturization,self-energy, and green. Flexible sensors play a great role in various fields of modern society. Fig. 1 shows the application architecture of flexible sensors, as shown in Table 1, which lists the applications of flexible sensors in various aspects of modern society.

The use of flexible sensors for demonstration teaching can be more specific to convey electromechanical expertise, and improve students' horizons, learning ability, independent thinking ability, innovation spirit, etc. This paper first introduces the principle of flexible sensors, then the introduction of sensors related to the field of electromechanical engineering, and finally the advantages and disadvantages of flexible sensors and the pros and cons of teaching applications.

2. Principle of flexible sensors

Different types of flexible sensors have different operating principles. At present, flexible pressure sensors, flexible gas sensors, and flexible humidity sensors are the more mature three types of sensors, which cover most of the types of flexible sensors [57].

2.1. Flexible pressure sensors

Flexible pressure sensors are sensing external pressure stimuli andconvertg them into electrical signals. Flexible pressure sensors are simply classified in terms of measurement principle into piezoresistive, capacitive, and piezoelectric types [57] (see Table 2).

Piezoresistive pressure sensors work on the principle of the piezoresistive effect. It mainly contains active materials, flexible substrates, and conductive electrodes [64]. Efficient sensing is accomplished by a durable and wear-resistant flexible substrate and a conductive material with a special microstructure. It is characterized by a simple structure, high sensitivity, large working range, fast response,e time, and high stability. The comprehensive performance of the sensor is also measured based on performance parameters such as sensitivity, sensing range, and response time.

The sensitivity (S) is the slope of the relative change in resistance with the applied pressure curve, as shown in Equation 1 [65].

$$S = (\Delta R / R_0) / \Delta P \quad (1a)$$

ΔR is the amount of change in resistance, R_0 is the initial resistance value when no pressure is applied, and ΔP is the applied pressure. The higher the value of $\Delta R/R_0$ at the applied pressure, the higher the sensitivity of the sensor. Another related concept called sensing range refers to a pressure range within which the sensor can properly convert the pressure signal into an electrical signal. What we seekares a large sensing range and a high sensitivity value, but due to material and process limitations, it is often difficult to combine both properties, and we need to balance sensitivity and sensing range to meet the needs of industrial

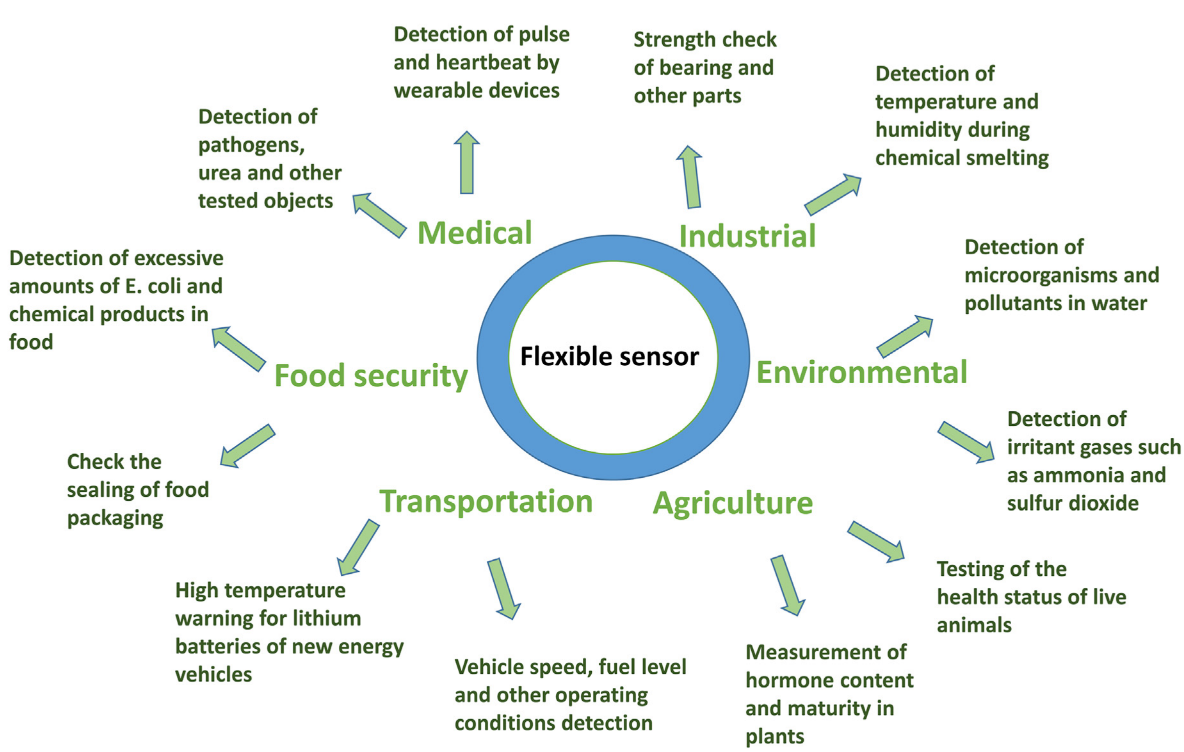

Fig. 1. Flexible sensors application architecture.

Table 1
Example demonstration of three mechanisms of pressure sensors.

Applications	Specific Applications	Products	Company	References
Medical treatment and health	detection of pulse and heartbeat by wearable devices	Lief Therapeutics Smart Patch Apple Watch Fitbit	List Therapeutics Apple Inc. Fitbit Inc	[36] [37] [38]
	Detection of pathogens, urea, and other tested object	– –	– –	[39] [40]
Industrial manufacture	Strength check of bearing	BMO-6204/048S2/UA008A BMB-6208/080S2/UB008A ABB Ability Smart Sensor for Dodge mounted bearings	SKF ABB	[41] [42]
	Detection of temperature and humidity during chemical smelting	–	–	[43]
Environmental protection	Check the sealing of food packaging	– –	– –	[44] [45]
	Detection of irritant gases such as ammonia and sulfur dioxide	– – –	– – –	[46] [47] [48]
Agricultural industry	Testing of the health status of live animals	InFlect™ flex sensor， FlexSensor™ Flexible Sensor	Brewer Science Royole Corporation	[49] [50]
	Measurement of hormone content and maturity in plants	–	–	[51]
Transportation	High temperature warningfor lithium batteries of new energy vehicles	– –	– –	[52] [53]
	Vehicle spee. fuel level and other operating conditions detection	TLE4959C FX Flexible Transmission Speed Sensor	Infineon	[54]
Food security	Check the sealing of food packaging	Seal Scope™	Engilico	[55]
	detection of excessive amounts of E.coli and chemical products in food	–	–	[56]

production. Response time is the time required for the resistive signal of a flexible piezoresistive pressure sensor to reach 90% of its stable output value. Stability is the strength of the performance of the sensing capability under repeated use conditions and represents the reliability of the device's operation. Also introduced are the sensing mechanisms of flexible piezoresistive pressure sensors, which have the following four main sensing mechanisms.

1. Based on the energy band structure change of semiconductor materials, the energy band structure of semiconductor materials changes under the external deformation, thus changing the resistivity value and thus responding to the electrical signal.
2. Based on the percolation theory of conductive polymer composites.
3. Based on the tunneling effect of conductive polymer composites.
4. Based on the change of interfacial contact resistance.

Typical applications of flexible piezoresistive pressure sensors include: Yu et al. used piezoresistive sensors for detecting subtle muscle movements (facial expressions and throat swallowing) and body movements based on the characteristics of piezoresistive sensors. The sensor has a sensitivity of up to 136.8 kPa^{-1} at pressures $<$200 Pa applied in compression and a range factor (GF) of up to 6.85 in tension. The highly sensitive flexible piezoresistive sensors developed by Yu et al. have shown great promise in health monitoring, post-operative rehabilitation,n and other medical fields [66].

The working principle of the piezoelectric pressure sensor is closely related to the piezoelectric material, when it is subjected to external stress, the piezoelectric material generates a corresponding electrical charge and converts the output electrical signal to reflect the change in stress. The principle of the piezoelectric pressure sensor is mainly the piezoelectric effect, it is the use of electrical components and other mechanical parts to be measured by the pressure into electricity, and then the relevant measurement of precision instruments, is used to measure the force and can be converted into force of non-electrical physical quantities, such as acceleration and pressure. It has the advantages of lightweight, reliable work, very simple structure, high signal-to-noise ratio, high sensitivity and wide signal frequency. It has an important role in aerospace, construction, military and other fields.

The principle of the capacitive pressure sensor is to convert the capacitance of the external pressure into an electrical signal to measure the pressure. Generally, consists of electrodes and the ielectric layer, when the external pressure changes, the middle of the dielectric material structure changes, resulting in changes in dielectric properties, so the capacitance of the sensor will change. This type of sensor has the advantages of small energy loss and high response repeatability. The formula for calculating the capacitance of a capacitive pressure sensor is shown in Equation (2).

$$C = A\varepsilon_0\varepsilon/d \tag{2}$$

Where is the relative dielectric constant of the dielectric layer material; ε_0 is the vacuum dielectric constant (8.82×10^{-12} F/m); A and d are the effective squared area (m^2) and distance (m) of the top and bottom electrodes, respectively. In capacitive pressure sensors, the pressure magnitude is positively correlated with the capacitance value. The packaging method, electrode material, and dielectric layer of capacitive pressure sensors all affect the nature of the pressure-capacitance curve in capacitive pressure sensors.

2.2. Flexible gas sensors

Flexible gas sensors are arranged with gas-sensitive thin film materials on the electrode surface, which are flexible, ductile, and can be produced in large areas. It is extremely well adapted to the requirements of convenience and low power consumption of gas sensors in special environments. Ma et al. proposed an effective strategy to prepare self-powered gas sensors based on two-dimensional materials, driven by

Table 2
Example demonstration of three mechanisms of pressure sensors.

Product	Core Materials	Performance Indicators	Sensing principle	References
3D conductive sensing piezoresistive sensor	Three-dimensional network thermoplastic elastomer (TPE) base material、Carbon nanotube (CNT) conductive layer	The sensor has a sensitivity of up to 136.8 kPaˆ(-1) when the pressure applied during compression is < 200Pa	Piezoresistive	[58]
Piezoresistive silicon pressure sensor 33A-015D	Room temperature vulcanized silicone rubber (RTV) 、Nickel、Aluminum	Working pressure 10psi 、Accuracy 0.05%	–	[59]
New stretchable elastic flexible sensor	–	Capable of distinguishing between strains as small as 0.4% and pressure (12Pa)	Capacitive	[60]
Printed capacitive Sensors	Polyethylene terephthalate (PET) fibers	Measures up to 1% strain with a maximum capacitance change of 0.7%.	–	[61]
High-sensitivity polymer piezoelectric thin film sensors LS-YD 001	Polyethylene terephthalate(PET) Substrate、 Upper and lower electrodes、Piezoelectric film layer、Insulation protection layer	Frequency band<100 MHz、Number of bending>1 million times、Piezoelectric constantd33 18–30 pC/N	Piezoelectric	[62]
Composite piezoelectric sensors	Titanate-bismuth ferrite/polyvinylidene fluoride BT-BFO/PVDF nanocomposites	Dielectric constant of 55.71、Electrical loss of 0.03、Signal voltage of 3.35 V at 100 kHz	–	[63]

the indoor light (500Lx,0.9 mW/cm^2, this WS2–0.2/G-WS2/G heterostructure identifies NO_2 gas by the positive change of the photocurrent and the limit of detection (LOD) toward NO_2 is 50 ppb with a response time of 110 s. The sensing performance of the defect-engineered heterostructure remains stable even after 1000 cycles of bending, confirming the application potential as a flexible device, to meet the emerging IoT (Internet of Things) needs [67]. Zhai et al. introduced UiO-66-NH_2 into the flexible sensing layer of nanofibers through electrostatic spinning and aqueous phase synthesis [68]. The capacitive sensor constructed using UiO-66-NH_2 nanofiber membrane and carbon nanotubes have high oporositygood flexibility and fully dispersed adsorption active sites, and exhibits excellent sensitivity and long-term stability for SO_2 gas detection. The flexible sensor maintained 73.33% of sensing performance even after 24 h of water washing, providing a pathway for measuring SO_2 gas. Ramesh et al. synthesized GNPs-CeO_2 nano complexes using cerium oxidemicro flakess immobilized on graphene nanosheets (GNPs) for room temperature detection of CO gas at low concentrations using a solvothermal method and characterized them structurally and morphologically using various analytical techniques [69]. Thchemo resistiveve gas sensors were prepared using drop-cast nanocomposite solutions on cellulose paper as the substrate and silver paste as the electrode. The developed gas sensor has good sensitivity to different concentrations of CO and good selectivity to NO_2, SO_2 NH_3 and CO_2, and it has good stability and repeatability. Wang et al. epitaxially deposited ultrathin nanoporous Bi_2Se_3 layers on BiOCl nanosheets with strong electronic coupling through a topological chemical transformation process, leading to hybridized electronic states and further band gap narrowing [70]. The better surface roughness and film-forming ability even on the inkjet-printed flexible electrodes make this sensor have more excellent room-temperature NO_2 sensing performance.

2.3. Flexible humidity sensors

Flexible humidity sensors are covered with a film made of moisture-sensitive material on a substrate, and when water vapor in the air is adsorbed on the moisture-sensitive film, the resistivity and resistance value of the element changes and humidity can be measured using this property [57]. The sensing mechanism of the flexible humidity sensor can be simply summarized by the chemical formula $H_2O + H_3O^+ = H_3O^+ + H_2O$. The absorption process of water molecules can be divided into two steps, which include both physical and chemical adsorption. First, the first layer of water molecules is aisadsorbed on the surface of the active material by forming chemical bonds with hydroxyl groups or surface defects. When the relative humidity of both increases, more layers of water molecules are formed on the sensitive film by physical adsorption. As water molecules are easily ionized in an electrostatic field, hydronium ions are spontaneously generated and transferred between neighboring water molecules. This changes the nature of the sensitive layer and thus the output of the humidity sensor. Polymer materials such as polystyrene, polyimide, and acetate caseinate can be used to make polymer films for humidity sensors. Flexible humidity sensors have the advantages of low cost, low energy consumption, easy fabrication, and easy integration. Guo et al. developed a self-powered flexible humidity sensor based on a sandwich structure of polyvinyl alcohol (PVA), nano carbon powder (NCP), magnesium chloride (MgCl2), moisture-sensitiveThe dielectric film (PCMF), and copper-aluminum conductive adhesive tape [71]. This unique sandwich structure enables it to easily adsorb and diffuse water molecules in a humid environment, which greatly enhances the response of the flexible humidity sensor to humidity changes. Yao et al. successfully prepared a flexible humidity sensor composed of laser-induced graphene (LIG) and graphene oxide (GO) with good performance [72]. Graphene fork finger electrodes with good conductivity were prepared by laser-induced method. Then, GO dispersion droplets were coated on the forked finger electrode and heated to form a thin film as the sensing material. he sensor has a response/recovery behavior of 2 and 35 s and a humidity range from 11% RH to 97% RH. This humidity sensor not only has high sensitivity but also has a fast response time and wide sensing range. It can perform functions such as breath detection and non-touch switching. The respiration detection function can distinguish different respiratory states such as slow breathing, normal breathing, fast breathing, coughing, and rhinitis. The non-touch switch function can detect the proximity of fingertips to prevent the spread of infectious diseases in some cases.

3. Flexible sensors for mechatronic engineering education

Flexible sensors used in mechanical and electrical engineering education can be classified as physical, chemical, biological, nano, and smart sensing sensors with the specific characteristics shown in Table 3.

3.1. Flexible physical sensors

Flexible physical sensors transform physical signals such as pressure or temperature into electrical signals, and most of the flexible pressure sensors introduced above are within the category of flexible physical sensors. Here we introduce an emerging material, MXenes, with unique properties such as metal-like thermal and electrical conductivity, large surface area, biocompatibility, low toxicity, excellent electrochemical properties, superior chemical stability, antibacterial activity, and hydrophilicity.

Chen et al. developed a flexible biodegradable pressure sensor by sandwiching porous MXenes-impregnated thin paper between a biodegradable polylactic acid (PLA) sheet and a cross-finger electrode-coated PLA sheet, which has a detection limit of 10.2 Pa, a detection range of up to 30 kPa, a response time of 11 ms, and good stability over 10,000 cycles, and this pressure sensor can produce good squeeze corresponding to

Table 3
Characteristics of various types of sensors.

Types of sensor	Materials	Research Contents	Applications	Advantages	References
Flexible Physical Sensors	porous MXenes impregnated thin paper	Development of a flexible biodegradable pressure sensor with porous MXenes impregnated paper sandwiched between a biodegradable polylactic acid (PLA) sheet and a cross-finger electrode coated PLA sheet	Human pulse detection	It has a detection limit of 10.2 Pa, a detection range of up to 30 kPa, a response time of 11 ms, and good stability over 10,000 cycles	[73]
	Sponges	A piezoresistive pressure sensor based on polyurethane (PU) sponge was developed by treating the skeleton of PU sponge	Suitable for human pulse detection	It has a detection limit of 30 μN (pressure of 9 Pa) and a response time of 19 ms， and it remained stable over 5000 cycles	[74]
	paper sandwich and polydimethylsiloxane	A novel structure of an epidermal flexible sensor fabricated by sandwiching paper between polydimethylsiloxane (PDMS) layers was investigated	Wearable electronics, health monitoring, and other fields	It has 56% stretch, 5000 stretch release cycles, 59 ms response, and 88 ms recovery speed	[75]
	Graphene	A convenient and low-cost graphene UV-curable additive manufacturing electronics process was investigated, and the flexible sensors fabricated by this additive manufacturing process of GUDE	Manufacture of advanced electronic devices and other fields	Excellent humidity responsiveness	[76]
Flexible chemical sensors	rGO-CNT、MnO2 nano and Co nano	Design of a self-supporting flexible sensor based on H2O2 sensing and cancer biomarker detection	Detection of cancer biomarkers	Highly selective for H_2O_2 detection， and excellent stability	[77]
	Polyacrylamide and agar	Preparation of a flexible sensor based on polyacrylamide and agar hydrogels with interpenetrating double network structure	Wear on the body to detect various body movements	Exhibits good mechanical and electrochemical properties	[78]
	Highly soluble sodium polyacrylate microgel	Preparation of bionic hydrogels with strain stiffening properties for flexible sensors by regional chain entanglement	Wearable and implantable electronic devices and other areas	Sensors have low Young's modulus (22.61–112.45 kPa), high nominal tensile strength (0.99 MPa) and high sensitivity with a gauge factor of 6.77 at a strain of 300%.	[79]
Flexible biosensors	Carbon Nanofiber	Developed carbon nanofiber wearable biosensor	Sensitive detection of uric acid in artificial urine	Improved microscopic morphology, flexibility and thermal stability of biomass-based carbon nanofibers (CNFs) for flexible sensors	[80]
	P-Mel and PGA	Flexible biosensor for monitoring Shigella fowleri bacilli prepared	Production models for detecting pathogens	Excellent recovery rate, stability	[81]
	rGO	Developed a flexible biosensor	Helps detect cervical cancer early to improve patient recovery	Accurate results	[82]
Flexible Nano sensors	Double-sided heterogeneous top layer、double-layered micro-cone structure ionic gel and single-sided LMS	Proposed full-skin bionic electronic skin driven by artificial intelligence method	Accurate monitoring of different physiological states of the human body	Sensitivity of up to 8053.1 kPa-1 (<1 kPa) and response time of <5.6 ms	[83]
	Electrostatic spun polyvinylidene fluoride (PVDF) nanofibers	A single electrode piezoelectric nanogenerator (SPENG) based sensor was studied	For truly autonomous robots	Self-powered, can sense temperature changes	[84]
	Monocrystalline silicon nanofilms	Combining origami technology with single-crystal silicon nanofilms and fabricated on flexible plates to simulate compound eyes for a silicon-based optoelectronic imaging system	For the image sensor, detecting the image	Small size and simple design	[85]
	Monocrystalline silicon nanofilms	Application of silicon nanofilms to make flexible strain sensors	Widely used in portable wearable electronic devices	High sensitivity 、 good stability、measurement factor of 43 and good repeatability	[86]
	Monocrystalline silicon nanofilms	A high-performance, low-power flexible Schottky diode based on silicon nanofilms for hydrogen sensors was developed	Widely used in portable wearable electronic devices	Power consumption ranges up to milliwatt	[87]
	Silicon Wafers	A method for producing monocrystalline silicon thin-film solar cells using silicon wafers and transferring them to flexible substrates is proposed	Widely used in flexible photovoltaic devices	Flexible and translucent properties	[88]
	Three-dimensional silicon film	A three-dimensional silicon thin-film solar cell designed based on capillary force-driven self-folding	Widely used in flexible photovoltaic devices	Low-cost, simple and effective	[89]
	Si/SiGe	Experiments were conducted to determine the ability of Si/SiGe bilayer nanomembranes with convoluted microtubular structures to serve as a culture substrate for primary cortical neurons	Widely used in cell culture	Size and wall thickness can be precisely controlled	[90]
Flexible Smart Sensors	Gold nanowires	Development of a high cycle, highly compressible, flexible pressure sensor based on gold nanowires	Checking the different physiological signals of the human body	Sensors can detect strains from 0.01% to 350% with a response time of less than 22 ms	[91]
	Graphene oxide and gold metal ions	A method for sensing NO2 by reducing graphene oxide and gold metal ions to the graphene surface was designed	It can be used as a miniature sensor for environmental monitoring	The sensor has a fast response and recovery, with a response rate of 3.2% for 50 ppm NO2 gas	[92]
	Ag	A flexible temperature sensor was studied			[93]

(*continued on next page*)

Table 3 (*continued*)

Types of sensor	Materials	Research Contents	Applications	Advantages	References
			Enables intelligent measurement of human surface temperature	It has an average sensitivity of 2.2×10^{-3} °C^{-1} and good linearity with less than 5% hysteresis	
	–	Integrating 548 flexible sensor arrays into a glove	The array of sensors has a wide range of applications in human prosthetics, intelligent soft robot gripping and human-robot interaction	Costs as low as $10, haptic dataset scales to 135,000 frames and can interact with 26 different objects simultaneously	[94]
	Carbon nanomaterials and piezoresistive materials	A flexible strain sensor made by integrating hybrid carbon nanomaterials and piezoresistive materials using emerging materials smart fabrics and interactive textiles	Greater application in smart wearable devices	The measurement factor of the resulting sensor PET textile (≈7.64) was twice as high as that of the PET film (≈4.57)	[95]
	AgNWs and rGO	A bio-based flexible piezoresistive sensor based on the "dynamic bridging effect" of silver nanowires (AgNWs) to reduced graphene oxide (rGO) was investigated	Detects pulse and body movement by wearing	Detects pulse and body movement by wearing	[96]
	Polypyrrole conductive fabrics	The fabric sensor for posture monitoring was creatively fabricated based on three different polypyrrole conductive fabrics prepared for the needs of flexible wearable products.	Real-time monitoring of human upper limb movement	Flexible operation	[33]
	Borophene	A high-performance gas sensor was manufactured	Enables monitoring of gases such as nitrogen dioxide	Large detection range (200 ppb–100 ppm), fast response (the 30s), fast recovery (200s).	[97]
	ZnO and HMT	It investigated the effect of hexamethylenetetramine (HMT) additive on the humidity sensing performance of zinc oxide coated FBG sensors	It can be used in various industries for the detection of air humidity	The sensor responds 400% better to changes in relative humidity and functions in the 40-80RH% range	[98]

human motion monitoring [73]. Wang Shan and other researchers developed a sponge-based piezoresistive pressure sensor using chitosan (CS) to obtain a positively charged CS/polyurethane (PU) sponge and then dipped and coated with a negatively charged Ti3C2Tx MXene sheet by treating the skeleton of PU sponge, which has a detection limit of 30 μN (pressure of 9 Pa) and a response time of 19 ms. A researcher developed a sponge-based piezoresistive pressure sensor using chitosan (CS) to obtain a positively charged CS/polyurethane (PU) sponge and then dipped and coated with a negatively charged Ti3C2Tx MXene sheet by treating the skeleton of PU sponge, which has a detection limit of 30 μN (pressure of 9 Pa) and a response time of 19 ms. It remained stable over 5000 cycles, and the piezoresistive response was stable at 85% at a pressure strain of 245.7 kPa. The sensor also exhibited stable performance after 1 h of washing in water. This sensor has practical applications for human pulse detection, among others [74].

Paul et al. investigated a novel structure of an epidermal flexible sensor, fabricated by sandwiching a paper sandwich between layers of polydimethylsiloxane (PDMS), which also uses physical properties to deliver stimuli that are converted into electrical signals. The sensor can sense multimodal mechanical stimuli such as stretching, bending, tapping, and twisting. The sensor senses changes in human form and has a large stretch of 56%, a remarkable durability of 5000 stretch-release cycles, and the time required for the sensor to accept the stimulus and respond immediately is 59 ms, the stimulus stops and the time required for the sensor to recover to its initial state is 88 ms. This novel, simpscalableable physically flexible sensor will have applications in wearable electronics, health monitoring, and other fields [75]. Zhang et al. investigated a convenient and low-cost graphene UV-curable additive manufacturing electronics process, and the flexible sensors fabricated by this additive manufacturing process, Graphene UV-Cured Direct Electronic (GUDE), saved raw material cost [76]. In addition, the large specific surface area and hydrophobic properties of graphene enhance the adsorption ability of the GUDEGUDE-printed face microstructure, resulting in the fabrication of flexible moisture-sensitive sensors with excellent humidity response. The GUDE process, as a fast and direct additive manufacturing process, holds great promise for the preparation of flexible, high-performance electrical sensors and has great potential for the fabrication of advanced electronic devices.

3.2. *Flexible chemical sensors*

Flexible chemical sensors use chemical/catalytic reactions of substances with sensors to transform them into electrical signals. Meng et al. designed a self-supporting flexible sensor based on H_2O_2 sensing and cancer biomarker detection. Reduced graphene oxide-carbon nanotube (rGO-CNT) flexible hybrid films were first developed, and then MnO_2 nano and Co nano were anchored on rGO-CNT by electrodeposition. The uniformly distributed MnO_2 on rGO-CNT exhibited excellent catalytic properties for H_2O_2, and the role of Co was to improve the electrical conductivity of the films and to provide a second active substance for H_2O_2 sensing, The sensor is highly selective for H_2O_2 detection and can monitor the excess release of H_2O_2 from hepatocellular carcinoma cells. The sensor is based on rGO-CNT as the substrate material, which provides many suitable active sites for the in situ growth of the active material, which enables rGO-CNT to form a strong bond with MnO_2–Co. MnO_2 itself has excellent catalytic properties for H_2O_2, and the nanoflower-like 3D porous morphology provides more active sites for MnO_2 to catalyze H_2O_2. The small size of CoNPs not only solves the conductivity problem of MnO_2 but also significantly improves the catalytic activity and stability of toof$_2$O$_2$. the chemical reaction between MnO_2 and H_2O_2 after binding, which results in the output, which provided a new way for cancer biomarker detection with high stability [77].

Ma et al. designed a hydrogel with an interpenetrating double network structure based on polyacrylamide and agar and formed a continuous ion conduction path by doping with a high concentration of LiCl as the conductive material, and the flexible sensor prepared by this hydrogel can adapt to the low-temperature environment and exhibit good mechanical and electrochemical properties [78]. The sensor can be worn on the human body to detect various human movements. Other than that this hydrogel has high thermal sensitivity and the temperature coefficient of resistance (TCR) is used to evaluate the sensitivity of the thermal response and is defined by equation (1).

$$TCR = \frac{1}{R_0} \times \frac{\Delta R}{\Delta T} \tag{1b}$$

In the equation, R_0 is the original resistance, ΔR is the change in resistance with temperature, and ΔT is the temperature change. This hydrogel showed a highly linear thermal response during heating and cooling in the experiment. the TCR value achieved a transient electrical response to temperature, and the researchers used this property of the hydrogel to make a sensor for temperature measurement.

Cui et al. prepared bionic hydrogels with strain-stiffening properties by regional chain entanglement, which was achieved by embedding highly soluble sodium polyacrylate microgels as densely entangled microregions in a soft polyacrylamide matrix [79]. In addition, the sodium polyacrylate microgels can release Na + ions, which can impart electrical signals to the hydrogel. The resulting sensors have low Young's modulus (22.61–112.45 kPa), high nominal tensile strength (0.99 MPa), and high sensitivity with a gauge factor of 6.77 at a strain of 300%. This kind of flexible sensor has great potential in the field of wearable and implantable electronic devices.

3.3. Flexible biosensors

Biosensor technology is developed based on life sciences and information science and is the result of the collision and intermingling of biological, physical, and electronic disciplines. Biosensor is mainly composed of two parts: molecular recognition and transducer, which is an analysis and detection device made of immobilized sensitive material as a sensitive element in organic combination with the appropriate physical or chemical transducer. The effective information such as enzymes and DNA of the target object is extracted and analyzed, and then the extracted effective information is converted into an electrical signal that can be output through a transducer. Compared with the traditional detector, the bio-flexible sensor has the advantages of more miniaturization, more targeted detection, more accurate detection results, and higher sensitivity.

Wang et al. introduced carbon nanofibers to develop a wearable biosensor for the sensitive detection of uric acid in artificial urine. The introduction of phosphorylated lignin effectively increased the molecular interactions in the electrostatic spinning system and improved the microscopic morphology of biomass-based carbon nanofibers (CNFs), flexibility, and thermal stability of the flexible sensor. To verify the reusability of this sensor, CV characterization of two devices in 2 m K_3 Fel at 20 mV/S for 3 cycles. The resulting voltammogram of our system has the expected redox peak with good repeatability. It provides a more convenient method for the detection of uric acid in urine in the future [80].

Ali et al. prepared a flexible biosensor for the monitoring of Shigella fowleri bacilli. To prepare the biosensor, detection probes (capture probes) were immobilized on the surface of poly melamine (P-Mel) and poly glutamic acid (PGA), and Anthraquinone-2-sulfonic acid monohydrate sodium salt (AQMS) was used as a signal indicator for the detection of *Shigella flexneri* [81]. The developed flexible biosensor showed excellent recovery and stability in the detection of *Shigella flexneri* in food samples. Therefore, this biosensor was used as a production model for the detection of other pathogens. Human papillomavirus 16 (HPV16) is a high-risk type that can be infected through sexual transmission, close contact, and indirect contact. It can cause malignant tumors such as genital and cervical cancers. Early detection and treatment are needed. Rawat Reema et al. developed a flexible biosensor that can help in the early detection of cervical cantor to improve patient healing. Rawat et al. investigated an electrochemical biosensor based on reduced graphene oxide (rGO)/DNA hybrid modified flexible carbon screen printed electrode (CSPE) for HPV16 detection. It was coated with rGO and then immobilized with probe DNA (PDNA). The nanostructures were characterized by UV–visible spectroscopy, Fourier transforms infrared spectroscopy, Raman spectroscopy, and X-ray diffraction [82]. Also involving flexible biosensors, we need to discuss the relationship between the sensory material and the contact area of the test object. The sensory material is the bioactive material used to identify the target substance, such as enzymes, antibodies, nucleic acids, cells, etc. The test object is the molecule or substance to be detected, such as blood glucose, drugs, pathogens, etc. The contact area is the effective contact area between the sensory material and the test object, which determines how much of the target signal the sensor can capture. In general, the larger the contact area between the sensory material and the test object, the higher the sensitivity of the sensor, as more target molecules can be identified and converted into detectable signals. However, the contact area should not be too large, as this may lead to non-specific adsorption or the influence of interfering substances, reducing the selectivity and stability of the sensor. Therefore, when designing biosensors, it is necessary to select a suitable contact area for different sensory materials and test objects and to use some methods to optimize the contact efficiency, such as surface modification, nanostructuring, microfluidics, etc.

3.4. Flexible nanosensors

In contemporary society, the rapid development of science and technology, in the process of development requires materials must be ultra-microscopic, intelligent, highly integrated components, and have ultra-fast transmission properties, this situation also provides a broad space for the application of nanomaterials. At this time, the use of nanomaterials and nanotechnology to create new flexible sensors has gradually entered the field of vision. The size of sensors made by applying nanotechnology is smaller than normal sensors, and the working accuracy has been improved. Nanotechnology exists above the atomic scale, and the sensors made by it will push the level of sensor development and expand the application field of sensors. Nanomaterials have properties such as surface and interface effects, small size effects, quantum size effects, and macroscopic quantum tunneling effects, which make them useful in the field of sensors. At this stage, there are two methods to make nanosensors: firstly, using nanostructured materials to fabricate sensors, and secondly, sensors made by manipulating single or multiple nano atoms into the desired structure in an orderly manner. Compared with conventional sensors, nanosensors can take full advantage of the properties of nanomaterials because they can be created from a microscopic perspective, and thus nanomaterials are characterized by high density, low power consumption, low cost, and multifunctional integration.

At present, researchers have developed a flexible wearable bionic haptic sensor with high sensitivity and stability, the artificial bionic electronic skin, using carbon nanotubes and nanofilm technology, through which different physiological states of the human body can be accurately monitored. After the popularity of artificial bionic skin, Niu et al. thought that the traditional electronic skin would lack the thinking and judging ability of the human brain, which is far from the intelligent modern society and cannot keep up with the intelligent era, so they proposed a whole-skin bionic electronic skin driven by using artificial intelligence method [83]. The e-skin simulates the human villi and epidermis with a double-sided heterogeneous top layer, a double-layered microcone structured ionic gel middle layer simulating the skin dermis, and a single-sided LMS bottom layer simulating the subcutaneous skin tissue. And because of its unique nanostructure, it exhibits a sensitivity of up to 8053.1 kPa^{-1} (<1 kPa) and a response time of <5.6 ms, realizing the evolution of tactile perception to advanced intelligent haptic cognition, this electronic skin is a new development and breakthrough. In turn, Wang et al. investigated a sensor based on a single-electrode piezoelectric nano-generator (SPENG), sensors made of electrostatically spun polyvinylidene fluoride (PVDF) nanofibers, which solves the drawback that the electronic skin based on a single-electrode triboelectric nano-generator (STENG) cannot sense temperature changes. The single-electrode piezoelectric nanogenerator is a device that converts mechanical energy into electrical energy by the piezoelectric effect and electrostatic induction. When a periodic force or vibration is applied externally, the piezoelectric film will deform and polarize, inducing a certain amount of free carriers on the working electrode, which will flow to the ground through the external load and form a displacement current, and when the force or vibration disappears, the piezoelectric film returns to its original state, the free carriers return to the working electrode, and the displacement current reverses. Through the reciprocal process, the single-electrode piezoelectric nanogenerator converts mechanical energy into alternating displacement current continuously and drives various micro- or nano-scale devices. The new sensor uses a capacitor instead of the ground wire of the STENG enabling it to be used in truly autonomous robots [84]. In addition to this, flexible nanosensors have many application scenarios in different directions. Zhang et al. combined origami technology with single-crystal silicon nanofilms and fabricated them on flexible plates to simulate compound eyes for a silicon optoelectronic device-based electronic imaging system. Their combination of tiny size and simplicity of design resulted in a practical technology for integration with conventional electronic devices [85]. This is a unique image sensor formed by using single-crystal silicon nanostructures for flexible sensors, and this unique approach is expected to gain popularity. Also Won et al. applied silicon nanofilms to make a flexible strain sensor, which has high sensitivity and good stability, good repeatability with a measurement factor of 43 [86]. Cho et al. developed a high-performance, low-power flexible Schottky diode based on silicon nanofilms for hydrogen sensors. This sensor was made by releasing silicon nanofilms and transferring them onto a plastic substrate, followed by selective deposition of palladium (Pd) and aluminum (Al) as sensing materials and electrodes to make a hydrogen sensor. The power consumption of this sensor can range up to milliwatt, leading to a wide range of applications for this sensor in portable wearable electronic devices [87]. Also, Yoon et al. proposed a method to produce single-crystal silicon thin-film solar cells using silicon wafers and transferring them to flexible substrates to achieve their flexible and translucent properties [88]. Guo et al. also designed a three-dimensional silicon thin-film solar cell based on capillary force-driven self-folding [89]. Both of these studies have led to the wide application of flexible nanosensors in flexible photovoltaic devices as well. Also, flexible nanosensors are widely utilized in cell culture, and Yu et al. conducted experiments to determine that Si/SiGe bilayer nanomembranes with a convoluted microtubule structure can be a culture substrate for primary cortical neurons [90].

3.5. Flexible smart sensors

With the development of the Internet of Things, artificial intelligence, and other fields in contemporary society, people's requirements for sensors are becoming higher and higher, and intelligence has become the goal to pursue. In contemporary society, if only a single sensor cannot meet the needs of the modern information age, intelligence becomes the future development trend of sensor technology. Intelligent sensors refer to intelligent sensing devices that can sense, collect and make independent judgments and analyses as well as the processing of the external environment. Smart sensors are multi-component integrated circuits with information acquisition, processing, exchange, storage, and transmission functions. Integrated sensors, communication modules, microprocessors, drivers and interfaces, and software algorithms in one system-level device. With diagnostic and self-compensation capabilities, as well as sensory integration and flexible communication capabilities. Intelligent sensing systems not only have the general function of collecting signals but also can connect sensors to design integrated circuits. Afterward, the use of neural network algorithms to process the collected signals, complete the intelligent analysis and processing of data eventually passed to the terminal display, intelligent sensors, and general sensors compared with the self-test, self-calibration, and self-diagnosis, sensory fusion, high accuracy, high reliability, cost-effective, functional diversity, and other characteristics, the current trend of intelligent sensors in the flexible sensors also has a greater development.

In recent years, people's concern for health has gradually increased, and therefore wearable flexible smart sensors have received widespread attention. Shu et al. successfully developed a high-circulation, highly compressible flexible pressure sensor based on gold nanowires [91]. The gold nanowires are up to 2 nm thick and 10 μm long, and the sensors can detect strains from 0.01% to 350% with a response time of less than 22 ms. The sensor can check different physiological signals of the human body, including arm muscle movement, cheek muscle movement, vocal cord movement, gesture changes, pulse monitoring, and so on, and this smart sensor can perform facial recognition and voice recognition. Meanwhile, Rattan et al. designed a method to achieve sensing of NO_2 by reducing graphene oxide and gold metal ions to the surface of graphene, which has a fast response and recovery rate of 3.2% for 50 ppm NO_2 gas and can be used as a microsensor for environmental monitoring [92]. Dankoco et al. I investigated a flexible temperature sensor to achieve intelligent measurement of human surface temperature, the thermistor of the sensor was formed by silver deposited on a polyimide substrate with an average sensitivity of $2.2 \times 10^{-3\circ}\mathrm{C}^{-1}$ and good linearity with less than 5% hysteresis [93]. Subramanian has integrated an array of 548 flexible sensors on a glove to analyze and process the data through deep convolutional neural network algorithms on the signal to achieve object recognition [94]. This array of sensors has a wide scope of application in the human prosthesis, intelligent soft robot gripping, and human-computer interaction. Costing as little as $10, the haptic dataset scales with 135,000 frames and can interact with 26 different objects simultaneously. Fabric substrates are also being used instead of traditional substrates to make sensors more like real clothing to improve people's comfort, allowing greater application of sensors in smart wearable devices. Taemin et al. used emerging materials smart fabrics and interactive textiles to make a flexible strain sensor by integrating hybrid carbon nanomaterials and piezoresistive materials [95]. The measurement factor of the resulting sensor PET textile (≈7.64) is twice as high as that of PET film (≈4.57) and can be used with a wireless transmitter to achieve wireless sensing. In their study, Wei et al. Wei et al. investigated a bio-based flexible piezoresistive sensor based on the "dynamic bridging effect" of silver nanowires (AgNWs) and reduced graphene oxide (rGO), which has high sensitivity (5.8 kPa-1) and excellent stability (>10,000 add/drop cycles), and has great potential for wearable electronics or simulating human motion has great potential [96]. Zhang et al. also creatively fabricated a posture monitoring fabric sensor based on three different polypyrrole conductive fabrics prepared for the needs of flexible wearable products, which can achieve real-time monitoring of human upper limb movement and can show the limb's bending, rotation and some other compound movements [33]. In addition, with the development of flexible smart sensors, a large number of sensors are used in the field of environmental monitoring. Chuang et al. fabricated a high-performance gas sensor [97], which can achieve the monitoring of gases such as nitrogen dioxide by the characteristics of borophene, with a large detection range (200 ppb–100 ppm), rapid response (the 30s), and fast recovery (200s), and the monitoring of the environment can achieve real-time results. Riza et al. investigated the effect of hexamethylenetetramine (HMT) additive on the humidity sensing performance of a zinc oxide coated FBG sensor. The sensor showed a 400% improvement in response to changes in relative humidity with a functional range of 40–80 RH% and its application in various industries for the detection of air humidity [98].

4. Discussion

The gradual arrival of the flexible era in contemporary society has become a consensus among contemporary scientists [83], and flexible sensors as an important component of flexible electronic devices are moving from basic research to industrialization. Flexible sensors are the basis for the realization of haptics and the manufacture of electronic skin, scientists use flexible sensors and general conductive materials can transform the external situation into electrical signals, which include force, heat, light signals, etc. The converted electrical signals are transmitted to a computer for processing and can even be made into transparent, extendable, flexible, freely foldable, and wearable electronic skin [99] to implement accurate detection of all relevant indicators of the human body. Flexible sensors are sensors made of flexible materials that are flexible, extensible, and even freely bendable or even foldable, and have flexible and diverse structural forms that can be arbitrarily arranged according to the requirements of the measurement conditions and can be very convenient for the detection of complex measurements. These advantages of flexible sensors allow them to have excellent application scenarios, such as medical electronics, environmental monitoring, and wearable fields. In the field of environmental monitoring, scientists have made flexible sensors that can be placed in devices to monitor air quality; in wearable, flexible electronic products can measure real-time human heartbeat, breathing, and various amplitudes of motion [100]. In addition to this, I think that flexible sensors will also excel in teaching electromechanics. Just as in the current classroom we usually conduct demonstration experiments in physical chemistry classroom teaching [101], we can use flexible sensors in the demonstration teaching of electromechanical courses and use them to improve the effectiveness of classroom teaching in electromechanical majors.

The electromechanical classroom as a standard engineering classroom is theoretical, logical, and systematic, and the basic concepts in the course of study are obscure and difficult to understand, with many formulas, and students usually feel that it is difficult and not easy to master, and over time students' interest will be greatly affected. Therefore, at this time, we can make various types of flexible sensors, integrate the flexible sensors into the classroom, do some simple demonstration experiments to show the effect of flexible sensors, and then explain the operation mechanism on this basis, combining theory and experiment to improve students' participation and interest in learning through classroom demonstrations. We must focus on students' independent learning ability and mobilize their enthusiasm in the process of classroom teaching. Independent learning ability is the performance of students who are responsible for themselves in the process of learning, which is self-directed, self-motivated, and self-monitored learning, and it is a focus that must be noted in higher education at present, which has an important role in developing students' abilities. The demonstration experiments are a way to activate students' self-directed learning ability, and such experiments are not just for students to watch, but also for them to participate in them personally. Using flexible sensors in the electromechanical classroom can improve student learning efficiency, stimulate student interest, increase participation, and turn the classroom into a quality classroom.

4.1. Benefits

Flexible sensors have significant advantages over general sensors, with good flexibility, ductility, bendability, etc. And due to the flexibility of materials and structures, flexible sensors can also be arranged differently depending on the specific scenario. In terms of sensing mechanism, we generally classify flexible sensors as flexible resistive sensors, flexible capacitive sensors, flexible piezoelectric sensors and flexible inductive sensors. Flexible resistive sensors are mainly used in contemporary society for smart wearables, electronic skin, health monitoring, etc. [102], traditional resistive sensors have the characteristics of large weight and narrow application range, often not fully suitable for signal transmission and reception scenarios, which leads to the inability to meet the application of wearable scenarios, while flexible resistive sensors have excellent flexibility, biocompatibility, this The volume and mass of the sensor is small to be able to stretch, compress, bend arbitrarily close to the surface of the body, so the traditional resistive sensors are widely used. Flexible capacitive sensors generally use a device based on the principle of parallel plate capacitance, by changing the distance between the flat capacitors to change the capacitance of the sensor. Flexible capacitive sensors also have the advantages of being less affected by temperature, accurate measurement, clear discrimination, response sensitivity, simple structure,e, and wide application compared to resistive sensors, and therefore are also widely interested by scientists [103]. Flexible piezoelectric sensors have light mass, thin thickness, good tensile properties, and flexibility and are commonly used to measure as well as quantify electrical signals due to human activities [104]. In contrast, flexible inductive sensors are also widely developed because of their simple structure, reliability, high sensitivity, accurate measurement, and high output power. In conclusion, the key to flexible sensors compared to ordinary sensors is more flexibility, which makes the range of application of sensors has been greatly enhanced, sensors are more suitable for a variety of places, more flexible in use, and more convenient for use in classroom experiments.

4.2. Challenges

The advantages of flexible sensors are many and the development trend is rapid, and they are now used in all major industries, but there are still many challenges to be faced in their development. First of all, when we use flexible sensors to detect human vital signs, we need not only the accuracy of signal acquisition but also to ensure that the human body can achieve a comfortable level during the use of the sensor, so we must require the manufacturing process of the sensor to minimize the size of the sensor and improve its biocompatibility. Improving device comfort and accuracy are the most obvious challenges in current flexible wearable sensors [105]. Also, in flexible sensors with high sensitivity and reliability, the design and fabrication of the sensor and its integration with the flexible network is a challenge. In today's use of society, flexible sensors are used with commercial sensors, which leads to poor reliability of the sensors, so we need to go further in the study of sensors to investigate the material issues to improve the performance of the sensors [106]. In addition, in the practical application of flexible sensors, the problem of energy consumption should not be ignored, so the signing process of the sensor needs to make the sensor has a low voltage and resistance, which will achieve the role of reducing energy consumption [107]. Self-driving devices in contemporary society will solve this challenge, not only by enabling flexible sensors to obtain high sensitivity but also by enabling them to provide their power supply, self-powered devices show great potential in this challenge [108]. Finally, in the contemporary era, the level of intelligence is gradually increasing, the development of wireless transmission technology and the combination of flexible sensors with it is also a major challenge, and in the future, then, remote measurement and control of sensors can be achieved through wireless technology [109]. With the development of science and technology, flexible sensors will encounter many challenges but will also show a broader application prospect.

4.3. Prospects

Flexible sensors are currently attracting widespread attention from the scientific and industrial communities, and substantial applications have been launched in numerous fields of application. In the medical field, flexible sensors are made into electronic skins capable of simultaneously sensing external stimuli such as force, temperature, and humidity for real-time monitoring of patient conditions [109]. In smart wearable devices, flexible sensors are made into bracelets and other equipment for motion detection [110]. In the field of robotics, flexible sensors can make robots closer to real humans. In the field of VR devices and metaverse flexible smart sensor products have been able to provide data connectivity services for virtual interactive experiences, which can be applied to a variety of virtual reality scenarios [111]. In addition to this we believe that in the university education classroom, flexible sensors can also play the role of classroom demonstration, which is used to improve student interest and classroom teaching efficiency.

As an engineering major, the knowledge is more complex and the concepts are more abstract and difficult to understand, the implementation of classroom demonstration can play a positive role, students will become active knowledge explorers from passive knowledge receivers, and students' independent learning ability will be enhanced and innovative thinking will be exercised. Sung et al. describe how the MIThril mobile IT education platform allows for rapid prototyping of wireless mobile multi-user applications in a classroom environment that can enhance the way people learn and interact with each other, and its application at MIT significantly increased student motivation and improved teaching effectiveness [112]. Sower et al. argue that students in business schools lack practical experience and understanding of the concepts, Sam Houston State University introduced a desktop flexible manufacturing unit for a quality assurance management course, and students' understanding of group technology, robotics, and flexible manufacturing improved significantly, with increased interest and positive feedback [113]. Pietroszek et al. studied a virtual reality remote classroom participation system that represented a face-to-face classroom in virtual reality, combining online education with face-to-face education, students felt more natural and had increased interest in the classroom [114]. Flexible sensor devices can also be fully utilized in the electromechanical classroom to improve classroom efficiency. Electronic skin made of flexible sensors can be used by students independently to understand the specific working principle and application occasions and potential, robots with flexible sensors can interact with students, allowing students to explore the principle of flexible sensors through robots, and VR devices carrying flexible sensors, students can go deeper into flexible sensors in VR devices. Real contained ct, the real experience can make students more active and active to learn knowledge.

5. Conclusion

Flexible sensors as necessary support for flexible electronics technology are widely used in all areas of life, metaverse interaction between the real virtual world, the medical field of bionic robots and electronic skin, etc., flexible sensors are playing an indispensable role, and today's society has entered the flexible era. Flexible sensors include three types flexible pressure sensors, flexible gas sensors, and flexible humidity sensors. Among them, flexible sensors that can be used in mechatronics education can be considered separately from physical, chemical, biological, nano, intelligent sensing, etc. These sensors in all can be present in the classroom of mechatronics engineering and used to improve the effectiveness of classroom teaching. The key to flexible sensors is flexibility and a wider range of applications. However, the size, energy consumption, and reliability of flexible sensors still face great challenges, and to a certain extent, limit the development of flexible sensors. Flexible sensors have been substantially applied in the field of smart wearable devices, robotics and VR devices, and metaverse, and these directions will also apply to classroom teaching. Stimulating students' curiosity, nurturing students' independent learning ability, and increasing students' participation to improve classroom efficiency, flexible sensors are bound to flourish in the future to appear in mechatronics education.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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