Research Article

Fabrication of Nanofiber Flexible Pressure Sensor and Application in Human Motion Monitoring

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Nowadays, people are increasingly concerned about body mass index and monitoring human movement has become a necessity for most people, and the nano/fiber flexible pressure sensor fully meets people’s needs, so the research on a nano/fiber flexible pressure sensor is very meaningful. The purpose of this article is to study a sensor with high sensitivity of the nano/fiber material of PVDF thin films. And this article conducts experiments through the prepared pressure sensor and other sensors, which test the three movements of humans taking off, squatting, and running. This article calculates the correct recognition rate, false-negative rate, and false-positive rate and then compares them. The experimental data show that the correct recognition rate of PVDF thin-film nanomaterials is as high as 90%, and the recognition rate of non-nanomaterial pressure sensors is even less than 80%. Nanomaterial pressure sensors will have more room for development.

1. Introduction

With the steady increase in the standard of living, the disadvantage of lacking of exercise is that the human body breathes in too much energy on a daily basis, which leads to some diseases, these diseases harm people’s bodies without knowing it, so people must pay attention to the health status of the body, and portable health monitoring equipment in this demand has appeared. Because of its sensitivity, it has attracted people’s attention and has become a research hotspot. The daily activities of the human body are diverse, so how to identify these movements is the object of many researchers.

In today’s society, people are becoming more active as the pace of life accelerates and there is less time to exercise; it is very necessary to monitor the status of the daily exercise of the human body. Then, flexible pressure sensors that can monitor these movements are very important. It allows people to reasonably arrange their daily activities and improves people’s health. However, in recent years, scholars have studied the application of various pressure sensors and only use nanofiber materials. Therefore, it is very important to study flexible pressure sensors of new material nanofibers.

This article describes the advantages of PVDF films and some fabrication methods. However, this article is mainly experimental, using three sensors (including non-nanofibers) for experimental comparison, which are then compared with them using the pressure sensor of this experiment. The innovations of the article are as follows: (1) this article studies the preparation of PVDF, a nanomaterial, and compares various fabrication methods. (2) It designs and implements a prototype system of human motion state monitoring. In this article, experimental tests were performed on 12 people using three pressure sensors, and the article then presents a comparative analysis. (3) In this experiment, the sensor of nanomaterials and non-nanomaterials was compared to make the experiment more convincing.

2. Related Work

As more people are concerned about their health, detecting human movement with flexible pressure sensors has become
Flexible pressure sensors are mainly divided into four types (Figure 1) [11]. The following describes these sensing principles in detail.

The capacitance value $C$ of the capacitive pressure sensor is

$$C = \varepsilon_0 \varepsilon_r \frac{D}{s}.$$  

Here, $\varepsilon_0$ is the dielectric constant of the vacuum, $\varepsilon_r$ is the relative permittivity, $D$ is the effective electrode area, and $s$ is the spacing between the panels. A resistance pressure transmitter converts pressure changes to other changes. Resistance determination is given as

$$R = \rho \frac{l}{S}.$$  

Here, $\rho$ indicates resistivity, $l$ indicates the length, and $S$ indicates the cross-sectional area. The basic principle of piezoelectric pressure sensor induction is the piezoelectric effect of electrical materials. The principle of the triboelectric pressure sensor is triboelectric charging. They are all mainly studied today, nothing more than optimizing the material, and its sensitivity is expressed as

$$S = \delta \left( \frac{\Delta Y}{Y_0} \right) \frac{1}{\delta P}.$$  

Here, $S$ represents the sensitivity, $Y_0$ indicates the value of the electrical output signal, $\Delta Y$ represents the variation in electrical signal, and $P$ represents the pressure on the sensor.

### 3. Fabrication of Nanofiber Flexible Pressure Sensors

#### 3.1. Nanofibers

Nanofibers refer to linear materials with a diameter of nanometers and a length of a certain aspect ratio [7]. Also, fibers that are modified by filling ordinary fibers with nanoparticles are also referred to as nanofibers. As far as we know, the theory uses nanomaterials whose physical and chemical properties will vary in length. This is due to the lack of coordination on the surface of adjacent atoms, and the surface energy increases instability and easily combines with other atoms.

#### 3.2. Flexible Pressure Sensor

The flexible pressure sensor is based on the traditional rigid pressure sensor, which uses a flexible material as a substrate to sense the surface of an object to fit with a flexible surface such as fabric or even skin [8]. Based on these unique advantages, it has gradually shown function for portable electronic applications, intelligent robots, biomedical devices, and the preparation of dexterous manipulators. It makes the research of the flexible pressure sensor attract more and more attention [9, 10]. With the advancement of scientific research and the demand for production, flexible pressure sensing devices can not only sense changes in pressure acting on their surface, but also sense the stretching of the device itself. At present, the flexible materials used to fabricate flexible pressure sensors are mainly polymers. People are increasingly aware of the environment and the economy, and concepts such as low cost, environmental friendliness, wearability, and convenience have been continuously proposed. The pressure sensors based on paper, fabric, etc. as flexible substrates attract attention because of their eco-friendliness.
process from 436 nanometers, 365 nanometers, and 246 nanometers. It is now 193 nanometers, and the dimensional accuracy that it can achieve so far is 130 nanometers [16]. The choice of photoresist is also divided into positive photoresist and negative photoresist. Negative photoresist is to copy the pattern opposite to the pattern on the mask to the surface of the silicon wafer; positive photoresist is to copy the same pattern as the pattern on the mask to the surface of the silicon wafer. Positive photoresist can save the area that is not protected by the mask, and negative photoresist can protect the unexposed area. Positive photoresist is decomposed under the action of ultraviolet light and can be dissolved by the developer. Under the action of ultraviolet light, the strength of negative photoresist is enhanced so that it is insoluble in organic solvents. In addition, some experimental equipment such as data collectors and microscopes should be prepared.

4. Experiment of the Flexible Sensor on the Basis of PVDF Nanofiber Material for Human Movement Monitoring

4.1. Human Body Monitoring Process. In this study, the nanofiber flexible pressure sensor monitors human motion, which is mainly determined based on acceleration. It then follows the research idea of statistical pattern recognition. The general process of human motion monitoring is shown in Figure 2 [17].

This article will not explain too much about data collection, data preprocessing, feature extraction, and selection. This article mainly supplements the method of classification and recognition, which classifies the objects to be recognized. There are many ways to solve the classification problem. This article mainly explains the decision tree method and Naive Bayes, and other methods will not be explained.

The decision tree is mainly used for classification and prediction, and it finds classification rules in a set of data without rules. It is a tree structure where each internal node represents a test on an attribute, each branch represents a test output, and each leaf node represents a category. Supposing $A$ represents a set of $a$ training samples, and there are $n$ classes $C_1, ..., C_n$ in total. $a_i$ indicates the number of samples in $C_i$, $p_i$ stands for the probability of the sample, which is part of the $C_i$, and $a_i/a$ is used to estimate the information entropy, which is

$$I(a_1, ..., a_n) = -\sum_{i=1}^{n} p_i \log_2 (p_i).$$

**Table 1: Different strengths and weaknesses of PVDF film preparation methods.**

| Method                        | Advantage                      | Shortcoming                     |
|-------------------------------|--------------------------------|---------------------------------|
| Elyncal spin coating          | The process is simple and mature, and the film is thin | Laboratory research, difficult to batch production |
| Solution casting method       | Easy to operate                | The film is thicker; it is easy to produce defects |
| Vacuum thermal evaporation method | Film uniformity is better      | Equipment requires a high requirements |
| Immersion portram             | Thin film is thin; easy to induce orientation | Film thickness is difficult to control |
| Thermocompression method      | Easy to film formation         | High experimental cost          |

Figure 1: Principles of different forms of pressure sensors.
As can be seen from the above formula, it is assumed that attribute $S$ is selected as the test attribute. Sample set $A$ can be divided into $m$ subsets, $\{A_1, ..., A_m\}$, and if $a_{ij}$ indicates the sample size of the $C_j$ class on a subset $A_j$, the information entropy of the subset divided by the test attribute $S$ can be expressed as

$$E(S) = \frac{1}{m} \sum_{i=1}^{m} a_{ij} + \cdots + a_{ij} I(a_{ij}, ..., a_{ij}).$$ \hspace{1cm} (5)

Here,

$$I(a_{ij}, ..., a_{ij}) = -\sum_{i=1}^{n} p_{ij} \log_2(p_{ij}).$$ \hspace{1cm} (6)

Here, $p_{ij} = a_{ij}/|A_j|$, and finally, the information gain entropy of $S$ is obtained by the difference between these two formulas.

The Bayesian classification algorithm is a method that uses Bayes’ theorem to calculate the probability of a sample. Bayes’ theorem is shown in the following formula:

$$p(X_i | Y) = \frac{p(Y | X_i) p(X_i)}{p(Y)}.$$ \hspace{1cm} (7)

It represents the probability that $Y$ belongs to class $X_i$. Because the distribution function $p(Y)$ is the same for different samples $Y$, the size of $p(Y | X_i) p(X_i)$ is calculated. The likelihood function derived from the conditional density probability $p(Y | X_i)$ is

$$p(Y | X_i) = \prod_{k=1}^{n} p(y_k | X_i).$$ \hspace{1cm} (8)

Here, $y_k$ represents the components of $n$-dimensional feature vector $Y$.

4.2. Placement of Sensor Locations. People have different accelerations in different positions of the body after performing an action. The sensor is placed on the chest, and the obtained acceleration data are stable and easy to carry. A triaxial accelerometer is placed at the chest position of the human body. The three axes of the sensor are $X$, $Y$, and $Z$ axes, as shown in Figure 3 \cite{18}.

On the ground, the gravitational component of the acceleration sensor is always constant; that is, it always points vertically downward on the ground. The vector synthesis is shown in Figure 4 \cite{19}.

Among them,

$$g = (b_x, b_y, b_z).$$ \hspace{1cm} (9)

When the person moves, the values on the accelerometer’s three axes are the sum of the acceleration component and the gravity component that arise when the human body moves along each axis. The component of the gravitational direction does not affect our research; therefore, the component of the vertical direction in this chapter includes the gravitational component and the human body acceleration component.

Let $(b_x(t), b_y(t), b_z(t))$ denote the three-axis acceleration vector of the sensor at time $t$. In order to find the vertical component of the acceleration signal in human motion, it is first necessary to calculate the gravitational component when the sensor is stationary. This gravity component and $(b_x(t), b_y(t), b_z(t))$ are then used to estimate the actual vertical component. In order to determine whether the sensor is in a stationary state, three parameters need to be
acceleration. In formula (12), \( \bar{a}_x \) is the average value of acceleration signal in the vertical orientation of the human body and interval between two adjacent peaks and troughs are used as characteristic values to build a decision tree for three actions: running, jumping, and squatting. The identification process is shown in Figure 5 [20].

After knowing the specific process of the sensor, it is necessary to understand the difference between the different responses of the sensor after each action. First, the vertical component analysis of the sensor is used to distinguish the two actions of “jumping” and “squatting” in place. In Figure 6, schematic diagrams represent the time-dependent changes in the vertical component of acceleration for a jumping motion and a squatting motion. The abscissa axis represents time \( t \) (unit is s), and the ordinate axis represents the vertical component of acceleration \( y \) (unit is \( \text{m/s}^2 \)).

Compared with jumping and squatting, the schematic diagram of running is relatively more obvious, showing a waveform, as shown in Figure 7 [21].

So now the distribution diagrams of the three states are clear, and then, it can start the experiment.

4.3. Comprehensive Experiments. The experimenters consisted of 6 females and 6 males, a total of 12 people, aged 20–24 years, 150 cm–180 cm in height, and 50 kg–75 kg in weight. It places the sensor on the experimenter’s chest. Each experimenter did three kinds of actions 10 times, and the interval between actions was more than 30 s. For the running test, each experimenter was required to run more than 8 steps.

According to the experimental plan, we counted all the data of the 12 experimenters and recorded the recognition of the three actions. The experimental data are displayed in Table 2.

This document contains statistics on the rate of correct detection, the rate of false negatives, and the rate of false positives for the three actions. The statistics of the experimental results of the three actions are shown in Table 3.

It can be seen that the recognition rate of the sensor for running is higher than that of the other two actions, and the recognition accuracy rate is 95.83%. However, the recognition rate of take-off and squat is relatively low, and the recognition accuracy rate of take-off and squat is 95.00% and 94.17%, respectively. From the jumping movements shown in the table, we can see that the number of jumps detected in females was significantly lower than in males, which is explained by the differences in weight and jump distance between males and females. The number of detections was significantly lower in males than in females, again due to differences in the body structure, while we did not overly restrict the experimenter’s movements. Combining Tables 2 and 3, it can be seen that the sensor has a high successful recognition rate for various actions of men and women in this experiment, reaching the expected results of the experiment.

This article only uses the sensor in this experiment, and it is difficult to see the advantages and disadvantages of this sensor. Therefore, in this experiment, a flexible pressure sensor of non-nanofiber material and another pressure sensor of other nanofiber material were used to monitor human motion. For convenience, nanomaterial 1 refers to the material of the PVDF
Thin film. Nanomaterial 2 represents the other nanomaterials used. Then, for these two sensors, running, jumping, and squatting were reused, and the experimental subjects were still the people who used them before. The results of the experiment are presented in Tables 4 and 5.

In addition, this article also summarizes the false positives and false positives of these two sensors, as displayed in Tables 6 and 7.

It compares nanomaterial 1 with nanomaterial 2 and a non-nanomaterial sensor, respectively. It uses bar graphs for comparison. Figure 8 shows the correct recognition numbers for the three movements of running, jumping, and squatting by the sensors of three materials, as shown in Figure 8.

And the comparison chart of the recognition rate of a specific person, as shown in Figure 9.

From the figure above, it is difficult to see the specific differences between them, and we can only note a general trend, namely, that the detection rate of the flexible pressure sensor made of nanofiber 1 is higher and more stable than that of the other two nanofibers [22, 23]. However, it is difficult to see how big the advantage is, and then, more specific bar graphs are needed, as shown in Figures 10 and
11. These graphs show both the correct rate and the false positive rate. It more clearly shows the advantages and disadvantages of pressure sensors of three materials:

The overall analysis of the data shows that the recognition rate of the pressure sensor made of nanofiber material is higher than 80%, while the recognition rate of the pressure sensor made of PVDF sheet material reaches 90% in this experiment. In general, the recognition rate of flexible pressure sensors of nanomaterials is still very high, but the pressure sensors of non-nanofiber materials are not good, and the recognition rate is not 80%. Moreover, the leakage rate and the wrong report rate of the pressure sensor made of PVDF film material are very low, which has little impact on the entire identification system. In general, this experiment is still very successful. The pressure sensor of nanomaterials has a high recognition rate of human motion, which needs further research.

5. Discussion

In this article, nanofiber materials are used to fabricate flexible pressure sensors. Based on the acceleration sensor, this article detects the human body’s take-off, squat, and start. At present, there are not many research methods in the field of nanofiber flexible pressure sensor. This article adds a human motion monitoring model to the existing sensor model. This article combines it with the working principle of a flexible pressure sensor to make a new attempt. This article initially studies the preparation of nanofibrous materials such as PVDF films. It will be applied to the sensor, and the experiments will be performed on three movements of jumping, squatting, and running. This article then uses a pressure sensor of another nanofiber material together with a pressure sensor of a non-nanofibrous material to conduct human motion monitoring experiments to obtain all the data. The analysis of the data shows that the correct recognition rate of the flexible pressure sensor of nanofiber material is higher than that of the non-nanofiber sensor. The pressure sensor that is also a nanofiber material depends on the sensitivity of the nanofiber material [24, 25].
Table 3: Statistics of the experimental results of the three actions.

|       | Total | Correct identification | Correct rate (%) | Lump | Leakage rate (%) | False | False alarm rate (%) |
|-------|-------|------------------------|------------------|------|------------------|-------|----------------------|
| Jump  | 120   | 114                    | 95.00            | 4    | 3.33             | 2     | 1.67                 |
| Squat | 120   | 113                    | 94.17            | 6    | 5.00             | 1     | 0.83                 |
| Run   | 120   | 115                    | 95.83            | 5    | 4.17             | 0     | 0.00                 |
| Total | 120   | 342                    | 95.00            | 15   | 4.17             | 3     | 0.83                 |

Table 4: Table of correct recognition times for three actions (nanomaterial 2).

| Experimental | Jump (10 times total) | Squat (10 times total) | Run (10 times total) |
|--------------|-----------------------|------------------------|----------------------|
| Female 1     | 10                    | 9                      | 8                    |
| Female 2     | 7                     | 8                      | 10                   |
| Female 3     | 9                     | 7                      | 7                    |
| Female 4     | 8                     | 8                      | 9                    |
| Female 5     | 7                     | 8                      | 9                    |
| Female 6     | 9                     | 9                      | 8                    |
| Male 1       | 8                     | 10                     | 10                   |
| Male 2       | 8                     | 7                      | 7                    |
| Male 3       | 9                     | 9                      | 10                   |
| Male 4       | 8                     | 9                      | 9                    |
| Male 5       | 10                    | 9                      | 9                    |
| Male 6       | 9                     | 8                      | 9                    |
| Total        | 102                   | 101                    | 105                  |

Table 5: Table of correct recognition times for three actions (non-nanomaterials).

| Experimental | Jump (10 times total) | Squat (10 times total) | Run (10 times total) |
|--------------|-----------------------|------------------------|----------------------|
| Female 1     | 7                     | 7                      | 7                    |
| Female 2     | 8                     | 6                      | 9                    |
| Female 3     | 5                     | 7                      | 6                    |
| Female 4     | 6                     | 6                      | 8                    |
| Female 5     | 7                     | 7                      | 9                    |
| Female 6     | 7                     | 8                      | 7                    |
| Male 1       | 9                     | 9                      | 9                    |
| Male 2       | 8                     | 8                      | 9                    |
| Male 3       | 7                     | 7                      | 9                    |
| Male 4       | 9                     | 7                      | 8                    |
| Male 5       | 8                     | 8                      | 8                    |
| Male 6       | 8                     | 8                      | 7                    |
| Total        | 87                    | 88                     | 93                   |

Table 6: Statistical table of test results for the three movements (nanomaterial 2).

|       | Total | Correct identification | Correct rate (%) | Lump | Leakage rate (%) | False | False alarm rate (%) |
|-------|-------|------------------------|------------------|------|------------------|-------|----------------------|
| Jump  | 120   | 102                    | 85.00            | 12   | 10.00            | 6     | 5.00                 |
| Squat | 120   | 101                    | 84.17            | 14   | 11.67            | 5     | 4.17                 |
| Run   | 120   | 105                    | 87.50            | 13   | 10.83            | 2     | 1.67                 |
| Total | 120   | 308                    | 85.56            | 39   | 10.83            | 13    | 3.61                 |

Table 7: Statistical table of test results for the three movements (non-nanomaterials).

|       | Total | Correct identification | Correct rate (%) | Lump | Leakage rate (%) | False | False alarm rate (%) |
|-------|-------|------------------------|------------------|------|------------------|-------|----------------------|
| Jump  | 120   | 87                     | 72.50            | 20   | 16.67            | 13    | 10.83                |
| Squat | 120   | 88                     | 73.33            | 22   | 18.33            | 10    | 8.33                 |
| Run   | 120   | 93                     | 77.50            | 19   | 15.83            | 8     | 6.67                 |
| Total | 120   | 268                    | 74.44            | 61   | 16.94            | 31    | 8.61                 |
Figure 8: The number of correct identifications of sensors for three materials.

Figure 9: The number of correct single-person identifications for the three materials.
Through this experiment, it can be known that the flexible pressure sensor of nanofiber material plays a very important role in human motion monitoring. When choosing a sensor, people should not only pay attention to whether the material prepared by the sensor is a nanofiber material, but also pay attention to whether the nanomaterial is good or bad [26]. Only by choosing the right sensor can we better monitor the physical condition and improve the body index.

6. Conclusion

In this article, the specific method of fabricating flexible pressure sensor from nanofiber material is not described in detail. It mainly studies the monitoring of the human body by the flexible sensor of the nanofiber. In this article, 12 volunteers (6 females, 6 males) were tested for 10 times of jumping, squatting, and starting movements. By observing the recognition of the three actions by the sensor, the correct recognition rate, the false alarm rate, and the false alarm rate are calculated. This article also uses two other sensors to conduct experiments together with PVDF thin-film pressure sensors. It is found that the recognition rate of the pressure sensor of the PVDF film is as high as 90%. The other two sensors have a lower recognition rate than it, and the pressure sensor recognition rate of non-nanofiber materials is even lower. However, there are some shortcomings in this experiment; that is, the experimenters may take off, squat, and run at random, which affects the reliability of the data. If conditions permit, experimental tests can be conducted on more people. It increases data reliability, and it can also increase action types. But in general, the experiment was successful, and the pressure sensor of nanofiber materials will be more and more studied in the future, and the recognition rate will be higher and higher.

Data Availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.
Conflicts of Interest
The authors declare that they have no conflicts of interest.

References
[1] B. Zhuo, S. Chen, M. Zhao, and X. Guo, “High sensitivity flexible capacitive pressure sensor using polydimethylsiloxane elastomer dielectric micro-structured by 3-D printed mold,” IEEE Journal of the Electron Devices Society, vol. 5, no. 3, pp. 219–223, 2017.
[2] W. Cheng, J. Wang, Z. Ma et al., “Flexible pressure sensor with high sensitivity and low hysteresis based on a hierarchically microstructured electrode,” IEEE Electron Device Letters, vol. 39, no. 2, pp. 288–291, 2018.
[3] Z. Yu, G. Cai, X. Liu, and D. Tang, “Pressure-based biosensor integrated with a flexible pressure sensor and an electrochromic device for visual detection,” Analytical Chemistry, vol. 93, no. 5, pp. 2916–2925, 2021.
[4] D. Y. Choi, M. H. Kim, Y. S. Oh et al., “Highly stretchable, hysteresis-free ionic liquid-based strain sensor for precise human motion monitoring,” ACS Applied Materials & Interfaces, vol. 9, no. 2, pp. 1770–1780, 2017.
[5] Y. Ai, T. H. Hsu, D. C. Wu et al., “An ultrasensitive flexible pressure sensor for multimodal wearable electronic skins based on large-scale polystyrene ball-reduced graphene-oxide core-shell nanocomposites,” Journal of Materials Chemistry C, vol. 6, no. 20, pp. 5514–5520, 2018.
[6] R. Zhang, P. Pan, Q. Dai et al., “Sensitive and wearable carbon nanotubes/carbon black strain sensors with wide linear ranges for human motion monitoring,” Journal of Materials Science: Materials in Electronics, vol. 29, no. 7, pp. 5589–5596, 2018.
[7] S. Z. Gurbuz and M. G. Amin, “Radar-based human-motion recognition with deep learning: promising applications for indoor monitoring,” IEEE Signal Processing Magazine, vol. 36, no. 4, pp. 16–28, 2019.
[8] C. Zhang, C. Fe Ng, P. Zhang et al., “k 0.25 mn 2 o 4 nanofiber microclusters as high power cathode materials for rechargeable lithium batteries,” RSC Advances, vol. 2, no. 4, pp. 1643–1649, 2012.
[9] J. Zhao, F. Li, Z. Wang, P. Dong, G. Xia, and K. Wang, “Flexible PDVF nanogenerator-driven motion sensors for human body motion energy tracking and monitoring,” Journal of Materials Science: Materials in Electronics, vol. 32, no. 11, pp. 14715–14727, 2021.
[10] R. Wang, W. Xu, W. Shen, X. Shi, J. Huang, and W. Song, “A highly stretchable and transparent silver nanowire/thermoplastic polyurethane film strain sensor for human motion monitoring,” Inorganic Chemistry Frontiers, vol. 6, no. 11, pp. 3119–3124, 2019.
[11] S. Zhang, F. Wang, H. Peng, J. Yan, and G. Pan, “Flexible highly sensitive pressure sensor based on ionic liquid gel film,” ACS Omega, vol. 3, no. 3, pp. 3014–3021, 2018.
[12] S. Chang, J. Li, Y. He, and H. Liu, “Effects of carbonization temperature and substrate concentration on the sensing performance of flexible pressure sensor,” Applied Physics A, vol. 126, no. 1, p. 40, 2020.
[13] C. Cai, H. Gong, W. Li et al., “A flexible and highly sensitive pressure sensor based on three-dimensional electrospun carbon nanofibers,” RSC Advances, vol. 11, no. 23, pp. 13898–13905, 2021.
[14] Z. Yu, G. Cai, P. Tong, and D. Tang, “Saw-toothed microstructure-based flexible pressure sensor as the signal readout for point-of-care immunoassay,” ACS Sensors, vol. 4, no. 9, pp. 2272–2276, 2019.
[15] S. Rao M and R. Rao, “Experimental investigation on the suitability of flexible pressure sensor for wrist pulse measurement,” Health Technology, vol. 9, no. 2, pp. 143–151, 2019.
[16] C. Xin, L. Chen, T. Li, Z. Zhang, T. Zhao, X. Li et al., “Corrections to "highly sensitive flexible pressure sensor by the integration of microstructured PDMS film with a-IGZO TFTs," IEEE Electron Device Letters, vol. 39, no. 8, p. 1262, 2018.
[17] F. X. Wang, S. H. Zhang, L. J. Wang et al., “An ultra-highly sensitive and repeatable flexible pressure sensor based on PVDF/PU/MWCNT hierarchical framework-structured aerogels for monitoring human activities,” Journal of Materials Chemistry C, vol. 6, no. 46, pp. 12575–12583, 2018.
[18] Y. Wang, J. Zhang, Y. Wang, X. Guo, and Y. Liang, “Integrated flexible piezoresistive pressure sensor based on CB/CNTs/SR composite with SR buffer layer for wide sensing range,” Journal of Materials Science: Materials in Electronics, vol. 31, no. 23, pp. 21557–21568, 2020.
[19] A. Choudhury, J. H. Kim, S. Sinha Mahapatra, K. S. Yang, and D. J. Yang, “Nitrogen-enriched porous carbon nanofiber mat as efficient flexible electrode material for supercapacitors,” ACS Sustainable Chemistry & Engineering, vol. 5, no. 3, pp. 2109–2118, 2017.
[20] H. Mai, R. Mutlu, C. Tawk, G. Alici, and V. Sencadas, “Ultra-stretchable MWCNT–Ecoflex piezoresistive sensors for human motion detection applications,” Composites Science and Technology, vol. 173, pp. 118–124, 2019.
[21] M. Nie, Y. H. Xia, and H. S. Yang, “A flexible and highly sensitive graphene-based strain sensor for structural health monitoring,” Cluster Computing, vol. 22, no. S4, pp. 8217–8224, 2019.
[22] F. Xiao, “Multi-sensor data fusion based on the belief divergence measure of evidences and the belief entropy,” Information Fusion, vol. 44, pp. 23–32, 2019.
[23] D. Guido, H. Song, and A. Schmeink, Big Data Analytics for Cyber-Physical Systems: Machine Learning for the Internet of Things, pp. 1–360, Elsevier, Article ID 9780128166376, 2019.
[24] Bo Gao, N. Xu, and P. Xing, “Shock wave induced nanocrystallization during the high current pulsed electron beam process and its effect on mechanical properties,” Materials Letters, vol. 237, no. 15, pp. 180–184, 2019.
[25] G. Bo, L. Chang, H. Chenglong et al., “Effect of Mg and RE on the surface properties of hot dipped Zn–23Al–0.3 Si coatings,” Science of Advanced Materials, vol. 11, no. 4, pp. 580–587, 2019.
[26] X. Xu, D. Shahsavari, and B. Karami, “On the forced mechanics of doubly-curved nanoshell,” International Journal of Engineering Science, vol. 168, 2021.