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Research Article

Application of Traditional Graphic Elements Based on Fiber Bragg Grating Tactile Sensor Technology

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In today's era, sensing technology has been very developed in the fields of machinery, medicine, safety monitoring, and so on. In order to be applicable to more fields, new sensing technologies are also evolving. Tactile and sensory states are two important indicators of human induction to external things. Based on the contact force information between fiber Bragg grating tactile sensor and human body, this paper uses a new fiber Bragg grating tactile sensing system to study the artistic elements of ink painting in modern graphic design. Subsequently, the structure and specific performances of the sensor experimental data are analyzed. With its small volume, low cost, high sensitivity, and good compatibility with the observed body, the new fiber Bragg grating tactile sensor will not be affected by external electromagnetic interference, various noise signals, complex integration, and other problems. According to the data observed by ink painters in this paper, the new tactile sensing technology of fiber Bragg grating can well control the external interference factors. In general, the technology is of great social and practical value.

1. Introduction

Tactile sensing is not only an important function of fiber Bragg grating sensor but also an important correlation part between human and robot hand [1]. In order to obtain the specific strength, temperature, angle, and other information, tactile sensing is also required, so as to help the robot hand complete the difficult operation of ink painting. The so-called fiber Bragg grating sensor is equivalent to the "skin" of the robot hand [2]. Tactile sensors are widely used in all walks of life, such as in modern graphic design [3, 4]. In the past, there were many graphic designers in the modern graphic design industry, but there was a special lack of technical talents of traditional ink painting technology [5]. According to relevant water information, the design fees of graphic designers of ink painting are very high, which cannot be borne by the general public. In recent years, it has been learned from relevant news information that the relevant technology of robot hand replacing human work has been gradually widely used in all walks of life [6]. So far, in all kinds of large, medium, and small factories using assembly line operation, robots have completely replaced human manual production, and the completion efficiency is also very high [7, 8]. However, for the past sensor technology, the graphic design direction of ink painting studied in this paper is simply impossible to achieve. In recent years, with the progress of science and technology, there are more and more types of sensors. With the emergence of fiber Bragg grating sensors, robots have also appeared in the field of modern graphic design to replace human operations [9]. By wearing the sensor on the observation body, the designer receives the data of strength, temperature, and other aspects in the graphic design of ink painting and finally applies it to the machine [10, 11]. Instead of human operation, machines do not need to consider external abnormal factors, which improve the use efficiency.

Tactile sensors have evolved many different forms in recent years [12]. In the past, there were current type, voltage type, piezoresistive type, and so on. Ordinary tactile sensors have a lot of problems at the level of electromagnetic signal interference and signal interference [13]. Compared with the traditional tactile sensor, the tactile sensor based on optical fiber technology has better performance in precision measurement, performance stability, and sensitivity

[14]. In recent years, there are more and more researches in polymer optical fiber. Many researchers say that sensors based on optical fiber technology can indeed promote the development of science and technology. Then, based on the above development of tactile sensors, the fiber Bragg grating sensing technology is proposed [15]. This technology can accurately observe all kinds of tactile index information of ink painting graphic designers in design.

Based on the above, the sensor often has the problems of inaccurate test data, large volume, and high cost. This paper creatively uses a new fiber Bragg grating tactile sensing system to study the artistic elements of ink painting in modern graphic design. A fiber Bragg grating structure is added to the fiber Bragg grating tactile sensor. The new FBG (fiber Bragg grating) tactile sensor is applied to the design of traditional ink painting. The FBG new tactile sensing structure is very sensitive to small forces, and strain can be analyzed by various forces. The new fiber Bragg grating tactile sensor has the advantages of small volume, low cost, high sensitivity, and good compatibility with the measured object and will not be affected by external electromagnetic interference, various noise signals, complex integration, and other problems.

This paper is mainly divided into three parts. The first part briefly describes the development of tactile sensing technology and fiber Bragg grating sensor. In the second part, the fiber Bragg grating sensor technology is selected to study the tactile observation of ink painting designers. First, the sensor structure in tactile observation of ink painting graphic designers is optimized, and Bragg (FBG) structure is added. Finally, the overall performance of FBG tactile sensor is designed and studied. In the third part, based on the fiber Bragg grating sensing technology, the sensor structure is analyzed through the tactile information obtained by the observer. And the results of each performance are analyzed.

2. Related Work

Tactile observation of ink painting designers is a part of tactile sensor technology. First, the tactile sensor is used to observe the tactility of the ink painting designer. Finally, the observed tactile information is saved. However, in the process of observing the designer, the intervention of some external temperature cannot be avoided, such as poor contact, temperature, noise, and other influencing factors [16]. In order to achieve the correct and comprehensive tactile information, fiber Bragg grating sensing technology has been used in designers' tactile observation in recent years [17, 18]. The core content of fiber Bragg grating sensing technology is to observe the behavior information of the observer in all aspects. A new tactile sensing structure of FBG is added to the core technology of this paper. Compared with the normal fiber Bragg grating sensing technology, FBG new tactile sensor technology can better observe the detailed data information [19]. It is more suitable for the designer to check the tactile behavior in the process of designing ink painting. In the new FBG tactile sensor, the performance of the sensor is also improved and analyzed. Through the design and performance analysis of fiber Bragg grating sensor in sensitivity, resolution, repeatability, and hysteresis, the tactile observation of ink painting designers is finally realized.

Sensor technology is mainly used in the field of robot creation [20]. At the beginning of contact with the sensor, the fingers are made of composite materials. Finally, after various experimental tests, the machine fingers in the experiment can grasp objects accurately. The force of grasping objects is very close to the human force [21]. Up to now, the robot technology manufactured has always been a global leader [22]. It can be seen that the use of sensors has promoted the development of intelligent robots.

The application of sensors has a great impact in the field of medicine. As we all know, the success rate of retinal minimally invasive surgery is very high. It is incredible that the application of sensor technology is added to the probe used in the operation, which is also the key to greatly improve the success rate of surgery [23]. According to relevant data, the research team spent five years studying this technology. Nowadays, the development of medical technology is also very mature.

Sensors are widely used in the machinery industry [24]. The speed of development of the automotive industry is obvious to all. In the automobile manufacturing industry, Germany uses sensors to simulate manual manufacturing. Through the addition of a manipulator, the speed and performance of manufacturing various automobile parts are greatly improved, and a large part of expenses are saved.

The application of sensors has become more and more extensive in the past decade. Nowadays, sensing technology is applied in the research of promoting human sleep. The sensor itself cannot promote sleep quality. The sensor is placed under the mattress to detect a series of behaviors during human sleep [25]. After analyzing the information through sensors, we can infer the sleep stage of human beings. Finally, the data is changed into tracks, and the switch and volume of tracks are automatically adjusted, so as to improve the sleep quality. Based on the fiber Bragg grating sensing system under the sensor, this paper collects the tactile information of the target person. Then, the FBG structure is added to the fiber Bragg grating sensing system to improve the overall performance. Then, put the sample data into the FBG new tactile sensor for performance test, and finally, apply the FBG new tactile sensor to the graphic designer of ink painting.

3. Research on Tactile Observation Technology of Graphic Designers of Ink Painting Based on Sensor Technology

3.1. Research on Sensor Structure Design of Tactile Observation for Graphic Designers of Ink Painting Based on Sensor Technology. When the FBG sensor receives the influence of both force and temperature, it will change the wavelength of the reflection center. The sensor achieves the sensing effect by collecting the parameter information generated by the observer and the wavelength of the reflection center. The fiber Bragg grating sensing experimental measurement system includes FBG sensor, PC, mediator, and other operating software. In this paper, the FBG sensor is combined with the fiber Bragg grating system. The demodulation software in the fiber Bragg grating system transmits the broadband light source to the FBG sensor. The FBG sensor modulates the light wave after receiving the light source information. Then, the modulated light wave is reflected into the fiber Bragg grating demodulation equipment through the sensor, the modulated light wave is decomposed, and finally, the decomposed light wave is transmitted to the PC. In short, the whole FBG new tactile sensor can feel the external parameter information on the ink painting designer. Finally, the information is transformed into wavelength change. The principle of the whole sensing system is shown in Figure 1.

As can be seen from Figure 1 is the information transmission process of the whole system of the whole FBG sensor in sensing detection. After designing the overall structure of FBG sensor, the components are integrated into the new tactile sensor, and the preliminary design of the whole sensor has been completed. In the whole FBG sensor system, there is also a major structural basis called fiber Bragg grating system. The construction diagram of fiber Bragg grating system is shown in Figure 2.

As shown in Figure 2, the PC accurately controls and stores various indexes and motion parameters transmitted by the observer through the sensor. In this way, according to the experiment in this paper, the parameters generated by the ink painting designer when designing his works can be stored on the PC. It can be seen from the above that the external parameters are formed by the changes of force and temperature and are also the main factors that can affect the wavelength change in the grating reflection of fiber Bragg. Under the condition of temperature change, the thermal effect and expansion effect of temperature will affect the refractive index and fiber grating period. The relationship formula between the above temperatures is

$$\frac{\mathrm{d}\lambda_\beta}{\lambda_\beta} = \left(\frac{1}{\eta}\frac{d\eta}{dT} + \frac{1}{\wedge}\frac{d\wedge}{dT}\right)dT. \quad (1)$$

In this formula, it is assumed that the thermal coefficient is $\varepsilon = (1/\eta)(d\eta/dT)$ and the expansion coefficient is $\alpha = (1/\wedge)(d\wedge/dT)$. The influence formula of temperature on fiber Bragg grating can be deduced. See the following equation:

$$\frac{\mathrm{d}\lambda_\beta}{\lambda_\beta} = (\alpha + \varepsilon)dT. \quad (2)$$

The influence of force on Fiber Bragg grating is mainly based on the axial and transverse deformation caused by force on the basis of fiber Bragg grating. Because the optical fiber will undergo axial deformation when stretched by force, the transverse deformation can be directly ignored. Based on the above information, the reflection center wavelength formula and variable formula are

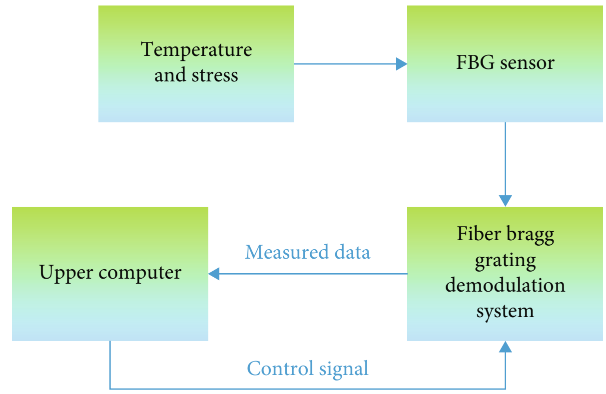

Figure 1: Schematic diagram of sensing system.

$$\lambda_\beta = 2\eta\wedge, \quad (3)$$

$$\frac{d\lambda_\beta}{\lambda_\beta} = (1 - P)\varepsilon_X. \quad (4)$$

P is the elasto-optic coefficient, and ε_X is the change of axial force. Combined with the above equation, the reflection center wavelength under the action of temperature and force is expressed as follows:

$$\frac{d\lambda_\beta}{\lambda_\beta} = (1 - P)\varepsilon_X + (\alpha + \varepsilon)dT. \quad (5)$$

With the addition of the technology of the above equation, the construction of the whole sensor can save more computation. The research direction of this paper is mainly based on a series of parameters produced by ink painting designers when painting. In selecting the types of sensors for observation, we should not only meet the conditions of small and portable but also meet the conditions of high performance and low cost. Compared with various devices, torque force sensing device is a good choice. The sensor is installed and detected by humans, as shown in Figure 3.

As shown in Figure 3, by installing the torque force sensing device on the brush, the parameter data can be observed when the ink painting designer holds the brush to draw. The sensitivity and resolution of the device are very high, which is very suitable for detecting more subtle tactile information. The probability distribution under the torque force sensing device is shown in Figure 4.

As can be seen from Figure 4, the torque force sensing device can recognize very small force, which also improves the tactile perception ability. When the torque force is added to the FBG tactile sensing system, deformation will occur, and the sensing element will feel the torque force. The

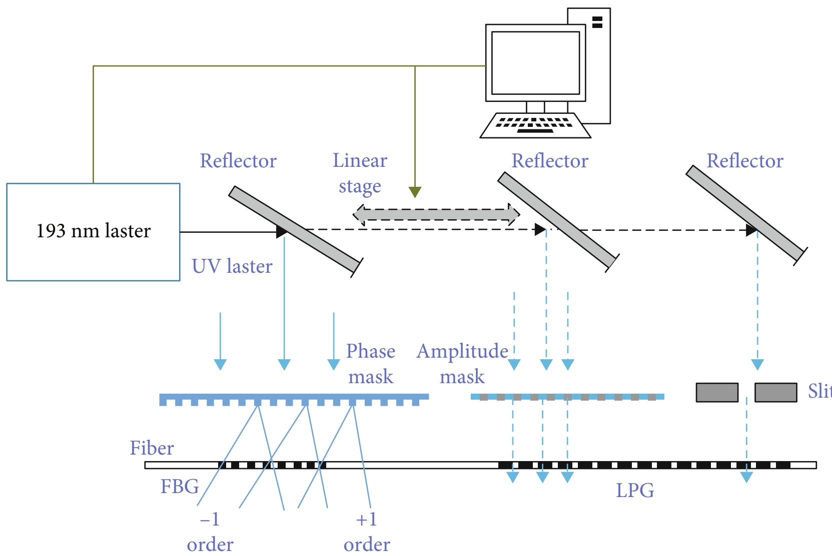

Figure 2: Construction diagram of fiber Bragg grating system.

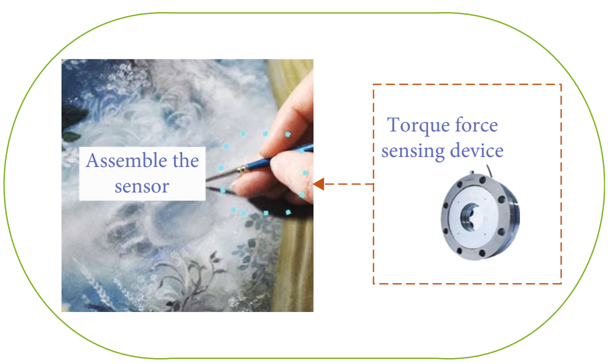

Figure 3: Application of torque force sensing device.

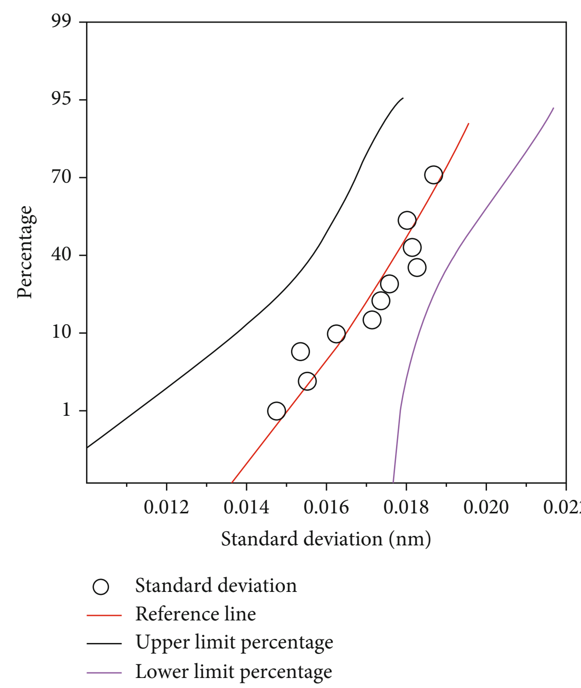

Figure 4: Probability diagram under torque force sensing device.

wavelength of the whole reflection center will also change, as shown in the following formula:

$$M = f\left(\Delta\lambda_\beta\right);F_z = f\left(\Delta\lambda_\beta\right), \tag{6}$$

$$\frac{\Delta\lambda_\beta}{\lambda_\beta} = K_T\Delta T + K_s\Delta\varepsilon. \tag{7}$$

Based on the above formula, the data generated under three different observation states are detected. The first torque detection expression is

$$\frac{\Delta\lambda_1}{\lambda_1} = K_T\Delta T + K_s\Delta\varepsilon 1. \tag{8}$$

The expression of the second reference optical fiber method is

$$\frac{\Delta\lambda_2}{\lambda_2} = K_T\Delta T. \tag{9}$$

The expression of the third reference axial force detection is

$$\frac{\Delta\lambda_3}{\lambda_3} = K_T\Delta T + K_{s2}\Delta\varepsilon 2. \tag{10}$$

In the above formula, the change value $\Delta\lambda$ of the reflection center offset, the initial center wavelength λ, and the sensitivity K between the torque force and the axial force are all subjected to stress-strain. After adding different group forces, the expression of center wavelength minus initial wavelength is

$$\Delta\lambda_1 = \lambda_1{}' - \lambda_1\,;\Delta\lambda_2 = \lambda_2{}' - \lambda_2\,;\Delta\lambda_3 = \lambda_3{}' - \lambda_3. \quad (11)$$

It can be seen from the above formula that in the torque detection of FBG sensor, in addition to calculating the torque force, the influence of indoor temperature on the sensor is also very obvious. Due to the constant change of indoor temperature, the test value is not stable enough. Therefore, the interference caused by indoor temperature must be eliminated. When other conditions remain unchanged, the output signal will drift with the change of temperature. In order to reduce this phenomenon, a certain algorithm is adopted to correct the output result to eliminate the influence of temperature change on the output signal of components within a certain range. The reference method of indoor temperature compensation in this paper is the optical fiber method. The calculation formula of indoor temperature compensation effect is

$$\frac{\Delta\lambda_1}{\lambda_1} - \frac{\Delta\lambda_2}{\lambda_2} = \frac{\lambda_1{}' - \lambda_1}{\lambda_1} - \frac{\lambda_2{}' - \lambda_2}{\lambda_2} = \frac{\lambda_1{}' - \lambda_2{}'}{\lambda_1} = K_{\varepsilon 1}\Delta\varepsilon 1. \quad (12)$$

From the formula and algorithm of indoor temperature compensation effect, it can be seen that the principle of temperature compensation is the same as that of axial force detection. The elimination formula of axial force interference is

$$\frac{\Delta\lambda_3}{\lambda_3} - \frac{\Delta\lambda_2}{\lambda_2} = \frac{\lambda_3{}' - \lambda_3}{\lambda_3} - \frac{\lambda_2{}' - \lambda_2}{\lambda_2} = \frac{\lambda_3{}' - \lambda_2{}'}{\lambda_3} = K_{\varepsilon 3}\Delta\varepsilon 2. \quad (13)$$

The above two formulas adopt the optical fiber method. By deleting the interference to temperature in torque force and axial force, the sensitivity of the new FBG sensor system is greatly improved. To transmit the torque force to the new FBG sensor, it is also necessary to bond the sensing element with the elastic beam. The displacement formula of elastic beam when receiving small torque force is

$$\Delta y = \frac{9\pi R^{1/2}}{2Eht^{5/2}} \cdot \sqrt{R(b-t) - \frac{1}{4}(b-t)^2 M}. \quad (14)$$

The elastic beam will increase the displacement under the action of force, which can enable the new FBG sensor to detect smaller tactile information. Ink painting is a superb skill. By adding an elastic beam, it can analyze data more accurately and improve the ability to sense touch.

3.2. Research on Sensor Performance Detection Design in Tactile Observation of Ink Painting Graphic Designers Based on Sensor Technology. After the structure of FBG new tactile sensor is completed, it should be designed and analyzed according to the indicators of sensing performance. FBG new tactile sensor carries out 3D printing and tactile sensing experiment after tactile perception obtained by ink painting designers. In this design, the new tactile sensing structure needs to detect the strain of axial force and torque force when painting with a brush, so it needs the tactile performance index after applying force, respectively. The experimental data show that the new FBG tactile sensor has excellent performance. This paper mainly studies and analyzes the performance of sensitivity, repeatability, and hysteresis. The above performance is also an important index to detect the powerful performance of the new FBG tactile sensor. First, the experiment of strengthening the torque force is carried out, then the reflected wavelength data shall be recorded in the torque force interval of one millisecond per meter, and the wavelength value shall also be recorded. Use Origin software to fit the data collected by ink painting designers. Torque force, wavelength value, and change trend are shown in Figure 5.

As can be seen from Figure 5, the wavelength value in each torque force gradient is in a stable state. A total of ten test data points were recorded. After linear fitting of data points, it can be found that the linearity of the fitted curve has been greatly improved. Because the indoor temperature difference of the observer during the test is not obvious and there is no obvious difference in the fluctuation of the wavelength value of the above data, it has always been a relatively stable state. The applied linear equation and sensitivity equation are

$$Y_L = \pm \frac{\Delta L_{\mathrm{MAX}}}{Y_{\mathrm{FS}}} \times 100\%, \quad (15)$$

$$K = \frac{\Delta Y}{\Delta X} = \frac{dY}{dX}. \quad (16)$$

According to the fitting curve obtained after the experiment, the slope of the fitting curve is the embodiment of sensitivity. By adding the linear equation, the smaller the linearity of the fitting curve, it is proved that the fitting curve is more consistent with the actual curve. Finally, the sensitivity of the sensor can be proved by establishing the relationship between wavelength value, torque force, and axial force.

Repeatability is the degree of difference in the measurement curve repeated several times in the same and single stroke. In this paper, the tactile observation sample data on each gradient in the forward and reverse travel are compared. In order to more directly see the trend between the observed sample data and the standard deviation, a trend chart is made according to the standard deviation of tactile data, as shown in Figure 6.

As shown in Figure 6, the red and blue lines represent the change trend of positive and negative travel, respectively. The maximum difference is generated at the peak in the volume data. The equation for repeatability is

$$Y_R = \frac{(2 \sim 3)\sigma_{\mathrm{MAX}}}{Y_{\mathrm{FS}}} \times 100\%. \quad (17)$$

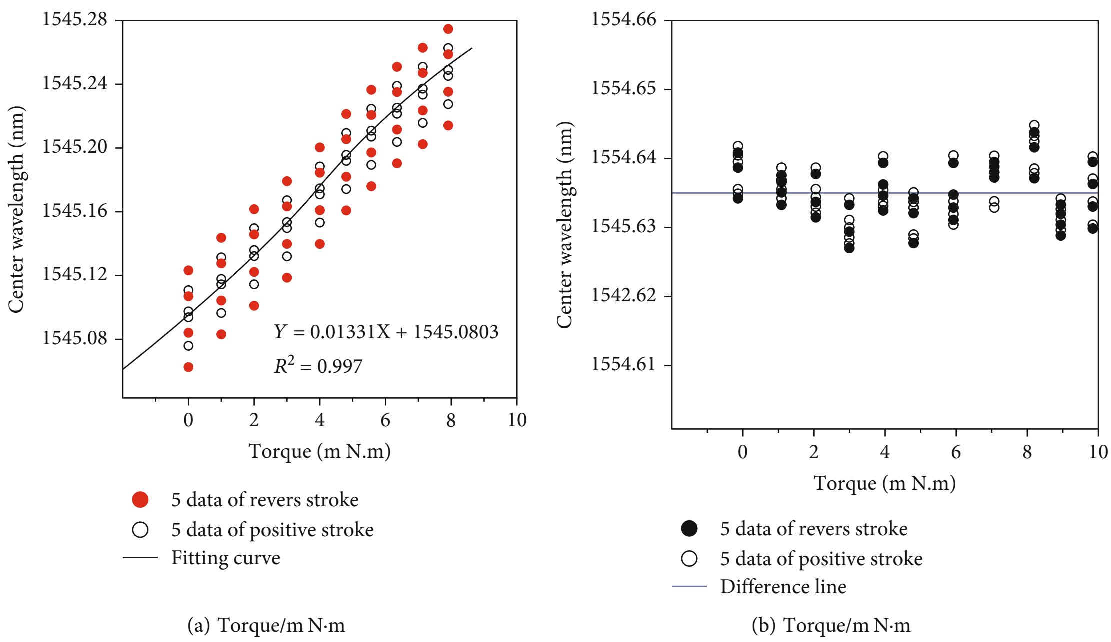

Figure 5: Torque force, wavelength value, and variation trend.

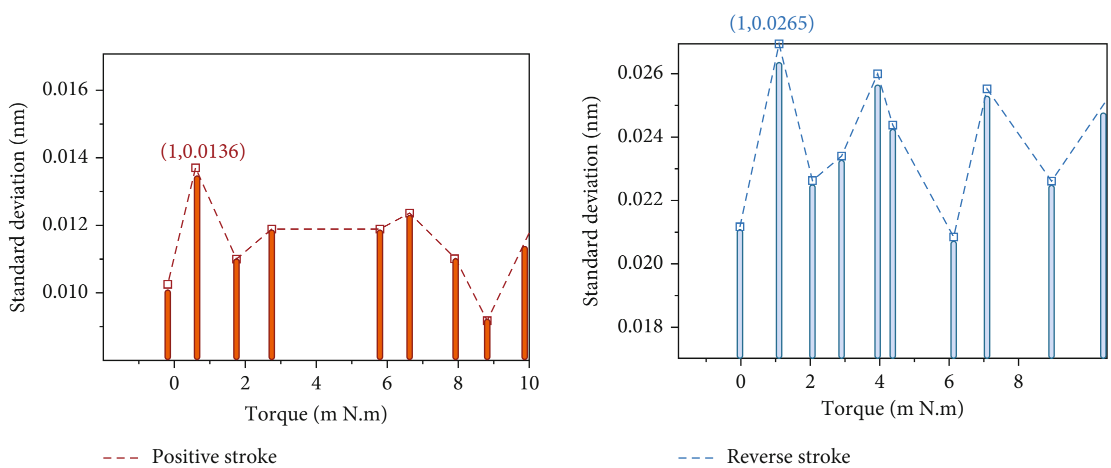

Figure 6: Trend comparison of standard deviation of tactile data.

According to the above formula, Bessel formula is used for calculation, as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}}. \tag{18}$$

Through the repeated measurement of torque force and axial force under the same stroke, the repeatability detection of torque force and axial force performance of the sensor is finally achieved. In addition to the above two properties, there is another property called hysteresis. In the torque force sensing experiment, the performance is calculated by comparing the maximum deviation value formed by positive and negative with the full formed output value under the same torque force gradient. The experiment was also carried out using the sample data of the designer's touch. Finally, the overall change direction of the maximum deviation between the positive and negative calibration points is obtained, as shown in Figure 7.

As shown in Figure 7, the maximum deviation value between gradients appears at the maximum peak, which is obtained at 6 and 10, respectively. Bring the maximum deviation value into the following formula:

$$Y_H = \frac{\Delta H_{\mathrm{MAX}}}{Y_{\mathrm{FS}}} \times 100\%. \tag{19}$$

Finally, the hysteresis of the FBG tactile sensor in this paper can be obtained from the results. Through the comprehensive analysis of the above three performance experiments, it can be seen that the sensing performance of the new FBG tactile sensor is very good.

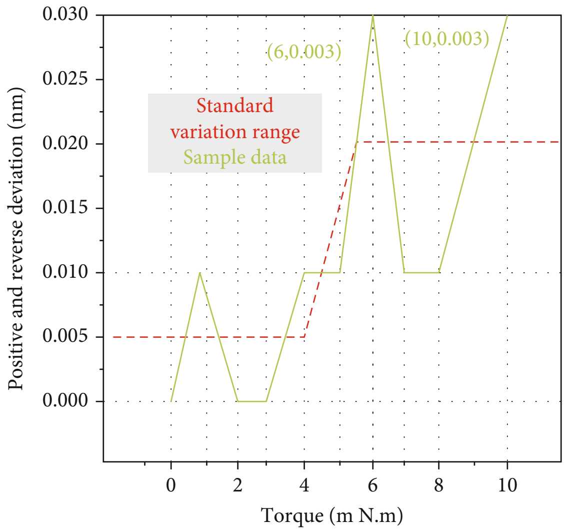

FIGURE 7: Variation trend of average calibration point deviation at each gradient.

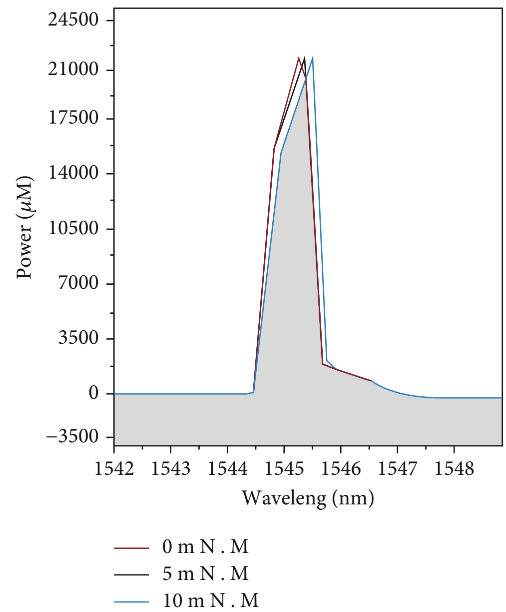

FIGURE 8: Reflection spectrum of torque force sensor.

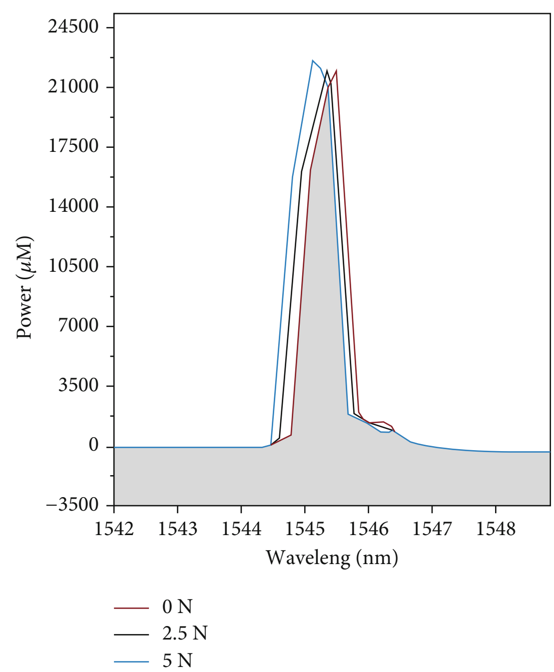

FIGURE 9: Reflection spectrum of axial force sensing.

4. Analysis of Research Results of Tactile Observation Technology for Graphic Designers of Ink Painting Based on Sensor Technology

4.1. Analysis of Sensor Structure Design in Tactile Observation of Ink Painting Graphic Designers Based on Sensor Technology. Based on the design of the sensing structure in the whole FBG fiber Bragg grating system, the reliability and speed of the FBG fiber Bragg grating demodulation analyzer for the collection of tactile information of ink painting designers can be seen. And the transmission of data to the PC is very considerable in the process of wavelength information demodulation. While the designer applies force to the brush, the fiber Bragg grating demodulator will quickly adjust the reflected center wavelength and refracted light intensity under different gradients. Finally, the torque force and axial force are stored under the tactile information data of the ink painting designer and then regenerated into the tactile reflection spectrum of the ink painting designer. The generated reflection spectrum can reflect the most intuitive result of FBG fiber Bragg grating system in observing the whole structure under the touch of ink painting designers. The torque force sensing reflection spectrum is shown in Figure 8.

It can be seen from Figure 8 that the reflection spectrum also has different change trends under different torque forces applied to the new FBG sensor. It is obvious that the displacement of the whole wavelength is also increasing with the increase of the applied force. Next, by applying axial force to the designer of FBG new sensor ink painting, the axial force reflection spectrum is generated, as shown in Figure 9.

As can be seen from Figure 9, after applying axial forces of different gradients to the new FBG sensor, with the increase of axial force, the wavelength displacement will also increase. Through the above analysis, under the torque force and axial force applied by the ink painting designer to the FBG new sensor, the reflected wavelength value will increase synchronously with the increase of force. The experimental results also prove that the new FBG sensor achieves the purpose of force tactile sensing of the observation object by adding the new FBG structure.

4.2. Analysis of Sensor Performance Detection in Tactile Observation of Ink Painting Graphic Designers Based on Sensor Technology. Based on the multiangle performance

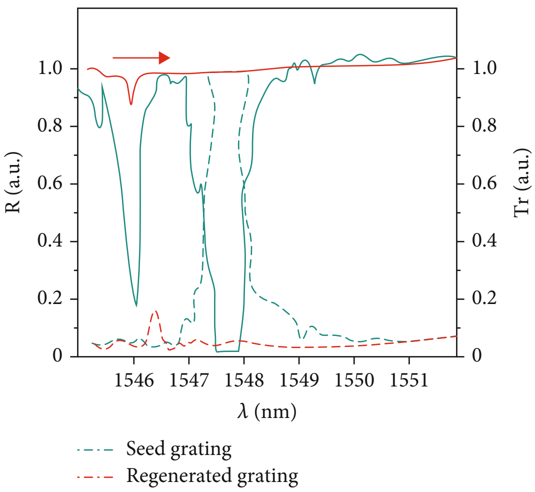

Figure 10: Initial reflection and projection spectrum and reflection and projection spectrum after data addition.

analysis of the new FBG sensor in the tactile experiment of ink painting designers, by using the optical fiber analysis method, the reflected wavelength is processed by difference, so as to achieve the experimental goal of temperature compensation. In order to further prove the influence of the optical fiber method on the data of temperature sensing performance, this paper makes an experimental study on temperature compensation. The purpose is to prove that the FBG new sensor system after passing the performance test can be better applied to the tactile collection of ink painting designers in different environments. The results show that temperature compensation can be made by recording simultaneous interpreting of two identical sensors in different environmental conditions. Different reflection spectra and projection spectra in the experiment are shown in Figure 10.

From Figure 10, we can see that the temperature compensation effect of two simultaneous interpreting sensors is similar under different environmental changes. Therefore, the experiment further proves the new FBG tactile sensor under the reference optical fiber method. The experimental results show that the new FBG tactile sensor can be applied to different external environments and can capture the tactile of ink painting designers normally. Therefore, the strain sensitivity of the whole tactile sensing system is greatly improved.

5. Conclusion

With the rapid development of science and technology, the FBG structure sensor is widely used in minimally invasive surgery, making fine parts, human tactile perception, and so on. The original ordinary tactile sensor cannot meet the capture and analysis of small movements at all. There are often some problems in the sensor, such as inaccurate test data, large volume, and high cost. After the sensors are used in various fields, the FBG structure can store and analyze small actions. Based on the above situation, the FBG structure is added to the fiber Bragg grating tactile sensor. The new FBG tactile sensor is applied to the design of traditional ink painting. The FBG new tactile sensing structure is very sensitive to small force and can analyze the strain through various forces. First, the new tactile sensing system is introduced, and the calculation algorithm related to torque force is added. The resulting difference data reflects the relationship with the FBG structure. The results show by adding the FBG structure. At the tactile data level, it contains more data of small forces. In the whole system structure level, the tactile perception of tactile sensor is greatly improved. Finally, the system structure is used to test the performance of the sample data of ink painting designers. In the research, the torque force and axial force are tested by the reference optical fiber method. The results show that the new FBG tactile sensor has very sensitive tactile sensing performance. In the tactile observation of ink painting designers, high-performance sensing devices can also better sense the occurrence of small forces and improve the comprehensiveness of data. However, the sensitivity of different axial forces of torque force is not discussed in this paper. Therefore, although the new fiber Bragg grating tactile sensor has very sensitive tactile sensing performance, the detailed parameters should be further discussed in the future research to obtain more mature applications.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

We declare that there is no conflict of interest.

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