Based on FBG Array Intelligent Sensor System

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Abstract. T In the assembly process of large workpieces, the clamping force distribution of the robotic arm has an effect on the installation effect of the workpiece. When the applied force is too large, it will cause damage to the workpiece; when the applied force is too small, it will cause the clamping to loosen. In order to realize intelligent assembly, an intelligent sensor module based on FBG array was designed. The system is composed of laser, demodulator, test module, etc. The sensing unit can be a single module or a module group, which is suitable for multi-location monitoring. This module can accurately monitor the stress field distribution and motion status of objects. The system structure is designed and its mathematical model is constructed. The experimental test module is implemented by embedding FBG array in the silica gel pad. For four FBGs, stress test experiments were carried out and the spectral response curves with time were given. It can be seen from the four sets of echo spectral data that the effect of lateral shear force on different FBGs is obviously different. The test results show that the sensitivity in the x-axis direction is 0.0051 nm/N and the sensitivity in the y-axis direction is 0.0063 nm/N. In short, the system composite design requirements have certain application prospects.

Keywords: FBG (Fiber Bragg Grating) · Intelligent sensing · Array design · Strain test

1 Introduction

In industrial applications, it is often necessary to clamp the object through the mechanical arm. The amount of force applied to the object needs to be reasonably controlled. If it is too large, it will easily cause damage to the object. Some applications also need to monitor the sliding degree of objects [1, 2]. Therefore, it is of great significance to study the sensor system with the ability to monitor the sliding state. Such sensors are roughly divided into: piezoelectric type [3], capacitive sensing type [4] and optical waveguide type [5]. Xu et al. used capacitive sensors to realize the orientation recognition of sliding detection. Although the system has high sensitivity and spatial resolution, it is susceptible to interference and has poor stability [6]. Kosaka et al. used a piezoelectric sensor array to realize a sliding sensing of about 4.0 cm 4.0 cm area, but its internal circuit layout is complicated, high cost, and easy to damage, which limits its wide application [7]. Yuan et al. have proposed the use of

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optical fiber sliding sensing to complete the control of the two-dimensional rotating plane mirror, but the process is complicated [8].

Fiber optic sensors have the advantages of small size, good flexibility and good anti-interference. Fiber Bragg grating [9–13] (FBG) is because the grating on the optical fiber greatly improves the strength of the echo signal and is more suitable for the detection and identification of weak signals [14]. Therefore, the area sensor unit based on the FBG array came into being. This article is a perception system with real-time monitoring capability based on FBG array.

2 System Structure Design

The system is shown in Fig. 1. The system consists of PC, light source, demodulator, transmission fiber and sensor unit. The demodulator integrates a swept laser light source to complete the sweep of all FBG coverage bands, and the demodulator fiber port part completes the collection of optical signals; the sliding sensor unit is implemented by FBG array, the effective length of FBG is 8.0 mm, at x Three FBGs are laid in the axis direction with a spacing of 10 cm, and two FBGs are laid in the center position in the y-axis direction with a spacing of 20 cm to form mutually orthogonal FBG arrays. The distance between the five FBGs in the z-axis direction is 4.0 mm.

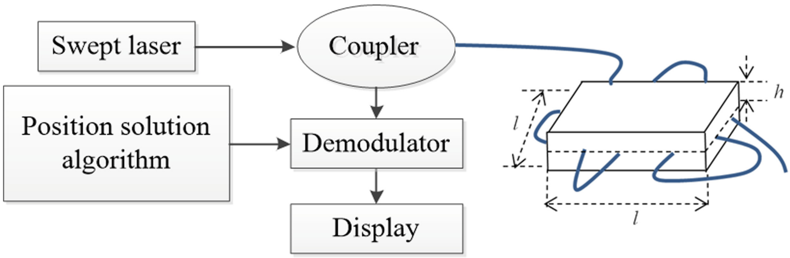


Fig. 1. FBGs sensing system

Because it is currently in the experimental test stage, only the FBG is fixed in the silicone structure, and the optical fiber is still in a free state. In the later practical application, the optical fiber of the sensor module can be directly encapsulated inside the silicone structure.

3 Theoretical Analysis

When the temperature is constant, the refractive index and grating period are constant after the FBG processing is completed, then the center wavelength of the echo is only affected by the strain, and when the FBG is only subjected to the axial strain ε_z, the wavelength offset is

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e)\varepsilon_z \tag{1}$$

Among them, λ_B is the center wavelength of the FBG echo, $\Delta\lambda_B$ is the wavelength offset, P_e is the effective corresponding coefficient of strain and light, and ε_z is the z-axis microstrain.

Let the shear force in the x-axis direction be F_x, the effective length of the sensing unit is l, the height h. FBG and the measured object did not slip before, then the shear strain is expressed in the form of force and deformation

$$\begin{cases} \Delta l = \frac{1}{Gh} F_x \\ G = \frac{E_m}{2(1 + v_m)} \end{cases} \tag{2}$$

Among them, E_m is the material's Young's modulus and v_m is its Poisson's ratio. Further simplification of Eq. (2) can be obtained:

$$\Delta l = \frac{2(1 + v_m)}{E_m h} F_x \tag{3}$$

Since all parameters except F_x are fixed values, this function can indicate that the amount of change in FBG and the degree of stress are unary functions.

It can be seen from the above formula that the first half of the function is related to the test unit parameters, and the second half is related to the magnitude and direction of the applied force. When the applied force direction is perpendicular to the FBG axis, the test effect of the shear force in the x-axis is the most sensitive; when the applied force direction is parallel to the FBG axis, the test effect of the y-axis shear force is the most sensitive.

4 Experiment

4.1 Experiment System

The experimental system includes a broadband light source, FBGs, computer and so on. The light emitted by swept lasers. The sensing unit is composed of a silicone body of 10.0 cm × 10.0 cm × 15.0 mm, and the embedded depth of FBG is 4 mm.

When the object to be tested is forced in the x direction, the center wavelength of the FBG moves, thereby determining whether sliding or the position of the sliding occurs. The elastic modulus is 6.9×10^{10} N/m^2, and Poisson's ratio is 0.33. Physical device of FBGs perception system is shown in Fig. 2.

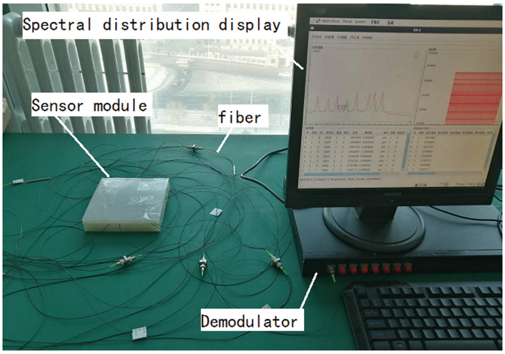
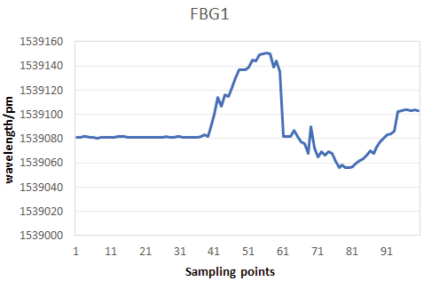


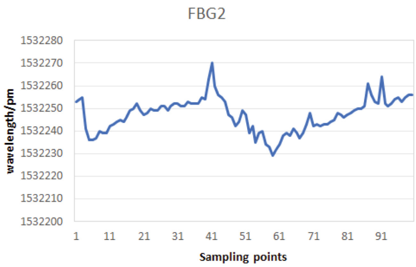
Fig. 2. Physical device of FBGs perception system

4.2 Results and Analysis

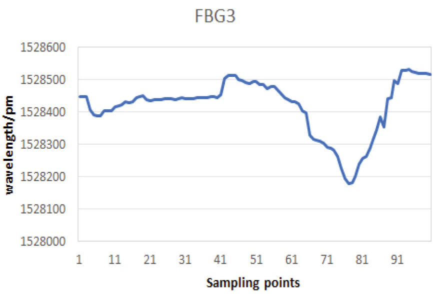
Drag the heavy object loaded on the sensing module along the x-axis. The wavelength change curve generated with time is shown in Fig. 3. The wavelength variation rules of the four FBGs in the perception module are given. The system samples 100 points per second.



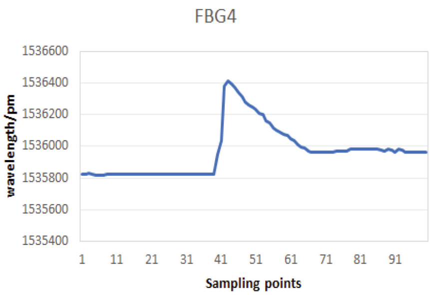
(a) FBG1



(b) FBG2



(c) FBG3



(d) FBG4

Fig. 3. Wavelength response curves of different FBGs

The experimental results show that when f_x is loaded, FBG1 and FBG2 produce a wavelength shift response, while FBG3 and FBG4 have a center wavelength that remains basically unchanged due to the shear force f_x and its axis; when f_y is loaded, FBG3 and FBG4 produce a wavelength The offset response, while FBG1 and FBG2 are perpendicular to its axis due to the shear force f_x, the center wavelength remains basically unchanged. Since the positional distance between FBG1 and FBG2 is the same as the positional distance between FBG3 and FBG4, they have similar strain-wavelength shift response curves when they are subjected to the same shear force in different axial directions. FBG1 and FBG3 are in a compressed state, and FBG2 and FBG4 are in a stretched state, so the slope of the fitted curve is slightly different. There are respectively 0.0051 nm/N in the x-axis directions and 0.0063 nm/N y-axis directions. In summary, the number and degree of wavelength shift response from FBG can identify the magnitude and direction of the shear force of the object to be measured.

At the same time, its linearity can reflect that the system has good stability. When there is no sliding friction of the measured object on the sensor unit, although there is a shear force in the x or y direction, the initial wavelength of the FBG does not change. The shear force has an effect on FBG, so that $\Delta\lambda$ is not generated. When the object slides, the force balance state is broken, and its lateral shear force changes, so that the center wavelength of the FBG at the corresponding position changes. In the end, when sliding at a stable and constant speed, although there is friction with the sensor unit, due to the balance with the FBG tension, the offset is almost zero, with a slight fluctuation.

4.3 Motion Data Analysis

When the object completes the process of moving from static to uniform speed within 1 s, the change data of the wavelength offset is shown in Table 1.

Table 1. Test data of wavelength offset in different states

Time/s	Wavelength shift/nm		
	Status A	Status B	Status C
0.0	0.0012	0.0015	0.0015
0.1	0.0021	0.0042	0.01692
0.2	0.0024	0.0035	0.03015
0.3	0.0013	0.0077	0.0415
0.4	0.0021	0.0048	0.0469
0.5	0.0013	0.0081	0.0495
0.6	0.0013	0.0061	0.0471
0.7	0.0021	0.0061	0.0401
0.8	0.0021	0.0124	0.0315
0.9	0.0013	0.0148	0.0176
1.0	0.0015	0.0135	0.0015

According to the data in Table 1, the A state is a static state, and the wavelength offset at this time is basically unchanged. Since there is no slippage, although there is a stress distribution on the silicone, the shear force and friction force are balanced. The B state is the state where the sliding reaches the average speed. This is the increase in the force of the FBG, but since the object has been moving at a uniform speed, the wavelength offset becomes larger and remains unchanged. The C state is the initial state of sliding. After the stress balance is broken, there is a sharp increase in the wavelength shift. It can be seen that three different states can be solved by the distribution of system data.

5 Conclusion

In this paper, a sliding detection system based on FBG array is designed, and structural design and simulation analysis are given. During the force test on objects of different weights, the results show that the system has sensitivity in the x-axis and y-axis directions. They are 0.0051 nm/N and 0.0063 nm/N, respectively. The analysis of the state of the object can be completed through the test data, which verifies the feasibility of the system.

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