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A Novel Cable Anti-theft Warning System based on Optical Fiber and Grating

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Abstract
This paper focuses on the fiber fence, the fiber fence, the research situation, the technical status of the discussion and argumentation, and on this basis of FBG fence were feasibility analysis, experimental analysis, build and verify the fiber Bragg grating demodulation system, and the FBG fence exhibition open signal analysis, software design and the results, the key problem of FBG fence is a more in-depth and systematic research.

Keywords: *Cable Anti-theft Warning System*, *Optical Fiber,Grating,Dual Grating Wavelength,Software Design.*

1. Introduction

Along the highway the cable facilities part of road layout and cable trench is covered by cable box or ditch cover, so it can determine whether there is cable theft incident through the cable trench cover / manhole cover opening and closing steals movements. At present, there are nearly 200 the relevant security results in the country through the identification and there are more than 100 series of related anti-theft devices which mainly can be divided into mechanical and electronic anti-theft.There are six kinds of methods were mainly adopted in the mechanical anti-theft device,that is ,chain connecting method, the hinge connection, export counter rotating technique, the bolt stopping hole technique, key lock method, fork joint linkage method. Among them, the first and the two were not well covered and the well locked together.Only the third kinds of reverse rotation in place can open the covers; the fourth blocked the hook hole bolt, but as long as the two ends of the arch wire the bolt head is inserted into the two groove, you can open the covers; the fifth and sixth can be well covered and the well ring lock for one, but for complex space and with high precision casting requirements with new covers, they cannot be the transformation of the existing manhole cover, cost is rather high, and solve the problem not "anti rust", with about half of their own also not open, not well. And the mechanical devices are passive protection, not active monitoring, can not meet the technical requirements.

Install anti-theft detector is composed of a sensor and a digital processor on the well cover, the digital signal through the cable uploaded to the host security, sensor according to the principle can be divided into ultrasonic or infrared sensor, angle sensor, pressure sensor, etc.. The electronic anti-theft device has the following shortcomings: the need for power, both anti-theft detector or security host, are the need for power, virtually increased the cost of maintenance, poor long-term reliability; capacity and distance is limited, because the manhole cover anti-theft host and anti-theft detector is wired digital signal transmission, the transmission distance can reach several hundred meters, covers anti-theft host but also through wireless network will alarm signal is uploaded to the monitoring center, the multiplexing capacity is limited. The existing anti-theft device can not meet the technical requirements of the application.

In summary, above the existing technology can not meet the underground in this harsh environment of multi-point distributed measurement, not to mention long-term reliability and maintenance free.

2. Major Technical Issues to be Resolved

Through the investigation and comparison of existing technology, covers the existing anti-theft technology cannot meet the application requirements. Although fiber Bragg grating sensing technology has the advantages of strong adaptability to the environment and a distributed sensing, but to apply to the manhole cover opening and closing of the alarm monitoring system, are necessary to solve the technical problems still exist.

2.1 Simple and Reliable Distributed Monitoring

Because fiber Bragg grating sensor is sensitive to temperature and strain, it is necessary to solve the problem of temperature compensation in order to adapt to the outdoor application environment. The general solution is to add fiber Bragg grating temperature sensor in the system, the absolute amount of wavelength signal processor and the detection wavelength, and then later operations solve the problem of temperature compensation, complex system and high cost. From the principle of design, we should consider the problem of temperature drift, so that the sensor is not sensitive to temperature, the design of the system should be simple and reliable and consider the cost of the problem.

2.2 Long Term Reliable Mechanical Structure

The mechanical structure of the sensor, the manhole cover opening and other mechanical quantity into the fiber Bragg grating strain. The existing mechanical structure for the design of electronic sensors, are using the contact type design, the use of wear to make long-term reliability variation. According to the characteristic of the fiber grating, a new type of mechanical structure of the sensor is designed to meet the technical requirements of long term reliability.

2.3 Quick and Accurate Alarm System

According to the design of the sensor, the improvement of the wavelength signal processor to meet the requirements of the existing system. PC oriented software development, judge alarm signal processing, intuitively shows the location of alarm and alarm content, user-friendly man-machine interface subsequent processing of the alarm, consider set aside into the existing management system interface.

3. Dual Grating Wavelength Control Technology based on Matched Filtering Method for Dual Grating Matching Demodulation

3.1 Disadvantages of Common Matching Method

When the sensing grating is affected by the external force, the center wavelength will be reduced or increased. When the grating sensor and matching center of the grating center wavelength difference between the larger, such as broken line graph and red two Gaussian reflectivity spectrum wave looks difference is bigger, the convolution between them is very little, PD detection to the optical signal will be very small, when channel noise ratio is very small, the measurement will have big error, if again with the increase of the grating center wavelength difference PD will be almost undetectable signal light. This limits the range of detectable strain or other physical quantities.

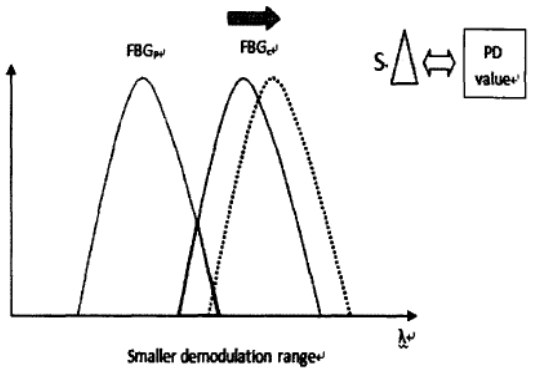

Fig. 1 Signal demodulation process of sensing and matching fiber Prague grating in common matching method.

The same current signal output by the photoelectric detector corresponds to two different wavelengths, the demodulation system can not determine the wavelength value corresponding to the matching grating at the same time, thus the measured signal can not be detected. As shown in Figure 2, the corresponding matching reflection spectrum are located in the solid red line and the red dashed line position, corresponding to the photoelectric detector to detect the optical signals are approximately equal. The problem solving system can not determine the value of the center wavelength of the matched grating, and then can not determine the change of the center wavelength of the sensing grating, so that the measured physical quantity can not be detected. In order to avoid the problem of double value, it is not enough to use only one side of the sensing grating reflection spectrum, which is not enough for many applications.

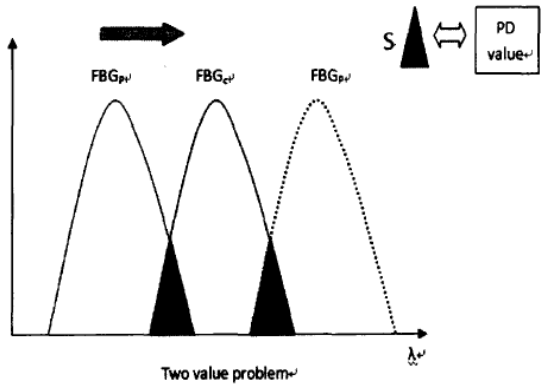

Fig. 2 Ordinary matching method.

3.2 Double Grating Matching Method

Dual grating matching demodulation technology based on the matched filter and its optimization. Solve the common matching method in the existence of the two main shortcomings. Two grating demodulation technique is used to realize the high precision and wide range strain sensing measurement of fiber Prague grating sensor by using the method of the cantilever beam tuning and two parallel two reflection matching demodulation grating.

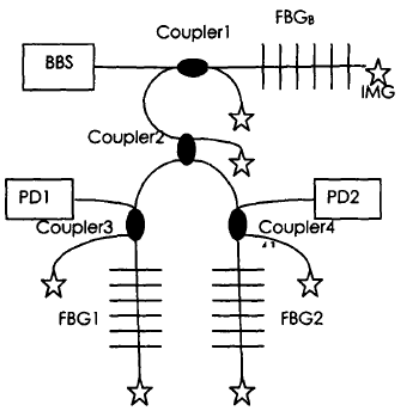

Fig. 3 Schematic of dual grating matching demodulation system.

As shown in Figure3, the system light path part of the dual grating matching demodulation method is shown. By means of parallel connection mode, the suitable matching grating wavelength is selected, the strain range can be detected, and the tuning accuracy can be improved by using the tuning of the cantilever beam. Fiber Prague grating sensing signal by two grating demodulation, the sensor signal input to the signal processing system with a single chip microcomputer as the core. The weak electrical signal output by the detector is processed by the single chip microcomputer system, and the physical quantity.

3.3 Demodulation Principle

As shown in figure 4,Two the reflection spectrum of the grating, in which the shadow part of the photoelectric detector (PD) can detect the signal.

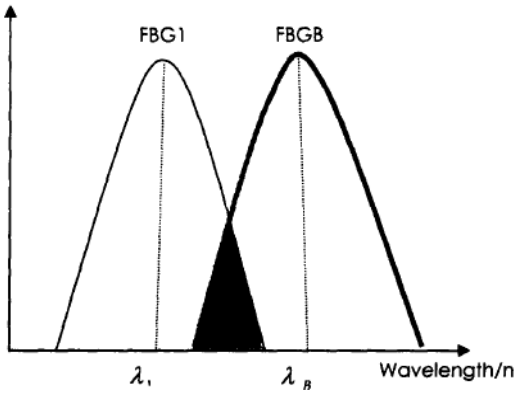

Fig. 4 Two grating reflection spectrum and photoelectric detector.

When subjected to compressive or tensile sensing grating and the wavelength will decrease or increase, as shown in Figure 4, when λ_1 and λ_B difference is larger, namely the red and black two Gaussian reflectivity spectrum central wavelength difference, the convolution between the two values is very small, PD detection to the optical signal will be very small, then you believe noise ratio is very small, the measurement will have big error. If the center wavelength difference of the grating is increased, the PD will hardly detect the optical signal. Therefore there is a threshold $\Delta\lambda$, λ_1 and λ_B value greater than the threshold $\Delta\lambda$, PD detection to the signal can not be from the noise. This closed value determines the range of detectable strain or other physical quantities.

Because the 3dB bandwidth of the common fiber grating is about 0.2nm, so the system can detect the strain or other physical quantity of the system can be detected by using a matched grating demodulation method. For example, the strain, usually calculated by pressing

$$\varepsilon = \frac{\Delta\lambda}{0.78 * \lambda_B} \quad (1)$$

In order to expand the measurement range, and usually the grating matching method different. Here is a selection of the two and the sensing grating 3dB bandwidth and reflectivity of approximately equal,but Bragg center wavelength difference of a certain value of fiber grating for two-way matching demodulation element detection. After the signal light is reflected by the sensing grating, the information of the signal is incident to the two matching grating by second coupling devices, and the reflected light signal is received by the PD. Each PD receives the spectral function of the optical signal intensity and the sensing grating, and the convolution value of the corresponding matching grating reflection spectrum function is proportional to the relationship between the optical signal intensity and the optical signal intensity. The system is mainly used to detect the positive strain, corresponding to the sensing grating and the matching grating center wavelength to meet the wavelength of $\lambda_B < \lambda_1 < \lambda_2$ .When the reflection spectrum of the sensing grating and the reflection spectrum of the first matched grating is decreased, the overlapping area of the reflection spectrum of the sensing grating and the second matched grating is gradually increased. That is, the first photoelectric detector to detect the power reduction, second photoelectric detector to detect the power increase. The detection power of the second photoelectric detector is still not zero, even if the detection power of the first photoelectric detector is reduced to zero. This method can make use of two matching grating to increase the overlap and realizes the sensing measurement of a wide range of strain or other physical quantities. At the same time, it can also release a single grating demodulation in order to avoid double eigenvalue problem only with FBG reflection spectrum unilateral constraints. As shown in figure 5,

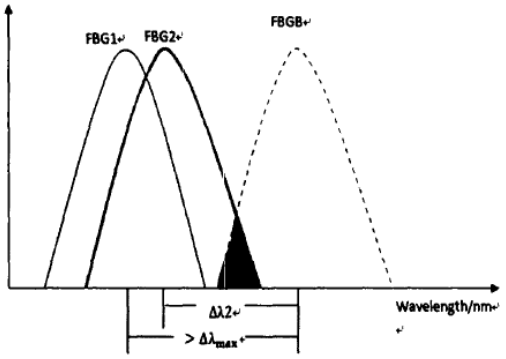

Fig. 5 Two grating matching method to expand the scope of measurement.

FBGI and FBGZ are two parallel matching grating, a certain extent expanded the sensing grating center wavelength can be varied in the double grating matching demodulation system.Between the grating and the sensing grating reflection spectra of convolution or convolution value is too small, another matching grating reflection spectrum and FBG reflection spectrum convolution. The first problem is solved by the common matching method, and the measurement range is enlarged. As shown in Figure 6,

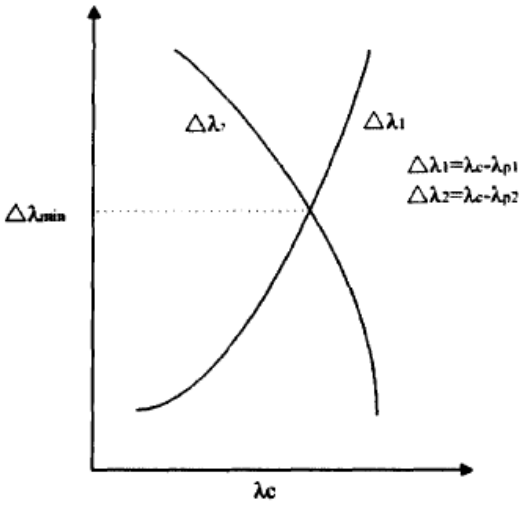

Fig. 6 Expand the scope of measurement.

λ_{p1} and λ_{p2} are respectively represented by the center wavelength of two parallel matched gratings.

λ_c is the center wavelength of the sensing grating $\lambda_{p1} < \lambda_c < \lambda_{p2}$. From Figure 6, we can see that there is at least one photoelectric detector can be used for the output of the signal can be used for demodulation. Dual grating matching problem solving method can solve the problem of double value. When the grating occurs at a certain strain, the two PD receive the signal, but the received optical power is different, the output voltage is different. That is to say, the two output signal corresponding to a measurement of the strain and the two signals from different PD output, as long as we select the right of center wavelength and bandwidth can be according to the way to lose out to determine the output of a road is corresponding to the way may corresponds to a double value. So the dual grating problem solving method has already had the ability to solve the problem of dual value in essence.

4.The Overall Design of Cable Box Cover Cable Security Alarm System

4.1 Cable Box / Ditch Cap Sensor

A sliding bar seat installed in the upper part of the shell, the sliding rod base at the lower part of the shell is connected with a base plate, a sliding bar seat within a cylindrical cavity, a spring is arranged in the cavity of the sliding rod base, sliding rod are fixed on the upper part of the pressing spring plate, the sliding rod through the sliding bar seat in the spring, the spring plate is pressed on the upper spring the slide bar at the top of the head, and the slide bar at the bottom of a slider, slide in a square cavity of the sliding sleeve, the sliding sleeve is installed on the bottom side of the shell, the other side of the base plate with the base plate, installed in the shell, a magnet mounted within the slider, the magnet two mounted on the free end of the two spring, the magnetic iron and magnet in installation, shrapnel is arranged in the middle part of fiber grating, the base plate is connected with a reference grating, grating sensor and reference grating is a fiber Prague grating wavelength signal processor by fiber series remote access. Fiber Bragg grating covers the opening and closing of the detector installation fixed in wellhead along the inner wall of the plug against the manhole cover, when the cover is closed, presses the plug down, compression spring, sliding rod drives the slide block to slide at the bottom of the sleeve, shrapnel from magnet mutual exclusion effect in the vertical position, sensing FBG and reference FBG reflection spectrum overlap, open the manhole cover, spring is extended and the sliding bar drives the sliding block to slide sleeve top, a magnet and a magnet second generation mutual exclusion effect for making the elastic sheet bending, the sensing FBG and reference FBG reflection spectrum of separation.

4.2 Alarm Monitoring System

Alarm monitoring system includes a fiber grating covers retractable sensor, fiber Bragg grating downhole sensor, wavelength signal processor, computer and cable, the fiber Bragg grating (FBG) covers the opening and closing of the sensor and fiber Bragg grating sensor distribution at the monitoring site, through cable series and transmitted to the signal processor of the control room in, fiber Bragg grating signal processor will result covers the opening and closing state information and the corresponding location information for the pass to the host computer. The wavelength signal processor is a multi-channel, and the number of channels can be determined according to the number of sensors needed by the system, and each channel is supported by 8 sensors in series. Because the system is the detection of the wavelength, the intensity of the impact, so you can monitor the scene and the monitoring room 20km no relay transmission.

5.Selection and Design of System Device

5.1 Light Source

Laser light source is a key component in fiber grating demodulation system. Choose connet Fiber Optics Communication Technology Co., Ltd. of ASE light source and the laser with high output power, in the C-band range covered with excellent flatness. The main body of the light source is a high performance of the pump laser and erbium doped fiber, through the high precision of the ATC and APC circuit control laser pumped to ensure the stability of the output optical power and output power is adjustable in a certain range. Its structure is shown in figure 7,

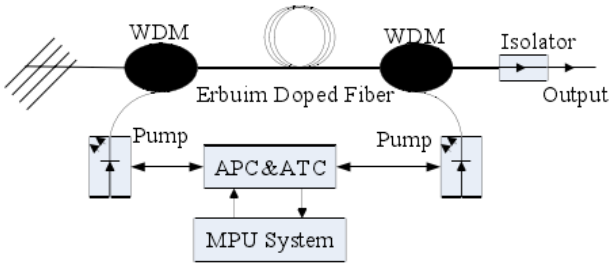

Fig. 7 ASE light source structure.

The working wavelength range of the light source is 1525~1565nm, the output light power is 13dBm. In order to test the flatness of the output spectrum of the light source, we design a spectrum test experiment to test the light source. The test results are shown in Figure 8,

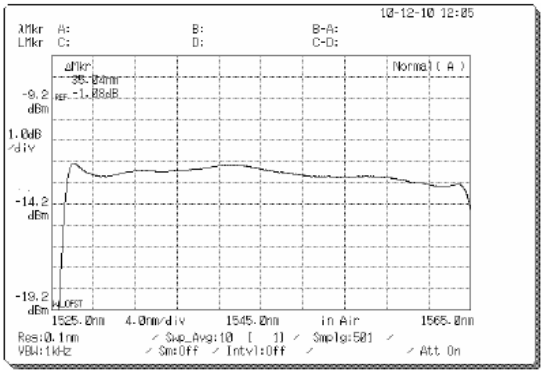

Fig. 8 Spectrum test output.

Tests show that the light source has a good spectral flatness (less than 1dBm) from the 1528nm to 1560nm, which meet the needs of the system's output power of the light source.

5.2 FBG I-MON Analysis Module

Select the Danish company Ibsen I-MON 80D fiber Bragg grating (FBG) low wavelength demodulation module, as shown in Figure 9, mainly including IMON 80D-L fiber Bragg grating wavelength monitoring module and peripheral arm-fpga circuit composition, IMON-80D-L module in the band 1529nm~1561nm. Its on adjacent wavelengths can distinguish interval is 1.2nm, namely the maximum wavelength division multiplexing access 26 FBG sensor and demodulation accuracy can be as high as 1pm, scanning frequency ~ 20Hz dynamic adjustable.

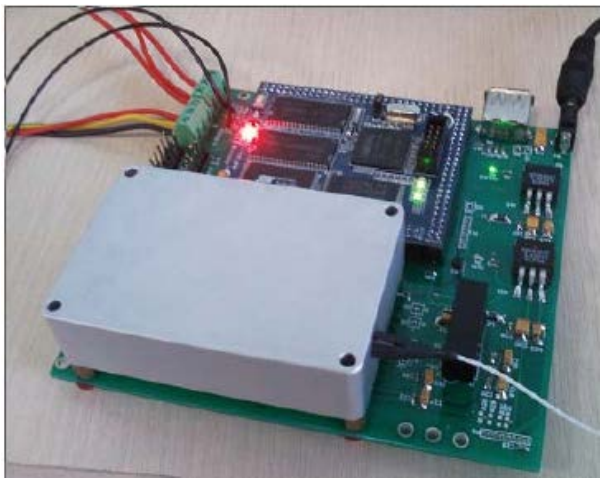

Fig. 9 I-MON Wavelength Analysis Module.

5.3 Optical Circulator

The main effect of the optical system in the optical system is that the incident light of a certain port is allowed to be output from the determined port, and the non reciprocal device output from the other port is reflected. For the three port circulator, port 1 of the input optical signal can be from the output port 2, and port 2 input optical signal can only from the three output ports, in the fiber Bragg grating demodulation system, converting the optical signal from the port 1 injection fiber, FBG by wave points multiplexing access at the mouth of the No. 2 end, the reflection wavelength will from the three output ports to wavelength analysis module. In the test system, we adopt the circulator mainly the following characteristics: the insertion loss and isolation high, high return loss, the device has the advantages of small volume, good environment, working wavelength 1525~1565nm, polarization dependent loss is less than 0.05 dB, polarization mode dispersion 0.05 PS, maximum insertion loss of 0.8 dB, return loss is more than 50dB, the isolation is more than 50dB.

5.4 Optical Switch

Optical switch is a kind of optical device with one or more selectable optical input or output optical fiber connector, which can convert optical signal in transmission line to each other or logic operation. In the optical fiber grating system, optical switch can realize the measurement of fiber FBG sensor is different channels of the FBG by time division multiplexing of optical access system, expanding the fiber system capacity, as shown in Figure 10.

Fig. 10 Optical switch object(1*16).

6.Software Design of Fiber Bragg Grating Demodulation System

FBG I-MON analysis module through the serial port and PC communication, based on the C++ Visual design of fiber Bragg grating demodulation system software to achieve the serial communication, optical switch dynamic switching, real-time information display, and other functions. The software function module consists of serial communication module, optical switch control module, dynamic display module, real-time temperature compensation module.

6.1 Serial Communication Module Design

In the FBG I-MON module using DB9 (9 core type D socket) ,2, 3, 5 pin connection serial communication (2 pin received data, 3 pin to send data, 5 pin ground). I-MON acquisition FBG reflection wavelength signal through the serial port will contain the scanning FBG wavelength information is sent to the computer, communication parameters: 115200 baud, 8 data bits, parity bit null, stop bit 1. In communication with I-MON, "FEFE" is used as the starting frame header, and the length of the command code is included in the control command to ensure the synchronization of the transmission byte. I-MON control command parameters are as follows,

Table 1: FBG I-MON wavelength analyzer control command definition

Frame head (2 bytes)	***Command type (1 bytes)***	***Command code (2 bytes)***	***Length byte (1 bytes)***	***Command data***	***Default***
FEFE	1/2/3	A0~A9	Back byte length	Parameter setting	Channel switching parameter

Fiber Bragg grating demodulation system by optical switch extension can access 16 fiber grating, each maximum capacity for 26 FBG sensors, each wavelength data with four byte floating-point data, when I-MON in maximum sweep frequency 20Hz, coupled with the data of the starting character, command type, length bytes, the data 17600bit I-MON sent per second, the speed of 115200bps completely can meet the need. I-MON to computer to send the command format is as follows,

Table 2: Definition of data format for FBG I-MON wavelength analyzer

Command name	***Frame head***	***Command type***	***Length byte***	***Command data***
Respond to current status	FEFE	A6	1	State value
Response temperature	FEFE	AC	2	Temperature value
Transmit spectrum data	FEFE	A8	163	Spectral data

Transmit wavelength data	FEFE	A2	According to the number of FBG	Wavelength data
Response gain	FEFE	A9	1	0 low and 1 high
Average number of responses	FEFE	A4	1	Average number of times
Response algorithm	FEFE	A0	1	Algorithm

In the demodulation system, when the program starts, to search and serial port initialization and I-MON is connected, the received response to send I-MON startup command when I-MON began initialization and initialization parameters returned to the computer. Upon receiving the read command wavelength I-MON will scan the wavelength data is sent to the computer. Computer monitor in real time serial is written to the event, check the serial port of a computer buff, when data is written, to decode the data, the data to judge the significance, if the wavelength, wavelength is sent to the display module for displaying.

In MFC provides a serial communication control MSComm, the flexibility of the class is not enough, in order to meet the needs of the demodulation system for serial communication, we have written a serial communication class CSerialComm. This kind of the asynchronous communication mode and in serial read and write data, both can be executed synchronously and can overlap (asynchronous) performed in the synchronous execution, function until the operation is complete before returning,which means synchronous execution thread is blocked.

It can lead to under the program efficiency, when using overlapped execution, even serial operation has not been completed, calls the function will return immediately, the time-consuming part of the I / O operation in the background of the operation system through the CPU time slice rotation response.

6.2 Optical Switch Control Module

The module through the serial port to send control commands to control the FBG I-MON wavelength analysis module and optical switch interface voltage, so as to achieve the optical switch channel switching. Through this module, it can realize the control of the switching speed of the optical switch.

Using the SetTmer function Win32API to design the timer, the timing of the transmission channel information.When using the SetTimer, system started a timer. When the fourth parameter set to null to use the default system callback function Ontimer. In the callback function called the serial port communication object write method to transmit data control commands to control the light switch interface voltage. The logic table of the switch is as follows,

Table 3: Optical switch switching channel logic

D1	*D2*	*D3*	*D4*	*PORT*
0	5	0	0	1
0	5	5	5	2
0	5	5	0	3
0	5	0	5	4
5	0	0	0	5
5	0	5	5	6
5	0	5	0	7
5	0	0	5	8
5	5	0	0	9
5	5	5	5	10
5	5	5	0	11
5	5	0	5	12
0	0	0	0	13
0	0	5	5	14
0	0	5	0	15
0	0	0	5	16

D1, D2, D3, D4 said optical switch and I-MON interface voltage, high voltage is 5V, program channel switching control commands, high eight to zero, low eight effective: D4-D1 data corresponding to the optical switch channel switching logic table values, such as to switch to channel 1, the parameters should be set to 0010.

7. Experimental Test and Result Analysis

Optical devices to build the system in kind, as shown in Figure 11, test images as shown in figure 12.

Fig. 11 Integrated optical fiber grating demodulation system.

Fig. 12 Hard software system alignment.

We will center wavelength 1580.315nm FBG access of demodulation system of FBG sensors and FBG is placed in a warm box, dynamic adjustment of temperature box, under the different temperature using FBG demodulation system to measure wavelength, by viewing the wavelength and temperature value to judge demodulator demodulating wavelength accuracy, experimental temperature adjusting range is 0 ~ 120 degrees. The experimental results are as shown in Figure 13,

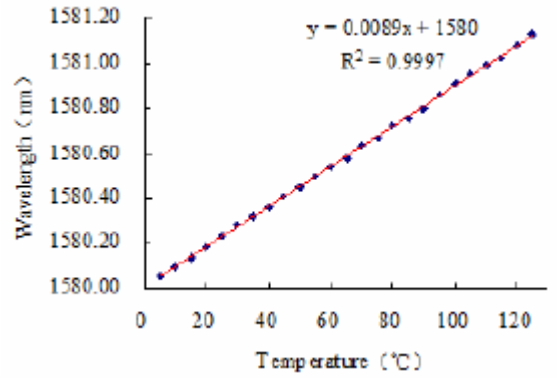

Fig. 13 Temperature experiment of fiber Bragg grating demodulation.

As can be seen from the graph, the correlation coefficient of FBG wavelength and temperature is up to 0.9997. When the temperature increases, the FBG wavelength increases linearly, and the characteristic of FBG is consistent with the characteristic of the temperature.

8. Conclusions

Aiming at the shortage of the existing security methods of Expressway cable, this paper puts forward a new warning system for the prevention and control of the expressway along the optical fiber micro vibration. The system set computer technology, photoelectric technology in one, the physical characteristics of the optical fiber sensing, in the laying of cables and laying one or several sensing fiber, pressure and vibration signals around the pickup cable, analysis and signal processing, rapid judgment and accurate positioning of the cable in the vicinity of the mechanical interference and man-made destruction events, in the cable being cut and steal before can be realized immediately report to the

police, to nip in the bud of the anti-theft effect. The utility model has the advantages of can realize long-distance distributed monitoring, fast test speed, high positioning accuracy, can the cable safety warning, nip in the bud, the greatest degree of protection of the highway of normal operation and safety of the, to avoid the indirect economic loss of a large number of direct economic losses and immeasurable. The technology will reach the leading level of domestic cable security, can be popularized in the whole country and even worldwide, and has a wide prospect of application.

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