RESEARCH ON INTELLIGENT LIGHTING CONTROL SYSTEM BASED ON FIBER OPTIC IoT

Zhao LIU[1], Chunrong YU[2*], Aiwen YU[3], Dan LIU[4]

To achieve intelligent lighting with multiple targets on a large scale and improve the energy utilization rate of the system, we design an intelligent lighting control system based on the fiber optic Internet of Things (IoT) and propose a neural network algorithm based on deep combination. After learning and analyzing the test data of fiber optic sensing networks, it provides a threshold solution method for selecting lighting equipment based on target location in a large range of lighting areas. Based on the neural network structure, it analyzes the lighting state control process with fiber optic IoT echo response as the input layer. In the lighting target recognition test, vehicles and pedestrians were tested separately. The results show that the maximum response voltages of the vehicle after amplification are 3.47V and 0.91V, respectively. The maximum response voltages of the pedestrian after amplification are 1.81V and 0.65V, respectively. The spectral distribution can distinguish the motion states of pedestrians and vehicles. The response amplitude of the vehicle is strong and the delay is long. The amplitude intensity of pedestrian movement is small and the delay is short. In the illumination experiment, according to the distribution changes of P1-P4, the target is always at the optimal illumination position in the illumination area. Its light energy utilization rate is the highest, which means its electrical energy utilization rate is also the best. It has certain advantages for intelligent control of large-scale lighting.

Keywords: Intelligent lighting; Fiber optic Internet of Things; Deep combination; neural network

1. Introduction

With the continuous expansion of urbanization, the scale of large buildings is also increasing year by year, and their internal lighting has become the main problem of high energy consumption in buildings [1]. The intelligent control of building lighting has become an important means of energy conservation [2]. The lighting electricity in buildings accounts for about 20% of the total energy

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consumption [3], with excessive lighting being particularly prominent. For example, many underground parking lots use 24-hour uninterrupted power supply, but the actual utilization rate is very low. Excessive lighting not only causes waste of resources, but also increases the operating costs of enterprises.

Controlling lighting fixtures solely based on one's own work experience, increasing the number or duration of lighting can easily lead to excessive waste of lighting resources. It is necessary to adopt an intelligent dimming system that utilizes detection devices such as light intensity detectors and vehicle detectors to form an intelligent dimming system, and automatically adjust the amount of lighting in the lighting area through the light intensity control system. At present, the commonly used vehicle detectors mainly include induction coils and video detectors [5]. Electrical sensors have high maintenance costs and are difficult to install in special road sections such as bridges and tunnels [6]; Video detection in tunnel environments is easily affected by interference factors such as light and smoke [7]. Fiber optic sensing networks have the advantages of wide testing range, small size, low cost, and immunity from electromagnetic interference, making them very suitable for networking and docking with intelligent lighting IoT. By utilizing fiber optic sensing technology, the vibration signals of vehicles and personnel can be converted into lighting driving signals for the target area, which can achieve intelligent lighting within the lighting area. Wen Y J et al. [8] used dynamic network calculations to obtain reasonable lighting sequences, resulting in a 10% reduction in total energy consumption per unit time. Kandasamy et al. [9] improved the energy utilization efficiency of the lighting system by 20% by controlling the lighting equipment through light pose. Sidelnikov et al. [10] studied abnormal disturbance signals near the sensing area, which have certain value in eliminating abnormal interference in the testing area. Tian Miao et al. [11] used a combination of basis function neural networks and modal decomposition to monitor four common regional active targets, with an average recognition rate of 86%. Xu et al. [12] used support vector machines to analyze the feature information of test data, in order to analyze interference sources such as stepping and knocking, with an average recognition rate of over 90%.

The existing IoT lighting systems mainly use pressure sensors to obtain target positions or use cameras to take photos and locate them [13-16]. The innovation of this article lies in the use of fiber optic sensing to obtain the target position and complete feedback control of lighting equipment. The pressure sensor needs to be pre laid in the area to be tested, and due to its use of electrical signal transmission, it is susceptible to interference and requires additional waterproofing treatment. The optical fiber sensing part of this system can be directly laid, with strong anti-interference ability. The optical fiber itself is waterproof and corrosion resistant. The cost of this system is also much smaller than the detection method of camera photography.

In summary, in order to meet the demand for fast lighting response at multiple points in a large area of illumination, this paper designs a fiber optic sensing array structure and proposes a signal type recognition algorithm based on deep neural networks. By presetting the signal characteristics of interference sources, cross learning is performed on test data to reduce the impact of interference items on the accuracy of system illumination.

2. Fiber Optic IoT Lighting System

The intelligent lighting system based on the fiber optic Internet of Things consists of two parts: a fiber optic sensing network and a lighting control network. The overall structure of the system is shown in Fig. 1.

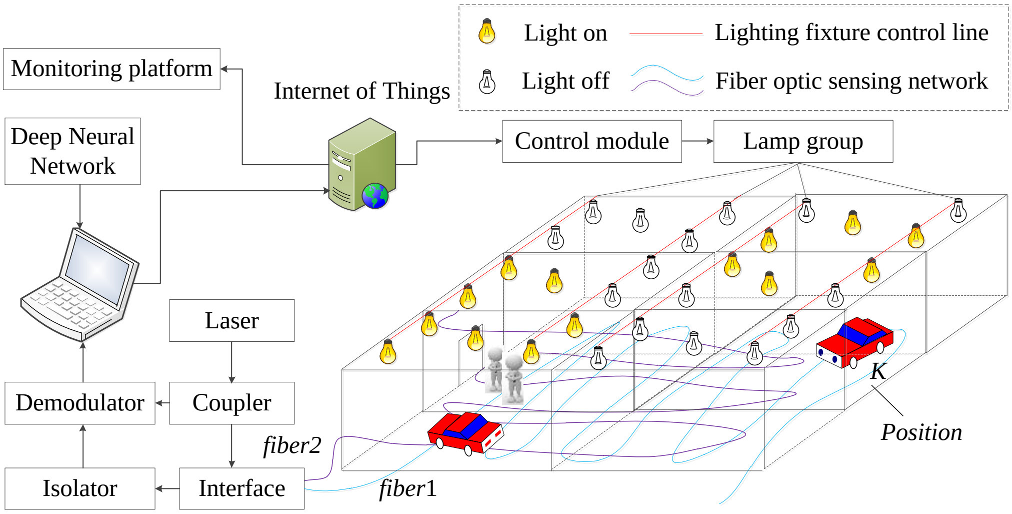


Fig. 1 Intelligent Lighting Control System Based on Fiber Optic Internet of Things

The fiber optic sensing network includes sensing fibers, transmission ports, isolators, beam splitters, laser light sources, and demodulators. When personnel or vehicles pass through the ground with a fiber optic sensing network, the fiber optic sensing network will provide a response signal. The system can analyze whether it is a vehicle, pedestrian, or interference source based on the amplitude and phase of the echo signal and execute corresponding commands. The lighting control network includes IoT servers, monitoring platforms, control modules, and light group control switches. The control module controls the fiber optic communication network to control the lighting on/off and lighting intensity of all lighting areas. Distribute state acquisition modules at the main locations of the lighting area and send real-time lighting information to the data processing system. The system analyzes and judges the positions of personnel and vehicles in the lighting area based on deep neural network algorithms, and ultimately provides feedback on the system to turn on, off, enhance or weaken corresponding lighting units, thereby achieving intelligent energy-saving lighting design that meets lighting requirements. In the figure, when the fiber response at the target location exceeds a certain threshold, the corresponding lamps around it will be lit, while the positions without response will remain off. This can significantly reduce overall electricity consumption and improve energy utilization rate.

3. Data Processing Methods

3.1 Network Construction

According to the system structure, a deep neural network is constructed to extract effective signals from test data [17]. In the illumination area, the test data at the same point is obtained from two orthogonal distributed optical fibers. The perception coefficients of the two optical fibers are different, so the input data needs to be grouped. In the hidden layer, the mapping relationship between the two is calculated to form a deep neural network structure. The first hidden layer completes primary filtering and signal matching based on the test data of fiber 1 and fiber 2, respectively. Then enter the second hidden layer and iterate the input information of the double array. After iteration, the effective signal is enhanced and input into the third layer (classification layer) of the hidden layer. Complete the final recognition output. The network structure is shown in Fig. 2.

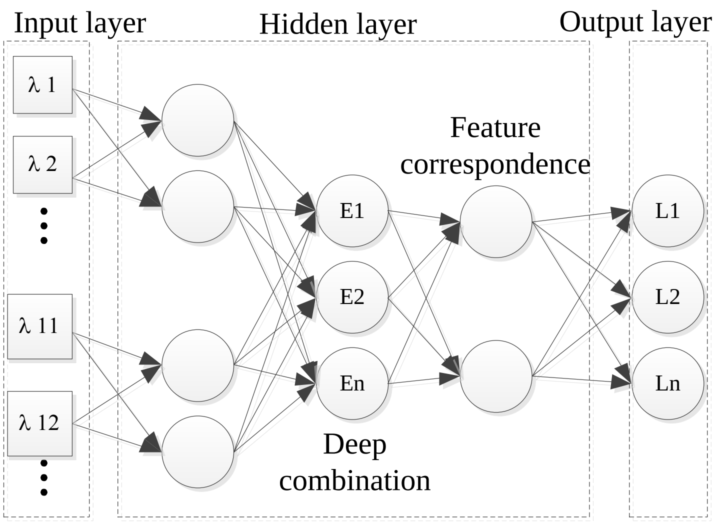


Fig. 2 Distribution of neural networks based on deep combination

3.2 Signal Inversion

Intelligent lighting is to reduce energy consumption while achieving sufficient lighting levels [18]. Quickly obtaining the location of personnel and vehicles is an important step. By calculating the signal based on the position of personnel and vehicles, automatic adjustment of lighting equipment switches can be achieved. The signal originates from the fiber optic network, so it is necessary to analyze the signal. The laser signal obtained from the receiving end serves as the initial pulse signal, which includes:

$$E(t) = E_0 \exp i\left(2\pi \frac{c}{\lambda} t + \varphi_0\right) \tag{1}$$

Among them, t is time, c is the speed of light, λ is the central wavelength transmitted in the optical fiber, E_0 is the amplified laser pulse intensity, and φ_0 is the initial phase. When the position of point K in the area to be tested shifts the phase of its scattered signal, then at the t_K time corresponding to the position of point K, the light intensity signal has

$$E(t_K) = E_K \exp i\left(2\pi \frac{c}{\lambda} t_K + \varphi_K\right) \tag{2}$$

Among them, E_K is the laser pulse intensity value at point K, φ_0 is the initial phase, and other parameters are the same as above. If the delay of the optical switch is T_s, then the length of the fiber extension line $L=c\cdot T_s$ is used, which can synchronize the initial optical signal of fiber 1 with the initial optical signal of fiber 2 at the arrival time of the test position, thereby providing a reference signal for differential homologous vibration events [19]. From this, it can be seen that the correlation coefficient after energy normalization is

$$\rho_{12} = \frac{\int_{-\infty}^{+\infty} E_1(t) E_2(t) dt}{\sqrt{\int_{-\infty}^{+\infty} E_1^2(t) dt} \sqrt{\int_{-\infty}^{+\infty} E_2^2(t) dt}} \tag{3}$$

Among them, E_1 and E_2 represent the laser echo signal strengths of fiber 1 and fiber 2, respectively. Usually, time delay affects the calculation of signal correlation [20]. However, in the hardware design of this system, the delay between signals can be ignored due to the use of delay lines in conjunction with optical switches. After signal convolution, there are:

$$E_1(\tau) * E_2(\tau) = \int_{-\infty}^{+\infty} E_1(t) E_2(\tau - t) dt \tag{4}$$

Among them, τ is the time constant. From this, it can be concluded that the autocorrelation function of the signal and the spectral density of the self energy are Fourier transform relations. From this, signal extraction can be completed through Fourier transform.

4. Algorithm Design

Divide the lighting area into regions and use the smallest level as the minimum lighting recognition range for the area. Each smallest lighting unit is a square area of 10m × 10m. There are 5 lighting lights in the minimum lighting unit, located at the four corners and center positions. Control the switch of different position lights through the position response of the optical fiber. At the same time, obtain the location information of personnel and vehicles to complete the lighting control of the response position. The program flow design of the deep neural network is shown in Fig. 3.

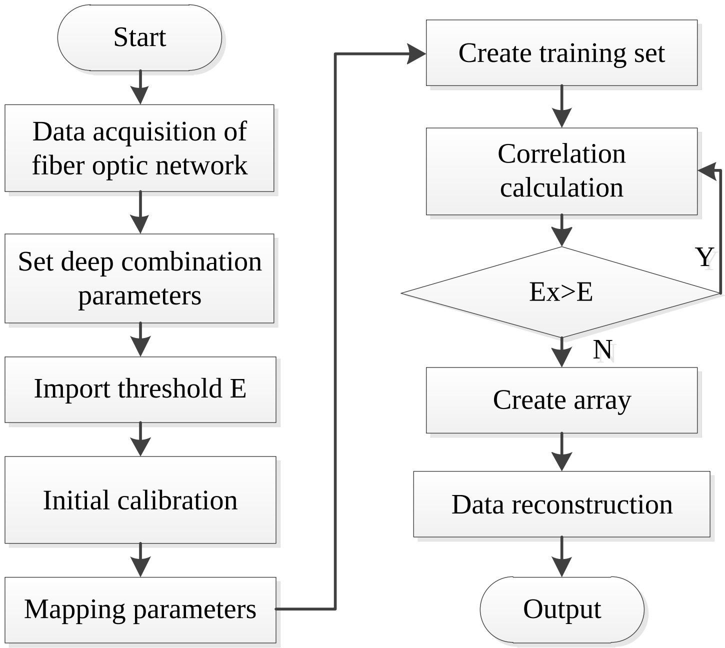


Fig. 3 Flow chart of deep neural network recognition algorithm

The algorithm implementation is mainly divided into three parts: first, complete the data collection of the fiber optic sensing network, and input the first hidden layer of the deep neural network separately. Match filtering is performed based on the sensitivity coefficients of different packaging methods of the two fibers, thereby completing the parameter configuration of the initial data; Secondly, input the preprocessed two sets of data into the second hidden layer (correlation calculation layer) to complete the correlation calculation of the two sets of data, and reconstruct the signal array based on the correlation coefficients between the calculated data; Thirdly, by introducing known vibration data sources to construct a test set, a mapping function model between echo spectral distribution data and intrusion event types is trained. This data source is a parameter distribution relationship obtained through network learning using signals from known events in advance. This parameter relationship is embedded in the neural network as a control condition for the third hidden layer.

The machine learning algorithm in this article is completed on a computer. The basic configuration of the computer is a Core i7 processor, with a host memory of 16 GB and a 6GB NVIDIA graphics card. The running environment is Python 3.7, using sm. fusion_ The matrix () function module performs classification processing on fiber optic echo data. Taking the lighting effects of the 6 test areas in Fig. 1 as an example, there are 5 lighting fixtures in each area. Test the movement trajectory of the target vehicle and personnel within 3 minutes, update the data every 3 seconds, iterate the algorithm 60 times, and output the confusion matrix. The test results are shown in Table 1.

Table 1

Confusion matrix for characteristic wavelengths recognition rate

	L1	L2	L3	L4	L5	L6
L1	300	12	0	14	2	0
L2	8	296	9	1	15	2
L3	0	7	300	0	2	12
L4	15	2	0	300	13	0
L5	1	16	2	9	295	12.
L6	0	2	15	0	16	300

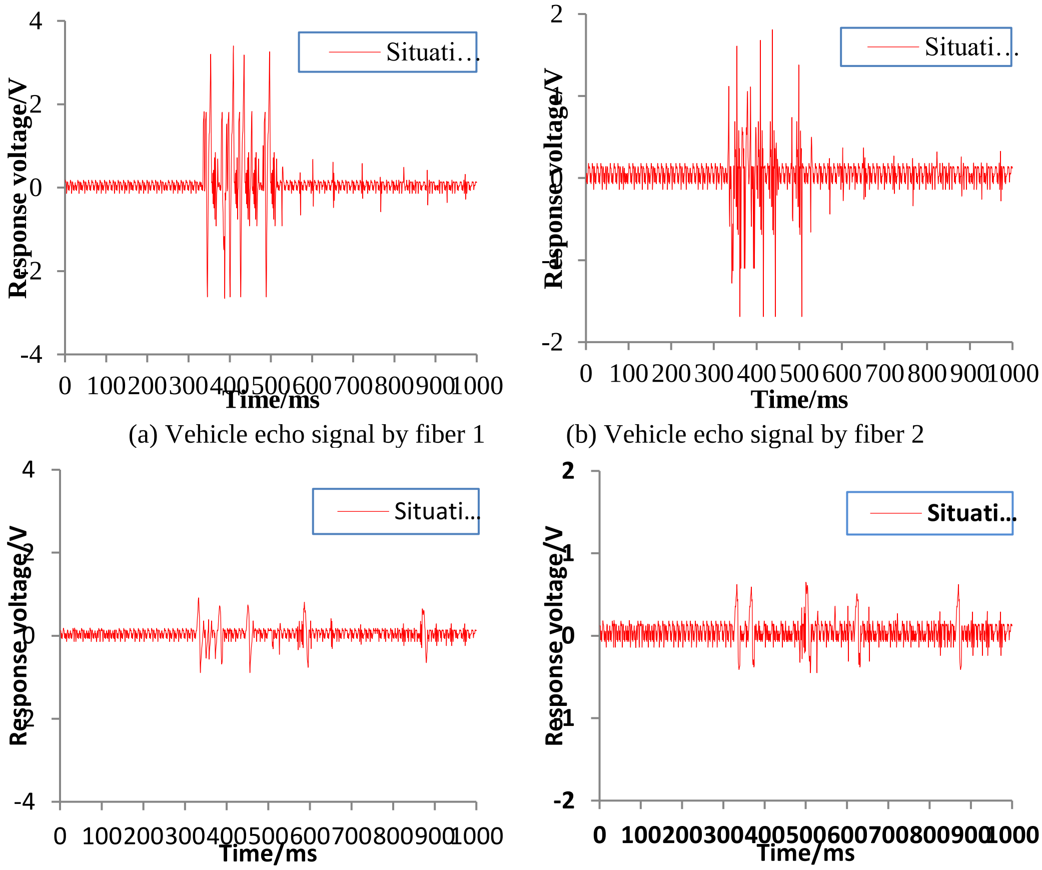
From the confusion matrix in Table 1, it can be seen that the test data with a result of 0 indicates that there is no correlation between the two lighting regions, that is, they do not interfere with each other. When the lighting test area crosses different areas, the lighting false detection rate is 0. The TP=300 for L1, L3, L4, and L6 indicates that lighting will definitely be activated when there is a target in this area. This setting is to ensure that the lighting fixtures respond when the target has an illuminated area. The mismeasurement values at other positions are mainly caused by the interference of the target position deviation between adjacent lighting areas, but for a single lighting area, there are 5 lighting fixtures, so the lighting quality of the target area can still be guaranteed to a certain extent.

5. Experiments

The experiment used a TIKN-E16 narrow linewidth fiber laser. Its wavelength modulation range is 1530nm -1570nm, line width is 1.0kHz, and its initial power is 2.0W. The modulator adopts T-M05 fiber optic demodulator. The amplifier adopts GR1315 fiber optic amplifier, with a typical output power value of 20.0dBm. The testing location is the garage under the mall, and the signal acquisition frequency is 1.0kHz.

5.1 Test Data Collection

In order to verify the sensitivity of the testing system and the recognition ability of the algorithm, vehicles at different distances from the testing point K (case 1) and pedestrian movements (case 2) were tested and analyzed. Extract the data containing signals during the testing period and complete a 1.0s data volume analysis. The system test results are shown in Fig. 4.



(a) Vehicle echo signal by fiber 1 (b) Vehicle echo signal by fiber 2

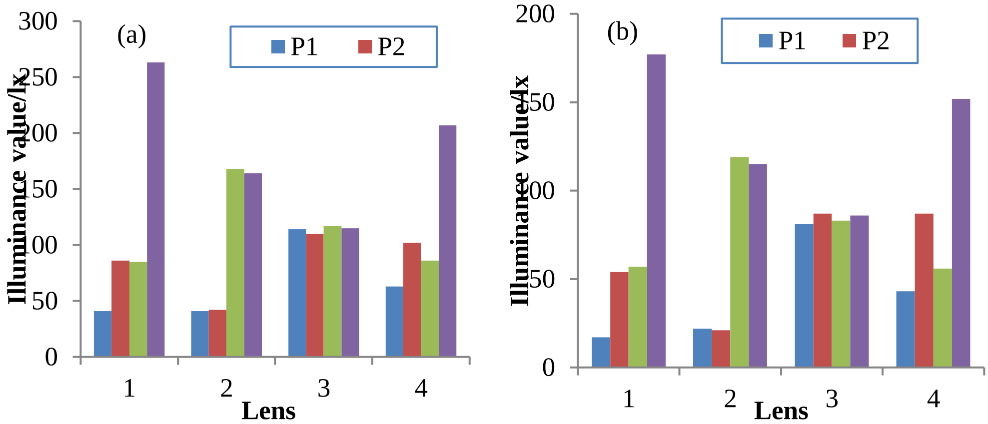
(a) Pedestrian movement echo by fiber 1 (b) Pedestrian movement echo by fiber 2

Fig. 4 Response changes of fiber optic sensing network to different targets

In Fig. 4, (a) and (c) are the test results for fiber 1, with the maximum amplification voltages of 3.47V and 0.91V, respectively. (b) and (d) are the test results for fiber 2. The maximum amplification voltage values are 1.81V and 0.65V, respectively. Due to the different packaging materials of fiber 1 and fiber 2, the response amplitude of the test data of fiber 1 is relatively obvious, but its noise amplitude is also large. Although the overall amplitude of the test data of fiber 2 is small, the white noise is weakened significantly. By performing correlation calculations on the two sets of data, the signal-to-noise ratio of the data can be further improved. The pulse width ranges of the four test curve signals are 140-150ms, 80-90ms, 45-55ms, and 15-25ms, respectively. In this test, signals near the peak positions of the test signals are used for comparison, which can increase the universality of signal recognition. From the spectral distribution, it can be seen that the response amplitude of the vehicle is strong and the delay is long. The amplitude intensity of pedestrian movement is small and the delay is short. But after filtering, the effective signals are very clear.

5.2 Illumination Test

In order to verify that the illumination in the area meets the design requirements, a PIC type illuminometer is used to analyze the illumination at the target location. The experiment tests the minimum lighting unit, with the K position in Fig. 1 as the center and tests the illumination values at the three adjacent lamp positions (P1, P2, and P3) and the position directly below the vehicle (P4). The illuminance distribution 1m and 2m away is shown in Fig. 5.



(a) Test value at 1m (b) Test value at 2m

Fig. 5 Distribution of Light Response at Different Positions

From Fig. 5 (a), it can be seen that at a distance of 1m, the illumination at position P1 is the weakest, with a minimum value of 48lx. The illumination is strongest at position P4, with a maximum value of 263lx. As shown in Fig. 5 (b), at a distance of 1m, the illumination at position P1 is the weakest, with a minimum value of 19lx. The illumination is strongest at position P4, with a maximum value of 187lx. From the distribution changes of P1-P4, it can be seen that the target is always at the optimal lighting position in the irradiation area, and its light energy utilization rate is the highest, that is, the combination of this type is also the best for electricity utilization rate. After analyzing all the total and measured values, it can be concluded that 80% of the total value is the actual value. It is believed that the sum of the test values for a single LED is significantly greater than the total value because the illuminance tester is collinear with the test LED in the cross-sectional normal direction during each single LED test, while the illuminance tester is placed horizontally during measurement, so there is an impact of the incident angle on it. However, due to the linear proportional relationship of its test data, it does not affect the testing effect. From the test results at positions 1, 2, 3, and 4, it can be seen that the increase in illuminance with distance is approximately quadratic in magnitude with the distance value. From this, it can be seen that based on the optimization control of lighting equipment in this system, the target area can achieve the best lighting effect, while ineffective lighting equipment will be turned off, achieving energy conservation.

6. Conclusions

This system can identify the type and quantity of targets to be tested in the illumination area through the waveform characteristics of the echo signal of the fiber optic sensing network. The wavelength response generated by vehicle movement has a short duration and a response voltage of approximately 2V. The wavelength response generated by personnel walking has a longer duration, with a response voltage of approximately 0.9V. The response intensity of FBGs in different deployment directions varies slightly, but the overall trend is similar.

Machine learning used to classify and learn the test data of fiber optic sensing arrays. A mapping parameter array was constructed in the hidden layer to complete the deep combination of data. By combining classification, the recognition rate of similar response data has been improved. Machine learning can obtain more accurate characteristic wavelengths and spectral ranges of fiber optic echoes. Therefore, using machine learning can significantly suppress the interference of stray signals on target signals in fiber optic echo data.

According to the perception module in this system, real-time target position information can be provided for the lighting system, thereby achieving closed-loop feedback of intelligent lighting. The illumination test in the illumination area based on this system found that the target is always at the optimal illumination position in the illumination area. The light energy utilization rate is always adjusted to the optimal state, and this system can achieve the optimal electricity utilization rate of the overall lighting system. It has made certain contributions in the field of large-scale multi-objective intelligent lighting.

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