Noise Analysis and Compensation Strategy of Photoelectric Detection Circuit

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Abstract. A photoelectric detection circuit was designed for improving the accuracy of photoelectric detection and reducing the system error. On the basis of analyzing the noise of the photoelectric detection circuit, the error compensation was proceeded on photoelectric detection circuit using lookup method, linear interpolation method, surface fitting method and adaptive neuro-fuzzy inference method, and the effects of the major error compensation method were compared. The measured data of photoelectric diode experimental platform was used as the sample data. The simulation results in the MATLAB environment demonstrate that under the same condition, the adaptive neuro-fuzzy inference method (ANFIS) can improve the detecting accuracy, and is more effective than lookup method, linear interpolation method, and surface fitting method.

1. Introduction

The photoelectric detection circuit is mainly composed of an input circuit, photodetector and preamplifier. Among them, the photodetector mainly implements the effective conversion of the photoelectric signal, which can convert the optical signal into an electrical signal; the input circuit can generally be light The device provides a basis for smooth operation and matches the preamplifier; the biggest function of the preamplifier is to amplify the signal, mainly because the electrical signal is relatively weak, and it needs to be amplified by the amplifier, and on this basis, the post-processing circuit matches in real-time. In the photoelectric detection circuit, the photodetector is an important part of the entire detection process, which can convert the optical signal in real-time. From this, it can be seen that the performance of the photodetector directly determines the detection accuracy, but due to the relatively large variety of photodetectors in the market. The performance is uneven in the selection process, we need to choose high-quality, high-performance products according to the actual situation, only in this way can ensure the quality of the test results.

2. Composition of the photoelectric detection system

The function of the photodetector system is to comprehensively detect the physical quantity of the equipment to be detected. During the detection of the line, the photoelectric detector needs to convert the equipment signal into an optical signal, and then take effective measures to convert the optical signal into an electrical signal. To complete the detection process. The photoelectric detection system mainly includes the following aspects:
(1) The photoelectric detection system of the light source needs to collect signal information on the detected object during the detection process. This needs to be based on the light source. During the detection of different devices, different light sources need to be completed, such as natural light sources, artificial light sources, etc.

(2) Signal light. After the light source appears in the process of detection, chemical and physical effects will be formed. On this basis, the signal of the detected object is converted into an optical signal.

(3) Matching processing. After the light source appears during the detection process, the physical properties will change to varying degrees. This requires matching the light source. Its role is to be able to match the photodetector and the light source of the detected object so that the light in the detected object can be matched. The physical information of the light source is effectively transformed.

(4) The optical signal is converted into an electrical signal. The most important thing in the photoelectric detection system is the conversion of the electrical signal. The object signal and the light source are converted into the electrical signal by the photodetector, which can serve to improve the accuracy and sensitivity of the system. In addition, in order to improve the conversion efficiency, the application of advanced science and technology is required. Only in this way can the improvement of detection efficiency be ensured.

(5) Amplify and process electrical signals. In the process of amplifying electrical signals, pre-amplifiers are mainly used to amplify weak photoelectric signals in real-time and digitally filter the electrical signals of objects.

3. Photoelectric detection circuit design

The PIN photodiode, which has a constant current source, is proportional to the input of luminous flux and saturated photoelectric quantity to form a signal voltage. If it is connected to the reverse-biased photodiode in the load resistance, it will be mismatched due to impedance. There is a problem with overheating of the signal amplitude. In the process of converting photoelectricity, the trans-impedance amplifier needs to be applied, which has better linearity and noise characteristics, which can effectively maintain the level of photoelectric noise and ultimately improve the signal-to-noise ratio. In addition, in the process of designing the photoelectric detection circuit, the trans-impedance amplifier should be applied according to the actual situation. During the setup period, the amplifier gain, bandwidth, and noise intensity need to be analyzed in-depth, and the signal should be improved on this basis. Bandwidth, which increases the equivalent noise during this process, will also increase the signal bandwidth. Therefore, increasing the bandwidth of the preamplifier will increase the noise to different degrees. In the process of selecting a low-noise preamplifier, the choice of resistance is particularly important. The size of the resistor needs to be selected according to the first-stage amplifier components. With higher specificity, it will increase the resistance and increase the input light, and it will also increase the throughput. The saturation light and current will also increase to varying degrees in this process. For this reason, by operating the circuit with a high-resistance load, the signal voltage can be maximized, but if the photodiode is operated in the process of reverse bias, a certain impedance will be formed, which ultimately reduces the signal strength. It can be seen from this that an over-impedance converter should be used to convert high-impedance power supply to a low-impedance power supply before connecting the load.

![Figure 1. Photodiode preamplifier circuit](image)
4. Noise type of photoelectric detection circuit

The photoelectric detection circuit is mainly composed of an input circuit, a preamplifier, and an optoelectronic device. Noise is prone to occur during the detection of the circuit, mainly including shot noise, thermal noise, and 1/f noise, etc., which will cause differences in circuit operation Degree of influence.

4.1. Shot noise

Shot noise is mainly related to the transistor because the PN connection current will change with the change of the number of carriers per unit time to form an irregular average value. In addition, randomly emitted electrons or irregularly run electrons, the change around the average value leads to the occurrence of shot noise. In addition, photoelectric detection shot noise will appear in the process of all circuit detection, including During the detection, discontinuous photoelectric carriers and random changes will be formed.

4.2. 1/f noise

In the process of the photoelectric detection circuit, the probability of occurrence is relatively high. This noise is mainly due to the frequency and power, spectral density, and relatively low frequency range that produce a proportional relationship, mainly because the frequency range of the noise is below 1KHZ, so After detecting the photoelectric system's necrosis, 1/f noise is prone to appear. Therefore, in the process of controlling this, it is necessary to take effective measures to control the flat band noise less than 1KHZ, which has obvious effects. But during operation, the uneven surface of the detector will also increase the noise frequency, so this noise is also called surface noise.

4.3. Thermal noise

The photodetector is particularly important in the process of photoelectric detection. In fact, it is also a current source and an equivalent resistance. The equivalent resistance will be obtained by changing the electrical signal, and a noise voltage will be formed on both sides of the equivalent resistance. The thermal noise caused by the change of current is generally caused by the micro-thermal movement of electrons. Any conductor will form a resistance, so resistive carriers will be formed in the detection circuit, thereby forming thermal noise. Thermal noise is the most influential noise in the photoelectric detection circuit. It has a wide range of resistance frequencies. This noise can process noise that only meets the frequency of the amplifier through the amplifier. In this process, it can form a smaller noise. In addition, the amplifier will also affect the amount of amplified electrical signals, but it will also affect the useful small signals. The wider the frequency band formed in actual operation, the greater the temperature will increase, increasing the resistance value, resulting in thermal noise occur.

4.4. Amplifier noise

Since the electrical signal obtained by the photodetector in the process of converting the signal is weak, in order to improve the detection accuracy, the signal needs to be amplified. However, in the process of amplification, the signal noise is still large. If the signal is weak, it will be masked by the noise of the amplifier itself. Therefore, in the process of designing the photoelectric detection circuit, a two-stage amplification method needs to be adopted, preamplifier + main amplification Among them, the preamplifier can effectively control the output noise. The preamplifier is mainly composed of different components. In this device, each component can operate independently and be connected to each other. Noise sources are formed during operation, mainly due to the relatively large number of amplified originals, which makes it impossible to conduct an in-depth analysis of the types and sources of noise. Therefore, an amplifier noise model is required.

5. Error compensation method of the photoelectric detection circuit

There are two main error compensation methods for photoelectric detection circuits: hardware compensation method and software compensation method. The hardware compensation method is
mainly to optimize the detection circuit and impedance matching, etc. The hardware compensation method is complicated and increases the production difficulty, and it is difficult to achieve full compensation, and Compensation hardware can cause new errors, and the compensation effect is not ideal; this paper mainly analyzes and studies the software compensation method, and using software to replace part of the complex hardware circuit can achieve good results. Software compensation methods mainly include table look-up method, interpolation method, surface fitting method, and adaptive neuro-fuzzy inference method.

5.1. Look-up table method
For photoelectric detection, the light information value or noise error value is calculated by the formula, and it is solidified in the memory of the microprocessor in the form of a table. When the relevant amount is input to the microprocessor, a table lookup operation is performed to call out the corresponding data and output it. However, this method can only contain limited data, and its accuracy is closely related to the size of the hardware circuit and the table. To obtain higher detection accuracy, the table will be very large and the speed will be slower. Under the requirement of large amount of data and high precision, it is necessary to combine linear interpolation method with a table look-up method, so as to solve the shortcomings of a simple table look-up method. In the photoelectric detection experiment, there are two related quantities of illuminance: temperature and photocurrent, so ordinary piecewise linear interpolation method cannot be used to approximate the function, and the two-dimensional interpolation method needs to be cited. The two-dimensional interpolation method is to separate these two variables. To interpolate, first use one variable as a constant to interpolate another variable, then fix the previous variable to interpolate the second variable, and then store all the data in a table in memory.

5.2. Surface fitting method
Surface fitting is to use a set of discrete data points on or close to the surface to find the optimal surface equation so that the surface represented by the surface equation is close to the set of discrete data points. In order to obtain the best fitting parameters, the least square method should be used to fit it. The least-square method is a nonlinear approximation method and the most commonly used method for data fitting [7]. The surface generally does not pass through the discrete data points but is based on the square sum of the difference between the value of the fitted surface at the sampling point and the actual discrete data value. That is, the sum of squares of the calculated errors is:

$$E(f) = \sum_{i=1}^{n} (f(l_i) - Z_i)^2 = \sum_{i=1}^{n} \left( \sum_{j=1}^{m} A_j B_j (l_i) - Z_i \right)^2$$

(1)

Although the least-squares surface fitting method has a large amount of calculation and complicated calculations, the fitting effect is very good. The surface can smoothly transition and reduce the influence of large point errors.

5.3. The adaptive neuro-fuzzy inference method
The adaptive neuro-fuzzy inference method has the advantages of both fuzzy technology and neural network technology. It constructs a fuzzy inference system by setting a given input and output data set. It is a fuzzy inference system (ANFIS) based on the Takagi-Sugeno model [8]. The network structure model is shown in Figure 2.
Layer 1 nodes are used to fuzzy input variables, layer 2 nodes are used to match the antecedents of the rules and each rule is calculated for the suitability, and layer 3 nodes are used for normalized calculation of the rule's suitability, layers 4 is used to calculate the output of each rule, and the layer 5 node calculates the refined output of all input variables. The system uses a back-propagation algorithm or a combined learning algorithm combined with least squares to adjust the membership function parameters and generate fuzzy rules, and then train and learn the sample data by gradient descent method to obtain empirical knowledge, through the above five layers of processing, and finally enable the system to simulate the given sample data [9].

6. Comparative analysis of simulation results

The data used in the simulation are measured on the photodiode experiment platform. The measured temperature T ranges from 6 to 20°C, and the illuminance Ev ranges from 0 to 200L x. In order to reduce the influence of the dark current of the photodiode, the data is measured without bias in the actual measurement. By detecting the photocurrent data at different illuminances and temperatures, the effect of temperature is analyzed, and after error compensation calculation, the illuminance information at a certain temperature and photocurrent can be given.

| Classification                        | 6-8°C | 9-11°C | 12-14°C | 15-17°C | 18-20°C | Mean square error |
|---------------------------------------|-------|--------|---------|---------|---------|------------------|
| First-order non-segmentation          | 2.2671| 2.2671 | 2.2671  | 2.2671  | 2.2671  | 2.2671           |
| Second-order non-segmentation         | 1.9898| 1.9898 | 1.9898  | 1.9898  | 1.9898  | 1.9898           |
| First-order divided into five sections| 1.7505| 1.4242 | 1.2861  | 1.2896  | 2.2617  | 1.6024           |
| Second order divided into five sections| 1.2077| 1.0567 | 0.9502  | 1.0461  | 1.8646  | 1.2251           |

The simulation of the interpolation method was built in MATLAB software, the temperature step is set to 1°C, the photocurrent step is 0.1μA, and its interpolation data is obtained, and the root means the square error is calculated to be 0.4298. As the number of steps increases, the accuracy will also increase, but the table will also become larger, and the time to look up the table will become longer. The level of the fitting order of the surface fitting method and the number of segments have an effect on the fitting accuracy. When performing simulations, data are obtained in the case of 5 segments and non-segmented and first and second orders, respectively. The comparison and analysis data of the root-mean-square error of the fitted data and the measured data are shown in Table 1. From the experimental results, it can be seen that the standard deviation of the segment is smaller than that of the whole process, so it can be deduced that as the segment increases, the data The accuracy of the fitting is improved accordingly; the error of the higher fitting order is smaller, but not the higher the better. It is necessary to find a suitable fitting order to meet both the accuracy requirements and the processing power of the actual computer. For the adaptive fuzzy inference method, enter the measured data as sample data into the ANFIS network, set the type of the two input membership functions to be Gaussian functions, output functions to linear functions, set the tolerance of the error to the default value of 0, choose The hybrid algorithm of the backpropagation method and the least square method is used to train the data [10]. Through the training of the ANFIS five-layer network, the membership function parameters are corrected. Fuzzy rules, fuzzy rules are more objective and realistic.
7. conclusion and future work

In this paper, a comprehensive analysis of the photoelectric detection circuit noise is carried out, and the photoelectric detection noise error compensation method is researched under the Matlab software using the measured data under the photodiode experimental platform. The accuracy of table lookup method combined with linear interpolation is related to the size of the table which is suitable for the case of a small amount of data; the fitting accuracy of the surface fitting method is related to the degree of fitting and the number of segments, and the complexity is correspondingly increased when the order is high and the segment is many; the adaptive fuzzy inference method is used to compensate the photoelectric detection, and the accuracy is very high, which shows that ANFIS has a strong nonlinear approximation ability. This method is superior to the first two methods. In short, in practical applications, reasonable algorithms should be selected according to different accuracy requirements and hardware conditions.

References

[1] Chen Ruzhuo. Design of stepper motor controller based on FPGA [J]. Science and Technology Information, 2009 (8): 4372439.
[2] Ye Weiwei. Stepping motor high precision subdivision method and its control system [D]. Guangzhou: South China Normal University, 2002.
[3] Yu Hongjuan, Pan Song. Application of FPGA in arbitrary subdivision drive of stepper motor [J]. Journal of Hangzhou Dianzi University, 2005, 25 (3): 9212.
[4] Zou Daosheng. Application of EDA technology in stepper motor drive [J]. Journal of Jiangxi Normal University: Natural Science Edition, 2006, 30 (4): 3502354.
[5] Pan Song, Huang Jiye. Practical Course of EDA Technology [M]. 3 Edition. Beijing: Science Press, 2006.
[6] Chen Jianrong, Ye Wencai. Design of multi-mode stepper motor controller based on FPGA [J]. Journal of Jimei University, 2007, 12 (2): 1562160.
[7] Pan Shou, Cheng Gengguo. Realization of FPGA for stepper motor controller [J]. Modern Electronic Technology, 2009, 32 (1): 1482150.
[8] Wang Haihua, Song Lei. Design of stepper motor controller based on CPLD [J]. Microcomputer Information, 2008, 24 (10): 992101.
[9] Han Tuanjun. Development of stepper motor controller based on VHDL [J]. Computer Knowledge and Technology, 2009, 25 (5): 730027302.
[10] Wu Lianghong, Cheng Jixun. Design of a controllable stepper motor distributor based on CPLD [J]. Control Engineering, 2005, 12 (1): 94297.