Using Photoelectric-Diode Volt-Ampere Characteristic to Detect Visibility

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Abstract. Based on the linear relationship between light illumination and output current of photoelectric-diode under reverse bias voltage, several photoelectric circuit was design. According to Bouguer-Lambert's law and Koschmic principle, the relationship between output voltage and illumination is changed into a quantitative relationship between output voltage and visibility. Using the relation, We can get the relationship between light transmittance and output voltage, and use the photoelectric circuit to detect visibility. Through the experiment, we find the results matched our theory. With the aid of these relationships, We can measure instant visibility.

Introduction

Using photoelectric-diode’s photo-voltaic conversion and preamplifier can measure physical quantity by measuring electronic quantity. By using a photoelectric conversion circuit to detect light brightness and convert it to digital signals is a useful method. Optical detection circuits can be used for CT scanners, hematology analyzers, smoke detectors, locations sensors, infrared pyrometer and chromatographic analyzer systems. In these circuits, the photoelectric-diode produces a weak current proportional to the illumination. The preamplifier converts the current output signal of the photoelectric-diode sensor to an available voltage signal. In this paper, through using the volt-ampere characteristic of the photoelectric-diode\textsuperscript{[1,2]}, we convert the light intensity to voltage signal to measure the visibility in the air. Visibility\textsuperscript{[3]} is the visible distance of the target, which is the maximum distance from the background when the target object is observed. It is an important item in terrestrial meteorological observations, and low visibility has many adverse effects on the transportation and electricity supply of ferries, civil aviation, highways and so on. The accurate measurement of visibility is of great importance in the fields of power supply, communication engineering and industrial and agricultural production. The estimation and measurement of visibility is influenced by a number of subjective and physical factors, and usually we use the meteorological optical vision (atmospheric transparency) as the basic atmospheric physical volume to express visibility.

This paper is organized as follows. In section 2, we present the measuring principle, the method how to measure visibility. In section 3, Photoelectric-diode volt-ampere characteristic and our model is given. Finally, the summary and conclusions are given in section 4.

Visibility Measuring Model

In this paper we use the volt-ampere characteristic of photoelectric-diode to detect the visibility of air, and the design principle is shown in the Figure 1. As the dust and particles in the air cause the reflection and scattering, which cause the light intensity of the light being attenuated according to certain rules. Usually we use extinction coefficient to describe it, and the coefficient is due to absorption and scattering caused by the measurement of attenuation. The attenuation of the light in the atmosphere for determining the distance of a path through, the Bouguer-Lambert law\textsuperscript{[4]} gives the following relation:
\[ I = I_0 e^{(-RB)} \]  

(1)

where \( I \) is the luminous flux received through the path length in the atmosphere, \( I_0 \) is luminous flux when \( b = 0 \), \( R \) is extinction coefficient, \( b \) is the distance (baseline size) between the emitting light and the receiving diode.

The transmission detection method used in this article is based on the design principle of the formula (1), to counter the proportional relationship between the receiving light and the emission light. Using the relationship between the received light intensity of the photoelectric-diode and the generated photo-current, and through the photoelectric conversion circuit, the relationship between the output voltage and the extinction coefficient is obtained, thereby measuring the visibility in the air. By measuring the transmittance \( (I / I_0) \) between the emitting light and the receiving diode to calculate extinction coefficient \( R \). From equation (1), it can be seen that the extinction coefficient measurement formula is nonlinear. That is,

\[ R = -(1/b) \ln(I / I_0) \]  

(2)

According to the Koschmic principle[5], visible distance (visibility) can be expressed as \( L = -\ln(0.05) / R = 2.996 / R \). Where 0.05 is the visual threshold for the human eye, it is usually selected as 0.05 for instrumental measurement. In 1924, Kosmidid proposed that when the target object is observed in the field (with a viewing angle of 0.5° or more), the human visual threshold value is 0.02. Therefore, under different circumstances, we can adjust the visual threshold parameters in the data simulation to achieve accurate measurement.

**Measuring Principle, Photoelectric Conversion Circuit, Model**

**Photoelectric-Diode Volt-Ampere Characteristic**

The photoelectric-diode can have a reverse current passing even under no bias operation. when the incoming light power is constant, in the case of reverse bias, the light current is almost independent of the bias voltage and load resistance in a large range, so it can be considered as a constant current source. Under the condition of no bias, the optical current of the photoelectric-diode varies greatly with the load resistance. That is, even when the load resistance is small, the photo-current is proportional to the incident light power. When the load increases, the photo-current and the light power are nonlinear. Under the condition of reverse bias, the optical current has a good linear relationship with the incident light power in the range of the applied voltage and load resistance. The relationship of the SPD short-circuit current and incoming light power is called the photoelectric characteristics of the photoelectric-diode, and photoelectric characteristics are reflected in the slope of the I-P coordinate system

\[ r \equiv \Delta I / \Delta P(\mu A / \mu W) \]  

(3)

The \( r \) is defined as the response degree of the photoelectric-diode, which is an important parameter to characterize the photoelectric conversion efficiency of photoelectric-diode.

The volt-ampere characteristic of photoelectric-diode can be expressed as

\[ I = I_0[1−\exp(qV / kT)]+I_L \]  

(4)
where $I_0$ is a light-free reverse saturation current, $V$ is the end voltage of the diode (positive voltage is positive and reverse voltage is negative), $Q$ is an electronic charge, $k$ is the Boltzmann constant, $T$ is the junction temperature, and $I_L$ is a short-circuit current in the absence of bias under the light, which is proportional to the light power of the light. In the Fig2, we show the curve of ampere-volt characteristic of photoelectric-diode.

![In this work, we use the silicon photoelectric-diode, the typical value of responsivity is between 0.25–0.5 μA/μW.](image)

**Photoelectric Conversion Circuit**

We received the output in this article through the photoelectric conversion circuit, as shown in the diagram of the photoelectric conversion circuit schematic diagram (Fig3), in which the $R_f$ is the feedback resistor. Here we should add a capacitor $C$ as the feedback capacitor, which parallels in the $R_f$ ends. The capacitor $C$ can effectively prevent the $R_f$ caused by the detection circuit self-excited, and reduce the detection circuit bandwidth, suppress noise interference. Integrated operation of the positive and negative power pins connected to two 0.1uF of the small capacitance for high-frequency filtering. In order to prevent the oscillation and noise interference, the circuit access to two bypass capacitors.

![Figure 3. Photoelectric conversion circuit schematic.](image)

![Figure 4. Pre-differential amplifier circuit.](image)

As for a single channel input condition, when we put an unstable error signal in it, the instability of the error signal will directly affect the output, then results in the stability of the circuit decline.

Therefore, we use the dual-channel differential amplifier to enlarge the front signal. The differential amplifier circuit has strong ability to restrain common-mode signal, and it can reduce the effects and errors of the device due to dark current and external temperature changes. By analyzing the Fig4, we can get the relationship between the output signal and the input signal:

$$V_o = -\frac{R_f}{R_i}V_1 + \left(\frac{R_i}{R_2+R_3}\right)(1 + \frac{R_f}{R_i})V_2$$

(5)
Measuring Principle

Through the analysis of the photoelectric conversion circuit and pre-differential amplifier circuit, considering the high input impedance of the Inverting input terminal, the optical current generated by the photoelectric-diode is almost all flowing through the $R_f$ and generate a voltage drop on it, with a high open-loop voltage gain and a reverse input with the same zero potential as the same input end, its output voltage is $V_m = IR$. Therefore, we can convert the luminous flux (light intensity) which needs to be measured into an intuitive voltage output mode, which can be retrieved by using the established program.

According to the formula (1), We can see that the output voltage is used to represent the luminous flux (light intensity) received by the photoelectric-diode. Accordingly, extinction coefficients can be described in the form of output voltages,

$$ R = -(1/b)\ln(V/V_0) $$

(8)

Then, visibility can be expressed as

$$ L = -\ln(0.05)/R = 2.996/R = -2.996b/\ln(V/V_0) $$

(9)

Data Acquisition, Program Implementation and Conclusion

According to the formula (7), we get the relationship between visibility and output voltage, through the use of Single-chip computer programming language can be measured voltage conversion to visibility, and intuitive response in our output, so as to achieve real-time measurement purposes.

By calculating the result, the relationship between the visible distance from the simulation and the output voltage is given in the Fig5. The curves represent the simulation results when the distance between the emitting light source and the receiving diode is 10cm, 15cm, and 20cm, respectively. At the same output voltage, it can be seen that the distance $b$ and the visibility is almost linear. This is the same as the qualitative analysis. Therefore, for the accuracy of measurement, we can adjust the distance to multiple measurements, and the measurement results of the statistical average will give more accurate results. At the same time, we can also give the right time at any moment in the air to see the real-time situation.

![Figure 5. The simulation result of model.](image_url)

From this, by using this property when the photoelectric-diode is under a certain reverse bias, the input illumination is linearly related to the output current. We can establish the relationship between
the output voltage and the input illuminance which calculated by the Bouguer-Lambert Law and the koschmic principle to detect visibility.

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