Optimization of Tunnel Image Short-Distance Transmission Method Based on Visible Light Communication

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Abstract. Visible light communication (VLC) technique has a wide range of applications in the daily life, the penetration rate of it is further improved in recent years, and it provides a new possibility for information transmission without traditional communication signal coverage like the tunnel or the basement. Based on the analysis of the latest research by domestic and foreign scholars, and the research of the existing device for image transmission through visible light and the particularity of the tunnel environment, this paper studies the optimization of the light source distribution, the measurement of the illuminance at the receiving end, the signal modulation and demodulation, and the encoding and decoding technology. Through the simulation experiment and the selection of existing components and technologies, the optimization of the original device is realized, so that it can be used in the tunnel information transmission and can provide certain reference for future visible light communication technique research.

1. Introduction
In recent years, the LED lighting industry has developed rapidly, and VLC using LEDs as a carrier has attracted more and more attention. By studying the current situation of VLC at home and abroad [1], it has been experimented in actual scenarios, such as data transmission under water [2], which is closely integrated with the actual situation. It can be seen that VLC is developing rapidly. Without doubt, there are still many problems. For example, the performance of existing optical transmitting and receiving devices needs to be improved; the existing information channel theoretical model has not fully taken into account of the impact of various factors in practice.

The traditional wireless way of communication is difficult to cover closed areas such as tunnels and underground parking lots, which brings difficulties in positioning. The VLC is suitable for such occasions. Using ubiquitous lighting facilities, by connecting to the external communication network, it can play the role of positioning and communication [3]. Although there have been applications for tunnel positioning [4], there is few researches on image transmission in tunnels. Therefore, this article will focus on three aspects: optimizing the distribution of light sources in the tunnel, improving the illuminance measurement method at the receiving set, improving signal modulation and demodulation, and encoding and decoding technologies.

2. Light Source Distribution Optimization

2.1. LED Distribution Optimization

2.1.1. The Characteristics of Lighting in the Tunnel. The tunnel VLC system mainly considers the downlink. At the same time, we can ignore the multipath effect caused by the diffuse line-of-sight link
in the tunnel, and only consider the direct line-of-sight link [5]. Also, the distribution of LED is regular, which means the distance between the two lights is constant and the properties of the lights are basically the same. Therefore, we firstly optimize the distribution of the LED positions at the cut planes. The average illuminance of the lower plane reaches the requirement and the average optical power of the lower plane is maximized, which provides a powerful prerequisite for the later image transmission device [6].

2.1.2. Best Received Optical Power. (1) The model of the direct channel link is shown in figure 1.

![Figure 1. The direct channel link.](image)

The radiation of a single LED conforms to the Lambertian radiation illuminance model, and the received illuminance $E_{\text{received}}$ is

$$E_{\text{received}} = \frac{(m+1)I \cos^m \phi \cos \psi}{2\pi d^2}$$  \hspace{1cm} (1)

where $m$ is the radiation pattern, $\phi$ is the emission angle, and $I$ is the LED’s total luminous flux, $\psi$ is the incident angle at the receiving end, and $d$ is the Euclidean distance between the LED and the receiving point.

And the received power $P_{\text{received}}$ is represented by the following formula:

$$P_{\text{received}} = \frac{(m+1)A}{2\pi d^2} \cos^m \phi T_s(\phi) g(\psi) \cos(\psi) P_s$$  \hspace{1cm} (2)

where $A$ is the light receiving area, $T_s(\phi)$ represents the optical filter gain, $g(\psi)$ represents the optical concentrator gain, and $P_s$ is the radiated power of the LED.

We take $T_s(\phi)$, $g(\psi)$ to be 1 when assuming, so it is only necessary to maximize the average illuminance. According to the JTG/T D70/2-01-2014, the illuminance should be greater than 4.5 lux as a general rule.

(2) Simulation

The simulation environment is MATLAB R2019a. The simulation parameters refer to the parameters of general highway tunnels. The radius of the tunnel is 5m. The radiated power of a single LED is 100lm. There are three lanes in the tunnel symmetrically distributed along the axis and the width is 3m. Since the vehicle is generally driven in the middle of the lane, it is assumed that the optical signal receiving end of the device is located at the centerline of each lane.

The illumination fitting images are shown in figures 2-4.

Assuming that the probability of passing through the left, center, and right lanes is same, we take the average of the illuminance of the three lanes as the average illuminance, and the fitting image is shown in figure 4.

(3) The result

When the device is applied to a real situation, according to the fitting image, when $h=1.8$m, the average illuminance and average optical power reach the maximum. In order to minimize the degree
of power difference received at the lower plane, where the degree of difference is represented by $D$, when $\frac{\partial D}{\partial X_1} = \frac{\partial D}{\partial Y_1} = 0$, the received optical power of the lower plane obtains the best average value. In this fitting condition, there is the optimal solution when the distance between two LEDs is 9.3 meters. Since the fitting condition of the radiant power of a single LED is 100lm, the final result does not meet the standard. According to the illuminance formula, we can increase the received power by increasing $T_s(\varphi)$, $g(\varphi)$ and $A$.

![Middle lane illumination fitting](image1)

**Figure 2.** Middle lane illumination fitting.

![Right lane illumination fitting](image2)

**Figure 3.** Right lane illumination fitting.

![Three-lane average illumination fitting](image3)

**Figure 4.** Three-lane average illumination fitting.

### 2.2. Illumination Detection Optimization

To detect the illuminance better, an illuminance detection system based on the PO188 illuminance sensor is designed. The system is mainly composed of PO188 illumination sensor, filter amplification module, STC89C52 single-chip microcomputer and LCD1602 liquid crystal display module.

#### 2.2.1. The Principle of Light Detection System

First, the characteristics of the photo-resistor are used to obtain illuminance information. Then use A/D digital-to-analog conversion to convert the resulting voltage signal into a digital signal. After that, we can use a filter amplification module to filter out clutter to reduce the impact of natural light, and then use STC89C52 microcontroller to collect data and process it, and finally display the light intensity through the liquid crystal module.

The illuminance detection device has a wide detection range, it can detect the illuminance of various environments in the range of 0-1000 Lux, which can well meet the measurement requirements of this article. The module can not only directly display the illumination, but also record data through the serial port by connecting to the computer, which is very convenient. The overall frame diagram is as shown in figure 5.

The circuit is shown in figure 6.
2.2.2. The Components of Light Detection System. (1) PO188: We use the PO188 illumination sensor to detect the illumination. It has several advantages. The current generated by this sensor changes linearly with the increase of illumination. It is highly sensitive and has a wide sensing range. It has optical filtering effects and meets the accuracy requirements of this article.

The traditional light sensor mainly uses a photo-resistor, it is easily affected by temperature, and the response speed is slow. Therefore it is not suitable for a detection element.

The PO188 illuminance sensor uses the principle of photo-resistor, which will produce different resistance values under different lighting conditions. Then use the voltage division principle to obtain different voltage values. After being filtered, the signal is processed by amplifier, then converted from digital to analog form, and finally processed by the single chip microcomputer. Then the final illuminance data is shown.

(2) STC89C52:

STC89C52 MCU is low-power, and has fast response speed, fast operation speed. Also, it is easy to operate.

3. The Signal Modulation and Demodulation Technology, and the Encoding and Decoding Technology

3.1. Duty Cycle Fixed M-ary Variable Period Modulation Technique

In order to improve the data transmission rate of VLC system and meet the modulation requirements of bandwidth efficiency, light source flicker, light and shade control and other factors in VLC, we choose to use the Duty Cycle Fixed M-ary Variable Period Modulation Technique.

3.1.1. Duty Cycle Fixed M-ary Variable Period Modulation Principle. DCF-MVPM is an improved MVPM modulation technology. Firstly, the input signals will be preprocessed into multilevel digital signals, then they will be input into DFC-MVPM modulator. In the modulation process, because the image transmission system is sensitive to the bit error rate, the original data \( m_i \) is mapped to the modulation waveform period \( T_i \) according to the gray code mapping rule.

\[
T_i = t_H + t_L + G_i \cdot t_{slot}
\]
where $m_i$ is the Gray code corresponding to $G_i$, $t_{H0}$ and $t_{L0}$ are the duration of basic high level and low level of DCF-MVPM modulation waveform respectively when $G_i$ equals zero. When $G_i$ is no longer zero, the $t_{Hi}$ and $t_{Li}$ can be evaluated by the following expressions.

$$T_i = t_{H0} + G_i \cdot \frac{t_{H0}}{t_{H0} + t_{L0}} t_{Slot}$$  \hspace{1cm} (4)

$$T_i = t_{L0} + G_i \cdot t_{Slot} - G_i \cdot \frac{t_{H0}}{t_{H0} + t_{L0}} t_{Slot}$$  \hspace{1cm} (5)

According to the preset modulation parameter $t_{H0}$, $t_{L0}$ and $t_{Slot}$, DCF-MVPM modulator can build the corresponding DCF-MVPM modulation waveform. Due to bandwidth requirements, preset parameter $t_{H0}$ and $t_{L0}$ are related to the cut-off frequency of LED. And the preset parameter $t_{Slot}$ is the time resolution interval between modulation symbols.

3.1.2. Duty Cycle Fixed M-ary Variable Period Demodulation Principle. The key step of demodulation is to measure the period $T_x$ corresponding to each waveform at the receiver. Because DCF-MVPM modulation waveform is continuous, $T_x$ can be obtained by measuring the time interval between two adjacent rising edges with the high-speed clock counter. After $T_x$ measurement, the DCF-MVPM demodulator obtains the gray code $G_x$ by the maximum likelihood decoding method. Then, the original data $m_x$ is obtained from the inverse gray code mapping.

$$m_x = dec^{-1}[G_x]$$  \hspace{1cm} (6)

3.1.3. Analysis of the Duty Cycle Fixed M-ary Variable Period Modulation. The published literatures show that the DCF-MVPM modulation technology can improve data transmission rate by changing the $t_{Slot}$ and base number. When the modulation bandwidth of the VLC system is limited in the tunnel environment. And the duty cycle of DCF-MVPM modulation technology is fixed, which can effectively avoid the flicker of light source caused by inconsistent transmission data [7].

3.2. RS-Turbo Concatenated Code

In order to ensure the reliability of information transmission in VLC channel, it is necessary to select channel coding technology with high error correction capability and high error detection capability. Based on the background of short distance image transmission in the tunnel, combined with the modulation technology of multi-system variable period, we choose RS-turbo concatenated code as our coding scheme. RS-turbo is an effective way to obtain long code in visible light channel under the tunnel environment. The specific process is shown in figure 7.

![Diagram](image_url)

**Figure 7.** The flow chart of signal processing.

Turbo code has superior performance in the environment of low signal-to-noise ratio, and has high anti-interference ability and error correction ability. However, if the error rate is reduced by increasing the number of iterations of Turbo code, it will increase the difficulty of decoding and the delay. However, when RS code is used as the outer code, replacing complex long code with multi-level
A simple short code can not only further reduce the error rate and frame error rate of Turbo inner code, but also reduce the difficulty of decoding and shorten the decoding delay [8].

The published literature shows that in the process of image compression and transmission, when the turbo code needs three iterations to make the receiving end recover the original image visually, the RS turbo concatenated code only needs one iteration of Turbo code to show the same effect, which meets the requirements of complexity and real-time for information transmission [9].

4. Conclusion

In this paper, the existing visible light image transmission knowledge is used to optimize the picture transmission system based on VLC from three aspects based on a specific tunnel environment. We use MATLAB to make illuminance fitting images under different light source distributions at different positions in the tunnel. After obtaining the best LED light source distribution, the PO188 sensor is selected to use the characteristics of the photo-resistor to obtain illuminance information by studying the advantages and disadvantages of different components. AD digital-to-analog conversion module realizes photoelectric conversion. Finally, when researching the coding and decoding and modulation and demodulation technology of the transceiver, this paper use the duty cycle fixed multi-ary variable period modulation technology and RS-Turbo coding and decoding technology to improve the data transmission efficiency of VLC system. However, there are still many shortcomings in this paper. For instance, the fitting of the light source distribution has not been realized in all directions, the physical device has not been completed, and there are still many conclusions through simulation experiments need to be verified.

Acknowledgments

The research was sponsored by The Fundamental Research Funds for the Central Universities: Research on Indoor Positioning System Based on LED Visible Light Communication (2009MS005).

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