The design of analog signal communication system based on visible light

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Abstract. With the rapid development of science and technology, communication mode has made a great leap forward, and visible optical communication has also been developed around the world. This paper mainly studies the audio signal transmission of LED visible light indoor communication. The system uses audio chip to generate audio signal. We have not only established a channel model, but also received optical signal through BH1750FVI module. In addition, we adopt the direct pulse counting frequency discrimination method for modulation and demodulation, and finally recover the original signal, achieving the purpose of voice signal transmission.

1. Introduction
At present, with the increasing development of LED lighting industry, visible light communication, a means of communication using led light as a media, has been gradually paid attention to and developed globally.

Compared with traditional incandescent lamps, LEDs consume less energy, and are more environmental friendly, so they gradually replace the lighting status of incandescent lamps. In addition, LED modulation performance is good. The communication function can be realized by loading the information to optical signals through modulation technology.

What is more, compared with radio communication, visible light communication is safer and more efficient without electromagnetic interference. Based on this, it can be used for many special occasions, such as hospital, aircraft, military and so on. By controlling the light exposure range, its space reusability is good. Also, basic lighting network is ubiquitous, and the access to communication networks can be realized at low cost.

Therefore, the visible light communication technology based on LEDs has a high research value and application prospect.

2. Model establishment
2.1. Channel model
2.1.1. Characteristics of visible light communication channel. The Figure1 shows the linear base-band transmission model of the indoor visible light communication system, where the pulse response $h(t)$ reflects the channel characteristics of the system.
In the indoor visible light communication system, the transmitter light source is white LEDs, and the intensity modulated signal is $X(t)$. The receiver uses a photoelectric sensor, and the photocurrent signal $Y(t)$ received is expressed as

$$Y(t) = RX(t) * h(t) + N(t)$$

Where $R$ is the photoelectric conversion efficiency of the photoelectric sensor; $X(t)$ is the transmitted light power; $h(t)$ is the impulse response of the channel; $N(t)$ represents additive Gaussian white noise.

2.1.2. Calculation of impulse response. The impulse response algorithm presented in this paper refers to the calculation method proposed by J.R. Barry et al. and the improved algorithm proposed by J.B. Carruthers et al.

First of all, we build the model of the light source and receiver. Light source can be generally decided by the position vector $r$, the unit direction vector $n$, the power $P$ and radiation mode function $R(\phi, \theta)$. $R(\phi, \theta)$ is defined as the energy emitted by a light source at a unit solid angle which has an angle of $(\phi, \theta)$ with $n$. When the light source of the transmitter adopts Lambert radiation model, the radiation intensity of the light source can be expressed as

$$R(\phi, \theta) = \frac{n+1}{2\pi} P \cos^n(\phi), \phi \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$$

Where $n$ is called the Lambert radiation ordinal number, whose value is related to the half-power intensity angle of the light source, and their specific relationship is

$$n = \frac{-\ln 2}{\ln(\cos \theta_2)}$$

Then the model of reflection surface is made. Assuming that all emission surfaces are ideal Lambert diffuse reflections, the radiation pattern is independent of the incident angle of light.

Finally, we use the impulse response algorithm. As for a specific light source called $S$ and receiver called $R$, the impulse response can be expressed as follows:

$$h(t; S, R) = \sum_{k=0}^{\infty} h^{(k)}(t; S, R)$$

Where $h^{(k)}(t)$ is the $k$ time reflection of the response.

We calculate the impulse response of zero degree reflection, which represents the transmission coefficient of light from one point to another without reflected light power. The impulse response of the $k$ time reflection can be iterated by the impulse response of the $(k-1)$ sub-reflection.

2.2. The model of modulation and demodulation

Assume that the modulation signal also called analog signal can be represented by a single frequency signal expressed as

$$u(t) = U \cos \omega t$$

carrier for

$$u_c(t) = U_c \cos \omega_c t$$

According to the definition of frequency modulation, the instantaneous angular frequency of FM signals is

$$\omega(t) = \omega_c + \Delta \omega(t) = \omega_c + k_t u(t)$$
It is on the basis of $\omega_c$, increased with the frequency offset proportional to $u_0(t)$. Where $k_f$ is the proportionality constant, which is called modulation sensitivity, and its unit is Hz/V. $\varphi(t)$ is the integral of instantaneous angular frequency $\omega(t)$ with respect to time, i.e.:

$$\varphi(t) = \int_0^t \omega(t) dt + \varphi_0$$  \hspace{1cm} (8)

$\varphi_0$ in the formula is the starting angular frequency of the signal. For convenience of analysis, suppose that $\varphi_0 = 0$, so

$$\varphi(t) = \omega_c + m_f \sin \Omega t$$  \hspace{1cm} (9)

Where $m_f$ is the frequency modulation index. Then the expression of FM wave is

$$u_{FM}(t) = U_c \cos[\omega_c t + m_f \sin \Omega t]$$  \hspace{1cm} (10)

The information of a modulated signal is modulated at the frequency of an FM wave. Therefore, in order to obtain the original modulation signal, it is necessary to recover the original modulation signal from the FM wave, namely, frequency discrimination. The frequency of the signal is related to the number of zeros passed in the unit time of voltage. So, the direct pulse counting frequency discrimination method is adopted.

3. Model implementation

3.1. Overall framework

The optical signal communication device can be divided into two parts: optical signal generation system and optical signal receiving system. The overall frame diagram is as shown in Figure 2.

![Figure 2. Overall frame diagram.](image)

3.2. Optical signal generation system

Optical signal generation system includes analog signal input module, modulation and optical signal output module.

3.2.1. Analog signal input module. We use the audio module analog output circuit based on audio chip, including microphone and LM386 amplifier. If the input of the circuit is audio signal, voltage signals at different times can be obtained from the output named J3 of the circuit. The internal schematic diagram is as shown in figure 3.
Sound travels in the form of waves. When encountering obstacles in the propagation path, pressure will be generated on the surface of obstacles, which is sound pressure. The microphone can detect sound pressure. The sound pressure is reflected in the microphone output level. The output level of the microphone is amplified through LM386, which is convenient for the single-chip microcomputer to read data.

### 3.2.2. Modulation and optical signal output module

The output voltage of the J3 of the sound sensor module is converted into digital voltage by AD conversion module of single-chip microcomputer and read into the single-chip microcomputer for frequency modulation. According to the result of frequency modulation, PWM wave of the corresponding frequency is output by MSP430 to control the flashing frequency of LEDs.

A digital-to-analog conversion is initiated by an ascending edge of a sampled input signal called SHI. After synchronization with ADC10CLK, the sampling timer sets SAMPCON to the height for the selected sampling period. The total sampling time is $t_{\text{sync}} + t_{\text{sample}}$ synchronization. SAMPCON starts analog-to-digital conversion when it changes from high to low, which requires 13 ADC10CLK cycles. The sampling sequence is shown in the figure.

After the current analog signal value is obtained by the single-chip microcomputer, the original signal is modulated to the high-frequency carrier by means of frequency modulation, as shown in the figure 5.
Finally, the MSP430 output modulated PWM wave is used as the control signal and connected with the LED drive module to realize the LED flashing according to the timing sequence of the modulated wave.

3.3. Optical signal receiving system

Optical signal receiving system includes the photoelectric sensor, the demodulation module and the audio output module.

3.3.1. Photoelectric sensor

Traditional light sensor mainly uses photosensitive resistances, but its photoelectric characteristic is non-linear, so it is not suitable for detection components. What is worse, photosensitive resistances need to use A/D converter to convert its signals into digital signals, the circuit is complex, high-cost, and its signal acquisition accuracy is not so ideal.

However, the ambient light sensors have the characteristics of low dark current, low illumination response, high sensitivity and linear change of current with the enhancement of illumination. Among them, BH1750FVI module is adopted as the digital photoelectric sensor, which has a wide induction range and is less affected by infrared ray, meeting the accuracy requirements of this paper. It adopts low-cost microcontroller for control, and uses I2C bus interface for data transmission, and can display real-time light intensity measurement values on the LCD.

3.3.2. Frequency demodulation module

The demodulation method adopted in this paper is the direct pulse count frequency discriminator method, and its frequency discriminator diagram is shown in the figure. $V_5$ is the input frequency modulation signal. It realizes the amplification and limiting of the bandwidth through the frequency limiter, and becomes the frequency square wave signal $V_1$. Then an equal height and shape of the same pulse sequence $V_2$ is obtained by differential network. Next, the pulse forming circuit is transformed into the corresponding rectangular pulse sequence $V_3$. Finally, we obtain the output demodulation voltage $V_4$ by low-pass filter.

The figure 6 is the frequency discriminator composition diagram.

3.3.3. Audio output module

Because the demodulation signal is very small, a small signal amplifier circuit is designed. The audio signal is amplified and eventually played through the speaker.

4. Conclusion

Based on the visible light communication of LED lights, this paper designs a system to simulate the indoor environment by using the semi-closed cubic space of 100cm*100cm*100cm. Through the optical signal generation system and the optical signal receiving system, the audio signal is modulated and demodulated, and finally the signal transmission is realized. Therefore, it can be seen that optical communication not only is safe, efficient, energy saving and environmental friendly, but also has good modulability and no electromagnetic interference. So, it has a good development prospect and research value.
Reference
[1] Chi N 2013 LED visible light communication technology Beijing: Tsinghua University Press, 2013, 33-35
[2] Liu ZH, Zhang M, Tang QW, Li JW and Qu YT 2016 Voice transmission based on visible light communication China New Communications
[3] Liao BX and Li QH 2018 Design and implementation of visible light digital and analog communication system Jiangxi Science
[4] Jovicic A, Li J, Richardson T. Visible light communication: opportunities, challenges and the path to market[J]. IEEE Communications Magazine, 2013, 51(12):26-32
[5] Chen T, Liu L, Weiwei H U. Visible Light Communication[J]. International Journal of Engineering Trends & Technology, 2013, 4(3):1337-1338