Design and Implementation of Indoor Visible Light Communication System based on High Order PAM

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Abstract: At present, most indoor visible light communication systems use switch keying, pulse position modulation and digital pulse interval modulation. These three modulation methods cannot effectively overcome the inter-symbol interference caused by the multipath effect in the visible light communication system. Compared with the above three modulation methods, high-order pulse amplitude modulation (Pulse Amplitude Modulation, PAM) transmits more bits in the same symbol, which can further improve the modulation efficiency and the communication rate of the system. At a given data rate, the inter-symbol interference caused by multipath effects can be reduced. Using TMS32C6748 floating-point DSP as the control chip of the optical communication system, an indoor visible light communication system based on high-order PAM is designed and implemented. The communication performance of the system is verified by building an experimental platform. The experimental results show that the communication system has the advantages of low bit error rate, high modulation efficiency, and high reliability, and meets the requirements of high-performance indoor visible light communication systems.

1. Introduction
LED has the advantages of low power consumption, high brightness, frequency bandwidth, no frequency license, etc., which has attracted wide attention from domestic and foreign scholars [1]. Visible Light Communication (VLC) technology is divided into indoor VLC technology and outdoor VLC technology. Outdoor VLC technology is commonly used in unmanned driving and intelligent transportation systems [2]. The indoor VLC system is mainly used for broadband access to the network [3]. At present, the realization of an actual VLC system still faces many problems [4], such as the influence of indoor multipath dispersion and shadow occlusion on the communication performance of the system [5].

The domestic VLC research is relatively late, and the research on indoor VLC mainly focuses on the modulation method to improve the VLC rate. At present, most indoor VLC systems use On-Off Keying (OOK), Pulse Position Modulation (PPM), Binary Phase Shift Keying (BPSK) and other modulations [6], which cannot be effectively overcome Inter-symbol interference caused by multipath effects in indoor VLC systems. High-order pulse amplitude modulation (Pulse Amplitude Modulation, PAM) can transmit more bits in the same symbol. At a given data rate, high-order PAM modulation can reduce inter-symbol interference caused by multipath effects [7]. In view of the above problems, the use of high-order PAM modulation in a short-distance indoor VLC system can further improve the modulation efficiency of the system and reduce inter-symbol interference caused by multipath effects. This article uses a data processor with TMS320C6748 as the core (this DSP has a lower power consumption...
design [8] compared to other TMS320C6000 platform DSP), based on high-order PAM design and implementation of a high-reliability indoor VLC system, and conducted performance testing and verification indoors.

2. Optical communication system

2.1. The overall design of the system

The overall block diagram of an indoor VLC system based on high-order PAM is shown in Figure 1, which mainly includes two parts: the transmitter and the receiver. This system mainly includes personal computer (Personal Computer, PC), DSP, digital to analog (Digital To Analog Conversion, DAC) module, high-speed LED driver, photo detector module, analog to digital (Analog-To-Digital Converter, ADC) as well as other modules.

![Figure 1. Block diagram of indoor visible light communication system](image)

At the transmitting end, first send the source data from the PC to the DSP processing module via the serial port, then the DSP encodes the data by M-PAM, then adds the frame header to the encoded data and encapsulates it into a frame, and then modulates the modulated data. The M-PAM data frame is converted into an analog signal through the DAC, and finally the modulated signal is emitted through the LED.

At the receiving end, after the modulation signal sent by the LED reaches the receiving end through the indoor channel transmission, the optical signal is first converted into a current signal through the APD module, and the current signal is converted into a voltage signal by the current voltage conversion module, and then the ADC converts the analog voltage signal into digital signals, the DSP performs frame synchronization judgment. After the synchronization is completed, the data is transmitted to the DSP for demodulation and decoding. Finally, the decoded information is transmitted to the PC via the serial port, and real-time error rate analysis is performed.

Indoor VLC links are generally divided into two types: one is a direct line-of-sight link, and the other is a diffuse reflection link [9]. The two types of visible light link channel models are shown in Figure 2. The direct line-of-sight link method is that the LED light source directly illuminates the photodiode. This method has the advantages of high power utilization, low background noise, low channel loss, and easy construction. However, this link has high requirements on the transmission channel. If an obstacle occurs in the link, the communication quality will be reduced, or even communication interruption will occur. The diffuse reflection link method is used for communication that is not easy to be blocked by obstacles, and the communication coverage is wide. Since the light beam will be reflected at least once, the communication system will have multipath effects and limit the communication rate. After comprehensive consideration, the first direct transmission method is selected as the link of the indoor VLC system.
2.2. **Hardware design**

2.2.1. **DSP control module**

In this paper, the TMS320C6748 digital signal processor is selected as the control chip of the indoor VLC system. The DSP is a floating-point processor based on C674xDSP. It not only has fast calculation speed, low power consumption, high integration, rich resources, but also the handy chip. There is a floating point operation unit inside, which can effectively improve the calculation performance and algorithm execution speed.

The DSP adopts a 6-layer board layout design in the design, strictly equals the length of the non-volatile memory (NOR FLASH) and synchronous dynamic random access memory (SDRAM), and uses the professional power management chip LM26480 to power the chip. The DSP board resources as shown in Figure 3. It includes: 1 piece of 1Gbit DDR2_SDRAM, 1 piece of 64Mbit Nor Flash, MAX706 professional reset circuit, MAX3232 serial port, 1 USB_OTG, 1 SD card, 1 100M Ethernet, 1 IIC_EPPROM, external EMIFA bus, etc. 400M main frequency clock is provided by 25M active crystal oscillato.

![Figure 3. Physical picture of TMS320C6748 development board](image)

2.2.2. **High-speed LED drive circuit**

There are two main factors that affect LED high-speed modulation: carrier lifetime and junction capacitance. Affected by these two factors, the modulation bandwidth of LEDs is usually only tens of MHz, which will limit the application of LEDs in high-rate systems. By designing a reasonable LED drive circuit, the modulation bandwidth of the LED can be increased, and the quality of the drive circuit directly affects the modulation bandwidth and modulation effect of the LED. The specific driving principle of the LED is shown in Figure 4. If the LED works in the linear range and emits light stably, a stable constant current source is required to provide the bias voltage , and the quality of the constant current source will also affect the service life of the LED. In order to increase the received
light intensity of the photodiode at the receiving end and reduce the spread of the light beam sent by the LED, a lens can be added in front of the LED to improve its light-gathering ability.

![Diagram](image)

Figure 4. Block diagram of LED drive modulation principle

2.3. Software design

2.3.1. Transmitter implementation

The indoor VLC system based on high-order PAM mainly includes transmitter software and receiver software. The transmitting terminal program is mainly including that the DSP receives the data sent by the PC through the serial port, and then the DSP encodes the data in PAM4, and encapsulates the frame synchronization sequence into a complete data frame. The DSP transmits the modulation information to the DAC (AD9708) through the GPIO, thereby The digital quantity is converted into an analog quantity, and finally loaded to the LED through the LED drive circuit for transmission. The program flow chart of the sending end is shown as in Fig.

![Diagram](image)

Figure 5. Program design flow chart of the sender

A schematic diagram of the frame structure based on high-level PAM indoor VLC is shown in Figure 6. The data frame header is composed of a Barker code synchronization sequence and a symbol synchronization sequence. The frame synchronization sequence used in this design is \{6,9,5,11,3,15,4,15,12,7\}, each of which represents the position of the high-level time slot in the modulation. The longer the sequence of the Barker code, the higher the error tolerance rate during frame synchronization, but the longer the sequence, the higher the difficulty of decoding.

![Diagram](image)

Figure 6. Schematic diagram of data frame structure
2.3.2. Receiving end realization

The indoor VLC receiver program is mainly divided into two parts: frame synchronization and data demodulation. First, the DSP judges the frame header, and needs to adjust the time slot after the frame synchronization is completed. This is because the sampling points cannot be aligned in the two-end discrimination algorithm. In order to solve this problem, the system adjusts the time slot based on the sliding window algorithm, as shown in Figure 7. This method needs to process each sampling point, that is, each time the accumulation window moves one sampling point, moves 10 times in sequence, and then starts to compare the two ends. When the middle value is the maximum value, the time slots are considered to be aligned.

![Figure 7. Use the sliding window algorithm to complete the time slot adjustment](image)

Subsequent DSP performs high-level PAM decoding and demodulation, CRC check, and sends the demodulated data to the PC. The flow chart of the receiving software is shown in Figure 8. The demodulation of PAM4 is to use AD (AD9280) for 10 times sampling, and the 10 times sampling value of each time slot is accumulated, and each accumulated value will be at the corresponding decision interval threshold, and finally the binary code of PAM4 is demodulated. "00", "01", "10", "11".

![Figure 8. Receiver software flow chart](image)

3. Experimental results and analysis

In order to verify the communication performance of the indoor optical communication system designed in this paper, a high-order PAM4 indoor VLC system was built according to the overall scheme shown in Figure 1. The electrical and optical modulation are shown in Figure 9 and Figure 10, respectively. Connecting the DSP of the sending end and the receiving end to the PC through the serial port, and read the uploaded text information with the bit error rate analyzer written by the internal staff of the laboratory on the PC end, and then transmit it to the sending DSP. The sending end DSP modulates the received data by PAM4, and then loads the modulated data to the DAC module, and finally the drive circuit sends the data in the form of optical signals; the receiving end uses the APD module to convert the optical signals into electrical signals, which are demodulated Then send the data to the PC through the serial port. The bit error rate analyzer counts the error code elements and calculates the bit error rate in real time.
The bit error rate is an indicator that reflects the accuracy of data transmitted within a specified time and is an important parameter of the communication system. Therefore, in order to verify the stability of the system hardware platform and the feasibility of the sliding window algorithm, the communication rate is 10Mbit. Under different communication distances, analyzing the bit error rate of the designed PAM4 indoor VLC system, The bit error rate obtained by the test is shown in Table 1.

| distance (m) | Send symbol (bit) | Number of error symbols (bit) | System error rate |
|-------------|-----------------|-------------------------------|------------------|
| 1.0         | 110860          | 59                            | 3.37e-4          |
| 1.5         | 110860          | 101                           | 5.63e-4          |
| 2.0         | 110860          | 241                           | 1.30e-3          |
| 2.5         | 110860          | 859                           | 4.75e-3          |

PAM4 with sliding window algorithm

| distance (m) | Send symbol (bit) | Number of error symbols (bit) | System error rate |
|-------------|-----------------|-------------------------------|------------------|
| 1.0         | 110860          | 0                             | 0                |
| 1.5         | 110860          | 0                             | 0                |
| 2.0         | 110860          | 1                             | 5.52e-6          |
| 2.5         | 110860          | 29                            | 1.54e-4          |

It can be seen from the above table that if the sliding window algorithm is not used for time slot adjustment, when the communication distance is 1 meter, the system error rate is about 10^-4, and when the distance increases to 2 meters, the system error rate exceeds 10^-3. If the sliding window algorithm is used for time slot adjustment, when the communication distance is 1 meter, the system error rate is below 10^-6, and when the distance increases to 2.5 meters, the system error rate is about 10^-4. It is verified that the sliding window time slot synchronization algorithm can improve the frame synchronization effect of the indoor visible communication system, enhance the stability of the system, and the test achieves the expected results. At the same time, the test found that when the LED light source is not equipped with a lens. Because the optical signal passes through the channel attenuation and divergence, the signal at the receiving end becomes worse and the bit error rate increases sharply.

4. Conclusion
Indoor VLC technology is a new communication technology with an important position in the field of wireless communication. This article designs and implements an indoor VLC system based on high-level PAM. In order to solve the power consumption problem of the TMS320C6000 series, the TMS320C6748 floating-point digital signal processor with high speed and lower power consumption is selected as the core processing chip of this design, and the indoor is realized by using ADC, DAC, LED driver and APD detector. Reliable communication with visible light. The test results show that the use of time slot synchronization algorithm can improve the reliability of frame header.
synchronization and reduce the system error rate. This system has the advantages of simple structure, stable and reliable, low bit error rate, etc., and has certain engineering application value.

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