Research and Prospect on Key Technologies of Indoor Positioning Based on Visible Light Communication

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Abstract. Indoor positioning has become a research hotspot because of its important application value in industrial production and daily life. Traditional wireless positioning technologies such as Wi-Fi and Bluetooth are difficult to achieve high-precision indoor positioning due to electromagnetic interference and multipath effect. The modulated white LED can not only meet the needs of lighting, but also transmit the location information to achieve high-precision indoor positioning. This paper introduces several modulation methods commonly used in visible light positioning systems, compares the characteristics of different modulation methods, and proposes a modulation method suitable for visible light positioning. Then, two demodulation methods of the visible light positioning system are introduced and discussed; After that, several visible light location algorithms are introduced, and the performance of each algorithm is analyzed in detail; Finally, the problems in visible light positioning are discussed and prospected.

1. Introduction
Compared with the traditional indoor positioning scheme, the visible light indoor positioning technology is based on the visible light communication, so it has the characteristics of high positioning accuracy, low cost, less additional facilities modules, high confidentiality and lighting. There are two kinds of existing visible light positioning technology schemes. The first one loads position information on the LED light source. The characteristic of this kind of scheme is that the positioning accuracy is mainly determined by the lighting area of the lamp. The other is to achieve positioning by obtaining the light intensity of LED. The characteristic of this kind of scheme is that the positioning accuracy is mainly determined by the lighting area of the lamp. The other is to achieve positioning by obtaining the light intensity of LED. The feature of this method is that it can improve the positioning accuracy, even reach centimeter level, but it has higher requirements for mobile phone software and hardware [1].

2. Overview of Visible Light Positioning System Structure
The typical structure of LED visible light positioning system is shown in Figure 1.

![Figure 1. Schematic diagram of visible light positioning system](image-url)

A complete visible light positioning system is composed of driver module, LED lamps, receiver and other parts. The transmitter of the system is an array composed of multiple LEDs, which can provide illumination and emit light information. The light signal is transmitted through the space
channel and received by the receiver, and the position of the receiver is calculated through the positioning algorithm. The workflow of the system is mainly divided into three steps: optical signal modulation, optical signal receiving and position calculation. Optical signal modulation loads the position information to each led through modulation, so that the LEDs in different positions carry different position information. Optical signal reception refers to the use of a specific receiver (CCD, PD, etc.) to receive the LED signal. Generally, when receiving the optical signal, there is a photoelectric conversion process, which converts the optical signal into electrical signal for processing. Finally, the signal received by the receiver is processed by the positioning algorithm to calculate the position coordinates of the receiver. Visible light positioning system generally realizes positioning through the above three steps. Next, this paper introduces the key technologies of visible light positioning system from three aspects of signal modulation, receiving demodulation and positioning algorithm.

3. Visible Light Positioning Modulation Method
Visible light positioning is an indoor positioning method based on LED visible light communication technology. IEEE 802.15.7 defines the standard of visible light communication, mainly for the research of modulation scheme and dimming support of visible light communication. In order to make efficient use of energy and meet the lighting needs of different scenes, visible light communication requires LED light source to have dimming function, so that the system can maintain normal communication at any light intensity level. At present, the mainstream modulation methods used in research include OOK modulation, PPM modulation, OFDM modulation, FSK modulation and so on. Because the purpose of visible light communication is to achieve high-speed and effective transmission of information, a modulation mode with high speed and strong anti-interference is needed. But the visible light positioning is different from communication. In the visible light positioning system, each LED, as the transmitter of the signal, only sends its own location information. Compared with the general communication system, the amount of information transmitted is much less, so there is no high requirement for the information transmission rate, which can be met in tens of Kbps. In contrast, the visible light positioning system pays more attention to the anti-interference ability and the overall complexity of the modulation mode. FSK modulation has low complexity, simple implementation and good anti-interference ability, so it is an ideal adjustment scheme for the current visible light positioning system (Table 1).

| Modulation mode | Velocity | Dimming | Flicker problem | Anti-interference | Complexity |
|-----------------|----------|---------|-----------------|-------------------|------------|
| OOK             | Slow     | Support | High            | Weak              | Low        |
| PPM             | Secondary| Support | Supported       | Middle            | Secondary  |
| OFDM            | High     | Unsupported | Low          | Strong            | High       |
| FSK             | Secondary| Unsupported | Low          | Middle            | Lower      |

4. Visible Light Positioning and Receiving Method
At present, the receiving methods of visible light positioning system are mainly divided into two kinds, one is to use image sensor for imaging receiving, the other is to use photodiode and other equipment for non imaging receiving.

4.1. Imaging Reception Formatting the Title
Image sensor can be used to receive optical signal. There are many ways to receive optical signal using image sensor. In reference [2], the LED array was imaged by the method of image sensor and lens, and the target position was calculated by the geometric relationship of distance. In addition, the widely used camera of smart phone is a typical image sensing device [3]. Because there are a large number of photodetectors on the camera sensor, the camera does not scan all the pixels at one time, but scan line by line, which is the rolling shutter effect of the camera. The rolling shutter effect of the
camera can improve the transmission rate of information. As shown in Fig. 2, for the FSK system, suppose that the LED constantly switches between the light and dark states when sending signals. When the LED is in the "on" state, the image sensor will receive a line of bright stripes (Fig. 2a). When the LED is in the "dark" state, the image sensor will receive a line of dark stripes (Fig. 2b). Repeat the above process, Finally, the image sensor receives the image of LED light with light and dark stripes (Fig. 2C). According to the fringe spacing of the received image, the optical information sent by the LED transmitter can be calculated.

4.2. Non Imaging Reception

In the non imaging receiving of optical signal, photodiode is a typical method to receive optical signal. This receiving scheme needs an independent module, in which the optical electrical signal conversion is completed. Figure 3 is an optical signal receiving module developed by Beijing leibosi Optoelectronic Technology Co.Ltd. the signal can be received by the photodiode and transmitted to the mobile phone through the audio interface for subsequent calculation and processing (Figure 3a), or the positioning solution can be completed in an independent module with calculation function (Figure 3B), and then the calculated position information can be sent out through Bluetooth and other methods.

Compared with the image sensor, the sampling rate of photodiode is higher, which can reach the megahertz level.

5. Analysis of Visible Light Location Algorithm

At present, visible light localization algorithms are mainly divided into imaging localization and non imaging localization. Image location algorithm uses image sensor to receive signals from multiple LED lights, and then calculates the location information. Non imaging localization algorithms include ID method, scene analysis method, triangulation method and so on. Triangulation method realizes positioning calculation by measuring distance or angle, including angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA) and signal strength (RSS). The classification of visible light location algorithm is shown in Figure 4.
5.1. Imaging Location Algorithm

The whole system structure is shown in Fig. 5. The system uses three LEDs whose coordinates are known as the transmitting end. The light emitted by the LEDs passes through the imaging lens and is received by the image sensor at the receiving end, and their three-dimensional position coordinates are calculated. The accuracy of imaging positioning algorithm is related to the resolution of sensor, and generally has high positioning accuracy [5].

5.2. Non Imaging Localization Algorithm

In visible light positioning, non imaging positioning algorithms mainly include simple ID positioning method, scene analysis method by analyzing and comparing light intensity information, and triangulation method by calculating distance. Triangulation method calculates position by measuring angle, time, light intensity and other parameters.

ID Method. In the led-id positioning method, the control terminal loads the position information to the LED lamps through coding modulation, so that each LED lamp carries its own unique position information [4]. LED will send out the information in the form of optical signal, which is received by the receiver at the receiving end. Through the identification of the optical signal, the received ID information is determined to achieve positioning, as shown in Figure 6.
Figure 6. Schematic diagram of ID positioning method

**Scenario Analysis.** The scene analysis method compares the light intensity information received by the receiver with the known light intensity distribution, and finds out the points with similar light intensity characteristics as the coordinates of the receiver. The scene analysis method is mainly divided into two steps: the establishment of fingerprint database and real-time positioning. Generally, the establishment of fingerprint database is to grid the scene, measure the light intensity information of each point and record it in the fingerprint database. In the real-time positioning stage, the light intensity signal received by the receiver is compared with the points in the fingerprint database, so as to find the similar points as the positioning coordinates.

**Triangulation.** AOA method realizes positioning by measuring the angle of multiple LED lights reaching the receiver, and its principle is shown in Figure 7.

Figure 7. AOA positioning principle

Toa positioning system calculates the distance (RI) between the receiver and LED lamps by measuring the time (TI) from the LED transmitter to the receiver, \( RI = C \times Ti \), where \( C \) is the speed of light. To achieve the positioning of the receiver, at least three LED signals need to be received. The system principle is shown in Figure 8.
Figure 8. Toa positioning principle

RSS positioning algorithm calculates the distance by detecting the light intensity, so as to achieve positioning. The accuracy of RSS positioning method is related to the distribution of light intensity. Establishing a reasonable channel model can greatly improve the positioning accuracy.

5.3. Summary of Positioning Methods

| Location algorithm      | Accuracy | Complexity | Velocity | Anti-interference | Portability | Cost   |
|-------------------------|----------|------------|----------|-------------------|-------------|--------|
| Imaging location        | High     | Higher     | Fast     | Strong            | Strong      | Higher |
| Non imaging ID Method   | Uncertain| Low        | Faster   | Weak              | Weaker      | Low    |
| Scene analysis          | Uncertain| High       | Faster   | Weak              | Weaker      | Higher |
| Triangulation AOA       | High     | Higher     | Middle   | Stronger          | Strong      | Higher |
| TOA                     | Higher   | Lower      | Middle   | Stronger          | Strong      | Higher |
| TDOA                    | Middle   | Higher     | Middle   | Stronger          | Strong      | Higher |

The performance and characteristics of the above LED indoor visible light positioning algorithms are compared, and the results are shown in Table 2. Image location algorithm uses image sensor to estimate the distance of LED, and then realizes the location. The positioning accuracy of this method is related to the resolution of each part of the system, and generally has high positioning accuracy. Due to the popularity of smart phones, using mobile phone cameras as image sensors to receive and process signals can effectively reduce the cost and complexity of the system. Therefore, the scheme has high research value and application prospect. In the non imaging positioning algorithm, ID positioning method uses the label signal from each led to achieve positioning. This method has the advantages of simple system and easy implementation. However, the positioning accuracy of ID method depends on the density of lamps, so the positioning accuracy is generally low and the anti-interference ability is poor. Scene analysis method uses the collected optical signal to compare with fingerprint database to achieve positioning, which has fast positioning speed, no distance calculation process and low power consumption. However, the scene analysis method needs to establish fingerprint database in advance, which has poor portability for different scenes. In addition, due to the attenuation of LED luminous flux, the fingerprint database data will gradually become invalid with the passage of time, affecting the positioning effect.

Triangulation is one of the traditional positioning algorithms. In triangulation, AOA algorithm calculates azimuth by angle measurement, which has high accuracy. However, because AOA algorithm needs specific angle sensor, it is not easy to combine with existing intelligent devices and promote. TOA and TDOA algorithm calculate the distance by measuring the time of arrival or the
time difference. Although TDOA algorithm does not need the clock synchronization between the sender and the receiver, both algorithms need the synchronization between the LEDs at the sender. In the case of large indoor environment area and large number of LEDs, it is difficult to achieve synchronization between each transmitter, so these two methods are not convenient for large-scale promotion and application. RSS starts from the channel model of LED downlink, establishes the relationship between illumination and distance, and calculates the distance by measuring light intensity. At present, it has achieved positioning accuracy within 10 cm. To sum up, RSS positioning algorithm has high accuracy, simple system and easy implementation. It is a high neutral price positioning algorithm for visible light positioning algorithm.

6. Summary and Prospect
In this paper, the modulation, receiving scheme and positioning algorithm of visible light positioning system are introduced and compared. In all modulation and algorithm schemes, considering the positioning effect and system cost, the positioning scheme based on FSK modulation and RSS algorithm is proposed. Compared with other positioning schemes, the system has higher positioning accuracy and anti-interference ability, and has the advantages of simple structure, easy implementation, low cost and high promotion value. The following technical problems need to be solved in the future: for NLOS channel, an appropriate iterative algorithm is used to solve the problem of accuracy degradation caused by multipath effect such as wall reflection in RSS algorithm; 2) For Los channel, it is necessary to solve the noise interference caused by ambient light (such as sunlight); 3) The integrated positioning algorithm combining visible light positioning and inertial navigation positioning is developed to solve the problem that the visible light positioning cannot work due to the occlusion of light signal; 4) Through the design of the optical antenna at the transmitter and receiver of the positioning system, the overall accuracy and stability of the positioning system are improved.

With the advantages of high accuracy, no electromagnetic radiation and low cost, visible light positioning has a very high application prospect in industrial production scenes such as warehouse positioning, underground mine positioning and daily life fields such as shopping malls, underground parking lots and hospitals. With the large-scale promotion and application of LED, it is believed that visible light positioning will become the mainstream of indoor positioning in the future.

7. References
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