Research on Indoor Visible Light Positioning System Based on FDM-RSS

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Abstract. As people become more active in indoor activities, the demand for indoor positioning technology is increasing. This design is a visible light indoor positioning device based on frequency division multiplexing technology. The device uses three LED lamps as the optical signal generating device and performs photoelectric conversion using the photoelectric sensor Po188 to obtain a voltage signal reflecting the light intensity. Finally, we use stm32 microcontroller to read the voltage signal obtained through the amplifier circuit and filter circuit, and use the three-side positioning method to calculate the position of the sensor in the plane, thus achieving the positioning function.

Introduction

At present, with the increasing demand for positioning and navigation services, positioning technology has received more and more attention. Although GPS has been widely used in outdoor environments, its accuracy is limited due to the attenuation of wireless signals and the effects of multipath effects indoors. The current mainstream indoor positioning system uses a radio frequency signal [1], which is susceptible to interference when traveling in the air. Therefore, it is limited to be used in special scenarios such as airplanes and hospitals.

Recently, with the rapid development of the LED lighting industry, visible light communication (VLC) has been developed globally. The indoor positioning technology based on visible light communication has the advantages of high accuracy, safety and freedom from electromagnetic interference. It can meet the lighting needs, but also reduces power consumption and costs. Therefore, it has increasingly important practical significance and broad application prospects.

Overall Structure

The visible light indoor positioning device consists of three parts: an optical signal generating system, an optical signal receiving system, and a signal processing positioning system. The overall idea is as follows.

The optical signal generation system uses the three pins of the msp430 microcontroller to output PWM waves of three frequencies. The signal controls the on and off of the transistor switch to achieve three LED lights flashing at three preset frequencies respectively. The frequency of the optical signal and the intensity of the optical signal at different locations convey the encoded information and position information of the LED lamp. This is the process of encoding the optical signal.

The optical signal receiving system receives the light signals of the three LED lights simultaneously using the light illuminance sensor Po188, and converts the light signals into the voltage corresponding to the light intensity at this time. The frequency of this voltage change is the superposition of the three LED flashing frequencies. After obtaining the voltage signal, we process...
the voltage signal through a signal processing system including an amplifier circuit and a Butterworth band-pass filter, and restore the voltage signal to three original frequencies and output them separately. This is the process of decoding optically encoded information. The voltages at these three frequencies depend on the distance between the sensor Po188 and the corresponding small lamp. Therefore, we use the different frequencies obtained after filtering to calculate the distance of the sensor from the corresponding frequency LED lamp. According to the three-side positioning algorithm, we can calculate the distance of the sensor from the three light sources through the stm32 single-chip microcomputer, so that the position of the sensor on the plane can be obtained. Ultimately, we can achieve visible light indoor positioning based on frequency division multiplexing.

System Principle

Channel Model

The positioning device based on LED is shown in Figure 1. Three LED lights on the board constitute a signal module, emitting light signals of different frequencies under the control of MCU. For ease of calculation, the module is proposed to adopt an equilateral triangle arrangement. LED belongs to Lambertian light source and the transmission environment is direct link. So the functional relationship between received power \( P_j \) and transmitted power \( P_{ij} \) is:

\[
P_j = P_{ij} \times H(0)
\]

\( H(0) \) can be called the DC gain and in the Lambeitian radiation model \([2]\), it is:

\[
H(0) = \frac{A(m+1)}{2\pi d^2} \cos^m(\theta) Z(\phi) \cos(\phi)
\]

\( M \) is the light order, and its expression is:

\[
m = -\frac{\ln 2}{\ln(\cos(\theta/2))}
\]

\( A \) is the receiving area, \( d \) represents the distance between light source and receiver, \( \theta \) can be regarded as radiation angle, \( \phi \) is the incident angle, and \( z(\phi) \) is the gain. Obviously, the received power is related to the angle of the light, the transmission distance and the nature of the light source itself.

We introduce the photosensitivity constant \( \tau \), and then equation (1) can be expressed as:

\[
P_j = P_{ij} \times \frac{\tau}{d^2}
\]

Because the induced current is proportional to the received power \( P_j \), which is \( P_j = ki \), the distance \( d \) is:

\[
d = \sqrt[2]{\frac{\tau}{ki}}
\]

In the analysis above, we discussed the changes of the relevant physical parameters in the process of receiving signals and gave the calculation methods for converting the physical into geometric, which make the computer modeling calculation realized.
FDM Filtering Principle

The periodic signal’s Fourier transform is:

\[
F_T(j\omega) = 2\pi \sum_{n=-\infty}^{\infty} \hat{F}_n\delta(\omega - n\omega_1)
\]  
(6)

\[
\hat{F}_n = \frac{1}{T} \int_{-T/2}^{T/2} f_T(t)e^{-j\omega t} dt
\]  
(7)

The periodic rectangular pulse emitted by the LED can be transformed into

\[
F_T(j\omega) = \frac{2\pi\tau}{T} \sum_{n=-\infty}^{\infty} S\left(\frac{n\omega_1}{2}\right)\delta(\omega - n\omega_1)
\]  
(8)

Spectral density is closely related to its cycle and the impulse function is decentralized relatively at high frequency, so three signal generators adopt different frequencies. For instance, Filter A is put into use at the frequency range from \(a\) to \(b\), while Filter B is worth choosing from \(b\) to \(c\). In a similar way, between \(b\) and \(c\), Filter C is suited.

The experiments proved that when filters are chosen in overlapping sections, the high-frequency signal has few effects on the low-frequency signal, because of their small band-pass and low impulse signal density in correspondence with high-frequency signal.

After a band-pass filter working, the composite signal from the three kinds of LED light source is separated out. The amplitudes of their frequency and voltage are not the same. Besides, frequency
corresponds to the light source, and there is a kind of functional relationship between voltage and distance.

**RSS Triangulation Algorithm**

After receiving the LED signals of different frequencies, the sensor induces a composite current. The current can be changed into three sets of information by FDM filtered and we can gain the distance of $D_1, D_2, D_3$.

The sensor coordinates $(x, y)$. There is [3]:

\[
\begin{aligned}
D_1^2 - H^2 &= d_1^2 \\
D_2^2 - H^2 &= d_2^2 \\
D_3^2 - H^2 &= d_3^2
\end{aligned}
\]

$H$ is the height of the LED to the lower board. By solving

\[
\begin{aligned}
(x - x_a)^2 + (y - y_a)^2 &= d_1^2 \\
(x - x_b)^2 + (y - y_b)^2 &= d_2^2 \\
(x - x_c)^2 + (y - y_c)^2 &= d_3^2
\end{aligned}
\]

we can get the location of the sensor, $(x_a, y_a), (x_b, y_b), (x_c, y_c)$ are regarded as the coordinates of the three LED projections.

**Hardware Test**

We packaged the entire device in a cubic space of $80\text{cm} \times 80\text{cm} \times 80\text{cm}$ (including the top, bottom, and three sides). Three white LED lights were placed on the top of the plane, controlled and driven by the LED control circuit. The bottom plane was divided into five areas, identified as A, B, C, D, E, respectively, drawn by vertical and horizontal coordinate lines (space 5cm) with a total of 64 small squares (as is shown below).

![Bottom plane coordinates](image)

In order to ensure that the device can realistically simulate the actual environment, we turned off the lights and withdrew the curtains to gain natural lighting as well as avoid direct sunlight conditions.

The test process is mainly composed of four parts. Firstly, the illuminance sensor simultaneously accepted the light signals of the three LED lights and was converted into the voltage corresponding to the light intensity at this time. Then the distance between the sensor and LED lamp with the corresponding frequency was calculated by the voltage values at different frequencies after filtering, the precision reaching 0.1 cm. Afterwards, because the entire coordinate system was divided into 5 large areas, the position of the sensor on the plane could be intuitively displayed. Finally, the time from the beginning of each position measurement to the locked display of the measured coordinate...
value was 2.95 s. Besides, if an unexpected situation did not result in a correct visible light coordinate point, this positioning could be displayed in error.

We selected the center points of 64 small squares as the test points, and obtained the voltage value to reflect the received light intensity at each point. The simulation charts are as follows.

![Figure 6. LED1 light intensity distribution.](image1)
![Figure 7. LED2 light intensity distribution.](image2)
![Figure 8. LED3 light intensity distribution.](image3)
![Figure 9. Overall light intensity distribution.](image4)

In addition, considering the interference of external factors such as noise, we choose area A to analyze the error, and read the voltage values at (10.1,-30.3) at intervals of 2.95s, as is shown in the data sheet.

| Number | Position [cm] | Voltage [V] | V1  | V2  | V3  |
|--------|---------------|-------------|-----|-----|-----|
| 1      | (10.1,-30.3)  |             | 2.157 | 2.458 | 0.541 |
| 2      | (10.1,-30.3)  |             | 2.154 | 2.462 | 0.541 |
| 3      | (10.1,-30.3)  |             | 2.161 | 2.467 | 0.537 |
| 4      | (10.1,-30.3)  |             | 2.166 | 2.477 | 0.546 |
| 5      | (10.1,-30.3)  |             | 2.163 | 2.490 | 0.543 |

We regard the first set of data as a reference and use the second, third, fourth, and fifth sets of data for absolute error analysis. The results of the data are shown in the table below.

| Number | Absolute error | △V1 | △V2 | △V3 |
|--------|----------------|-----|-----|-----|
| 1      | 0.000          | 0.000 | 0.000 |
| 2      | -0.003         | 0.004 | 0.000 |
| 3      | 0.007          | 0.009 | -0.004 |
| 4      | 0.009          | -0.011 | 0.005 |
| 5      | 0.006          | 0.032 | 0.002 |

According to the test results above, their absolute values are about 0.01 cm. Therefore, the device has a high accuracy and is less affected by external disturbances.
In summary, this visible light indoor positioning device can correctly achieve positioning.

Conclusion
The visible indoor positioning technology, with LED light as the carrier, has the advantages of no electromagnetic radiation, high bandwidth, high speed, energy saving, environmental protection and so forth. This device has a well-designed architecture, better functional circuits, and an excellent system performance. By using Butterworth band-pass filter, the narrow bandwidth is 50Hz, so the filtering effect is very good. And the integral ADC is used in the positioning to eliminate the AD sampling error caused by glitches. In addition, the introduction of frequency division multiplexing technology in optical communication is suitable for high-speed data transmission with a high time utilization rate, a strong anti-interference ability, and less limited environmental conditions, which has a certain development and innovation for the indoor positioning technology. At present, visible light indoor positioning is in the development stage, and it has good application prospects in smart home and Internet of things.

References
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