# Study of NLOS effect on Indoor Visible Light Positioning in Different Room Sizes

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## ABSTRACT

*In indoor visible light positioning systems, indoor reflections in different room size will cause different impact on positioning accuracy. In this work, we investigate the RSS-based positioning errors with different room size. Results show that when the room size increases, positioning accuracy is becoming higher. When room size reaches 15m*15m*3m, the maximum positioning error due to non-line-of-sight (NLOS) is only 1 mm worse than that for line-of-sight (LOS) case. Thus, if room size exceeds this value, we can ignore NLOS effect. We also considered the effect of LED half power angle and receiver field-of-view changes on maximum positioning error. Results show that the former has greater impact on positioning.*

**Keywords:** *non-line-of-sight (NLOS), room size, maximum positioning error, RSS, field-of-view*

## 1. INTRODUCTION

The researches on visible light communication (VLC) could be traced back almost two decades ago. The first proposed VLC using white-light LED was in 2000 [1]. Due to LED small size, high luminous efficiency, long life, low light decay and energy saving, it is also possible to be one of the best choices for indoor positioning.

Most researchers usually assume that the indoor channel is a line-of-sight (LOS) model for the positioning system. However, in the actual complex indoor environment, it will cause reflection, and positioning distortion is inevitable. In order to reduce the impact of multipath, many methods are proposed. For example, adopting OFDM can reduce the influence of positioning caused by reflection [2]. In [3], the LOS-NLOS signal recognition algorithm is proposed. Although these methods can reduce the effect of reflection on positioning, it can bring computational complexity and other new problems. Fundamental research show that different room sizes have different effects on reflection, but we do not know how large for a room we can ignore the effects of reflection. The research has also shown that changing in transmitter half power angle and receiver FOV can reduce the reflected signal, but we do not know how the respective attenuation affects the final positioning accuracy. Therefore, the impact of different room sizes, LED half power angle and receiver field-of-view (FOV) on NLOS will be mainly considered in this paper.

The layout of this paper is as follows. In Section 2, we briefly introduce the VLC optical channel. In section 3, Three-point positioning algorithm based on RSS is analyzed. Then we consider the impact of different room sizes, LED half power angle and receiver field-of-view (FOV) on positioning, respectively. We show simulation results and discussions in section 4. Section 5 gives the conclusion.

## 2. SYSTEM MODEL

We consider a typical indoor positioning system using VLC as shown in Fig.1. The three LED lights source are installed in the ceiling. The received is located in the 4m*4m square area. Due to the reflection through the walls has a greater impact on positioning, so we only consider walls are treated as the reflected surfaces. Model parameters relevant to the system are listed in table1.

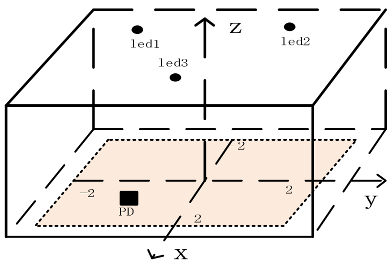


Fig.1. System Model

Table1 System Parameters

| Parameter | Value |
|---|---|
| LED power | 3w |
| Position of the LED (x, y, z) | (-1.25, -1.25,3) m, (-1.25, 1.25,3) m, (1.25,0,3) m |
| LED half power angle | 80 deg |
| FOV | 80 deg |
| Room size | (5*5*3) m, (7*7*3) m (9*9*3) m, (15*15*3) m |
| Reflection coefficient | 0.66 |
| Receiver area | $10^{-4}m^2$ |

In the line of sight (LOS), the channel DC gain is given as:

$$H_d(0) = \begin{cases} \frac{(m+1)A\cos^m(\theta)\cos(\psi)T_s g}{2\pi d^2}, (0 \le \psi \le \psi_C) \\ 0, (\psi > \psi_C) \end{cases} \quad (1)$$

Where $\theta$ and $\psi$ are the emission angle of the light source and the incident angle of the receiver respectively. *Ts* and g respectively represent the optical filter gain and the optical focusing gain of the receiver; *A* is receiver effective receiving area; *d* is the linear distance between the receiver and the LED; $\psi_c$ denotes the width of the field of view at a receiver; *m* is the Lambertian emission order of LED sources

For NLOS, the received power is given by the channel DC gain on directed path $H_d(0)$ and reflected path $H_{ref}(0)$:

$$P_r = \sum^{leds} \left\{ P_t H_d(0) + \int_{walls} P_t dH_{ref}(0) \right\} \quad (2)$$

The channel DC gain on the first reflection is [4]:

$$dH_{ref}(0) = \begin{cases} \frac{(m+1) A\rho dA_{wall} \cos^m(\Phi)\cos(\alpha)\cos(\beta) T_S g \cos(\Psi)}{2\pi d_1^2 d_2^2}, 0 \le \Psi \le \psi_c \\ 0, \Psi > \psi_c \end{cases} \quad (3)$$

Where $d_1$ is the distance between an led and a reflective point, $d_2$ is the distance between a reflective point and a receiver, ρ is the reflectance factor, $dA_{wall}$ is a reflective area of small region, $\Psi$ is the angle of irradiance to a reflective point, $\alpha$ is the angle of irradiance to a reflective point, $\beta$ is the angle of irradiance to the receiver.

## 3. THREE-POINT POSITIONING ALGORITHM BASED ON RSS

The RSS method is widely used in indoor visible light positioning systems. We apply three-point positioning based on RSS. As equation (1) described, due to LED plane and receiver plane are parallel, so

$$\cos(\theta) = \cos(\psi) = \frac{h}{d_i} \quad (4)$$

Therefore, the distance $d_i$ between $i^{th}$ LED and receiver can be calculated as [5]:

$$d_i = \sqrt[m+3]{\frac{(m+1)AT_S g P_t h^{(m+1)}}{2\pi P_r^{(i)}}} \quad (5)$$

Given $d_i$, the horizontal distance can be calculated as:

$$r_i = \sqrt{d_i^2 - h^2} \quad (6)$$

According to the three-point positioning, the receiver coordinates (i.e., (x, y)) can be obtained using following equations:

$$(x - x_i)^2 + (y - y_i)^2 = r_i^2 \quad (7)$$

Where i =1, 2, 3 in our system, $(x_i, y_i)$ express the horizontal coordinates of the $i^{th}$ transmitter decoded from the LED. The receiver coordinate $X = [x, y]^T$ can be calculated with linear estimation as:

$$X = (A^T A)^{-1} A^T B \quad (8)$$

$$A = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \end{bmatrix} \quad (9)$$

$$B = \frac{1}{2}\begin{bmatrix} (r_1^2 - r_2^2) + (x_2^2 + y_2^2) - (x_1^2 + y_1^2) \\ (r_1^2 - r_3^2) + (x_3^2 + y_3^2) - (x_1^2 + y_1^2) \end{bmatrix} \quad (10)$$

## 4. EFFECT OF DIFFERNCE ROOM SIZES ON POSITIONING

Since the light will reflect through the wall, the receiver will not only receive the direct signal but also the reflected signal. Known from the channel DC gain (3), changing the value of $d_1$ or $d_2$ will affect the first channel.

We assume that the LED source and receiver are fixed in position. Only the influence of the front, rear, left and right walls of the room on reflection is considered. We increase the length and width of the room, then the value of $d_1$ or $d_2$ will be also increase. Thus, with attenuated the first components, the impact on positioning will be reduced due to increased room size. When the room size is increased to a certain extent, the reflection from the wall will have almost no influence on the positioning. At this time, the receiver could only receive the direct signal, thus the positioning accuracy is very high. When $\Psi$ exceeds the LED half power angle or $\beta$ exceeds the receiver FOV, the receiver cannot receive the signal reflected by the wall, so the first reflection gain is reduced in (3), and the effect of NLOS on positioning is also reduced.

### 4.1 Scenario for the LOS path

If we don't consider the first reflection, the receiver only receives direct optical signals and noise signals. The positioning error is shown in Fig.2.

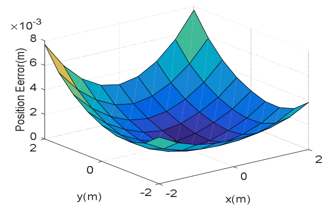


Fig.2. Position Error distribution with LOS

The worst positioning error is around 8mm as an ideal scenario. When no reflections are considered, the position errors only come from the thermal noise and shot noise which are small [6].

### 4.2 Scenario for NLOS path in different room sizes

In the room, different room sizes will cause different positioning effects. Four different room sizes were considered.

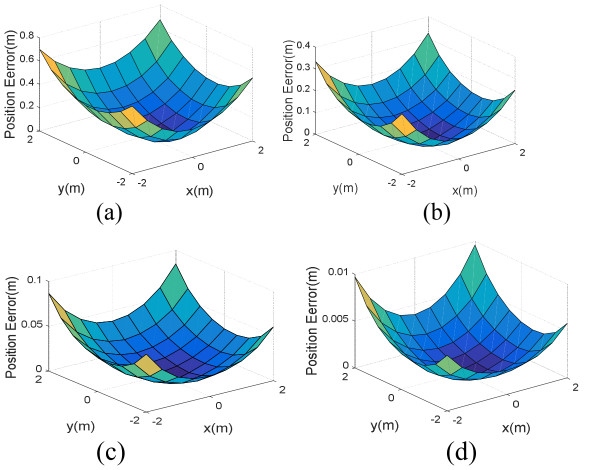


Fig.3. Positioning error distribution with the first reflection based on different room sizes: (a) 5m*5m*3m, (b) 7m*7m*3m, (c) 9m*9m*3m, (d) 15m*15m*3m

From the Fig.3, we can find that with the size of the room continues to increase, the positioning error becomes smaller. It can be seen that increasing the size of the room can attenuate the adverse effects of the first reflection on positioning.

Fig.4 compares the maximum positioning error in different room sizes. We can find that with the length and width of the room continue to increase, the positioning accuracy becomes more accurate. When the indoor room size is 15m*15m*3m, the maximum positioning error is only 9mm. Compared with only considering LOS, positioning error is 1mm worse.

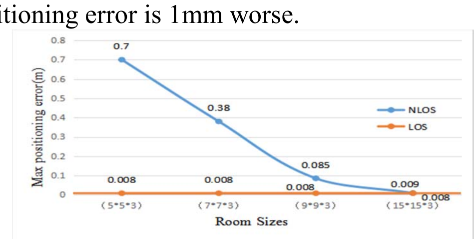


Fig.4. the maximum positioning error with different room sizes

### 4.3 Effect of LED half power angle and receiver FOV

We choose the indoor room size to be 5m*5m*3m, and evaluate the effect of NLOS on positioning by changing the LED half power angle or receiver FOV.

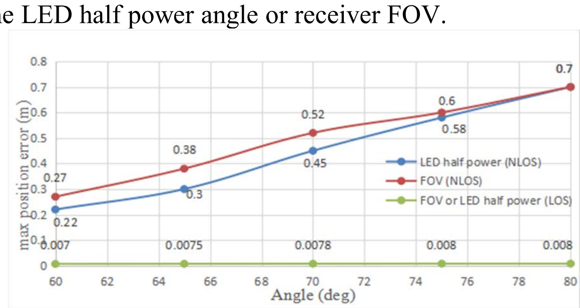


Fig.5. Analysis of the maximum positioning error when only changing the LED half power angle or receiver FOV in the case of LOS and NLOS

From the Fig.5, the LED half power angle or receiver FOV is from 80 deg to 60 deg. In the LOS case, the maximum positioning error remains almost unchanged and the two lines are approximately coincident. But the maximum positioning error is smaller in the NLOS case. We can also find that only when changing the LED half power angle, the maximum positioning error decreases faster than just changing the FOV. Therefore, it shows that changing the half power angle has a greater impact on NLOS. But, if the LED half power angle or the receiver FOV continues to decrease, it will eventually lead to positioning failure, because the receiver will not receive the transmitted light source at that time. So, in order to meet the basic requirements of positioning, the LED half power angle and receiver FOV should not be too small.

## 5. CONCLUSION

In this paper, we simulate and analyze the effect of room size changes on NLOS based on the RSS three-point positioning algorithm. Results show that with the increase of room size, the positioning accuracy can be higher. When the room size reaches 15m*15m*3m, consider the case of the first reflection and only consider in the case of a direct path, the positioning error is only 1 mm worse. So, if the room size exceeds this value, we can ignore NLOS effect. We also studied the effects of LED half power angle and receiver FOV changes with NLOS. Results show that the former will have more influence on the maximum positioning error.

## 6. REFERENCE


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