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Improved Received Signal Strength Ratio Based High Accuracy Indoor Visible Light Positioning Scheme

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Abstract

With the increasingly development of Light-emitting Diode (LED) lighting, in this paper, we proposed an Indoor Visible Light Positioning (VLP) Scheme by using visible LED lights for accurate localization. The basic idea of the position scheme is to improve received signal strength ratio algorithm. Received signal strength ratio (RSSR) is the relative ratio of optical powers detected between each LED and optical receiver. In this paper, we introduce concept of multiple LEDs selection to improve RSSR positioning algorithm. By three LEDs are reasonably selected from the multiple LEDs deployed in the room, the positioning accuracy of RSSR is improved. The system can be employed easily because it does not require additional sensors and occlusion problem in visible light would be alleviated. In addition, we performed the simulation experiments, and confirmed the feasibility of our proposed method.

Keywords: *Visible Light Positioning, Received signal strength ratio, Multiple LEDs selection, Occlusion.*

1. Introduction

Indoor positioning systems (IPSs) have become very popular in recent years. These systems provide a service called automatic object localization and there are many real-world applications that employ the techniques. A lot of positioning techniques using GPS, RFID, Bluetooth, WiFi [1, 2] have been investigated. Nevertheless, there is no perfect method for indoor positioning analogous to using GPS in outdoor positioning systems. Aside from the expense, RF-based systems also have disadvantages with security and safety issues because RF signals can go beyond the room [3]. RF signals are also unsuitable to use in hospitals, airplanes, or certain hazardous environments. Moreover, almost all existing methods have limitations such as low accuracy and poor security. Although decades of research have sought a viable method, there is still no system for indoor positioning that is cheap, accurate, and widely available [4].

Nonetheless, in recent years, an approach for indoor positioning using visible light from light-emitting diodes (LEDs) has received attention from some researchers. LEDs have many desirable properties such as low power consumption, low voltage, long lifetime, small size, and cool operation, and hold promise as being viable position sensors [5, 6]. This provides an unprecedented opportunity for visible light positioning (VLP) to overcome deficiencies in other methods. With the rapid development of LED technology, illumination systems using LEDs will be deployed in almost every building and they can be used to build indoor positioning systems with just a little extra cost. This is particularly

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very useful. Although previous studies have used visible light for indoor positioning [7–8], none achieves high accuracy or simple implementation.

These position methods based on LEDs mainly include image sensors [9], received signal strength (RSS), and time difference of arrival (TDOA) [10]. For indoor environment, the short distance between transmitter and receiver, which leads to the transmission time of the signal is very short, and require of the accuracy and synchronization of the transmitter and receiver are very high, which makes the TOA and TDOA technology difficult to achieve. In addition, it requires at least three anchors to obtain the plane-domain (2D) localization and four anchors for 3D localization. The RSS technology is one of the solutions for indoor positioning using visible light. RSS fingerprints can be easily obtained for most off-the-shelf equipment such as Wireless or ZigBee compatible devices. But RSS technology is easily affected by the indoor environment and multipath effect. When an electromagnetic wave propagates and encounters objects such as walls and floors, reflections, diffraction, and scattering occur. RSS is influenced not only by the distance but also by any obstacles between the transmitter and receiver [11]. Moreover, it is influenced by multipath effects. Thus, RSS is sensitive to the above factors.

South Korea S.Y.Jung et.al [12] first proposed the received signal strength ratio for indoor visible light positioning Method. This algorithm has the advantages of high theoretical accuracy and low system complexity. In this paper, we introduce concept of multiple LEDs selection to improve RSSR positioning algorithm.

2. Related Theory and Work

2.1 Outline of Proposed System

We shall present first an outline of the system leaving the design details of the VLP and improved RSSR model to following subsections. Figure 1 shows an outline of our system structure. Our system is setup in a room measuring 5×5×3 m^3. In next chapter we will give detail VIP and proposed position algorithm design.

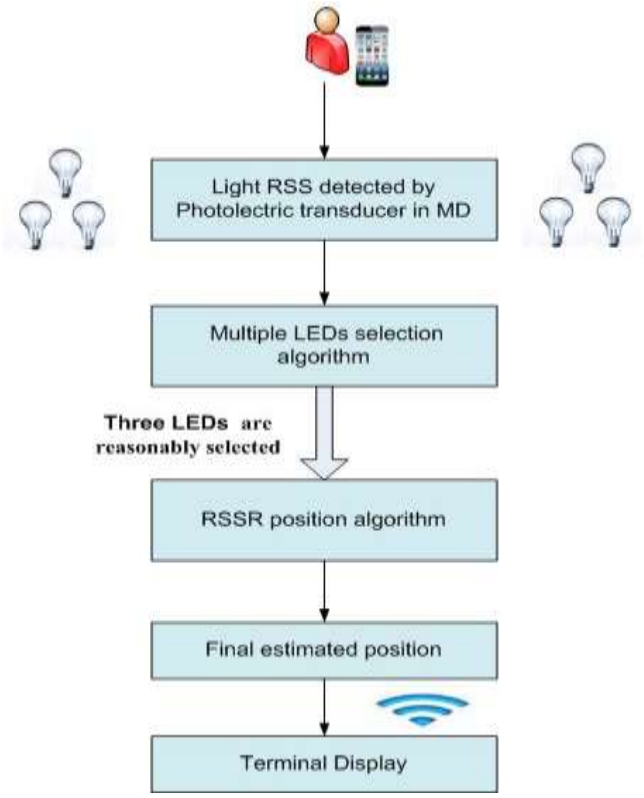


Figure 1. Outline of the System Structure

First, we use six LED lamps for illumination as access points that they continuously transmit different position information in a closed room. When a people (target) with photoelectric transducer in mobile device (MD) enter the room, the RSS information from six LED lamps will be detected by MD. These RSS information will be import to Multiple LEDs selection algorithm which is descripted in next section. In this algorithm, three LEDS are reasonably selected to as the source of parameters in RSSR position algorithm. The final estimated position obtained by RSSR position algorithm will be transmitted to display terminal via WIFI network.

2.2 Design and Model of VLP System

In the indoor VLP system, LEDs at a fixed position in the ceiling emits light signals with position information. The VLP system widely used in indoor positioning is illustrated in Figure 2. We see that the position of each LED panel is specified once the distance from the outer panel to its nearest wall is known [13]. The receiver can be placed anywhere under these LED panels

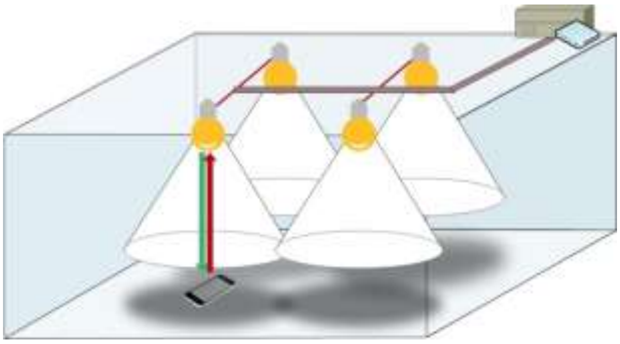


Figure 2. Position Model of VLP System

The light signals are decoded and demodulated after being detected by the light sensor carried by the moving target. Next, using the position algorithm, the position of the moving target is analyzed based on the position information. The communication structure of the VLP system is depicted in Figure 3.

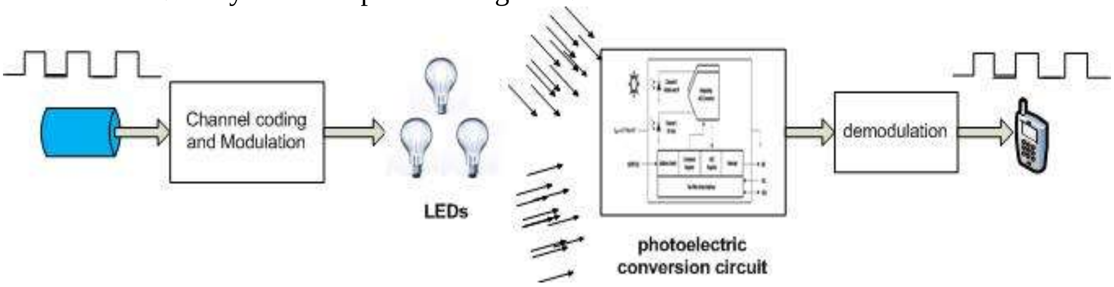


Figure 3. The Communication Structure of VLP System

In VLP system, the received power could be expressed using the distance between transmitter and receiver. The received signal power is inversely proportional to the square of distance. Assuming that the light radiated from LED and reflected from the walls having a Lambertian radiation pattern, the impulse response at the receiver of the direct and reflected light from LED lamp is given by equation (1). It is used in our simulation [14].

$$P_r = P_t \times H(0) \quad (1)$$

Where is the received power, also described as received signal strength (RSS) is the average transmitted optical power H(0) is the impulse response of the direct light given by Eq. (2),

$$H(0) = \frac{A_r(m+1)}{2\pi d^2} \cos^m(\emptyset) T_s(\varphi) g(\varphi) \cos(\varphi) \quad (2)$$

In the equations above, are the irradiance angles of the light from LED. d is the distance between the transmitter and receiver. is the physical area of the detector in the PD. and g(φ) are the optical filter and concentrator gain. m is the order of Lambertian emission, which is related to the semi-angle at half power $\Phi_{1/2}$ by the equation (3):

$$m = -\frac{ln2}{\ln(\cos(\Phi_{\frac{1}{2}}))} \quad (3)$$

2.3 Improved RSSR Position Algorithm

We load signal information into three LEDs at three different time slots, and the optical power values received by such three LEDs are PR_1, PR_2 and PR_3 respectively. Using Eq. (1) (2) (3), the RSSR between two LEDs, $RSSR_{12}$, is calculated by taking the relative ratio PR_1/PR_2 and is given by Eq. (4) as below:

$$RSSR_{12} = \frac{P_{r1}}{P_{r2}} = \frac{K/d_1^{m+3}}{K/d_2^{m+3}} = (\frac{d_2}{d_1})^{m+3}$$

(4)

For the same, $RSSR_{13}$ is calculated by taking the relative ratio PR_1/PR_3 as below:

$$RSSR_{13} = \frac{P_{r1}}{P_{r3}} = \frac{K/d_1^{m+3}}{K/d_3^{m+3}} = (\frac{d_3}{d_1})^{m+3}$$

(5)

Figure 4 shows the two possible trace of the object in the ratio of d_2/d_1 and d_3/d_1 from LED_1 and LED_2, LED_1 and LED_3.When the distance ratio d_2/d_1 is R_{12}, (LED_x, LED_y, h) are the coordinates of each LED lamp in the ceiling, and (x; y; 0) are the object coordinates at a random position on the floor, so we can deduce below equation.

$$\begin{cases} \dfrac{\sqrt{(x-LED2_X)^2+(y-LED2_y)^2+h^2}}{\sqrt{(x-LED1_X)^2+(y-LED1_y)^2+h^2}} = \dfrac{d2}{d1} = R_{12} \\ \dfrac{\sqrt{(x-LED3_X)^2+(y-LED3_y)^2+h^2}}{\sqrt{(x-LED1_X)^2+(y-LED1_y)^2+h^2}} = \dfrac{d3}{d1} = R_{13} \end{cases}$$

(6)

=>

$$(x-\frac{LED2_X - R_{12}^2 LED1_X}{1-R_{12}^2})^2 + (y-\frac{LED2_Y - R_{12}^2 LED1_Y}{1-R_{12}^2})^2$$

$$= \frac{R_{12}^2}{(1-R_{12}^2)^2}\{(LED1_X - LED2_X)^2 + (LED1_Y - LED2_Y)^2\} - h^2$$

$$(x-\frac{LED3_X - R_{13}^2 LED1_X}{1-R_{13}^2})^2 + (y-\frac{LED3_Y - R_{13}^2 LED1_Y}{1-R_{13}^2})^2$$

$$= \frac{R_{13}^2}{(1-R_{13}^2)^2}\{(LED1_X - LED3_X)^2 + (LED1_Y - LED3_Y)^2\} - h^2$$

(7)

As a special case of R_{12} or R_{13}, the trace of (x; y) is more simplified to a straight line. By Eq. (7), we can calculate MD's coordinate (x; y).

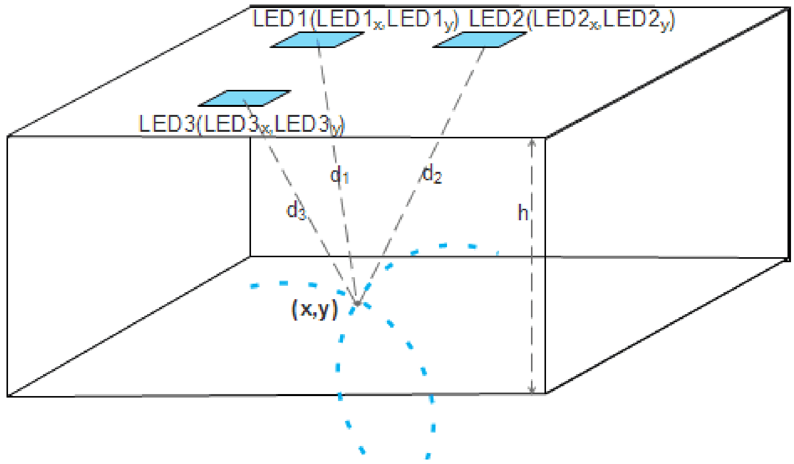


Figure 4. Position Trace of the Detector Satisfying Received Signal Strength Ratio (RSSR)

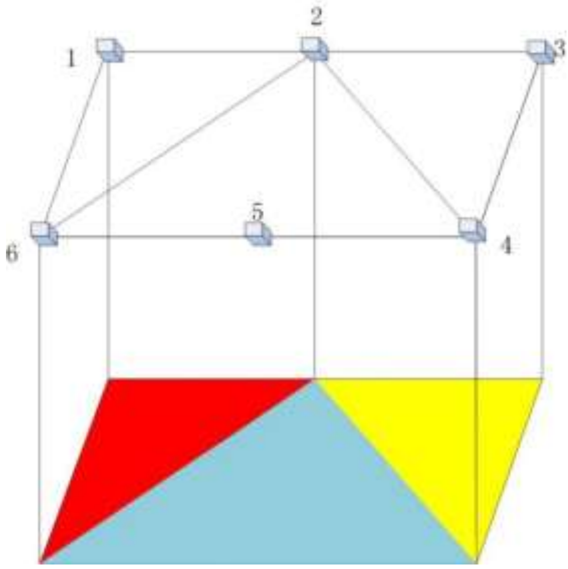
From Eq. (4) and (5), we can see that the MD position result will appear huge error if occlusion problem occur or the distance between AP and MD. Therefore we introduce six LEDs as input parameters of RSSR position algorithm. Under the condition of six LEDs, the number of LED combinations can be selected for the 20 species. A reasonable selection LED combinations can improve greatly the position performance. In this paper, we propose a LEDs combinations principle.

First, three LEDs cannot be a collineation in spatial distribution because equations will be no solution. Furthermore, these LEDs should construct strong signal acute triangle structure. It means that three sides of the triangle must meet:

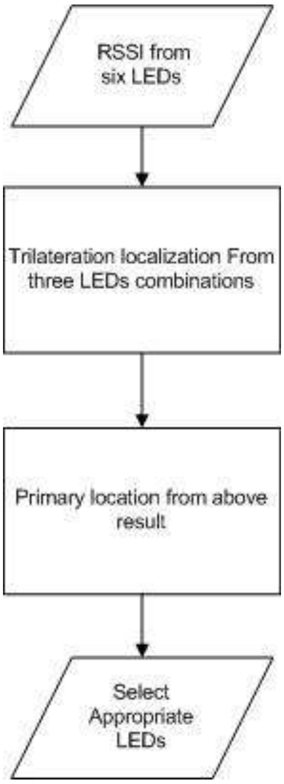
$$a^2 + b^2 >= c^2, (a > b > c)$$

(8)

Where a, b, and c means the distance between each LEDs. According to previous researches [15 - 16], the positioning accuracy is poor when a small angle exists in the triangle. On this basis, we further verified this conclusion by simulation. Simulation results show that positioning error of an obtuse triangle greater than straight and acute triangle. Figure5 shows the three of LEDs combinations. The Coordinates of LEDs are (0.5, 0.5), (4.5, 0.5), (4.5, 4.5), (0.5, 4.5), (2, 0.5), (2, 4.5). We divided the closed room into three LEDs combinations that they are (LED_1, LED_2 LED_5), (LED_2, LED_3, LED_4), and (LED_2, LED_4, LED_5), respectively. We obtain the primary coordinate of MD by triangle positioning from three LEDs combinations. And then system selects an appropriate LEDs combination as parameters output to RSSR algorithm. The flow of Multiple LEDs selection is shown as Figure 5 (b).



(a)



(b)

Figure 5. (a) Algorithm Application Model, (b) Flow of Three LEDs Selection

3. Simulation Result and Discussion

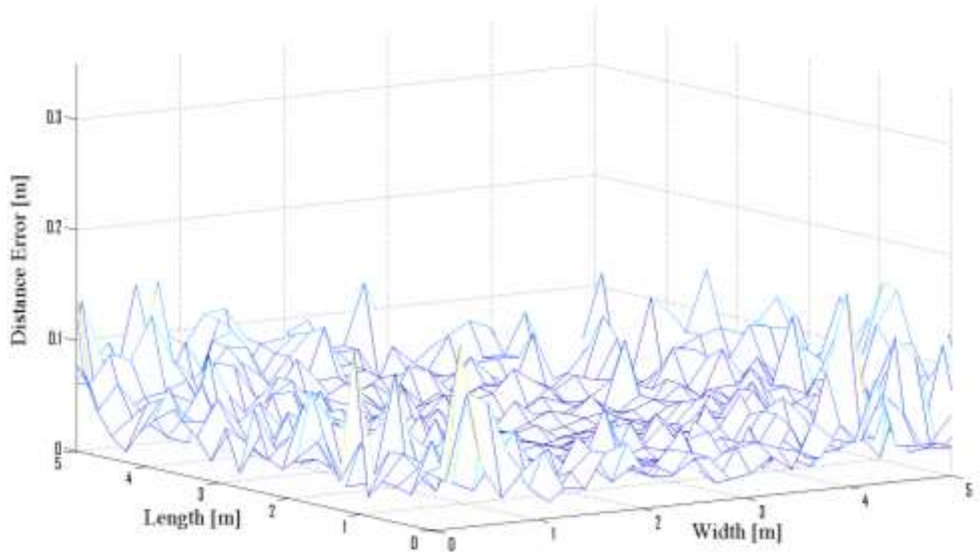
To investigate the feasibility of our proposed method, we performed simulation experiments. We begin by introducing the simulation environment and then give results and a discussion a comparison of results from various position determining methods.

Using the MATLAB platform, we simulate the system established earlier configuring the room and LED placements as described in Section. 2. The specifications of the LED array and room model are listed in Table 1. The coordinates of the LEDs are (0.5, 0.5), (4.5, 0.5), (4.5, 4.5), (0.5, 4.5), (2, 0.5), (2, 4.5) and the shadows on the floor are the illumination area. The lighting equipment is installed at a height of 0.5 m below the ceiling. 1000 simulated points are equally spaced in the room. Each simulated point will be at a distance of 0.16m from its neighbors. It not only makes sure the accuracy but also is feasible in practical application.

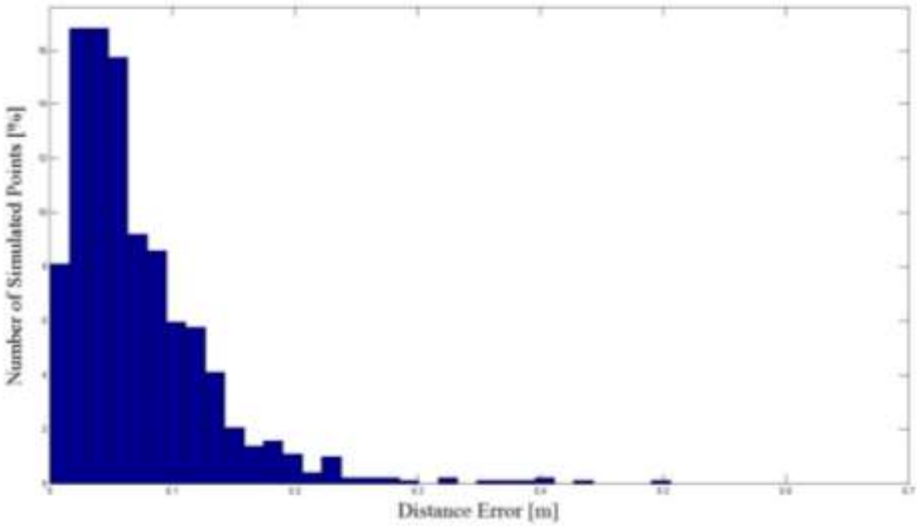
Table 1. The Specification of LED and Room Model

Parameters	Value
Room model	5*5*3 m^3
Coordinate of LEDs	(0.5, 0.5), (4.5, 0.5), (4.5,4.5), (0.5,4.5), (2, 0.5), (2, 4.5)
Experiment points	1000
Semi-angle at half power	70°
FOV at a receiver	60°
Gain of an optical filter	1.0
Detector area in PD	1.0 cm^2

Figure 6(a) shows the distribution of estimation distance errors in all over the room. It is easy to see that at the region near the walls and especially near the corner. The performance is not good compared to that at the center. This is because the reflected light has more impact than the direct light in these regions. On the whole, the error of the experiment points in the whole room is near a mean value. Positioning result did not appear too large fluctuations in several simulations. Figure 6(b) shows the histogram of the estimation distance error. We see that the distance error is less than 10.0 cm at most regions in the room. The average error is about 7.0 cm.



(a)



(b)

Figure 6. (a) The performance of positioning system. It is a distribution of estimation distance error. (b) Histogram of estimation distance error

In order to estimate the performance of proposed method, we simulate several mainstream positioning methods in the same computer environment to compare their advantages and disadvantages. Table 2 shows the comparison result of various positioning methods. From Table.2, we can see that average position error based on Fingerprint-database is the smallest, while that of proposed method is about 6.9 cm. Compared to the RSSR method, the improvement of proposed method is that the maximum error is reduced. Moreover, we notice that although the accuracy of Fingerprint method is relatively high, its running time is very long. The positioning time of Fingerprint is about several times more than that of our proposed method because each point needs to match the entire database to produce the best results. For practical applications, real-time is also an important factor. Proposed method has obvious advantages in this sense.

Table 2. The comparison result for different methods

Methods	Average position error (cm)	Maximum error (cm)	Running time
Fingerprint database	5.6	9.2	Long
Multimode fusion	10.2	18.9	Medium
RSSR	7.2	14.3	Short
Proposed method	6.9	10.6	Short

The advantages of positioning by improved RSSR algorithm in VLP system proposed in our paper are a) high efficiency as a result of avoiding many iterations and integral calculations and b) high accuracy especially when the obstacle happens in a room. The position error was mainly caused by measurement error, noises, and reflections from the wall.

4. Conclusion

In this paper, we propose an indoor visible light positioning based on improved RSSR algorithm. Using the RSSR, circle or straight line equations are obtained and the crossing point of the equations indicates the position. Based on it, we introduce concept of multiple LEDs selection to improve RSSR positioning algorithm. The positioning accuracy is improved by proposed method. The simulation results show that our system can achieve a high accuracy estimation of 7.0 cm in average. The advantages of proposed system are that the error could be alleviated when obstacle happens and high efficiency. As a future work, the proposed positioning system will be implemented and experimented.

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