A Novel Integrated Model for Positioning Indoor MISO VLC Exploiting Non-Light-of-Sight Communication

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***Abstract*— Visible light communication (VLC) has increasingly been a popular research area. Base on VLC, practical positioning solutions are provided. This work proposes a combination between a triangulation-based RSS and NLOS-based fingerprinting that estimates the object position in case of two transmitter blockages in a 4x1 multiple-input single-output (MISO) VLC system. A triangulation-based RSS is applied to identify the potential positions of the object. Then, the NLOS-based fingerprinting model determines the current of object location base on matching RSS of potential positions to offline reference data. The offline reference data is previously stored by calculating the received power from reflected light. This proposed solution is verified and evaluated through simulation.**

Keywords—Positioning, MISO VLC, Integrated model, Reflection, RSS, fingerprinting

I. Introduction

LED (light-emitting diode) is widely integrated into the light system of human society due to its long lifetime, reasonable price, low energy consumption, minimal heat operation lighting, well visibility. In addition, the LEDs can be modulated at extremely high frequency which results in provide a high-data-rate system. Taking these LED's advantages, the Visible Light Communication (VLC) based LED is promising wireless communication technology. In comparison with radio-frequency (RF), VLC can offer more outstanding points such as higher throughput, security, and larger multiuser capacity [1]. In terms of indoor positioning, Various positioning algorithms-based VLC has been extensively studied and demonstrates much higher accuracy than RF [2-3].

Theoretically, there are several positioning algorithms namely proximity, fingerprinting, triangulation. The triangulation is most paid attention to due to higher accuracy compare to others. The object position is located by using the geometric properties of triangles, including angulation and time delay. Involving angulation, the Angle of Arrival (AoA) scheme calculated the angle of signal arrival from the different LEDs to estimate the position of the object [4-6]. Whereas, the Time of Arrival (ToA) and Time Different of Arrival utilizes the arrival time of light to estimate the position [7-10]. A triangulation-based RSS obtains the user position through the measuring power of the received signal [11-12]. In this attempt, at least three transmitters are required to determine the exact position which is the intersection point of three circles with the center of the LED location.

Therefore, in the case of only two transmitters available, the mentioned positioning algorithm is not fully working and leads to the error position estimation. There are some existing works that addressed this issue. In [13-14], the current position is identified by calculating the distance between the possible points and an adjacent previous position. This scheme can achieve error estimation in case of the same distance value.

This paper introduces the integrated model of A triangulation-based RSS and NLOS-based fingerprinting. Similar to the proposed work, a triangulation-based RSS is used to find out the candidate points. Whereas, NLOS-based fingerprinting RSS matrix of reflection model as well as the offline-reference data. The RSS of the candidate point is scanned over the offline-reference data to estimate the current position. The scheme is demonstrated that despite two transmitters available, the proposed system is fully working with a reasonable result. This result is verified by MATLAB simulation.

The rest of the paper is organized as follows. Section II introduces the 4x1 MISO system. The proposed scheme is analyzed in section III. Section IV gives out the simulation result and discussion. Finally, Section V is the conclusion..

II. MISO VLC SYSTEM

A. MISO VLC system architecture

In this paper, the 4x1 MISO VLC is showed in Fig 1. There are four transmitters (LED array) that are installed in the ceiling, send multiple signals simultaneously direct to a receiver. The receiver is a photodiode detector (PD) which is located on the floor and can move randomly in a range of the 2-D geographic room.

B. Mathematic model of system

The communication system is figured out in fig 2. The transmitted data is denoted by $x_j, where\ j = 1, \dots k\ is\ the\ transmitter\ index$. Assuming that NRZ-OOK modulation technique is utilized to modulate the optical signal with pulse duration of T, the transmitted optical power is given as follow:

$$X_j = x_j \times u(t) \tag{1}$$

The LED is provided the power of P, the pulse function is given as follows:

$$u(t) = \begin{cases} P, & 0 \le t \le T \\ 0, & Otherwise \end{cases} \tag{2}$$

At receiver side, each transmitter is assigned ID to detect. the optical power received of corresponding X_j is given as follow:

$$Y_j = \sigma \times H \times X_j + N \tag{3}$$

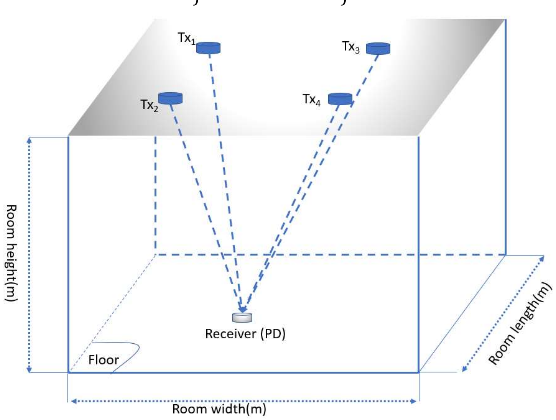

Figure 1. MISO VLC system architecture

There are three factors that impact directly recovered data. Firstly, σ the environmental coefficient determined by the weather condition. However, this proposed work take place in indoor place, it has no impact by environment and thus $\sigma = 1$. Secondly, N is the additive white Gaussian noise. Finally, the channel matrix H of dimension $1 \times j$ represents channel model, where j are the number transmitter. In this paper, we use four transmitters. *Eq.3* can be expanded as follow:

$$Y(t) = [h_{11} \quad h_{12} \quad h_{13} \quad h_{14}] \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{bmatrix} \tag{4}$$

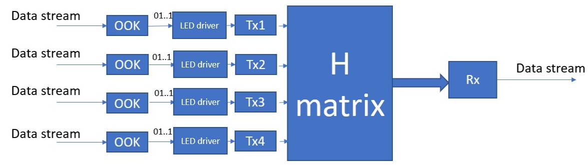

Figure 2. The channel model of 4×1 MISO VLC system

Depending on the form of communication link, the channel coefficient h_j is obtained. In this paper, we apply both the light-of-sight (LOS) and non-light-of-sight (NLOS) model to calculate h_j^{LOS} and h_j^{NLOS} in turn [13][15]. For LOS, the representation of DC gain of the j^{th} transmitter is as follow:

$$h_j^{LOS} = \frac{(m+1)\mu}{2\pi d_j^2} cos^m(\theta_j) cos(\Psi) F_s(\Psi) \tag{5}$$

The physical area μ of PD detector that area achieves the optical signal, d_j and θ_j are the distance and the angle of irradiance between transmitter j^{th} to receiver i^{th} , Ψ represents the incident angle of light, $F_s(\Psi)$ denote gain of optical filter. m is the Lambertian order of light emission and calculated as follow:

$$m = \frac{-ln(2)}{ln(cos(\phi_{1/2})} \tag{6}$$

where $\phi_{1/2}$ semi-angle of half luminance power of LED

In this paper, we assume that the field of view (FOV) of PD is 180^0 which means that $cos(\Psi\} = 1$, And the gain of optical filter also is 1. Therefore, the Eq.5 can be following rewrite:

$$h_{ij}^{LOS} = \frac{(\frac{-ln(2)}{ln(cos(\phi j/2)}+1)\mu}{2\pi d_j^2} cos^{\frac{-ln(2)}{ln(cos(\phi j/2)}}(\theta_j) \tag{7}$$

C. Object mobility and blockage transmitter stituation

Consider the reality of object movement in an indoor environment, there are potential cases of losing the direct signal from the transmitter. The lost signal results from the hidden of house facility as well as the transmitter itself problems, for example, the electric signal, life time and so on. Consequently, the *H-matrix* cannot be fully obtained, thus, the Eq(4) can rewrite:

$$Y(t) = [h_{11} \quad h_{12} \quad 0 \quad 0] \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{bmatrix} \tag{8}$$

The lack of information of transmitter is not only failing to data recover but also highly error estimation of the receiver position. To overcome the problem, this paper proposed the integrated model which uses both currently popular methods, RSS and fingerprinting.

III. INTERGRATED MODEL FOR MISO VLC POSITIONING

A. General triangulation method

In terms of positioning, triangulation is one of the reasonable solutions for indoor scenarios. To localize the receiver, at least three transmitters are required. Three transmitters will create the three equations respectively to calculate the receiver's coordination. Specifically, this coordination is the intersection point of three circles whose centers are the position of the transmitter as depict fig 3.

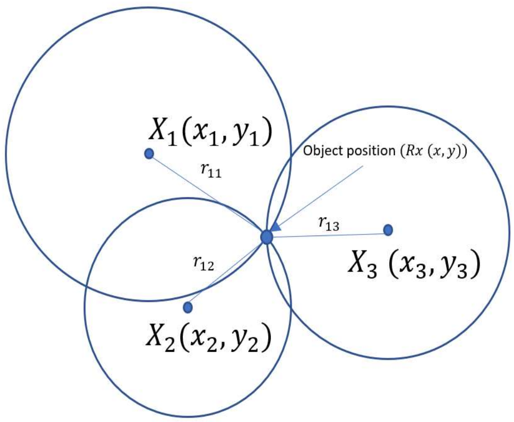

Figure 3. Object position with Triangulation method

The object's coordination $Rx(x, y)$ are solution of following equations:

$$(x - x_1)^2 + (y - y_1)^2 = r_{11}^2$$
$$(x - x_2)^2 + (y - y_2)^2 = r_{12}^2 \qquad (9)$$
$$(x - x_3)^2 + (y - y_3)^2 = r_{13}^2$$

Where the $(x_1, y_1), (x_2, y_2), (x_3, y_3)$ are coordination of transmitter X_1, X_2, X_3 respectively. The r_{11}, r_{12}, r_{13} which are the distance between the projection of transmitter and receiver position, can be derived by applying not only the received signal strength model (RSS) of corresponding transmitters but also trilateration methods as following clarification:

$$r_{ij} = \left| \sqrt{{d_j}^2 + (room\_height)^2} \right| \qquad (10)$$

B. The intergrated positioning model

As discussed above, in some cases which communication link of specific transmitters is able to disconnect. In this paper, we propose the integrated model to estimate object position based on information of only two transmitters. The integrated model includes the trilateration-based RSS model and NLOS-based fingerprinting model. The proposed method has two steps. The first step applies the trilateration-based RSS to achieve the potential candidates of object position as shown in fig.4. Let's consider the remaining transmitters are $X_1, and\ X_2$, the Eq.9 can rewrite:

$$(x - x_1)^2 + (y - y_1)^2 = r_{11}^2$$
$$(x - x_2)^2 + (y - y_2)^2 = r_{12}^2 \qquad (11)$$

Clearly, there are two intersection points that are presently under consideration for potential candidates of the receiver. In the second step, the NLOS-based fingerprinting is applied in order to eliminate one of two potential points. The NLOS channel is illustrator fig.5. The equation for the NLOS channel model is represented as following [15]:

$$h_{ij}^{NLOS} = \frac{(m+1)\mu}{2\pi \left(d_j^{re1}\right)^2 \left(d_j^{re}\right)^2} \rho dA_{wall} cos^m(\theta_j) cos(\beta_j)\ cos(\gamma_j) \qquad (12)$$

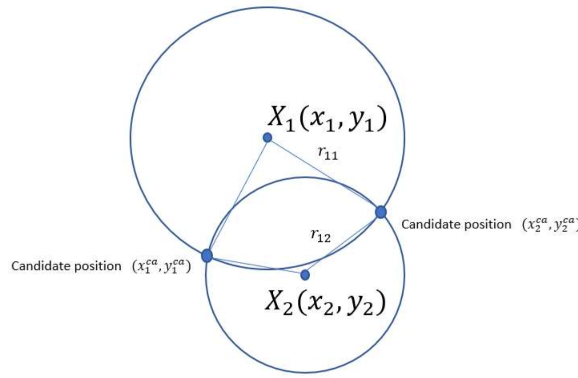

Figure 4 Position of candidate for trilateration-based RSS model

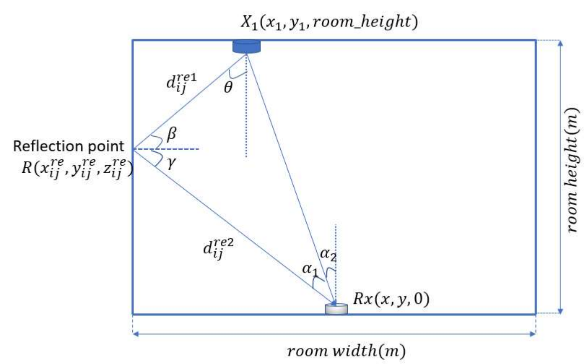

Figure 5. 2-D NLOS model of LED-PD Communication

Where d_j^{re1} is distance between a transmitter j^{th} to reflection point, and d_j^{re2} is distance between a reflection point to receiver, ρ is the reflective coefficient, it depends on the surface material. dA_{wall} is a reflective area (assume dA_{wall}=1), θ_j is the angle of LED irradiance to reflection point. β_j, γ_j are the angle incidence of reflection point and angle irradiance to receiver.

NLOS-based fingerprinting relies on uneven distribution of optical power of reflection which creates the energy matrix known as the offline-reference data. Then, the received optical power of candidates compare to offline-reference data to identify a matching point. The matching point is assigned the position of the receiver. To obtain an offline reference, firstly, the 50×50 points of the receiver are examined. The sum of received power of multipath refection of transmitter X_1 is measured. In this paper, we only calculate the total power of four reflections of light from the surrounding surfaces. The total power is collected and builds offline-reference data as shown in fig.7.

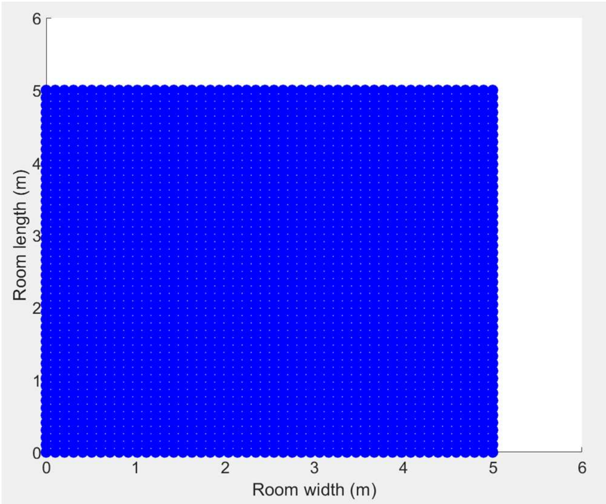

Figure 6. Movement matrix of Receiver Rx

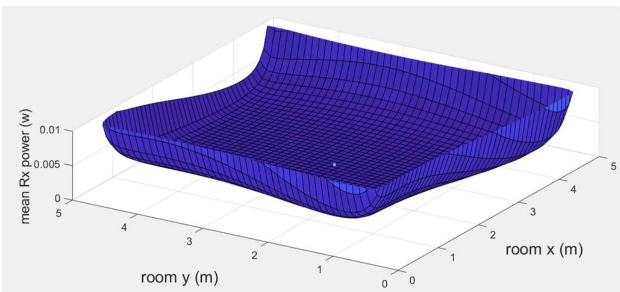

Figure 7. The offline-reference data X_1

IV. Simulation Result and Discussion

The simulated was conducted and evaluated by using MATLAB version R2018a. All simulation parameters are listed in table 1 and table 2. To compare the proposed work to existing work, the parameters is similar to [13].

TABLE I. Transmitter parameter and room dimension

Parameter	***Value***
Room_length × *Room*_ width × *Room*_height	$5m \times 5m \times 2.5$
Number of transmitters	4
Transmitter position (x,y)	X_1= [1.25 1.25]; X_2 = [1.25 3.75]; X_3 = [3.75 1.25]; X_4 = [3.75 3.75];
Transmitter power	10W
LED bandwidth	3 MHz
Data rate	2 Mbps
Transmitter pitch	2.5m

TABLE II. Receiver parameter

Parameter	***Value***
Photodetector (PD) type	OSD-15T
Receiver sensitivity	-30dBm
FOV	180^0
Receiver pitch	10cm
SNR	70dB

To demonstrate the well-operation of the proposed model, firstly, the traditional scheme that is triangulation-based RSS is applied for the remaining three transmitters scenarios. Obviously, the positioning error is quite small almost under 0.5×10^{-1} (m) as shown in fig.8. Whereas, in the case of two transmitters blocking, the error estimation reaches extremely high up to 4.5(m). NLOS-based fingerprinting is proposed. By using such a model, the proposed scheme is robust to obstacles that disconnect up to two communication links. he outstanding result has achieved an average of0.5×10^{-1} (m). This result is just slightly higher than the three transmitters available.

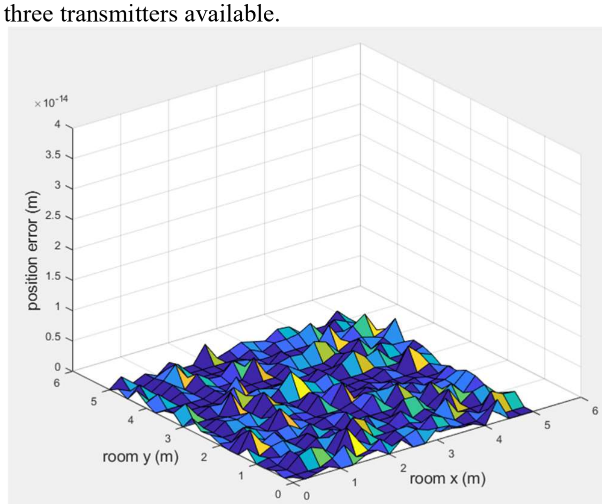

Figure 8. The positioning error with missing one transmitter

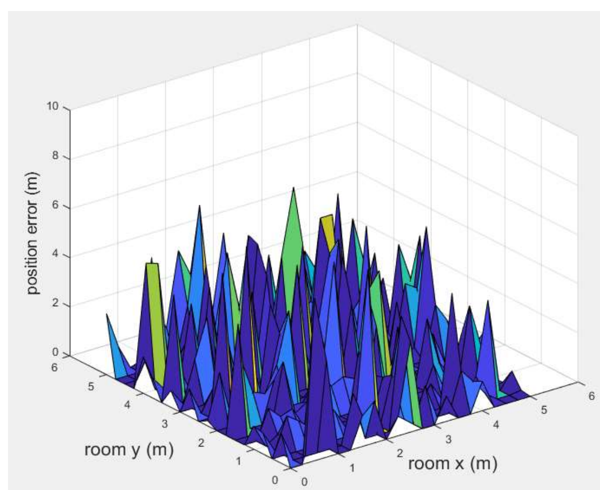

Figure 9. The positioning error with two remaining transmitters

V. Conclusitons

This study focused on the position estimation of indoor MISO VLC for two transmitter blockage scenarios. It is the fact applying both NLOS-based fingerprinting and triangulation-based RSS, the position error is obtained with acceptable outcome.

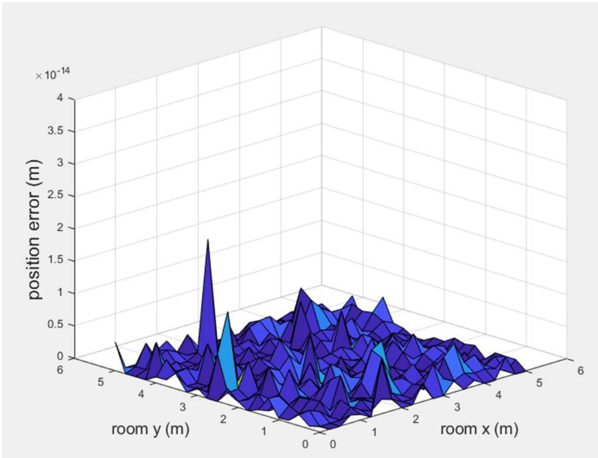

Figure 10. The result of error estimation for propose scheme

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