A BOOSTED POSITIONING MODEL FOR MISO VLC SYSTEM UNDER A SHADOWING SCENARIO

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Abstract - There are various positioning algorithms proposed for Visible Light Communication (VLC) which require at least three “alive” transmitters to locate the object’s position. In terms of indoor scenarios, the shadowing of Line-of-sight (LOS) signal leads to insufficient information for positioning in a VLC system. This work proposes a robust positioning algorithm using the trilateration algorithm for VLC under shadowing situations. This algorithm uses the integration of two models, namely the prediction model and fingerprinting model based on the NLOS beams to determine the object's location. The prediction model applies trilateration algorithm based on LOS beams to achieve the potential positions. Then the fingerprinting model uses coordination of these potential positions as input data to match fingerprints built in advance to determine the position of an object. Simulation result show that the positioning error under shadowing effects is small which is the same positioning error yielded under normal working conditions.

Key words - Positioning; MISO VLC; deterministic model, RSS, fingerprinting

1. Introduction

It is generally acknowledged that the Global Positioning System (GPS) is widely used for locating objects with high accuracy [1]. The GPS is applied in many fields the human life such as location, navigation, search and rescue. However, the GPS might not work in some circumstances, e.g. in metropolitan areas where the RF signal is blocked or weakened by the building and so on. As a result, GPS might not work well in indoor scenarios. In recent years, indoor positioning has attracted much attention from researchers. The high-accuracy indoor location can open many opportunities for various applications as well as novel businesses in many scenarios such as Virtual Reality – Augmented Reality (VR-AR), tracking the elderly person, IoT services, and so on. As a result, Wi-Fi and Bluetooth integrated into GPS are proposed to enhance the accuracy of indoor positioning [2]. However, to gain such high accuracy, many the Wi-Fi access points (APs) are installed resulting in not only high cost but also a complicated system.

In recent decades, VLC has been deployed as the new technique for indoor positioning systems. VLC-based positioning (VLCP) uses the visible light signal sending from the LEDs to determine the object's position [3]; therefore, it has many advantages over the RF-based positioning. Firstly, the VLCP system can fully work at an inexpensive cost because of utilizing the existing lighting system. Secondly, the VLCP can operate in many areas where RF is not attempted. For example, RF signals result in electromagnetic interference in the industry machine as well as hospital equipment such as MRI scanners, whereas, the VLC is safe for this situation. Thirdly, the VLC deploys LOS communication which is not influenced by multipath phenomenon, thus, VLCP gives a higher accuracy and reliable technique. Similar to RF-based positioning, there are various algorithms for VLCP such as proximity, fingerprinting, and trilateration. Specifically, proximity-based VLCP obtains the object position by LED identification (LID) [4], [5]. The LIDs are stored as a database which refers to the base-station coverage. In the case of an object contacting a specific LED base station, its location is a whole range of LID respectively. Regarding the fingerprinting technique, a received energy matrix is created by measuring the emitting power from a specific LED to every point of the receiving surface. The position is an element of the matrix whose power matches with current received energy [6]. Whereas, the trilateration approach exploits geometric features of triangles to locate the object's position [7], [8], [9]. However, those algorithms require the LOS of at least three LEDs to locate the receiver. This might be impossible due to shadowing effects caused by obstruction or user’s movement. This paper proposes the trilateration-based positioning model combined with fingerprinting model serving as additional data to help the receiver decide its location. Additional data is constructed in advance in the off-line stage based on reflective (or NLOS) beams.

2. VLCP system description

This paper uses 4x1 MISO VLC proposed and shown in Figure 1. Four LEDs as the Access Points (AP) broadcast the data directly to the Photodiode (PD) which assumes that randomly move of the 2-D geographic floor (Oxy coordination system).

2.1. System analysis

The emitted power from specific AP is denoted by P_e^i, where i = 1,...,4 is the AP index. The signal is modulated by the Non-Return-to-Zero On-Off-Keying (NRZ-OOK) technique with the pulse duration of T, and the optical power is emitted as the following equation:

$$P_e^i = x_i \times p(t) \tag{1}$$

For illumination requirement, all LEDs have the same transmitted power which is denoted by P, the pulse function is determined as follows

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

Assume that the object moves the 2-D floor plane. The received power P_r^i corresponding to tolerance on specific LED i is described as the following

$$P_r^i = \varepsilon \times P_e^i \times H + N \tag{3}$$

The received power is determined by environment coefficient ε, the channel model H, additive white noise N and the emited power P_e^i. However, lights are distributed within indoor scenario, thus suppose that the environment coefficient ε equals 1. The Figure 2 shows that the channel parameter H of MISO system is a matrix which has the dimension of $1 \times i$, where i are number of transmitters. The Eq.3 is rewritten as

$$\begin{bmatrix} P_r^1 \\ P_r^2 \\ P_r^3 \\ P_r^4 \end{bmatrix} = [h_{11} \quad h_{12} \quad h_{13} \quad h_{14}] \begin{bmatrix} P_e^1 \\ P_e^2 \\ P_e^3 \\ P_e^4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (4)$$

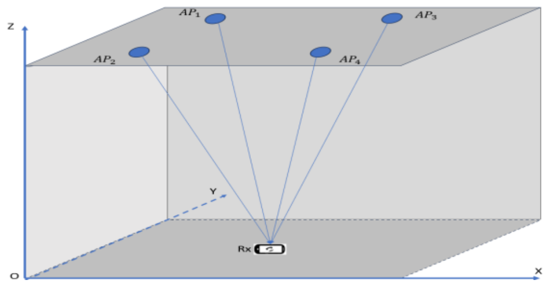

Figure 1. *A typical MISO VLC system*

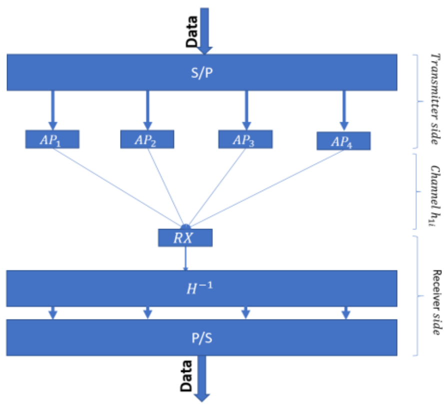

Figure 2. *Channel model of the MISO VLC system*

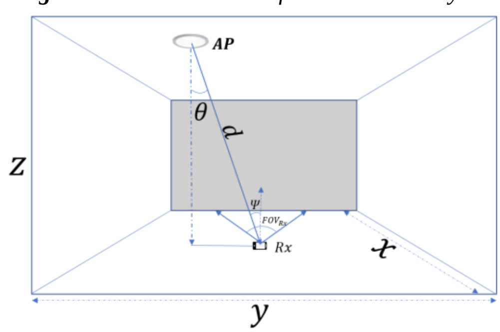

Figure 3. *The LOS model for VLC system*

In the proposed model, the LOS and NLOS beams are utilized as an integrated model in case of shadowing. Assume that h_i^{LOS} and h_i^{ref} are channel gain of LOS link and NLOS link respectively. The h_i^{LOS} is described by Eq. 5 and shown in Figure 3, whereas h_i^{ref} is described in Section III

$$h_i^{LOS} = \frac{(m+1)S_a}{2\pi d_i^2} cos^m(\theta_i) \cos(\Psi) F_G(\Psi) \quad (5)$$

where S_a is the active area of the PD detector, d_i and θ_i are the distance and the angle of irradiance respectively, Ψ denotes the angle of incident to the PD, $F_G(\Psi)$ represents gain of optical filter. m is the Lambertian order of light emission that is a function of semi-angle $\emptyset_{\frac{1}{2}}$ of half luminance power of LED:

$$m = \frac{-ln\,(2)}{ln\,(cos\left(\emptyset_{\frac{1}{2}}\right))} \quad (6)$$

Substitute the Eq.6 into Eq.5, the Eq.5 can be rewritten as follow:

$$h_{1i}^{LOS} = \frac{(m+1)S_a}{2\pi d_i^2} cos^m(\theta_i) cos\,(\Psi) F_G(\Psi) \quad (7)$$

2.2. Trilateration Algorithm for VLC Positioning

The trilateration algorithm is the high-accuracy solution for locating the object in GPS and the VLCP system. This algorithm uses a signal of Aps to calculate the object's position. Each AP draws the energy circle whose center and radius are projections of AP on 2-D of the object and distance projection point and object position respectively. Assume that the object moves the Oxy plane, as a result, the z coordinates are ignored. The location of the object (x_o, y_o) is an adequate solution of the following equations system

$$\begin{aligned} (x_o - x_{AP_1})^2 + (y_o - y_{AP_1})^2 &= r_1^2 \\ (x_o - x_{AP_2})^2 + (y_o - y_{AP_2})^2 &= r_2^2 \\ (x_o - x_{AP_3})^2 + (y_o - y_{AP_3})^2 &= r_3^2 \end{aligned} \quad (8)$$

where the (x_{AP_1}, y_{AP_1}), (x_{AP_2}, y_{AP_2}), (x_{AP_3}, y_{AP_3}) are in turn coordination of AP_1, AP_2, AP_3. The r_1, r_2, r_3 are the radius of circles of APs as shown Figure 4.

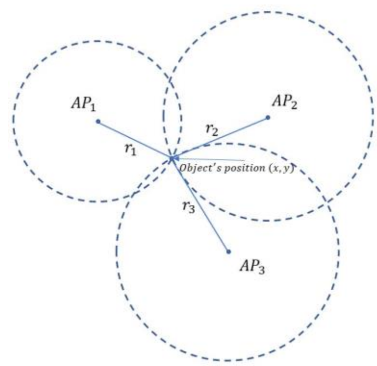

Figure 4. *Top view of the trilateration positioning model*

$$r_i = \left|\sqrt{d_i^2 - z^2}\right| \quad (9)$$

The object's location will be simply identified in case fully working system which means that at least three "alive" APs are required.

3. The impacts of shadowing effects and proposed model

3.1. Shadowing effects

In fact, the signal sending from a transmitter can be blocked due to shadowing effects and user's movement. Assume that the LOS signals of transmitter AP3, AP4 are missing, the trilateration model with two transmitters is illustrated in Figure 5.

The object's location can be identified as

$$\begin{aligned} (x - x_1)^2 + (y - y_1)^2 &= r_{11}^2 \\ (x - x_2)^2 + (y - y_2)^2 &= r_{12}^2 \end{aligned} \quad (10)$$

Clearly, there are two possible locations given after solving Eq. (10). Thus, the trilateration does not work well in this circumstance.

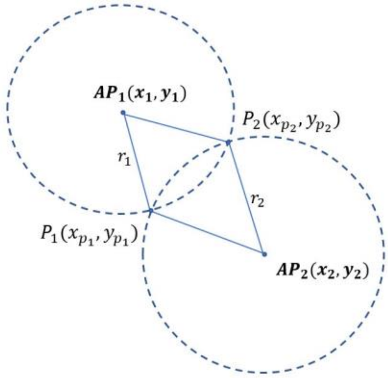

Figure 5. *RSS-based trilateration model with two transmitters*

Also, in case of missing LOS signals, the H-matrix of the MISO VLC system is incomplete as denoted in Eq. (11) because the receiver obtains insufficient channel state information (CSI). Assume that LOS signals of two transmitters AP_3 and AP_4 are blocked, the H-matrix is specified as

$$H = [h_{11} \quad h_{12} \quad 0 \quad 0] \tag{11}$$

Though the received power as shown in Figure 6 might be sufficient for illumination and communication (~16 dBm), the receiver cannot recover the transmitted data and determine its location under shadowing circumstance.

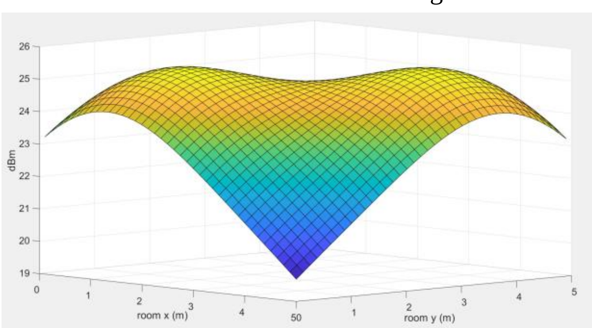

Figure 6. *The power distribution of two Aps*

The insufficient H-matrix leads to high position error of object. Therefore, to achieve the full H-matrix, this paper proposed the integration of the prediction model and the deterministic model. The prediction model identifies the candidates, whereras, deterministic model uses the off-line reference data to detemine the object 's position.

3.2. The proposed model

In this section, we propose a boosted positioning model for VLC to deal with shadowing effects by combining fingerprinting model and prediction model based on trilateration algorithm. The proposed model operates in two stages: off-line and on-line.

a. Off-line stage

In this stage, the fingerprints of the transmitters are pre-constructed based on the optical power of reflected beam (which is NLOS signal). This reflective channel is illustrated in Figure 7 and specified as follows [10]

$$h_i^{ref} = \frac{(m+1)S_a}{2\pi (d_i^1)^2 (d_i^2)^2}\rho dA_{wall} cos^m(\theta_i) cos(\beta_i)\, cos(\gamma_i) \tag{12}$$

where d_i^1, d_i^2 are distance between an AP i^{th} to reflective point and between the reflection points to the object respectively; ρ is the reflective coefficient which depends on the reflective surface. dA_{wall} is the reflective area; θ_j is the angle of irradiance to reflective point; β_i, γ_i are the angle incidence of reflection point and angle irradiance to receiver.

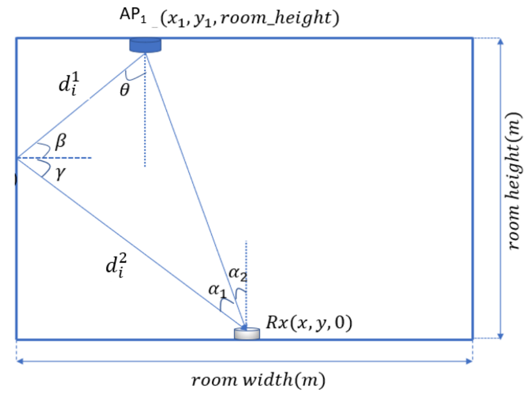

Figure 7. *NLOS channel model*

In the Figure 8, the 100×100 movement steps of the object are examined. It generates an off-line reference data which is the sum of received power from surrounding surfaces of both AP_1 and AP_2. This off-line reference data is considered as a replacement for missing LOS of AP_3 to help the receiver deciding its location.

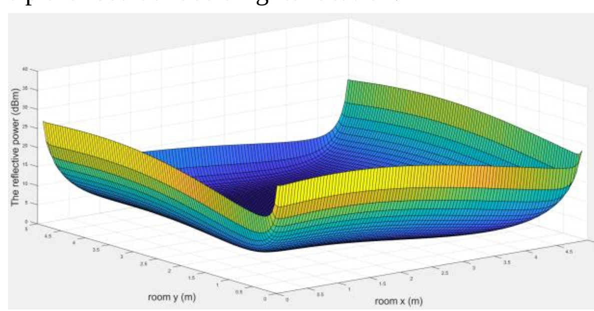

Figure 8. *The reflective energy grid of AP_1 and AP_2*

As the figure shown, the reflected light from Aps is distributed unevenly throughout the area, so each position of the room is assigned corresponding to a level of received reflected power and examined during the operation from the initialize of the VLCP system. Then, in the on-line stage, the position of the object is determined by matching the on-line received power to off-line reference data.

b. On-line stage

In this stage, the position of the receiver is predicted based on the trilateration algorithm as mentioned in Section 2.2. In case of missing LOS signal, e.g. AP_3, AP_4, the trilateration algorithm yields two possible positions as depicted in Figure 5 and Eq. (10).

To determine object's location, the receiver obtains its current NLOS receive power (on-line data) and compare it to the off-line data built in the off-line stage.

4. Simulation and Evaluation

The MATLAB is used to demonstrate the proposed algorithm. The TABLE 1 shows the simulation setups for transmitter side and receiver side respectively.

The metric of *positioning error* P_{error} is used to evaluate the proposed model, which is defined by the error between the actual positon and predicted position achieved by the proposed model.

$$P_{error} = \sqrt{\left(x - x_{predict}\right)^2 + \left(y - y_{predict}\right)^2} \quad (13)$$

Table 1. *Simulation parameter*

Parameter	***Value***
Room dimension	$5m \times 5m \times 3$m (length× width× height)
Number of transmitters	4
Transmitter position (x,y,z)	AP_1 = [1 1 3]; AP_2 = [1 4 3]; AP_3 = [4 1 3]; AP_4 = [4 4 3];
Transmitter power	40 dBm
LED bandwidth	5 MHz
Data rate	4 Mbps
Transmitter pitch	2.5m
FOV of LEDs	70^0
Receiver sensitivity	-30dBm
FOV of PD	180^0
Receiver pitch	10cm

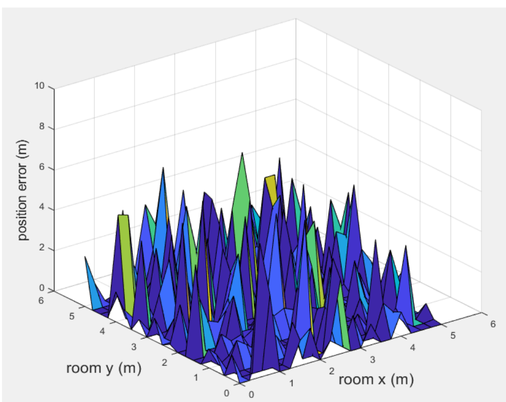

Figure 9. *Positioning error with the absence of two APs*

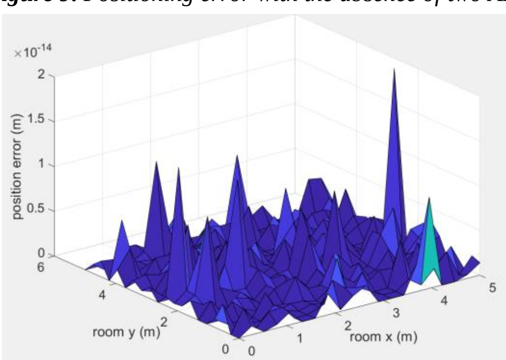

Figure 10. *Positioning error for proposed work*

To confirm the effectiveness, initially, the traditional trilateration-based RSS scheme is applied in the case of the remaining two APs. Figure 9 shows that the positioning error is up to 5 meters. This result points out that missing LOS signals of two APs leads to the failure of positioning in a VLC system. However, the proposed model proves that despite losing the LOS signal of APs, the system is still working as shown Figure 10.

In Figure 11, we exam the situation where the object moves in a random trajectory in a 2-D geographic room. The results illustrates that the predicted positions based on the proposed model matches well to the actual position of the object with positioning error of 0.1 (m) at maximum.

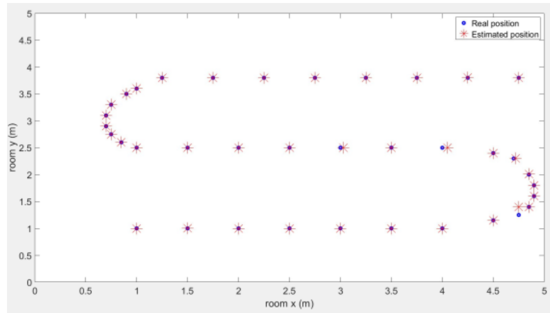

Figure 11. *Tracking position of the proposed model*

5. Conclusion:

In this paper, the proposed approach using integration prediction model and fingerprinting based NLOS model to determine the object's position. The prediction model is applied to identify the candidates in case of lack the LOS of AP_3. Then, the RSS of candidate are measured and compared to energy matrix grid of NLOS-fingerpriting. The simulation result demonstrates the despite of LOS signal of AP_3, the position error is still low.

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