Analysis and evaluation about the dimmable light affect positioning-based MISO visible light communication

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ABSTRACT

Visible light communication (VLC) is a new on-trend communication technology which offers high-speed data rate, great deployment potential in indoor enviroment. In VLC scenario, the positioning based on visible light communication (VLCP) has become one of interesting application of researchers. Most of existing proposed VLCP algorithms focused on mathematical analysis of multi-dimensional perspective based on the received signal strength (RSS) to enhance the accuracy without the consideration of dimming. However, regarding to physical characteristics of VLC devices and requirement of illumination, the light is increasingly dimmable along the time which leads to decrease transmitted optical power of LED as well as RSS received at the photodetector (PD)). Inspired by the above-mentioned constraints, this paper proposed the mathematical model to analyses the effect of dimming capability on the state-of-art RSS based positioning algorithms. Evaluation of the proposed model based on the metrics of RSS and position error (PE) is conducted on Matlab.

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1. INTRODUCTION

Light-emitting diode (LED) is a new lighting device popularly installed in illumination systems. Compared to traditional lighting devices such as incandescent or fluorescent lamps, the advantages of LED are long lifetime, reaseanable price, low power, and good visibility. Moreover, the switching time of LEDs is extremely fast which leads to support for high-speed communication. Thanks to this characteristic, visible light communication (VLC)-based LED attracts many researchers. Compared to radio-frequency, VLC provides several advantages, including ultra-high data transmission speeds, and improved safety [1]. There are several VLC-based positioning (VLCP) algorithms have been thoroughly researched in case of indoor case, showing more significantly more accuracy than that of RF-based systems.

The proximity-based VLCP is a positioning methodology that locates the object based on the known-location LEDs. Each LED has its ID which is used for authentication between the LED and object, consequently, the estimated position of the object is an area of LED coverage [2], [3]. Therefore, the proximity method pays less attention to VLCP. Meanwhile, the fingerprinting and triangulation-based VLCP have more precision. The fingerprinting method identifies the object's position by matching the online-phase data to offline-phase data [4]-[9]. The offline-phase data is the received energy matrix which is pre-measured from the transmitters, whereas the online-phase is the received signal strength (RSS) of the current object position. Triangulation-based VLC achieves object position using the geometric feature including angulation and side. Regarding angulation algorithm, the angle of arrival (AoA) method locate objects based on determining the direction of incident signals from multiple LEDs. Since gaining the angle of incidence, the location of the object is defined as the point of intersection of such bearings [10]-[15]. Whereas, the time of arrival and time difference of arrival thanks to the time of arrival signals in order to determine the distance as the side between LEDs to the object and then derive the position of the object [16]-[19]. Meanwhile, a triangulation-based RSS determines this distance from LED to object through the relational Lambertian equation of received power and transmitted power [20]-[25]. However, this approach requires the working of at least three transmitters to build the three-circle equations. The position of the object is a common solution of this equation.

It can be clearly seen that the lack of a fully working LED causes the high position error result. One of the reasons that leads to this situation is the dimming phenomenon. Dimming impacts directly on to change of received power as error position estimation. This paper introduces the 4x1 MISO indoor VLC system, and based on this system, the mathematical model is proposed to analyze as well as evaluate the dimming affect on the VCLP system. The remaining sections of this work is organized as follows: section 2 introduces the 4x1 MISO system. Section 3 concentrates on the the dimming effect. Section 4 verifies dimming effect on the position error through the simulation result. Finally, section 5 is the conclusion.

2. VLC SYSTEM ARCHITECTURE

The 4x1 MISO VLC has four LED operating as transmitters and one Photodiode as a receiver corresponding as shown in Figure 1. Assume that the receiver moves randomly on the floor of the room and receive light signal transmitting from the LED. Transmitted data from LED is modulated using non-return-zero on-off-keying (NRZ-OOK) scheme in time duration denoted by T. Suppose that each LED is generated by power of P. The equation shows the relationship between these parameter as follow:

$$S^i = s_i \times u(t) \tag{1}$$

Where:
S^i = transmitted signal of LED with index i
s_i = modulated data

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

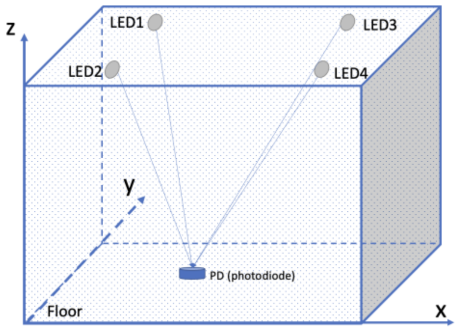


Figure 1. 4×1 MISO VLC system architecture

On the photodiode side as shown in Figure 2, at certain time, the photodiode receives the data from four LED and LED has its ID to differentiate from each other.

$$R_{PD} = \sum_{i=1}^{4} \epsilon \times S^i \times H^i + N \text{ with } R_{PD} \ge R \tag{3}$$

The received data depends on four factors including enviromental coefficience ϵ, transmited data S^i, channel modeling H^i and noise N. Thanks to indoor scenario, enviromental coefficience ϵ assumes to be equal to 1 and the absence of ambient light leads to no noise (N=0). The (3) can be rewrited under following matrix function:

$$R_{PD}(t) = [H^1 \quad H^2 \quad H^3 \quad H^4]\begin{bmatrix} S^1 \\ S^2 \\ S^3 \\ S^4 \end{bmatrix} \tag{4}$$

In addtion, received power equation is only calculated in case of adapting detector sensitivity of photodiode (R). Channel modeling H^i is Lambertian radiation function as following equation:

$$H^i = \begin{cases} \frac{(m+1)A}{2\pi d_i^2} cos^n(\theta_i) \\ 0, \quad otherwise \end{cases} \tag{5}$$

The physical area A of photodiode detector can archieves the trasmitted power, θ_{i} and d_{i} are the angle of irradiance and the range between LED *i* and PD. n is the Lambertian order:

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

Where $\Theta_{1/2}$ semi-angle of half intensity power of LED.

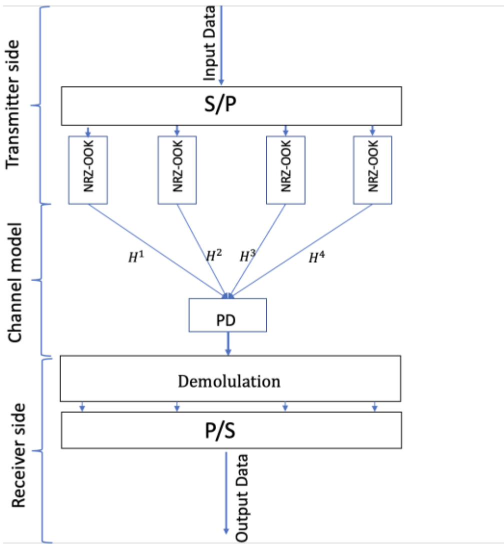


Figure 2. MISO VLC SYSTEM channel

3. DIMMING EFFECT

LED is increasingly dimmed over time due to the capacitor in the driver of LED. The capacitor acts the components which is responsible for keeping the stable current. However, the LED flicks extremely fast resulting to capacitor charging and discharging process occurring as fast as LED switching. Therefore, along the time, capacitor does not ensure full operation which leads to reducing the power of LED. Assume that the power of LED is a function of time, and intend decreasingly along the time as flowing:

$$P_c = P_i \times a^t \text{ with } 0 < a < 1 \tag{7}$$

Where P_c is the current power of LED, P_i is initial power, radix *a* and time *t* present the degradation along the lifetime of LED (L). The lifetime of LED depends on the operating hours of LED. In this paper, the white LED is assuming used, the lumen maintenance level of LED is experimented and demonstrated at 70% (L_{70}) and 50% (L_{50}) after 35.000 hours and 50.000 operation hours respectively as shown Figure 3. This level involved in the power distribution as well as the RSS of photodiode in MISO system as shown Figure 4. Figures 4(a), 4(b), 4(c) figures out the power distribution of LEDs correspoding different luminance level (L_{100}, L_{70}, L_{50}).

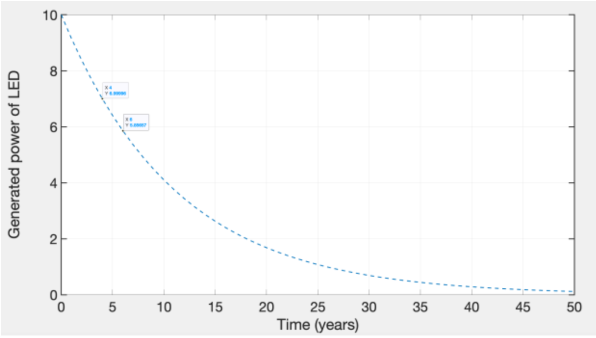
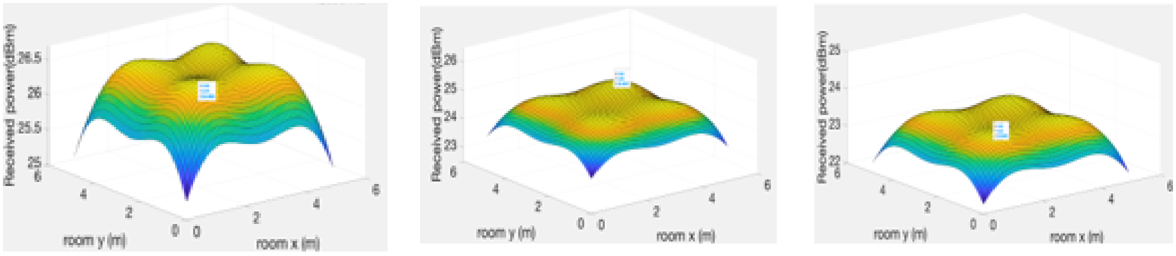


Figure 3. The degradation of LED along the time with P_i =10 w and a=0.91469



(a) (b) (c)

Figure 4. Power distribution of four LED with (a) L_{100}, (b) L_{70}, and (c) L_{50}

4. TRIANGULATION BASED VLCP

Triangulation is one of the logical positioning strategies for indoor environment. At least three transmitters are needed in order to localize the receiver. The position of receiver is common variable of three equation, which is obtained through three transmitters independently as shown in Figure 5. The centers of which represent the projection the LED's locations on the 2-D floor.

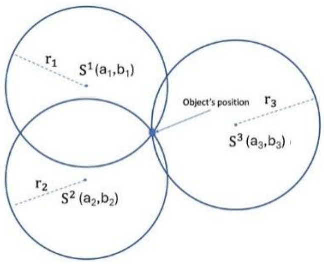


Figure 5. Triangulation based VLCP

Three circles can be written under the following equations:

$$(x - a_1)^2 + (y - b_1)^2 = r_1^2$$
$$(x - a_2)^2 + (y - b_2)^2 = r_2^2 \quad (8)$$
$$(x - a_3)^2 + (y - b_3)^2 = r_3^2$$

$(a_1, b_1), (a_2, b_2), (a_3, b_3)$ are coordination of center of circles as well as transmitter S^1, S^2, S^3 respectively. The r_1, r_2, r_3 which are radius of circles, they also are the range between the projection of transmitter to photodiode. These radius inferred from RSS of LED and trilateration methods depicted in Figure 6. the RSS of photodiode is one of data which is addressed to achieve d_i through channel model H^i, then, the radius r_i is caculated as a side of right triangle.

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

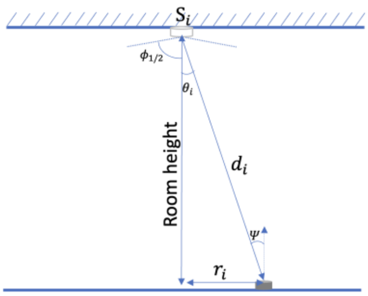


Figure 6. Propagation model of VLC system

5. SIMULATION AND DISCUSSION

The simulation is verified by using MATLAB software. 3x1 MISO VLC system uses the three LEDs as the transmitters and one Photodiode as one receiver. Tables 1 and 2 shows the simulation parameters.

Table 1. Transmitter coeficients

Parameter	Value
Dimension	2m × 2m × 3m (LxWxH)
Transmitters	3
Transmitter location (x, y)	S^1 = [0.5 0.5]; S^2 = [1 1.5]; S^3 = [1.5 0.75];
Transmitter power	10 W
LED bandwidth	3 MHz
Data rate	2 Mbps

Table 2. Rx parameter

Name	Value
Photodiode type	OSD-15T
Photodiode sensitivity	-30 dBm
Field of view	180°
SNR	70 dB

Firstly, the position of object is obtained by applying the fingerprinting algorithm. The fingerprinting algorithm ultilizes the mapping the offline mapping data to the online mapping data to achieve the object's position. Figure 7 show the position examination (x, y) in the dimension of room and Figure 8 depictes the offline is collected by the measuring the total received signal strength from the LED.

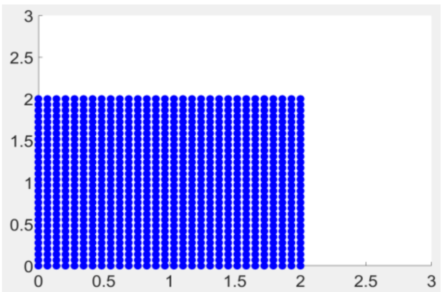


Figure 7. The examination step for obtaining the offline data

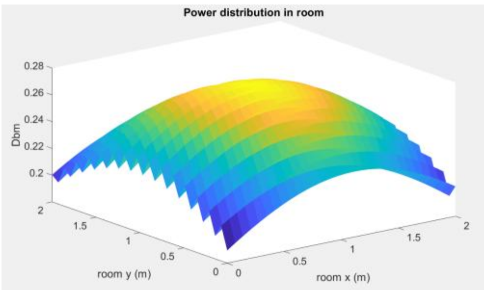


Figure 8. Offline data-based power distribution of LEDs

Secondly, to evaluate the effect of dimming phenomenon on the VLCP system. The position error (PE) of normal status of system (L_{100}) must be examined as shown Figure 9. In this case, the received energy of online phase is matched the offline phase, thus the PE is low under $0.5 \times 10^{-14}(m)$. Whereas, for status of lumen maintenance level L_{70}, the PE increases up to avarage of 1.5m as depicted in Figure 10. The reducing of the optical transmitted power leads the error in calculating the distance between LED to photodiode. Therefore, the dimming of LED is proportional to error distance as well as PE, this is more clearly demonstrated through Figure 11 in case of lumen maintenance level L_{50}, peak point of PE is 3 m.

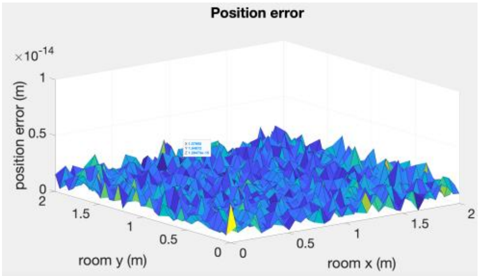


Figure 9. Position error for the normal case

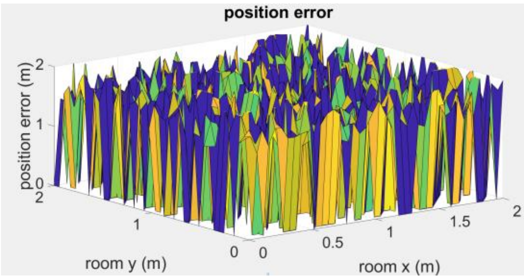


Figure 10. Position error for L_{70} case

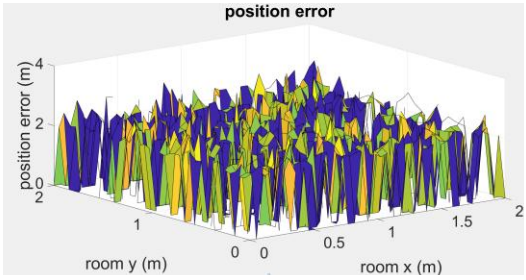


Figure 11. Position error for L_{50} case

6. CONCLUSION

The paper focuses on the proposing the 4x1 MISO VLC system and addresses the VLC based positioning. In addition, the dimming phenomenon is mentioned and analyse its impact on the power distribution of LED in room. The variation of received power leads to position error increase which is demonstrated and verify through simulation.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Dat Vuong	✓	✓	✓	✓	✓	✓				✓		✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. If there are no conflicts of interest, please include the following author's statement: Authors state no conflict of interest.

DATA AVAILABILITY

- The data that support the findings of this study are available from the corresponding author, [D. Vuong], upon reasonable request.

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