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High Precision Indoor VLC positioning Techniques

Jabeena A, G.Aarthi, Akash Reddy, Supreet Palabatla, Paidi Sasidhar

Abstract: ***Visible light communication(VLC) has been gaining a good deal of attraction because of its ability to use the transmitter -LED's for both communication and illumination. VLC can be used in an environment where wireless communication is not preferred such as hospitals and other chemical plants. Although Global positioning system (GPS) is generally acknowledged, within an indoor environment, VLC has the ability to provide results with better accuracy as it avoids attenuation and blocking. VLC positioning techniques such as Received signal strength (RSS) based trilateration and proximity method are currently being implemented, however the new proposed model which is the weighted k nearest neighbour(Wk-NN) models provides us with a better accuracy than some of the existing methods.***

Keywords: ***Visible Light communication, RSS based trilateration, proximity method, Wk-NN .***

I. INTRODUCTION

The motivation behind the application of VLC over GPS in an indoor environment is that it avoids attenuation/ blocking of electromagnetic signals and multipath interference which would otherwise occur using GPS. Implementing VLC techniques within an enclosed/indoor environment allows the user location estimation more accurately as the errors and positioning accuracies can be clearly identified [1].

VLC is put into use in places where wireless data communication is not desirable such as hospitals or chemical plants.The LED serves for both illumination and communication allowing the users to estimate their position or location within an illuminated environment during their motion.Therefore, it provides us with numerous beneficial applications which requires the function of navigation such as indoor robotic navigation, airport terminal directions and customer support in supermarkets [1]- [2].VLC positioning models such as RSS based trilateration and proximity method are currently being implmeneted [3]-[4]. To further improve accuracy in VLC positioning within an indoor environment, a new proposed technique called the Wk-NN (Weighted k nearest neighbour) is implemented. This technique helps identifying the position of the user (receiver) more accurately while nullyfying the effect of ambient light (external light sources).

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***** Correspondence Author
Jabeena A*, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
G.Aarthi, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
Akash Reddy, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
Supreet Palabatla, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
Paidi Sasidhar, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India

II. VLC PRINCIPLE

The four transmitters installed are used for both communication and illumination [2]. Depending upon the room dimensions, the number of LED's (transmitters) can vary [2], [5] and the receiver which is the Photo diode is free to move in the plane of the receiver having an area of L x W m^2 within the dimensions of the room.

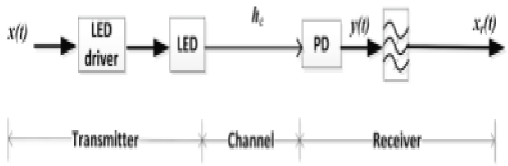

Fig. 1.VLC System

Fig. 1. Illustrates theVLC system which uses two techniques for input data stream x (t) ∈ {1, 0}to the transmitters(LEDs) directly through intensity modulation and direct detection. At the receiving end, the photo diode converts the received optical power from the LED's into photocurrent which allows to recover the transmitted signal [6]. This recovery allows us to estimate the RSS (Received signal strength).

III. VLC POSITIONING TECHNIQUES

There are several positioning techniques currently applied for VLC such as

i. RSS based Trilateration
ii. Scene Analysis
iii. Proximity Method, for the receiver position estimation.

A. RSS Based Trilateration

This method depends completely on the current RSS values – (online) and ultimately measures the receiver and the respective transmitter's distance [7] - [8]. The receiver is identified to be located at the point of intersection of all the three circles centred at their respective transmitters.Fig. 2. illustrates estimation of the position of the receiver in existing RSS based trilateration technique.This particular technique measures the distance by solely depending upon the RSS(online). Therefore, the accuracy in estimating the position of the receiver can be affected by ambient light (external sources such as sunlight).

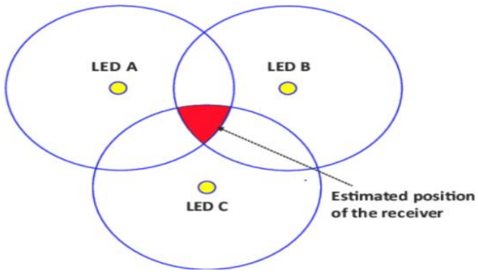

Fig. 2. Position Estimation – RSS Trilateration

B. Proximity Method

The proximity method is performed with prior knowledge of the positions of the transmitters. The transmitters having unique identifiers and pre-determined locations in the network allows us to associate the receiver with the transmitters (LED's) more easily and locate the receiver's position.

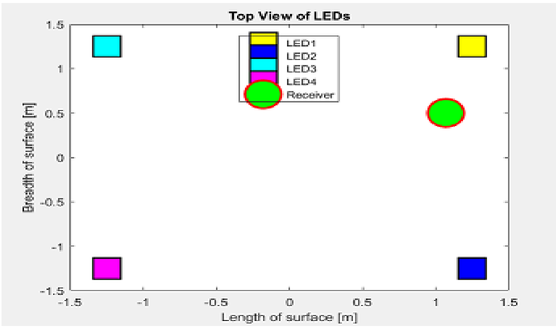

Fig. 3. Receiver proximity at LED 1

When the receiver is within the proximity of any of the transmitters, the transmitter (LED) senses the receiver (photo diode) [9]. If numerous transmitters are detected by the receiver, the transmitter with the highest RSS value is considered to be the closest to the receiver. Fig. 3 and Fig. 5 show the proximity of receiver at LED 1 and LED 2 respectively.Fig. 4 and 6 provide the calculated RSS for receiver proximity at LED 1 and LED 2 respectively. In each case RSS is obtained high with respective LED.

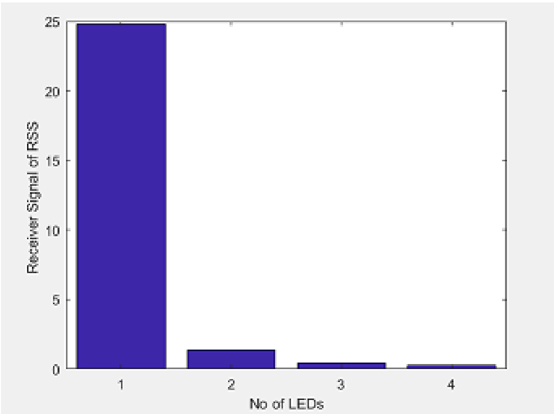

Fig. 4. RSS Calculation – Receiver proximity at LED 1

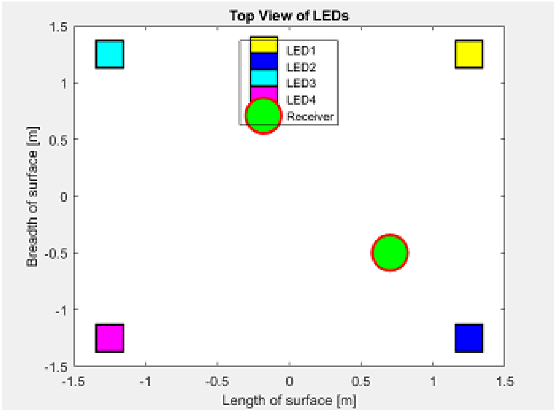

Fig.5. Receiver proximity at LED 2

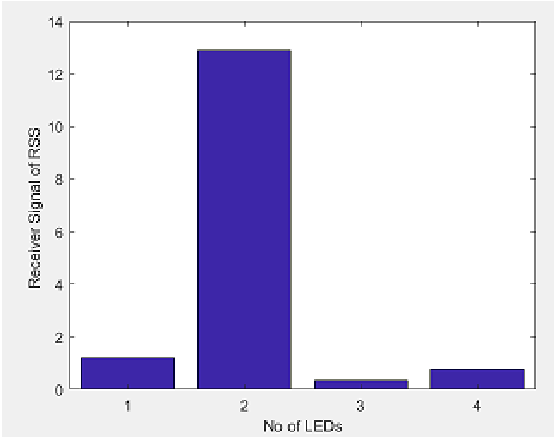

Fig.6. RSS Calculation – Receiver proximity at LED 2

IV. PROPOSED TECHNIQUE

Weighted k-nearest neighbour model

The Wk-NN model follows two methods/modes:

1. Offline mode
2. Online mode

A. OFFLINE MODE

In the offline mode, the fingerprints/sensors/nodes are generated within the area of the network based on RSS measured at the receiver for each LED.

B. ONLINE MODE

In the Online mode, the Euclidean distance is calculated by comparing the online RSS value (current position of receiver) and the offline RSS values (RSS values at nodes/fingerprints of the network) are measured during its movement [9] [10].Upon calculating the Euclidean distances by comparing both offline RSS and online RSS values, the receiver (photo diode) has the ability to identify the k nearest neighbours having the smallest Euclidean distancesas shown in (1).

$$d_E = \sqrt{\sum_{i=1}^{l} (RSS_{Ti} - RSS_i)^2} \quad (1)$$

Coordinates of the receiver can be calculated by averaging the coordinates of k-NN's as (2).

$$x = \frac{\sum_{i=1}^{k} x_i}{k} \quad y = \frac{\sum_{i=1}^{k} y_i}{k} \quad (2)$$

The number of nearest neighbours K is user defined. The accuracy of the VLC positioning technique which is the Wk-NN is dependent upon the number of nearest neighbours (K value) [11] - [12]. Without weighting, the position of the photo diode(receiver) is estimated to be at the central area established by the coordinates of the nodes/fingerprints (nearest neighbours). This might lead to an error of prediction and lower the accuracies of VLC positioningwhen the receiver's actual position is away from the centre formed by the k-NN's.To improve accuracy, based on the Euclidean distances, the k-NN's are weighted. The longer Euclidean Distance is considered as smaller weight and the smaller Euclidean Distance is considered as larger weight.Therefore, after weighting the nearest neighbours, the receiver's estimated position is in close proximity to the receiver's actual position and not the central area established by averaging the coordinates of k-NN's [12].

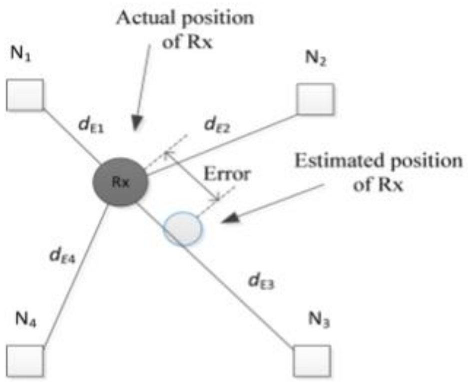

Fig.7. Estimated and Actual position of receiver - Accuracy

Fig. 7 illustrates the estimated and actual position of the receiver. It is a model which briefs us about the errors that occur when the k nearest neighbours are not weighted.

V. RESULTS AND DISCUSSIONS

VLC positioning techniques such as theProximity method and the Proposed Wk-NN, has been simulated using MATLAB 2017a, with the parameters as mentioned in the Table-I.

Table-I

PARAMETER	VALUE
Room dimension (L x W x H)	5m x 5m x 3m
Power of LED	10 W
Number of LED's	4
LED Position(x, y, z)m	A (-1.25, -1.25, 3) B(1.25,-1.25, 3) C(-1.25, 1.25, 3) D(1.25,1.25, 3)
Photo detector (PD) type	OSD-15T
Field of view	70°
PD active area	1 cm^2
Gain of the optical fiber (T_s)	1
Refractive index of the optical concentrator (n)	1.5
Absolute temperature (T_k)	300
Open loop voltage gain (G)	10
FET transconductance (g_m)	30 mS
FET channel noise factor (Ł)	1.5
Fixed capacitance of PD per unit area (η)	112 pF/cm^2
Background current (I_{bg})	740 µA

A. Impact of light power attenuation

In the absence of ambient light (external sources) on the VLC system, the received power relies on two important factors.

i. Distance between Receiver (PD) and Transmitter (LED)
ii. The angle of incidence.

The received power also termed as the equivalent illumination level has a concentration level right below the LED's which is directed towards the centre of the room [13].

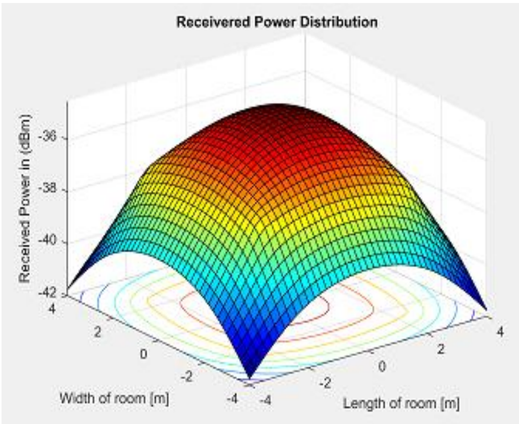

Fig.8. Received power distribution (dBm)

Fig.8 illustrates the received power distribution caused by the four LED's across the entire room.
As the receiver travels away from the room's centre towards the edges, the illumination level caused by the four LED's gradually reduces.For thereceiver's position estimation, the RSS based trilateration depends heavily on the power received at the receiver (photo diode) [14] [15]. This helps in calculating the radii of the circles. As the receiver travels away from the centre approaching the corners, the received photo current reduces and hence errors occur,which is dependent on the received power for estimation of receiver location.

B. Ambient light impact(sunlight and other visible light sources)

The receiver (PD) cannot differentiate the visible light sources transmitted from the LED's and from the external light sources (sunlight light) and hence all of the incident light at the receiver is converted to photocurrent [16]. The ambient noise is not a componentof our desired signal and hence the RSS value varies and in turn influences the accuracy for the VLC positioning .

C. Impact of ambient light on SNR

In the existence of ambient light, the SNR obtained at the receiver reduced considerably by 5dB and hence the degradation of SNR impactsthe positioning performance of any VLC positioning technique.

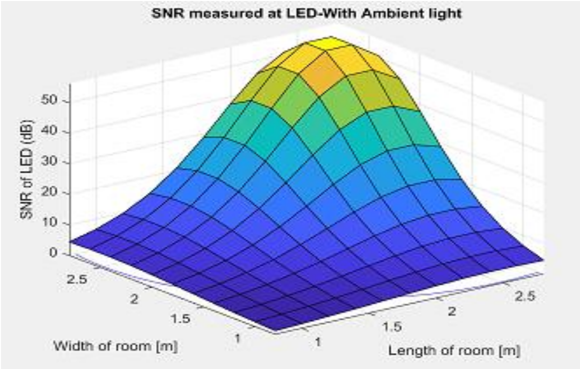

Fig.9. SNR – with ambient light

RSS based trilateration is sensitive to external sourcessuch as sunlight (ambient light) because this method identifies the location of the receiver based

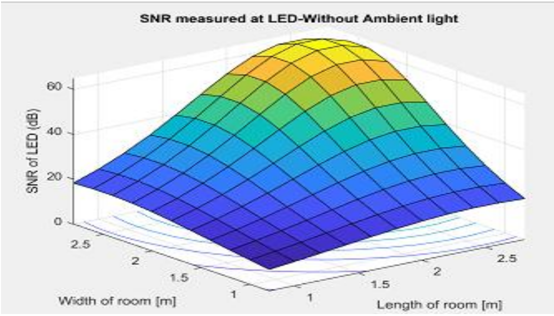

Fig.10.SNR – without ambient light

on the received signal strength sent from the other three transmitters [17].The presence of ambient light influences the RSS value of the receiver and thus impacts the accuracy of this particular technique. Fig. 9 and Fig. 10 illustrates the impact of ambient light on SNR.

D. Ambient light impact on positioning errors

Wk-NN technique avoids the impact of ambient light to some extent [18]. The purpose of the Offline stage is to generate and build a set of fingerprints/nodes in the absence of external light. Further, the online RSS values are compared with the offline RSS values to calculate the Euclidean distance. Positioning accuracy of k-NN and Wk-NN isa degree higher than the RSS-based trilateration method.

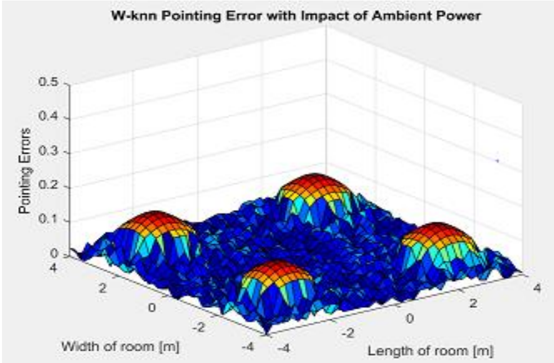

Fig.11.Positioning errors – ambient light – Wk-NN model

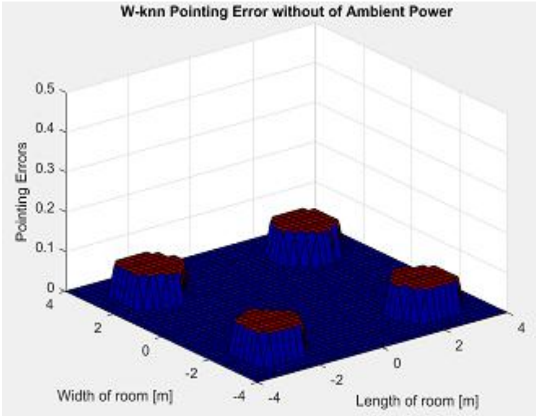

Fig.12.Positioning errors – without ambient light – Wk-NN model

Fig. 11 and Fig. 12 illustrates the impact of ambient light on positioning errors.

E. Histogram of positioning errors

The Wk-NN technique generates a lower average of positioning error and standard deviation (SD) in the absence of ambient light as compared to the presence of ambient light [19].

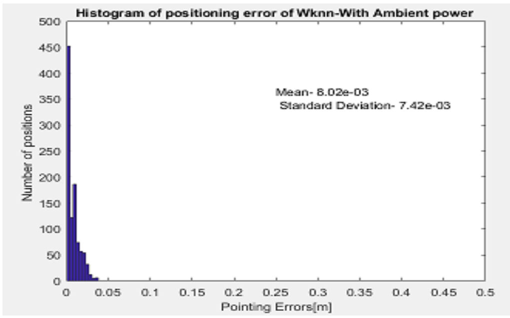

Fig.13. Histogram – Positioning errors – with ambient light

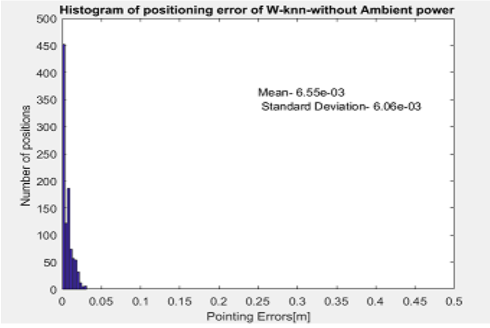

Fig.14.Histogram – Positioning errors – without ambient light

Fig. 13 and Fig. 14 provide a histogram of positioning errors, with and without ambient light respectively.

F. Ambient Light impact on Error Measurement

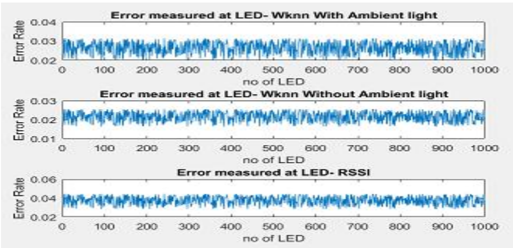

Fig.15. Error Measurement – Error rate

Fig. 15 illustrates the calculated error rate at the LED's in the Wk-NN model with and without ambient light and also calculates the error rate for RSS based trilateration.

G. Impact of number of neighbours k

Estimated position of the receiver is found to be at the centre of the area calculated by averaging the coordinates of k nearest neighbours [20]-[21]. This happens when the Euclidean distances of the k nearest neighbours are not weighted.K is user defined, the number of k nearest neighbouring has a significant impact on the accuracy of the Wk-NN model. It is observed that positioning errors of Wk-NN at k = 2, 3, 4, 5 have lower magnitude in the absence of ambient light as compared to the magnitude in the presence of ambient light. The reason behind this is the weighted Euclidean distances shift the estimated position close to the actual position, instead of the central area establishedby the k-neighbours.

H. Number of neighbours k impact on Positioning errors – With Ambient light

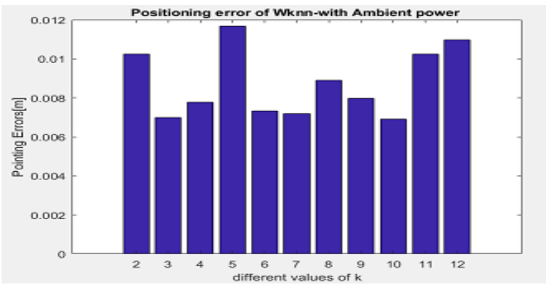

Fig.16. Positioning error of Wk-NN (Average) for different k values – with ambient light

I. Number of neighbours k impact on Positioning errors – Without Ambient light

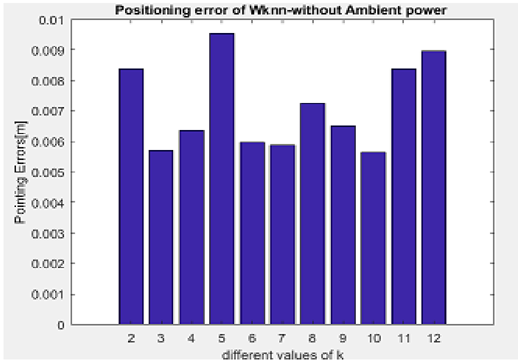

Fig.17.Positioning error of Wk-NN (Average) for different k values – Without Ambient light

Wk-NN model provides better positioning accuracy than the RSS trilateration method. The degree of accuracy is higher in the proposed Wk-NN technique.Fig.16 and Fig.17 depict the magnitude of positioning error for different values of k, with and without ambient light.

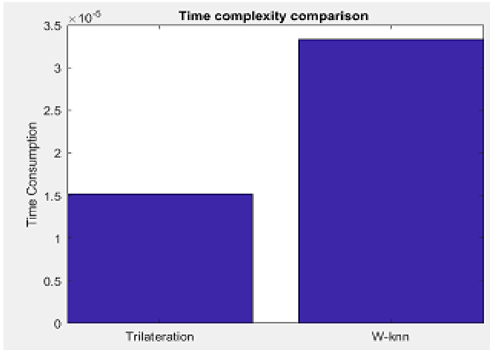

Fig.18. Comparison of Time complexity

However, although the Wk-NN provides better positioning accuracy as compared to RSS trilateration, the Wk-NN model consumes more time than the RSS based trilateration as it needs to scan and compare the online RSS values with all of the RSS values of the offline generated fingerprints/nodes. Therefore the average computational time for Wk-NN is greater than RSS based trilateration.Fig.18 shows the time required to execute the existing model based on RSS trilateration and the proposed Wk-NN model.

VI. CONCLUSION

The proposed Wk-NN model provides better accuracy than the existing VLC positioning techniques such as the RSS based trilateration and the proximity method with and without the ambient light impact.The Wk-NN model also provides better accuracy than k-NN in estimating the position of the user (receiver) as the Euclidean distances are weighted. Finally, we can obtain high precision indoor VLC positioning by using this method for VLC communication systems.

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AUTHORS PROFILE

Dr.A Jabeena, is a faculty in School of Electronics Engineering,Vellore Institute of Technology [VIT], Vellore. Her Research Interest includes application of Optical Wireless Communication, Optical Sensors and Visible Light Communication.

Dr. G. Aarthi, is a faculty in School of Electronics Engineering, Vellore Institute of Technology, Vellore. Her Research Interest includes application of Optical Wireless Communication, Free space optical communication and Visible light communication.

Akash Reddy, Supreet Palabatla and Paidi Sasidhar are Final Year B.Tech Electronics and Communication Engineering Students from Vellore Institute of Technology,Vellore , interested to work with VLC applications.