ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 3, June 2022, pp.300-310

Accuracy enhancement in indoor positioning system based on visible light communication

Mayasah Razzaq [1,2] * and Ibrahim Abdullah [1]
[1]University of Babylon, College of Engineering, Dept. of Electrical Engineering, Babylon-Iraq
[2] Al-Mustaqbal University College, Dept. of Medical Instrumentation Techniques Engineering, Babylon-Iraq

ABSTRACT

The travelled signals that used to estimate the distances between LEDs and the target undergo from non-line-of-sight (NLOS) link in indoor positioning system (IPS) utilizing visible light communication (VLC) technology. This could present a significant error in identifying their positions. In this paper, we design an IPS based on a new hybrid technique using VLC technology for accuracy enhancing. To begin, the target's position is determined using a weighted least square positioning method. Next, a maximum likelihood positioning approach is used to relocate the target's position, starting with the estimated position as an initial point. Simulations present that the created algorithm performs better than weight least squares and conventional maximum likelihood methods.

Keywords: Indoor positioning system (IPS), Visible light communication (VLC), Weight least square, Maximum likelihood, Received signal strength (RSS).

Corresponding Author:

Mayasah Razzaq Abdali
[1]University of Babylon, College of Engineering, Dept. of Electrical Engineering.
[2] Al-Mustaqbal University College, Medical Instrumentation Techniques Engineering Department
Hilla, Babylon-Iraq
E-mail: mayasah.razzaq@mustaqbal-college.edu.iq

1. Introduction

Visible Light Communication (VLC) is a subcategory of the optical wireless communication (OWC) that simultaneously illuminates and transmits data using light emitting diodes (LEDs). Its motivating characteristics have made VLC an appealing study field for research and business involve secure communication, deployment is a cinch, low price of implementation, no interference from radio and absence of a need for a license[1][2]. There are numerous potential uses for VLC technology. An example of how this technology could be used is to locate a receiver inside a building by integrating it with the established lighting system. When it comes to large areas like hospitals, and malls, this would be a great help[3].

In general, the global positioning satellite (GPS) system is unsuitable for use in indoor spaces due to it has a positioning error that can be several meters. It's because satellite microwave signals have a hard time penetrating the walls of a building. For this reason, radio-frequency (RF) systems (Wi-Fi as example) and other techniques have been considered as alternatives for indoor positioning[4]. The accuracy of these techniques is superior to that of GPS, but because of the higher location error and the additional infrastructure required, they may be less practical than GPS. An IPS that relies on the lighting infrastructure in a building to locate a receiver's position is a promising technology.

Many algorithms can be utilized to identify a target's location using VLC, such as proximity algorithm, fingerprinting methods, trilateration and triangulation. Trilateration that utilized the received signal strength (RSS) is the widely used positioning method since it's so simple[5]. The LED positions, the parameters of the transmitter and target, and the link model must be known before using this method. The receiver noise and the complexity of indoor environments are two of the most common causes of poor positioning accuracy. IPS based on VLC using the RSS approach has been limited to a line-of-sight (LOS) link between of LED and the target in most previous work on the subject. For the evaluations, a non-line-of-sight (NLOS) links must be taken into account because of reflections from different objects. To estimate the position, a linear least square method was used with a large error and no alternative was suggested to improve the accuracy.

To further improve the system accuracy, in this paper we offer the use of the modified version of Maximum likelihood estimator via making the initial point to be changeable based on a weight least square estimator outcome. The algorithm takes into account the LOS and NLOS channel model and noise.

After that, the remnant of the paper is arranged as stated. Section 2 depicts the related work. System model is given in detail in section 3. Experiment's parameters can be found in section 4 gives. Section 4 gives the results and discussion of the suggested algorithm. Section 5 concludes with a look ahead to what's next in the work.

2. Related works

Wenjun G. et al, in 2015[6], studied the multipath reflections effects in an IPS based on VLC for a typical room. Distance between transmitter and receiver can be determined using RSS data. When multipath is included in the calculations, there are positional errors of 0.806 m.

F. Mousa et al, [7] in 2018 discussed a two-dimensional (2D) IPS based on LED ceiling lamps using RSS. The trilateration approach was used to model the effects of optical power distortions received from three transmitters. For each user, an average error of 5 cm may be predicted using this positioning algorithm and a LOS system.

E. Lam et al. [8], in 2019, in a $4\,m \times 4\,m \times 1\,m$ volume test, they developed and tested Ray Surface Positioning (RSP) utilizing inexpensive components. For 95% of the test volume, the location estimate errors were fewer than 30 cm. In this study, the authors employed the least squares (LS) approach to locate a desired position.

G. Shi et al. [9], in 2019, used RSS methodology to construct analytical formulations of distances measurement error and the top limit of a positioning error. In a noisy VLC channel, the LOS and NLOS links are also taken into account. With this strategy, the average positioning error is 0.5 meters in the space. The walls have the worst positioning performance, whereas the center has the best. A VLC system can achieve an 8-millimeter positioning precision, according to the researchers' simulation data. To obtain an 8mm positioning precision, this experiment uses a very low reflectivity ($\rho = 0.01$) for the experiment.

D. Mai et al. [11], in 2020, proposed a full design for VLC-based IPSs, including PHY and link-layer solutions, has been presented in this paper. An RSS-based triangulation method was utilized by the authors in order to identify user locations. A location identification (ID) was encoded uniquely utilizing Optical Orthogonal Codes (OOC) for each LED at the receiver (OOC). Simulations reveal that the error in location was less than 0.5 meters. The writers, on the other hand, focus on the LOS channel.

Marcos S. et al, [12], in 2020, proposed and implemented a real-time IPS based on VLC. For this system, a photodiode-based mobile correlator receiver reads the ID codes transmitted by nine LEDs mounted in the ceiling of an interior environment. Receivers are capable of determining their position in relation to other objects by determining the distance between themselves and the transmitters. RSS is used to determine the system's physical properties, which are used to calculate the distances. At any time in the test room, the average 2D and 3D errors were less than 25cm and 35cm, respectively.

3. System model

Figure 1 depicts our IPS based on VLC, which is widely regarded. Observing a room with four LEDs, constant position transmitters are put in a lattice arrangement, a standard pattern for measuring the lighting fixtures' positions. Each LED location coordinate is anticipated to be downloaded by a mobile user ahead of time and stored locally on their device. OCC was assumed to be used for signals separation at the receiver[10]. The algorithm of the whole model of the proposed system is given in algorithm1. Detailed explanations of each step can be found in the sub-sections that follow.

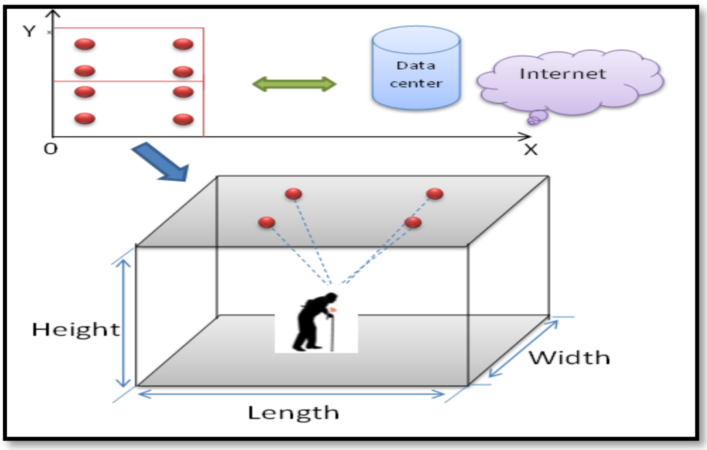

Figure 1. IPS based on VLC.

Algorithm 1 Positioning algorithm

```
1. Procedure LED's installation
Install $n$ LEDs in the ceiling. → In this experiment $n = 4$.
End procedure
2. Procedure Create the transmission algorithm.
Every LED sends information about its location (ID) to the detector.
    End procedure
3. Procedure LOS and NLOS channel

    a. LOS Case
$$P_{LOS}(t) = \begin{cases} \frac{P_t}{d_i^2} R_{LOS}(\theta_1) A_{PD} \cos(\psi_1) T_s(\psi_1) g(\psi_1) & 0 \le \psi_1 \le FOV \\ 0 & otherwise \end{cases} \tag{2}$$

    b. NLOS Case
$$P_{NLOS} = \begin{cases} \frac{P_t}{d_{1j}^2 d_{2j}^2} R_{NLOS}(\theta_{2ij}) \mu \, A_{PD} \cos\left(\psi_{2_{ij}}\right) T_s\left(\psi_{2_{ij}}\right) g\left(\psi_{2_{ij}}\right) & \\ 0 & otherwise \end{cases} \tag{4}$$

        End procedure
4. After Photodiode, Measure power for each LED
5. Adding AWGN noise.
6. Separate received signals →Optical Orthogonal codes (OOC)
7. Select 4 LEDs that having highest received power
8. Procedure Compute distances
9. Procedure Target (patient) location → WLS
$$\hat{P} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (A^T A)^{-1} A^T \, \hat{b} + \begin{bmatrix} Lx_1 \\ Ly_1 \\ Lz_1 \end{bmatrix} \tag{18}$$
    End procedure
10. Procedure Compute MSE for each group. → based on the measured distance
End procedure
11. Procedure Patient Relocation
Using modified ML algorithm → Changeable initial point
    End procedure
--------------------------------------------------------------------------------------------------------------------------
End algorithm
```

3.1 VLC Channel model

The total power received from LED lights is typically stated in eq.1:

$$P_{r-total} = R_{PD}(P_{LOS} + P_{NLOS}) + \sigma^2 \qquad (1)$$

where $P_{r-total}$, R_{PD}, P_t ,P_{LOS} and P_{NLOS} is the target's total received power, the photodetector responsivity, the LED's transmitted power by source, the received power LOS, and received power of the NLOS, respectively[13]. Finally, the σ^2 is the noise power which is discussed in section (3.2).

i. LOS Mathematical Modelling

When a direct path links the transmitter and receiver, as shown in figure 2, a LOS model is available. In the LOS scenario, the VLC channel's received power is given by eq.2[14].

$$P_{LOS}(t) = \begin{cases} \frac{P_t}{d_i^2} R_{LOS}(\theta_1) A_{PD} \cos(\psi_1) T_s(\psi_1) g(\psi_1) & 0 \le \psi_1 \le FOV \\ 0 & otherwise \end{cases} \qquad (2)$$

where,

- P_t : Average transmitted power,
- $d_i = d(T_{xi}, R_x)$: Distance from $i'th$ transmitter to the receiver Rx.
- A_{PD} : Physical area of PD.
- $T_s(\psi)$: Gain of optical filter.
- $g(\psi)$: Gain of optical concentrator.
- FOV: Field of View of the PD.
- θ_1 : Irradiance angle.
- ψ_1 : Incidence angle.
- $R_{LOS}(\theta_1)$: Radiation angle intensity in relation to the PD.

The LED serves as an optical transmitter, in this system, and its emission pattern simply represents that of the Lambertian model; so, $R_{LOS}(\theta_1)$ can be put as

$$R_{LOS}(\theta_1) = \frac{(m+1)}{2\pi} cos^m(\theta_1)$$

where m is the number of mode which is represented as

$$m = \frac{-\ln(2)}{\ln(\cos(\theta_{1/2})}$$

where $\theta_{1/2}$ denotes the LED's semi angle at half its brightness. So, the estimated distance from LED to the target can be given as in eq. (3)[[15].

$$d = \left\{ \frac{[R_{PD} P_t (m+1) A_{PD} h^{m+1} T_s(\psi) g(\psi)]^2}{4\pi^2 H_{LOS} P_t} \right\}^{\frac{1}{6+2m}} \qquad (3)$$

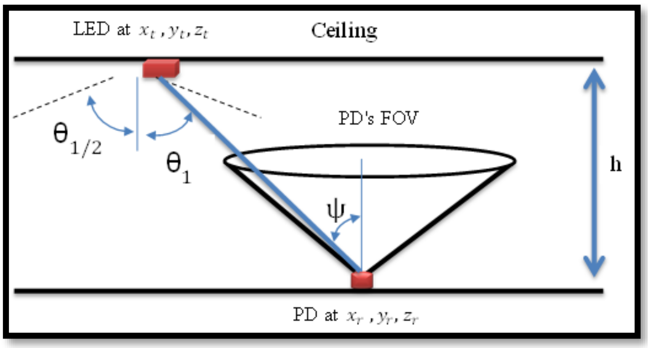

Figure 2. LOS link modelling [14]

ii. NLOS Mathematical Modelling

Figure 3 depicts a situation in which light is reflected off of a wall and travels a different path before reaching the receiver. Hence, the VLC received power is described as in eq.4 in the NLOS situation[15][7].

$$P_{NLOS} = \begin{cases} \frac{P_t}{d_{1j}^2 d_{2j}^2} R_{NLOS}(\theta_{2ij})\mu\, A_{PD} \cos\left(\psi_{2_{ij}}\right) T_s\left(\psi_{2_{ij}}\right) \mathrm{g}\left(\psi_{2_{ij}}\right) & \\ 0 & otherwise \end{cases} \quad (4)$$

With

$$R_{NLOS}(\theta_{2ij}) = \frac{(m+1)}{2\pi} cos^m(\theta_{2ij})$$

$$\mu = \frac{\rho dA_{wall}}{\pi} \cos(\alpha_{ij}) \cos\,(\beta_{ij}$$

where,

- μ : First reflection factor.
- $R_{NLOS}(\theta_{2ij})$: radiant intensity of the LED for the situation of NLOS.
- i : LED's index,
- j : multipath's index.
- ρ : Reflectance factor.
- dA_{wall} : Reflective area.
- α : Irradiance reflective angle.
- β : multipath irradiance angle to the PD.

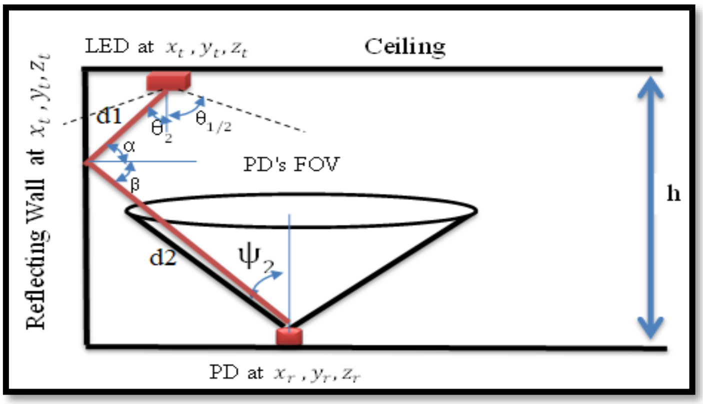

Figure3 : NLOS link modelling[14].

3.2 Noise Model

The aggregate noise will be treated as white Gaussian noise (AWGN) channel variance. It is the adding of the shot noise variance σ_{shot}^2 and the thermal noise variance$\sigma_{Thermal}^2$ as described in eq. 5

$$N = \sigma_{shot}^2 + \sigma_{Thermal}^2 \quad (5)$$

The shot noise variance is expressed by eq.6.

$$\sigma_{shot}^2 = 2qI_bI_2B_n + 2qR_{PD}P_{r-total}B_n \quad (6)$$

q is the electric charge, I_{bg} is the current due to background, I_2 and I_3 denotes the factors of the noise bandwidth and B_N is the noise bandwidth? On the other hand, the thermal noise variance is described by eq.7 [29].

$$\sigma_{Thermal}^2 = \frac{8\pi kT_K A_{PD} I_2 B_n^2}{Go} + \frac{16\pi^2 k\Gamma T_k}{gm} C_{PD}^2 A_{PD}^2 I_3 B_n^3 \quad (7)$$

whereT_K is the absolute temperature, k is the Boltzmann Constant, Go is the open-loop voltage gain,C_f is the fixed capacitance of receiver, Γ is the factor of the FET channel noise, and gm is the FET trans-conductance. The electrical SNR value is being used to evaluate the VLC system which can be expressed in eq.8[16].

$$SNR = \frac{(R_{PD}P_{r-total})^2}{\sigma_{shot}^2 + \sigma_{Thermal}^2} \tag{8}$$

3.3 Target positioning using weight LS

Knowing a target position in 3D need to measure the distances from at least four LEDs. Assume P= $[x_i; y_i; z_i\,]$ expresses the position of the target in Cartesian coordinates. Moreover, $L_i = [Lx_i; Ly_i; Lz_i]$ denotes the LEDs positions, i is the LED index $\{i = 2 \ldots\ldots\ldots n,\}$. Generally, the actual distance from LED to the target is given in eq. 9.

$$r_i^2 = \|L_i - P\|^2 = (Lx_i - x)^2 + (Ly_i - y)^2 + (Lx_i - z)^2 \tag{9}$$

As abovementioned, r denotes the actual distance and d the estimated distance, then the error could be calculated as presented in eq.10.

$$e_i = d_i - r_i \tag{10}$$

A straight gradient approach, for example, might be used to iteratively determine the estimated position as shown in eq. 11.

$$\hat{P} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix}_{k+1} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix}_k - \alpha \begin{bmatrix} \frac{\partial \varepsilon}{\partial x} \\ \frac{\partial \varepsilon}{\partial y} \\ \frac{\partial \varepsilon}{\partial z} \end{bmatrix}_{x=\hat{x}_k, y=\hat{y}_k, z=\hat{z}_k} \tag{11}$$

Where σ is a constant selected to reduce e. Also, $\hat{x}, \hat{y}, \hat{z}$ are the target (P) coordinates that measured. In this equation, it is necessary to give an initial position value, as well this situation is a nonlinear challenge. For nonlinear problems, the hyperbolic positioning algorithm turns the issue to a linear one that can be addressed using a least squares estimator (LS)[17]. When using the LS method, one of the sub-equations in eq. 9 is chosen as a reference equation and subtracting this equation from the remaining sub-equations. According to eq. 9, a target's distance from LED 1 is used as a reference equation in this work, as stated in eq. 12.

$$r_1^2 = (Lx_1 - x)^2 + (Ly_1 - y)^2 + (Lz_1 - z)^2 \tag{12}$$

As a result, Equation 13 shows the linearization solution.

$$r_1^2 - r_i^2 = (Lx_1 - x)^2 + (Ly_1 - y)^2 + (Lz_1 - z)^2 - ((Lx_i - x)^2 + (Ly_i - y)^2 + (Lz_i - z)^2) \tag{13}$$

Eq.14 is the result of adjusting eq. 13, as shown below

$$Lx_i^2 + Ly_i^2 + Lz_i^2 + r_1^2 - r_i^2 = 2x(Lx_i - Lx_1) + 2y(Ly_i - Ly_1) + 2z(Lz_i - Lz_1) \tag{14}$$

The matrix operation is implemented and results is shown as:

$$A = \begin{bmatrix} Lx_2 - Lx_1 & Ly_2 - Ly_1 & Lz_2 - Lz_1 \\ Lx_3 - Ax_1 & Ly_3 - Ly_1 & Lz_3 - Lz_1 \\ \vdots & \vdots & \\ Lx_n - Lx_1 & Ly_n - Ly_1 & Lz_n - Lz_1 \end{bmatrix}$$

Also, the measurement vector as exhibited in equation 15.

$$b = 0.5 \begin{bmatrix} (Lx_2 - Lx_1)^2 + (Ly_2 - Ly_1)^2 + (Lz_2 - Lz_1)^2 + \ r_1^2 - r_2^2 \\ (Lx_3 - Ly_1)^2 + (Ly_3 - Ly_1)^2 + (Lz_3 - Lz_1)^2 + \ r_1^2 - r_3^2 \ \vdots \\ (Lx_n - Lx_1)^2 + (Ly_n - Ly_1)^2 + (Lz_n - Lz_1)^2 + \ r_1^2 - r_n^2 \end{bmatrix} \tag{15}$$

where, r_1 denotes the actual distance from the reference LED to the target, and r_i denotes the distances from all LEDs excepting the reference LED to the target. Then, the coordinates of the target will be calculated as given in eq. 16.

$$P = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = (A^T A)^{-1} \, A^T \, b + \begin{bmatrix} Lx_1 \\ Ly_1 \\ lz_1 \end{bmatrix} \tag{16}$$

As we described previously, d expresses the estimated distance from the LED to the target. Hence, the estimated position $\hat{P}$ can be obtained by calculating the estimation value $\widehat{b}$ as given in eq.17.

$$\hat{b} = 0.5 \begin{bmatrix} (Lx_2 - Lx_1)^2 + (Ly_2 - Ly_1)^2 + (Lz_2 - Lz_1)^2 + \ d_1^2 - d_2^2 \\ (Lx_3 - Ly_1)^2 + (Ly_3 - Ly_1)^2 + (Lz_3 - Lz_1)^2 + \ d_1^2 - d_3^2 \ \vdots \\ (Lx_n - Lx_1)^2 + (Ly_n - Ly_1)^2 + (Lz_n - Lz_1)^2 + \ d_1^2 - d_n^2 \end{bmatrix} \tag{17}$$

Hence, the estimated patient $\hat{P}$ will be as shown in eq. 18.

$$\hat{P} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (A^T A)^{-1} \, A^T \, \hat{b} + \begin{bmatrix} Lx_1 \\ Ly_1 \\ Lz_1 \end{bmatrix} \tag{18}$$

The weighted least squares (WLS) method[18] is a new algorithm that uses the variance of the measured distance to improve positioning accuracy (eq. 18) [18]. For the WLS algorithm, the inverse variance of distance measurements is taken into consideration when adjusting the weight matrix (W).

$$W = \begin{bmatrix} var(d_1^2) + var(d_2^2) & var(d_1^2) & \ldots. & var(d_1^2) \\ var(d_1^2) & var(d_1^2) + var(d_3^2) & \ldots. & var(d_1^2) \\ & \cdot & & \\ & \cdot & & \\ & \cdot & & \\ var(d_1^2) & var(d_1^2) & var(d_1^2) + var(d_n^2) & \end{bmatrix}$$

A squared estimated distance from the reference LED to the target has a variance of $var(d_1^2)$ while the variance of all other LEDs to P has a variance of $var(d_n^2)$. To complete the WLS, insert the inverse of W into the final equation.

$$\hat{P} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (A^T W^{-1} A)^{-1} \, A W^{-1} \, \hat{b} + \begin{bmatrix} Lx_1 \\ Ly_1 \\ Lz_1 \end{bmatrix} \tag{19}$$

3.4 Target positioning using Maximum Likelihood

The maximum likelihood strategy optimizes the pdf of distance measurements to derive the agent's position, assuming that the range error distribution parameters are known, as shown in eq. 20[19].

$$\hat{P} = arg\ min_p \left(\sum_{i=1}^{i} \frac{(r_i - d_i)^2}{\sigma_i^2} \right) \tag{20}$$

Where σ^2denotes the variance and i expresses the LEDs index. Based on weight LS estimates of target positions computed in this study, the starting point is carefully chosen instead of being set and arbitrarily chosen in conventional ML.

4. Test parameters

With the hybrid technique described in this work, a novel indoor positioning system with improved accuracy has been developed employing a series of distinct procedures. In order to test the system, MatLab simulation is used. In this study four LEDs is placed at the ceiling and assumes a target walks through a room with a 5 ×5 ×3 m . The target holds the photodiode (PD) in his arm at a height of 0.85 meters from the ground. If optical light falls inside the PD's field of view, the location code can be picked up. It's believed that the receiver always receives four signals from separate propagation channels (LOS and NLOS). For thiswork, the simulation settings are shown on table 1.

5. Result and discussion

To begin, the procedures depicted in algorithm 1 are used to boost the system performance. When noise is considered, the system is tested. The AWGN function in MatLab is used to add noise into the received signal, and the SNR is calculated using eq.8.

Figure 4 depicts two different situations of track position for the evaluation step. In situations 1 and 2, the target travels around his room in a variety of directions. We chose five points that corresponded to his path inside the room to compute its position.

Table 1. Testing parameters

Parameter	Value
Room dimensions	$5 \times 5 \times 3m^3$
Room Reflectivity ρ	0.25
Reflecting area dA_{wall}	$1cm^2$
Lamberatian mode m	1
LED Power P_t	$4W$
PD's Responsivity R	$0.4\ W/cm^2$
Optical filter gain T_s	1
Concentrator gain g_s	1
LEDs' position	(1.25,1.25,3)(1.25,3.75,3) (3.75,1.25,3)(3.75,3.75,3)
PD's physical area A_{PD}	$1cm^2$
PD's height h	$0.85m$
FOV	$80\ deg$
Background Current I_b	$5100 \times 10^{-6}\ [A]$
Noise Bandwidth factor I_2	$0.562\ [A]$
I_3	$0.0868\ [A]$
Open-loop voltage gain G_o	10
O/E conversion Efficiency γ	$0.54\ [A/W]$
Noise Bandwidth B_n	$10^8[pulses/s]$
Absolute temperature T_K	$298[K]$
FET transconductance g_m	$30[mS]$
FET Channel noise factor Γ	1.5
Fix capacitance C_f	$112[pF/cm^2]$

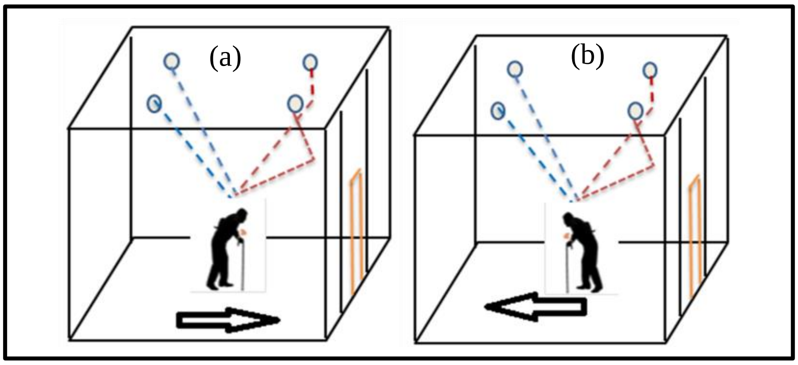

Figure 4. Testing activities in the room (a) Situation1, (b) Situation2

Last but not least, the suggested system is compared to weight LS and traditional maximum likelihood. Conventional maximum likelihood uses a fixed random location as the initial starting point for each iteration. The selected initial point is $(x = 5, y = 5, z = 0.85)$ and $(x = -5, y = 5, z = 0.85)$ for situation first and second situations respectively; however, in the suggested technique, we employ a changeable point that may be adjusted dependent on the WLS position as shown in tables 2 and 3 Another thing to consider is that conventional maximum likelihood's placement accuracy improves with increasing distance from its guess (starting) point, as shown in table point 5.

Table 2. System accuracy (MSE) for the three algorithms (Situation1)

Target Position	Weight LS	Maximum Likelihood	Proposed Algorithm
(0.25,1,0.85)	0.38	0.22	0.19
(1,4.5,.85)	0.43	0.21	0.2
(2.5,0.5,0.85)	0.51	0.34	0.21
(2.5,2.5,0.85	0.18	0.15	0.11
(4.75,4.75,0.85)	1.52	0.25	0.25
Mean	0.6	0.23	0.19

Table 3. System accuracy (MSE) for the three algorithms (Situation2)

Target Position	Weight LS	Maximum Likelihood	Proposed Algorithm
(-0.25,1,0.85)	2.56	0.92	0.29
(-1.5,2.5,.85)	0.24	0.19	0.17
(-2.5,3,0.85)	0.21	0.18	0.15
(-2.5,4.5,0.85	0.58	0.19	0.17
(-4,0.5,0.85)	1.03	0.25	0.22
Mean	0.93	0.34	0. 22

As shown in both tables, in LOS and NLOS channels, the proposed system's MSE averages $0.19m^2$ for situation 1 and $0.22m^2$ for situation 2, which is lower than the MSE of conventional ML and WLS, have an MSE for situation 1 about $0.6m^2$,0.23 m^2 and situation 2 have 0.93 m^2 , 0.34 m^2 respectively. Also. This shows that the system's performance is superior to that of other positioning methods in the same environment. Final results are shown in figure 5 for the first and second situations where the empirical cumulative distribution function (ECDF) to the MSE is computed as depicted.

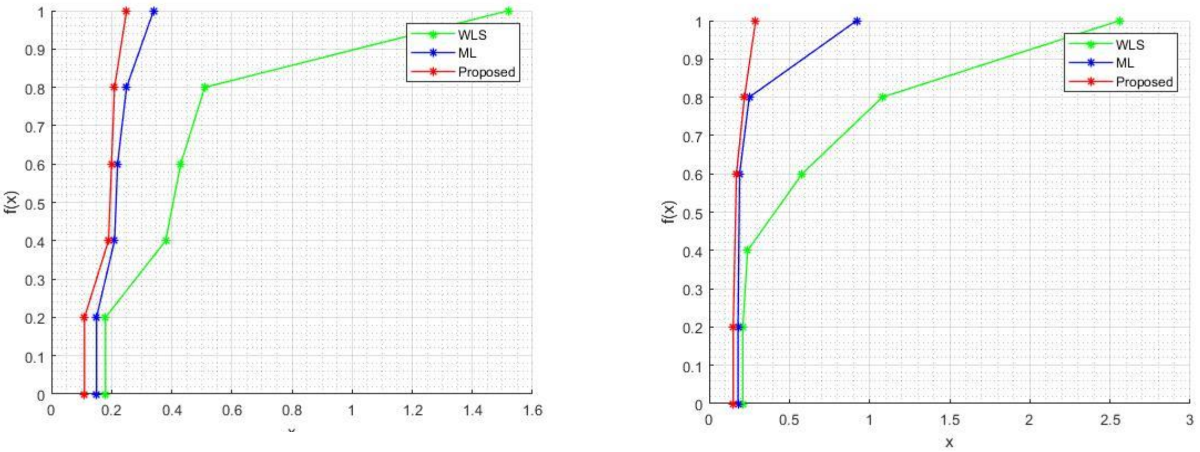

Figure 5. ECDF of MSE for the compared approaches in situations 1 and 2, respectively

6. Conclusions

In this work, a novel algorithm is proposed for locating and tracking a person utilizing VLC technology. The first step of the algorithm is to use the weight LS method to determine the target position. The position that was acquired is then utilized as the starting position to the maximum likelihood technique to re-identifying the position. Simulated results reveal that the suggested algorithm has better performance in term of MSE, about 0.19 m^2 for situation1 and 0.2 m^2 for situation 2, in comparison to weight LS and conventional maximum likelihood, that achieve an MSE for situation 1 about 0.6m^2 ,0.23 m^2 and situation 2 have 0.93 m^2 , 0.34 m^2 respectively. Our next step is to implement the method we've developed in a real-world setting.

Declaration of competing interest

The authors declare that they have no any known financial or nonfinancial competing interest.

Funding information

No funding was received from any financial organization to conduct this research.

References

[1] A. Jovicic, J. Li, and T. Richardson, “Visible light communication: opportunities, challenges and the path to market,” *IEEE Commun. Mag.*, vol. 51, no. 12, pp. 26–32, 2013.

[2] P. H. Pathak, X. Feng, P. Hu, and P. Mohapatra, “Visible light communication, networking, and sensing: A survey, potential and challenges,” *IEEE Commun. Surv. tutorials*, vol. 17, no. 4, pp. 2047–2077, 2015.

[3] L. Grobe *et al.*, “High-speed visible light communication systems,” *IEEE Commun. Mag.*, vol. 51, no. 12, pp. 60–66, 2013.

[4] H. Liu, H. Darabi, P. Banerjee, and J. Liu, “Survey of wireless indoor positioning techniques and systems,” *IEEE Trans. Syst. Man, Cybern. Part C (Applications Rev.*, vol. 37, no. 6, pp. 1067–1080, 2007.

[5] Y. Gu, A. Lo, and I. Niemegeers, “A survey of indoor positioning systems for wireless personal networks,” *IEEE Commun. Surv. tutorials*, vol. 11, no. 1, pp. 13–32, 2009.

[6] W. Gu, M. Aminikashani, and M. Kavehrad, “Indoor visible light positioning system with multipath reflection analysis,” *2016 IEEE Int. Conf. Consum. Electron. ICCE 2016*, no. Mmc, pp. 89–92, 2016, doi: 10.1109/ICCE.2016.7430533.

[7] F. I. K. Mousa *et al.*, “Indoor visible light communication localization system utilizing received signal strength indication technique and trilateration method,” *Opt. Eng.*, vol. 57, no. 01, p. 1, 2018, doi: 10.1117/1.oe.57.1.016107.

[8] E. W. Lam and T. D. C. Little, “Indoor 3D Localization with Low-Cost LiFi Components,” *2019 Glob. LIFI Congr. GLC 2019*, pp. 1–6, 2019, doi: 10.1109/GLC.2019.8864119.

[9] G. Shi, Y. Li, and W. Cheng, “Accuracy analysis of indoor visible light communication localization system based on received signal strength in non-line-of-sight environments by using least squares method,” *Opt. Eng.*, vol. 58, no. 05, p. 1, 2019, doi: 10.1117/1.oe.58.5.056102.

[10] N. J. Sattigiri, G. Patel, S. Mondal, R. Pal, and S. Prince, “Li-fi based indoor positioning system,” *Proc. 2019 IEEE Int. Conf. Commun. Signal Process. ICCSP 2019,* pp. 290–293, 2019, doi: 10.1109/ICCSP.2019.8697974.

[11] D. H. Mai, H. D. Le, T. V. Pham, and A. T. Pham, “Design and Performance Evaluation of Large-Scale VLC-Based Indoor Positioning Systems under Impact of Receiver Orientation,” *IEEE Access*, vol. 8, pp. 61891–61904, 2020, doi: 10.1109/ACCESS.2020.2984027.

[12] M. S. P. do. S. Lima Junior, M. P. Halapi, and E. Udvary, “Design of a real-time indoor positioning system based on visible light communication,” *Radioengineering*, vol. 29, no. 3, pp. 445–451, 2020, doi: 10.13164/RE.2020.0445.

[13] F. Esteban, “Robust localization system using Visible Light Communication technology for underground mines, ” PhD thesis, De Lorraine University, March, 2020.

[14] A. T. Hussein, “Visible Light Communication System,” no. December, 2016.

[15] F. Ibrahim, “Secure Visible Light Communication Systems Based on the Position of the User, ” PhD thesis, Northumbria University of at Newcastle,September, 2017.

[16] L. A. H. Azizan, M. S. Ab-Rahman, and K. Jumiran, “Analytical approach on SNR performance of visible light communication for modern lighting layout,” *ICIMTR 2012 - 2012 Int. Conf. Innov. Manag. Technol. Res.*, pp. 332–336, 2012, doi: 10.1109/ICIMTR.2012.6236413.

[17] B. C. Liu, K. H. Lin, and J. C. Wu, “Analysis of hyperbolic and circular positioning algorithms using stationary signal-strength-difference measurements in wireless communications,” IEEE Transactions on Vehicular Technology, vol. 55, no. 2, 2006.

[18] P. Tarrío, A. M. Bernardos, and J. R. Casar, “Weighted least squares techniques for improved received signal strength based localization,” Sensors, vol. 11, no. 9, 2011.

[19] K. Tong, “Location Estimation in Wireless Communication Systems, ” MSc. Thesis, University of Western Ontario, 2015.

.