On-Line Indoor Positioning System For Monitoring Elderly People Using Li-Fi Technology

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Abstract: This study aims to present an indoor positioning system that can locate a target in space. The created system has the flexibility to be modified online for precisely locating and monitoring an elder in an indoor environment by using Li-Fi technology. The designed system is based on a novel hybrid technique. It has different steps. Firstly, the combination method is used to divide the entire anchors into different groups. Secondlly, a weighted least squares (WLS) positioning approach is employed to compute the patient position by each group. Then, anchor selection is used online to select the group having the best positioning accuracy using the mean square error (MSE) metric. Finally, the selected group is chosen to relocate the patient using its estimated position as an initial point for the maximum likelihood (ML) positioning approach. The simulation results show that the proposed algorithm outperforms the WLS and conventional ML approaches.

Keywords: IPS, Li-Fi, RSS, WLS, ML.

1. Introduction

An Optical Wireless Communication (OWC) system has become increasingly significant in recent years to meet the demands of information and wireless communication technologies. The OWC includes a subset known as Visible Light Communication (VLC) (375 nm - 780 nm) that uses Light Emitting Diodes (LED). VLC is gaining popularity in academic and industry circles as a complementing and reliable alternative to RF solutions[1]. It provides users with a secure data connection from the light bulb closet to them, granting an system of artificial lighting with two functions: ambient illumination and high-speed data transfer at minimal power and complexity [2][3].

The Light Fidelity (Li-Fi) is one of the practical implementations of VLC based on wireless communication[4]. The term was introduced by Harald Haas in 2011[5]. This technology uses LED lights to send data with a higher speed up to 224 gigabits per second [6] compared to Wireless Fidelity (Wi-Fi), which is limited to several hundred Mbps[7]. Moreover, it is provided with high security and large bandwidth.
Newly, various favourable applications based on Li-Fi have been developed, and, in particular, indoor positioning (IP) services via Li-Fi have been known as very appealing applications[8]. Traditional techniques for indoor positioning rely on radio frequency (RF) like Wi-Fi [9], infrared [10], and lasers [11]. Among these methods, RF-based systems are well-known to have lower costs and are preferable in coverage [12]. However, the accuracy of these systems is the main issue because of the multipath fading effect. Furthermore, electromagnetic radiation poses a health risk and interferes with other electromagnetic waves in sensitive locations, therefore an indoor positioning system (IPS) based on RF cannot be used in these areas. IPS based Li-Fi can overcome the problems from the IPSs based RF. It provides high levels of security because the receiver is unable to receive signals from adjacent rooms. Therefore, the positioning algorithm will only use information supplied within the room in which it is required to compute its position accurately [13][14]. Moreover, it performs with higher accuracy at a lower cost. In addition, this system is resistant to electromagnetic interference and can be employed in RF-restricted environments (e.g., airports and hospitals).

A variety of indoor positioning approaches based on Li-Fi have been reported in various studies. Trilateration and angulation are two geometric properties that can be used to estimate indoor positioning [14 to 17]. The trilateration approach is used to estimate the location of a target by measuring distances between multiple reference points that have previously been determined. It is possible to estimate distance by utilizing various measurement techniques such as received signal strength (RSS) [15] and received signal strength ratio (RSSR) [16]. Alternatively, after the comparable trilateration philosophy of distance-based positioning, time of arrival (TOA) can also be used to find a target position in some applications[17].

Furthermore, the angulation approach estimates the target position by measuring angles from multireference nodes [18]. Among these approaches, angulation requires an extra peripheral for measuring the received signal angle. On the other hand, TOA relies on excellent synchronization between the transmitter and receiver in order to accurately compute the transmission distance. Therefore, RSS is considered one of the most practical approaches for VLC-based IPS due to its lower implementation and hardware complexity [19].

A vital slice benefiting from the indoor positioning system using Li-Fi is elderly people who live in a hospital environment. Thus, in this work, we assign the proposed approach to monitoring the position of elderly people. This system has the following contributions: i. Dividing LEDs into different groups (the LEDs are installed in the ceiling where each group has 4 to anchor nodes) using a combination method. ii. Making online Implement the anchor selection technique using modified mean square error metric (MSE) for selecting the group having the best positioning accuracy, iii. We modify the conventional Maximum likelihood (ML) estimation by online converting the initial point to be dynamic instead of static based on an Anchor selection outcome.

The remainder of this paper is organized in the following manner. Section 2 introduces a survey of related works to the proposed technique, which follows on from Section 1. Section 3 contains a description of the system model and its components. Section 4 contains the parameters that were used in the experiment that was conducted for this work. Section 5 presents the findings as well as a discussion of them. Section 6 comes to a close by drawing a conclusion and future work.

2. Related Works
K. Wang et al. [20] designed and tested an infrared optical wireless localization system to evaluate background light power in an indoor environment. According to the authors, the experimental results demonstrate that the impact of background light on localization accuracy can be eliminated, and that an average localization error of about 2.5 cm can be achieved on a regular basis. These results are also 80 percent more accurate than the previously announced optical wireless indoor localization systems, which were previously announced at a lower cost. Despite the fact that the system is capable of centimeter-level localization accuracy, its transmission distance (1 m) is significantly shorter than that of VLC, which can reach up to 10 m. It also leads to a higher cost since installing large numbers of infrared nodes in the room is necessary.

E. Lam et al. [21] built and demonstrated Ray Surface Positioning (RSP) using low-cost commodity components in a test of a 4 m × 4 m × 1 m volume. The results offered position estimate errors of less than 30 cm for 95 % of the test volume. The authors used the least square (LS) method to find a target position in this work. Additionally, they proved the effectiveness of the NLOS channel on the accuracy of VLC indoor positioning. The authors used a more conventional Lambertian and brighter source to give ample space for better signal strength and coverage.

G. Shi et al. [22] derived the analytical expressions of distance measurement error and the upper bound of a localization error using the least square method. In addition, they investigated the effect of Non-Line of Sight (NLOS) signals on the accuracy of VLC indoor localization systems based on the RSS technique. This method of calculating the received power results in an average localization error of 0.5 m throughout the room. When the SNR is low (20 dB), localization performance is poor (1.65 m at the walls), while the best performance (0 m at the center) is obtained when the SNR is high (23 dB). Furthermore, the researchers assert that the simulation results demonstrate that a VLC system is capable of achieving an 8-millimeter localization accuracy. This experiment, on the other hand, is carried out in a room-scale VLC system with extremely low reflectivity (= 0.01) in order to achieve a high localization accuracy of 8mm.

N. Sattigiri et al. [23] developed and implemented an Indoor Positioning System based on VLC. The VLC transmitter and receiver, as well as the Arduino Uno microcontroller unit, were used in the development of the prototyping. As a result of this work, the authors provided Finite State Machines (FSM) as a means for the receiver to differentiate between each code and thus realize the exact position under a node as the user moved. Unlike earlier works, D. Mai et al. [24] proposed an entire design of VLC-based large-scale indoor positioning systems, including physical (PHY) and link-layer solutions. For user localization, the authors used a triangulation method based on an RSS technique. Each LED's position was separated at the receiver by encoding a unique location identification (ID) with Optical Orthogonal Codes (OOC). The authors used optical orthogonal codes to distinguish the received signals simultaneously. However, the system model considered the Line-of-sight (LOS) link only. In this work, the mentioned gaps in the previous literature have been avoided to present an indoor localization system for elderly patient people using Li-Fi technology.

3. System Model and description
   a. System Model
   In this subsection, we present the block diagram of the entire model of the created system as shown in figure1[Each step will be explained in the following subsections].
b. System Description

1. VLC based IPS

Figure 2 shows our respected IPS-based LiFi. A large-scale building [hospital in our work] is observed, and fixed position transmitters are placed in a grid layout, which is a conventional layout for recessed lighting fixtures, to measure their positions. Prior to the event taking place, a mobile user is expected to get the database including all LED position coordinates and store them on his or her device (from the Map Database server).

2. Optical Orthogonal Code (OOC)

Generally, two serious problems when using RSS, namely, signal isolation and power estimation to determine the distance from the patient to the LED transmitter. In
the beginning, the OOCs are used as \((n,k,\lambda_a,\lambda_c)\) to classify several signals received at the receiver. The OOCs are a family of \((0, 1)\). Chips are referred to as 0 and 1. The code length, weight, and autocorrelation constraints are the following: \(n, k, \lambda_a, \lambda_c\). This code is seen with two features in equations 1 and 2.

\[
\sum_{t=0}^{n-1} x_t x_{t+\tau} \leq \lambda_a
\]  \hspace{1cm} (1)

\[
\sum_{t=0}^{n-1} x_t y_{t+\tau} \leq \lambda_c
\]  \hspace{1cm} (2)

For any \(x, y \in \mathcal{C}\) and any integer \(t, (0 < t < n)\). In the case that \(\lambda_a = \lambda_c = 1\), the maximum number of codewords \(|\mathcal{C}_{\text{max}}|\) is expressed in Equation 3:

\[
|\mathcal{C}_{\text{max}}| \leq \left[ \frac{n-1}{k(k-1)} \right]
\]  \hspace{1cm} (3)

More details about OOCs can be found in [25]. The remaining difficulty is the restricted cardinality (i.e., the maximum number of codewords \(|\mathcal{C}_{\text{max}}|\) of OOCs). For example, the code cardinality of \(\mathcal{C}(341,5,1,1)\) is only 16, which could be substantially less than the number of LEDs expected for a large-scale network. To increase the code cardinality, a longer code length is required, which thus increases the chip rate. A code reuse approach is used to use the code word resource to overcome this problem.

3. Code reuse strategy

In this method, for any network size, we need just six codewords to allocate. They are arranged so that two signals of the same codeword will not be interpreted simultaneously by the receiver.

Code reuse is depicted in Figure 4 using the 6x6 LED grid as an example. One set of six codewords includes: \((C1, C2, C3)\) and \((C4, C5, C6)\). The first, third, and fifth column LEDs are assigned to \((C1, C2, C3)\), while the second, fourth, and sixth column LEDs are assigned to \((C4, C5, C6)\) in the following mode. For LEDs divided into two LEDs using different codewords, the same codeword is assigned to each column. Additionally, separate codewords are allocated to six LEDs in each row. The lighting field of two LEDs with the same codeword will not interfere with each other.
4. Transmitter and receiver block diagram.

5. Figure depicts the transmitter and receiver block diagram. On the transmitter side, a unique identifier is utilized to identify the LED location. Using the fast Golay code, error correction is possible. If the number of errors exceeds three, we will be able to correctly read an LED's ID using this coding technique. Using a Golay code, the transmitter will have a greater range and be able to detect the patient's location even if they move. The Golay-coded ID is then OOC-coded for signal separation, as described above. Manchester coding is also used to reduce the flickering caused by on-off key modulation, so that the amount of high and low power pulses (representing bits '1' and '0', respectively) is equal. Finally, the transceiver uses a Preamble (synchronization header (SHR) field) to obtain optical clock synchronization with the packet that will enter the transceiver [26][27]. Receiver functions include: (1) calculating RSS by collecting the lowest power chip, (2) recovering the position ID of the LED. These functions are carried out in six steps, including PD optical-to-electrical (O/E) conversion, preamble identification, Manchester decoding, OOC decoding, RSS calculation, Golay decoding, and ID recovery. By synchronizing using the 8-bit preamble, the data frame is observed. The receiver uses the retrieved IDs to extract from the preloaded map the coordinates of LED transmitters, which are then used as parameters for trilateration [24].
6. Light propagation model

In general, the total received power from each LED light is expressed as in Equation 4.
\[ P_{r-total} = R_{PD} P_t (H_{LOS} + H_{NLOS}) + N \]  
where \( P_{r-total} \) is the total received power by the user, \( R_{PD} \), \( P_t \) and \( H_{LOS} \) are the photodetector’s responsivity, the transmitted power by LED source, and the channel gain part of line-of-sight (LOS) link. Finally, \( H_{NLOS} \) is the non-line-of-sight (NLOS) part. The noise \( N \) is channel noise such as shot noise or thermal noise. It is modeled as additive white Gaussian noise (AWGN)[28]. The impulse response of the VLC channel in the LOS case is expressed as in Equation 5.
\[ H_{LOS}(t) = \begin{cases} \frac{1}{d_i^2} R_{LOS}(\theta_1) A_{PD} \cos(\psi_1) T_s(\psi_1) g(\psi_1) \delta \left(t - \frac{d_i}{c}\right) & 0 \leq \psi_1 \leq \text{FOV} \\ 0 & \text{otherwise} \end{cases} \]  
with
\[ R_{LOS}(\theta_1) = \frac{(m + 1)}{2\pi} \cos^m(\theta_1) \]
where \( R_{LOS}(\theta_1) \) is the transmitter radiant intensity for the LOS scenario, \( \theta_1 \) is the irradiance angle, \( \psi_1 \) is the incidence angle, \( T_s(\psi) \) is the gain of an optical filter, \( g(\psi) \) is the gain of an optical concentrator, \( A_{PD} \) is the detector effective area, \( d_i = d(T_{xi}, R_x) \) is the distance between i’th transmitter and the receiver Rx, FOV is the field of view of the receiver, and \( m \) is the Lambertian emission, which is given as
\[ m = \frac{-\ln(2)}{\ln(\cos(\theta_{1/2}))} \]
with \( \theta_{1/2} \) being the semi-angle at half luminance of the LED. Thus, the estimated distance between the transmitter and receiver can be expressed as in Equation 6.
\[ d = \left\{ \frac{[R_{PD} P_t (m + 1) A_{PD} h^{m+1} T_s(\psi) g(\psi)]^2}{4\pi^2 H_{LOS} P_t} \right\}^{\frac{1}{2+2m}} \]  
On the other hand, in the NLOS case, the impulse response of the VLC channel is given as in Equation 7.
\[ H_{NLOS}(t) = \begin{cases} \frac{1}{d_{ij}^2 d_{2ij}^2} R_{NLOS}(\theta_{2ij}) A_{PD} \cos(\psi_{2ij}) T_s(\psi_{2ij}) g(\psi_{2ij}) \mu \delta \left(t - \frac{(d_{1ij} + d_{2ij})}{c}\right) & 0 \leq \psi_2 \leq \text{FOV} \\ 0 & \text{otherwise} \end{cases} \]  
with
\[ R_{NLOS}(\theta_{2ij}) = \frac{(m + 1)}{2\pi} \cos^m(\theta_{2ij}) \]
\[ \mu = \frac{\rho d A_{wall}}{\pi} \cos(\alpha_{ij}) \cos(\beta_{ij}) \]
Here $\mu$ is the coefficient based on Fresnel reflection, where $\mu$ is the first reflection factor, $R_{NLOS}(\theta_{2ij})$ is the transmitter radiant intensity for the scenario of NLOS, $i$ is the transmitter $i^{th}$ index, $j$ is the multipath $j^{th}$ index, $\rho$ is the factor of reflectance, $dA_{wall}$ is the small region reflective area, $d_1$ are the LED and a reflective point distance between them, $d_2$ is the effective point and a receiver distance between them, $\alpha$ is the reflective point angle of irradiance, and $\beta$ is the angle of multipath of irradiance to the receiver, as shown in figure 6 [29].

Figure (6) VLC channel modeling for LOS and NLOS links

7. **Noise Model**

The AWGN channel noise power can be characterized by equation 8.

$$N = \sigma_{\text{shot}}^2 + \sigma_{\text{Thermal}}^2$$

(8)

Where $\sigma_{\text{Thermal}}^2$ and $\sigma_{\text{shot}}^2$ are the thermal noise and shot noise variance, respectively. The shot noise variance is given by Equation 9.

$$\sigma_{\text{shot}}^2 = 2qI_{bg}I_2B_n + 2q\gamma P_{r-\text{total}}B_n$$

(9)

$q$ is the electric charge, $I_{bg}$ is the background current, $I_2$ and $I_3$ denotes the noise bandwidth factor $B_n$ is the bandwidth, $\gamma$ denotes the photodetector responsivity while the thermal noise variance is given by equation 10 [29].

$$\sigma_{\text{Thermal}}^2 = \frac{8\pi k T K A_{PD} I_2^2 B_n^2}{G_o} + \frac{16\pi^2 k T \Gamma k m}{gm} C_{PD}^2 A_{PD}^2 I_3 B_n^3$$

(10)

where $k$ stands for the Boltzmann Constant, $C_f$ is the fixed capacitance per unit area, $T_k$ is the absolute temperature, $G_o$ is the open-loop gain, $\Gamma$ is the FET channel noise factor, and $gm$ is the FET transconductance and $I_3$ is the FET channel noise factor. The computed SNR value evaluates the visible light communication system. SNR is given as below in equation 11[30].

$$\text{SNR} = \frac{(RP_{r-\text{total}})^2}{\sigma_{\text{shot}}^2 + \sigma_{\text{Thermal}}^2}$$

(11)

$R$ denotes the photodetector’s responsibility, $P_{r-(r-total)}$ is the total received power.
8. Combination method

After installing N LEDs in the ceiling for a generic scenario of IP with a VLC system, we select N’ (we chose N’=6) LEDs from the total number of LEDs (N) where N’ ≤ N. After that, the combination method is used, a clustering method to create different groups of LEDs. So, the total number of groups = \( \binom{N'}{4} + \binom{N'}{5} + \cdots + \binom{N'}{6} \)

Where

\[ \binom{N'}{6} = \frac{N'!}{6!(N' - 6)!} \]  

Based on [31], the authors have shown that the positioning accuracy is not increased dramatically when increasing anchor nodes, and typically from four to six anchor nodes is enough.


Estimating a patient position in three dimensions requires distance information from at least four LEDs. In this paper, a 3-D localization analysis is shown in a harsh indoor environment. Let \( P = [x_i; y_i; z_i] \) denotes the position of the patient in Cartesian coordinates. Additionally, \( L_i = [Lx_i; Ly_i; Lz_i] \) presents the positions of the LEDs. \( i = 1, ..., n \), where \( i \) expresses the LED index. In general, the actual distance to a point in space is presented in Equation 13.

\[ r_i^2 = \|L_i - P\|^2 = (Lx_i - x)^2 + (Ly_i - y)^2 + (Lz_i - z)^2 \]  

A positioning approach has to be employed once the ranges of various LEDs are computed to compute the patient location. As aforementioned, \( r \) expresses the actual distance and let \( d \) represent the estimated distance extracted by a wireless sensor as then the error could be computed as shown in Equation 14.

\[ e_i = d_i - r_i \]  

The estimated position could be calculated as presented in Equation 10, iteratively using a straight gradient method as an example.

\[ \hat{P} = \left[ \hat{x} \right]_{k+1} = \left[ \hat{x} \right]_k - \alpha \left[ \begin{array}{c} \frac{\partial e}{\partial x} \\ \frac{\partial e}{\partial y} \\ \frac{\partial e}{\partial z} \end{array} \right]_{x=\hat{x}_k,y=\hat{y}_k,z=\hat{z}_k} \]

Where \( \alpha \) is a scalar chosen to lower \( e \). Also, \( \hat{x}, \hat{y}, \hat{z} \) are the measured coordinates of the patient (P). In this approach, an initial value of the localization estimation is required, and this case is a nonlinear problem. The hyperbolic positioning algorithm converts this problem into a linear problem that can be solved with a least-square estimator[32]. To linearize the none linear problem in the LS technique, all sub-equations in Equation 13 are collected by choosing one of them as a reference equation and subtracting it from
all other equations. This work assigns the distance between LED 1 and the patient mentioned in Eq.13 as a reference equation, as shown below in Equation 16.

\[ r_1^2 = (Lx_1 - x)^2 + (Ly_1 - y)^2 + (Lz_1 - z)^2 \]  

(16).

Thus, the linearization solution is presented as in Equation 17.

\[ r_1^2 - r_i^2 = (Lx_1 - x)^2 + (Ly_1 - y)^2 + (Lz_1 - z)^2 - (Lx_i - x)^2 - (Ly_i - y)^2 - (Lz_i - z)^2 \]  

(17)

Where \( i = 2, \ldots, n \). By adjusting eq.17, we have eq.18, as shown below.

\[ Lx_i^2 + Ly_i^2 + Lz_i^2 + r_1^2 - r_i^2 = 2x(Lx_i - Lx_1) + 2y(Ly_i - Ly_1) + 2z(Lz_i - Lz_1) \]  

(18)

Then after implementing the matrix operation, we obtain.

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

And the measurement vector as shown in Equation 19.

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

where, \( r \) expresses the actual distance between the patient and the reference LED, and \( r_i \) expresses the range between all LEDs except the reference LED and P. Finally, the coordinates of the patient P will be computed as presented in Equation 20.

\[ P = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = (A^T A)^{-1} A^T b + \begin{bmatrix} Lx_1 \\ Ly_1 \\ Lz_1 \end{bmatrix} \]  

(20)

As we mentioned, \( d \) is the estimated distance between the LED and the receiving PD. Thus, we can compute the estimated position \( \hat{P} \) by computing the estimation value \( \hat{b} \) as shown in equation 21 below.

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

(21)

Thus, the estimated patient position \( \hat{P} \) will be as presented in Equation 22.

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

(22)

http://www.webology.org
To enhance the positioning accuracy, the equation (22) could be modified using the variance of the measured distance, and the new algorithm is named the weighted least squares (WLS) method [33]. The weights implemented in the WLS algorithm are adjusted, taking into account the inverse of the variance of the corresponding distance measurements as shown in the weight matrix (W) below. Then, using the inverse of W in the final equation of the WLS.

\[
W = \begin{bmatrix}
\text{var}(d_1^2) + \text{var}(d_2^2) & \text{var}(d_1^2) & \ldots & \text{var}(d_n^2) \\
\text{var}(d_1^2) & \text{var}(d_1^2) + \text{var}(d_2^2) & \ldots & \text{var}(d_n^2) \\
\vdots & \vdots & \ddots & \vdots \\
\text{var}(d_1^2) & \text{var}(d_1^2) & \ldots & \text{var}(d_n^2)
\end{bmatrix}
\]

where \(\text{var}(d_i^2)\) denotes the variance of a squared estimated distance between the reference LED and P and \(\text{var}(d_n^2)\) denotes variance of a squared estimated distance between all other LEDs and the P.

\[
P\hat{} = \begin{bmatrix}
x\hat{} \\
y\hat{} \\
z\hat{}
\end{bmatrix} = (A^TW^{-1}A)^{-1} AW^{-1} \hat{b} + \begin{bmatrix}
x_1 \\
y_1 \\
z_1
\end{bmatrix}
\]

10. Anchor selection

As explained in the following paragraph, we implemented the anchor selection technique created by [31] in this work. After clustering the anchor nodes (LEDs) into different groups and finding the patient position of each group using WLS, we check the positioning accuracy of each group using the MSE evaluation metric. The conventional MSE, which needs actual and estimated target values, could be written generically, as shown in Equation 24.

\[
\text{MSE} = E\left\{\|P - P\|^{2}\right\}
\]

(24)

where P and \(\hat{P}\) denote the actual and estimated positions of the patient. However, in this work, we need to make an MSE flexible in working with live statues to check the positioning accuracy of each anchor node group based only on the measured distances. The MSE used in this work, modified by [34], does not need an actual value and could be used to find the positioning accuracy of a positioning system online based only on the measured distances, as shown in Equation 25.

\[
\text{MSE}(T_x) = \left\{\sum_{i=1}^{n-1} \frac{E[\varepsilon_i]}{\det} \left( (k_{11} \sum_{i=2}^{n} x_i - x_1) - (k_{12} \sum_{i=2}^{n} y_i - y_1) - (k_{13} \sum_{i=2}^{n} z_i - z_1) \right) \right\}^{2}
\]

(25)

Additionally, MSEs for y and z coordinates, equation 26 and equation 27, is similar to x-coordinates and only will have the change to the index of k in equation 25.
\[
\text{MSE}(T_y) = \left[ \sum_{i=1}^{n-1} E[\varepsilon_i] \det \left( (-k_{12} \sum_{i=2}^{n} x_i - x_1) \\
+ (k_{22} \sum_{i=2}^{n} y_i - y_1) - (k_{23} \sum_{i=2}^{n} z_i - z_1) \right) \right]^2 
\]

(26)

\[
\text{MSE}(T_z) = \left[ \sum_{i=1}^{n-1} E[\varepsilon_i] \det \left( (k_{13} \sum_{i=2}^{n} x_i - x_1) - (k_{23} \sum_{i=2}^{n} y_i - y_1) + (k_{33} \sum_{i=2}^{n} z_i - z_1) \right) \right]^2 
\]

(27)

Where \( \varepsilon \) is computed in Appendix 1, subsection B for every coordinate \( i \). Where \( i = 2 \ldots n \) denotes the index of the anchor node, and \( n \) represents the total number of anchor nodes.

Finally, the compact equation of the derived MSE is expressed in Equation 28.

\[
\text{MSE}(\hat{T}) = \frac{\text{MSE}(\hat{T}_x) + \text{MSE}(\hat{T}_y) + \text{MSE}(\hat{T}_z)}{3} 
\]

(28)


Presuming that the ranging error distribution parameters are known, the maximum likelihood (ML) approach maximizes the pdf of distance measurement to get the agent position, as shown in Equation 29[35].

\[
\hat{p} = \arg \min_p \left( \sum_{k=1}^{n_k} \frac{(r_k - d_k)^2}{\sigma_k^2} \right) 
\]

(29)

Where \( r \) and \( d \) denote the actual and estimated distances, and \( r \) assumed is a zero-mean independent Gaussian process with variance \( \sigma^2 \). \( k \) denotes the total number of anchor nodes (LEDs). \( r_k \) represents the distance between an initial point and the anchor node. In the conventional ML, the initial point is fixed and randomly selected, but in this work, the initial point is carefully selected based on the MSE for all estimated positions of the target computed by each LEDs group using WLS.

4. Test parameters

This paper presents a novel indoor positioning system using a hybrid technique of different indoor positioning algorithms to get a reliable system with convenient accuracy, less complexity, and time conception. The created system is implemented using MatLab simulation. In this work, we presume a patient is walking through a room size 5 × 5 × 3 m and a corridor with 20 m. The lighting system consists of 6-LEDs for the room and 22-LEDs for the corridor, arranged as an anchor node at the ceiling. The patient wears the photodetector (PD) in his hand at 0.85 m above the floor. A PD could receive the location code if optical light is incident within its FOV. Based on the proposed scenario that the room has 6 LEDs installed in the ceiling and more than 6 LEDs outside the room (corridor), the receiver at least will receive 4 signals inside the room or the corridor based on the highest power. We assumed that the receiver always has 4 up to 6 signals coming through different propagation channels (LOS and NLOS). While we have six transmitters, we thought that the hand’s
orientation would not affect the bracelet reception, which always has at least four received signals. Table (2) presents the simulation parameters considered for this work.

Table (2) Simulation Parameters for VLC System

<table>
<thead>
<tr>
<th>Transmitter Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room size</td>
<td>$5 \times 5 \times 3 \text{m}^3$</td>
</tr>
<tr>
<td>Corridor length</td>
<td>$20 \times 3 \times 3 \text{m}^3$</td>
</tr>
<tr>
<td>Wall Reflectivity $\rho$</td>
<td>0.25</td>
</tr>
<tr>
<td>Reflecting element area $dA_{\text{wall}}$</td>
<td>1cm$^2$</td>
</tr>
<tr>
<td>Lambertian mode $m$</td>
<td>1</td>
</tr>
<tr>
<td>LED transmitter Power $P_t$</td>
<td>4W</td>
</tr>
<tr>
<td>Response Rate of PDs $R$</td>
<td>0.4 W/cm$^2$</td>
</tr>
<tr>
<td>Optical filter gain $T_s$</td>
<td>1</td>
</tr>
<tr>
<td>Concentrator gain $g_s$</td>
<td>1</td>
</tr>
<tr>
<td>LEDs position in the room</td>
<td>(0.5,0.5,3)(2.5,4.5,3)(4</td>
</tr>
<tr>
<td></td>
<td>(0.5,0.5,3)(2.5,0.5,3)(4</td>
</tr>
<tr>
<td>LEDS Position in Corridor</td>
<td>(6,1.5,3)(8,1.5,3)(10,1</td>
</tr>
<tr>
<td></td>
<td>(6,3.5,3)(8,3.5,3)(10,3</td>
</tr>
<tr>
<td></td>
<td>......and so on</td>
</tr>
<tr>
<td>Receiver Parameters</td>
<td></td>
</tr>
<tr>
<td>Surface Area of the PD $A_{\text{PD}}$</td>
<td>1cm$^2$</td>
</tr>
<tr>
<td>Receiver Plane $h$</td>
<td>0.85m</td>
</tr>
<tr>
<td>FOV of the receiver</td>
<td>80 deg</td>
</tr>
<tr>
<td>Noise Parameters</td>
<td></td>
</tr>
<tr>
<td>Current of daylight $I_b$</td>
<td>$5100 \times 10^{-6}[\text{A}]$</td>
</tr>
<tr>
<td>Noise Bandwidth factor $I_2$</td>
<td>0.562[A]</td>
</tr>
<tr>
<td>$I_3$</td>
<td>0.0868[A]</td>
</tr>
<tr>
<td>Open-loop voltage gain $G_o$</td>
<td>10</td>
</tr>
<tr>
<td>O/E conversion Efficiency $\gamma$</td>
<td>0.54[A/W]</td>
</tr>
<tr>
<td>Noise Bandwidth $B_n$</td>
<td>$10^8[\text{pulses/s}]$</td>
</tr>
<tr>
<td>Absolute temperature $T_K$</td>
<td>298[K]</td>
</tr>
</tbody>
</table>

http://www.webology.org
5. Results and Discussion

First of all, the steps in figure 1 are applied to obtain the performance of the system. The system is investigated when noise is taken into account. The residual noise is added into the received signal using the AWGN function from Mat Lab over the SNR calculated based on Eq. (11). Based on our algorithm, as shown in table 3, we select only six LEDs with more power. Then, we implemented the combination method to group the selected LEDs to create different groups when each group has 4 LEDs up to six. Each selected group is affected by different propagation channel (LOS and NLOS). Then WLS method is used by each group to compute the target position.

Table 3: Types of propagation channels for every group of LED.

<table>
<thead>
<tr>
<th>Group name</th>
<th>Number of leds</th>
<th>LOS channel</th>
<th>NLOS channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>4</td>
<td>2 LED</td>
<td>2 LED</td>
</tr>
<tr>
<td>G2</td>
<td>4</td>
<td>1 LED</td>
<td>3 LED</td>
</tr>
<tr>
<td>G3</td>
<td>5</td>
<td>2 LED</td>
<td>3 LED</td>
</tr>
<tr>
<td>G4</td>
<td>5</td>
<td>1 LED</td>
<td>4 LED</td>
</tr>
<tr>
<td>G5</td>
<td>6</td>
<td>2 LED</td>
<td>4 LED</td>
</tr>
<tr>
<td>G6</td>
<td>6</td>
<td>1 LED</td>
<td>5 LED</td>
</tr>
</tbody>
</table>

For the evaluation stage, figure (7) presents two scenarios of track positioning are implemented. In scenarios 1 and 2, an elderly person moves in different directions in his room; then, he leaves the room to walk through a corridor in front of the room door as presented. We compute the human position by computing ten points corresponding to his trajectory inside the room and along the corridor.

<table>
<thead>
<tr>
<th>Target position</th>
<th>MSE (WLS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
</tr>
<tr>
<td>(-0.25,0.25,0.85)</td>
<td>0.33</td>
</tr>
<tr>
<td>(-2.25,0.85)</td>
<td>0.15</td>
</tr>
<tr>
<td>(-3.5,3.0.85)</td>
<td>0.83</td>
</tr>
<tr>
<td>(-2.5,4,0.85)</td>
<td>0.61</td>
</tr>
<tr>
<td>(-4.5,0.5,0.85)</td>
<td>1.21</td>
</tr>
<tr>
<td>(-6.25,0.85)</td>
<td>3.39</td>
</tr>
<tr>
<td>(-11.375,0.85)</td>
<td>4.09</td>
</tr>
<tr>
<td>(-16.125,0.85)</td>
<td>5.61</td>
</tr>
<tr>
<td>(-21.15,0.85)</td>
<td>3.22</td>
</tr>
<tr>
<td>(-24.25,0.85)</td>
<td>2.54</td>
</tr>
</tbody>
</table>
Figure 7. Experimental activities inside the room and corridor (a) Scenario1, (b) Scenario2

Then, the derived MSE [34] is used to evaluate the estimated position for each group, as shown in Tables 4 and 5. The highlighted red numbers are the lowest value of MSE of each group of anchor nodes. The positioning accuracy will be improved gradually when the target moves directly below the LEDs. This is because the NLOS power in the room center is lower than in the corners. So, the best values of the MSE for the WLS approach are at \((x = 2.5, y = 2.5, z = 0.85)\) and \((x = -1.5, y = 2.5, z = 0.85)\) for scenarios 1 and 2.

Table 4: MSE for WLS method for different positions of the target in m\(^2\) (Scenario1).

<table>
<thead>
<tr>
<th>Target position</th>
<th>MSE (WLS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>((0.25,1,0.85))</td>
<td>(0.23)</td>
</tr>
<tr>
<td>((1,4.5,0.85))</td>
<td>(0.39)</td>
</tr>
<tr>
<td>((2.5,2.5,0.85))</td>
<td>(0.31)</td>
</tr>
<tr>
<td>((4.75,4.75,0.85))</td>
<td>(1.32)</td>
</tr>
<tr>
<td>((2.5,0.5,0.85))</td>
<td>(0.48)</td>
</tr>
<tr>
<td>((5.25,2.5,0.85))</td>
<td>(3.31)</td>
</tr>
<tr>
<td>((10,1.25,0.85))</td>
<td>(3.25)</td>
</tr>
<tr>
<td>((17,3,0.85))</td>
<td>(4.17)</td>
</tr>
<tr>
<td>((20,2.5,0.85))</td>
<td>(2.11)</td>
</tr>
<tr>
<td>((25,3.75,0.85))</td>
<td>(4.20)</td>
</tr>
</tbody>
</table>

Table 5: MSE for WLS method for different positions of the target in m\(^2\) (Scenario2)
After having the MSE values of every estimated position, the group having the least MSE value is selected with its estimated position to be used as the initial point for the modified ML approach to calculate the final position of the target.

The last step in this work is to evaluate and compare the proposed system with two related approaches, WLS, conventional ML. In the traditional ML, a fixed random point is used as the initial point for iteration purpose [we chose \((x = 10, y = 5, z = 0.85)\) and \((x = -10, y = 5, z = 0.85)\) for scenario 1 and 2 respectively], but, in the proposed algorithm, we make the initial point as a dynamic point that could be changed based on the best position obtained by AS approach as shown in tables 7 and 8. Also, we should mention when the target position is close from the guess (initial) point of the conventional ML, the positioning accuracy of the ML will be enhanced and vice versa, as mentioned in points 5, 7, 8 in the tables.

Then, the obtained points using the proposed approach and two different related approaches are evaluated using the MSE Mat Lab function, as shown in table.

Table (6) MSE for the proposed system compared to ML and WLS algorithms in m² (Scenario1)

<table>
<thead>
<tr>
<th>Point</th>
<th>(target position)</th>
<th>WLS</th>
<th>ML</th>
<th>(proposed algorithm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(0.25,1,0.85)</td>
<td>0.23</td>
<td>0.20</td>
<td>0.18</td>
</tr>
<tr>
<td>2</td>
<td>(1.45,0.85)</td>
<td>0.38</td>
<td>0.19</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>(2.5,0.5,0.85)</td>
<td>0.48</td>
<td>0.31</td>
<td>0.19</td>
</tr>
<tr>
<td>4</td>
<td>(2.5,2.5,0.85)</td>
<td>0.15</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>5</td>
<td>(4.75,4.75,0.85)</td>
<td>1.49</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>6</td>
<td>(5.25,2.5,0.85)</td>
<td>1.96</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>7</td>
<td>(10,1.25,0.85)</td>
<td>3.25</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>8</td>
<td>(17.3,0.85)</td>
<td>3.62</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>9</td>
<td>(20.2,5,0.85)</td>
<td>2.11</td>
<td>0.80</td>
<td>0.15</td>
</tr>
<tr>
<td>10</td>
<td>(25.3,75,0.85)</td>
<td>4.20</td>
<td>1.19</td>
<td>0.21</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>1.78</td>
<td>0.34</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table (7) MSE for the proposed system compared to ML and WLS algorithms in m² (Scenario2)

<table>
<thead>
<tr>
<th>Point</th>
<th>(target position)</th>
<th>WLS</th>
<th>ML</th>
<th>(proposed technique)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(-0.25,0.25,0.85)</td>
<td>3.49</td>
<td>0.88</td>
<td>0.27</td>
</tr>
<tr>
<td>2</td>
<td>(-1.5,2.5,0.85)</td>
<td>0.15</td>
<td>0.14</td>
<td>0.11</td>
</tr>
<tr>
<td>3</td>
<td>(-2.5,3,0.85)</td>
<td>0.78</td>
<td>0.19</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>(-2.5,4.5,0.85)</td>
<td>0.58</td>
<td>0.17</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>(-4,0,5,0.85)</td>
<td>1.21</td>
<td>0.21</td>
<td>0.19</td>
</tr>
<tr>
<td>6</td>
<td>(-6.3,0.85)</td>
<td>3.36</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>7</td>
<td>(-11.3,75,0.85)</td>
<td>4.09</td>
<td>0.16</td>
<td>0.27</td>
</tr>
<tr>
<td>8</td>
<td>(-16.1,25,0.85)</td>
<td>3.61</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>9</td>
<td>(-21.1,5,0.85)</td>
<td>3.92</td>
<td>0.50</td>
<td>0.17</td>
</tr>
<tr>
<td>10</td>
<td>(-24.2, 5.0,0.85)</td>
<td>2.54</td>
<td>0.73</td>
<td>0.16</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>2.37</td>
<td>0.32</td>
<td>0.18</td>
</tr>
</tbody>
</table>
We can see in both tables that the MSE of the proposed system has an average of 0.18 m$^2$ for scenario 1 and 0.15 m$^2$ for scenario 2 in LOS and NLOS channels, compared with WLS and conventional ML that have an MSE for scenario 1 about 1.78 m$^2$, 0.34 m$^2$ and scenario 2 have 2.37 m$^2$, 0.32 m$^2$ respectively. Also, this indicates that the performance of the created system highly outperforms the other positioning approaches for the same environment.

The actual and estimated trajectories, including the proposed algorithm with two related approaches, WLS, and conventional ML, are shown in figure 8 for scenarios 1 and 2. As shown, the position of the proposed system is more confined with actual position than other approaches.

![Real and estimated trajectories](image)

Figure (8): Real and estimated trajectories in m for scenarios 1 and 2, respectively.

Finally, the empirical cumulative distribution function (ECDF) of the MSE for every positioning algorithm is computed as shown in figure (9) for scenarios 1 and 2.

![ECDF](image)
6. Conclusion and Future Work

Indoor positioning technique in the hospital environment for elderly people plays an essential role in helping medical staff give urgent and fast care to save human life. In this work, we present a novel approach to online modifying the positioning system for locating and monitoring an elder person in a harsh environment using Li-Fi technology. The created algorithm has four main steps. In the first step, the entire LEDs are divided into different groups using the combination method. In the second step, the target position is computed for each LED group using the WLS approach. In the third step, the group with the best positioning accuracy is selected (AS technique) with its obtained position. Finally, the obtained position is used as the initial point for the ML approach to relocating the target position of the selected group. The simulation results show that the proposed algorithm has the lowest MSE, about 0.18 m² for scenario 1 and 0.15 m² for scenario 2, compared with WLS and conventional ML that have an MSE for scenario 1 about 1.78 m², 0.34 m² respectively and for scenario 2 have 2.37 m², 0.32 m² respectively. We can confidently declare that the proposed algorithm outperforms the most indoor positioning systems for human localization in the market. In future work, we are planning to carry out the created algorithm in a real environment.

Figure (9): Empirical disrupted function of MSE for the Proposed, [33], and [35] indoor positioning approaches for scenarios 1 and 2, respectively.
References


[28] “Robust localization system using Visible Light Fabián Seguel To cite this version: HAL Id: tel-02863495 soutenance et mis à disposition de l’ensemble de la Contact: ddoc-theses-contact@univ-lorraine.fr,” 2020.


