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Indoor Positioning by Weighted Fuzzy Matching in Lifi Based Hospital Ward Environment

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Abstract. Core technologies of the fourth industrial revolution include AI (Artificial Intelligence), IoT (Internet of Things), and Big Data. The field of effective use of these technologies is the field of navigation. However, in indoor navigation, the accuracy is very low due to objects and walls placed in various positions. In this paper, we propose an indoor location tracking technology based on LiFi (Light Fidelity) communication to determine the exact location of a user using location tracking technology and communication technology. First of all, the fingerprinting database is constructed by measuring the CIR (Channel Impulse Response) value of each SP (Sample Point) using the fingerprinting technique. Then we use the Weighted Fuzzy Matching Algorithm to track the user's location. The simulation results show that the performance of the LiFi environment is superior to that of the WiFi (Wireless Fidelity) environment.

1. Introduction

The Fourth Industrial Revolution is underway worldwide. The core technologies of the fourth industrial revolution are AI (Artificial Intelligence), IoT (Internet of Things) and big data. The areas of effective use of these three key technologies are navigation. Most people have an IoT device called a mobile phone. The device then uses AI to determine the exact location. The data is accumulated through Big Data and the data is used later.

The most important technique in navigation is the technique of tracking the user's location. If you don't know your location correctly, you'll be taken to a strange route to your destination. For outdoor navigation, GPS (Global Positioning System) can be used to pinpoint your location relatively accurately. However, indoor navigation is a variety of objects and small areas placed indoors, GPS can’t determine the exact number and location of users. There is also a risk of guiding a strange path if the user is determined to be located over the wall. Therefore, many location tracking and communication technologies are used for indoor navigation. Representative communication technologies include WiFi (Wireless Fidelity), LiFi (Light Fidelity), and Bluetooth, and location tracking technologies include triangulation and fingerprinting. WiFi and Bluetooth use RF (Radio Frequency) to communicate with users. The location is then tracked using triangulation and fingerprinting using RSSI (Received Signal Strength Indicator) values for the user's location. However, because both methods use RF, signals spread through windows and errors occur in buildings of two or more floors. In addition, the installation cost increases when installing multiple APs (Access Point) to determine the exact location. LiFi uses VLC

(Visible light communication) to communicate with the user. VLC uses the visible range to not interfere with existing RF bands. It can also be used in environments where RF use is limited, such as in hospitals and airplanes, because it does not cause EMI (Electromagnetic interference) problems. And light doesn't penetrate the walls, indicating the exact number and location of layers. In addition, it is possible to use it as an AP by mounting a module on an existing LED (Light Emitting Diode). And in the saturation of the current frequency spectrum, LiFi can be used without limiting the frequency usage. In this paper, we use LiFi method which has this advantage.[1]

In this paper, we use fingerprinting algorithm for location tracking in LiFi environment. Fingerprinting algorithms include offline sampling and online positioning steps. The offline sampling method builds a sample fingerprinting database by measuring the CIR values of the sample points. In addition, the online positioning method includes a weighted fuzzy matching algorithm. [2-3]

Fingerprinting algorithm has the advantage of only knowing the CIR values of AP and sample point. The location can be measured using only that data, so there is no need to use existing devices and add other devices. However, there is a problem that offline measurement takes a long time to build a CIR database. In addition, if a variable occurs in the environment, the database must be rebuilt. The result is a sharp increase in the cost of indoor positioning systems. Therefore, the method of reducing errors through online positioning method is most efficient.

In this paper, we use Weighted Fuzzy Matching Algorithm as an online positioning method. This method reduces the error by re-tracking the exact location of the user by using the CIR data of the sample point location established through the fingerprinting algorithm.

The paper is organized as follows. In section II the mathematical formulation is presented. Then compare the simulation with LiFi and the simulation with WiFi. Finally, the paper is concluded in Section IV.

2. Modelling of the positioning system

The design of a fingerprinting algorithm depends primarily on the map that contains the measured CIR or the fingerprints for predefined locations. In this section, System model, fingerprinting Structure and Weighted Fuzzy matching algorithm will be introduced.

2.1. System Model

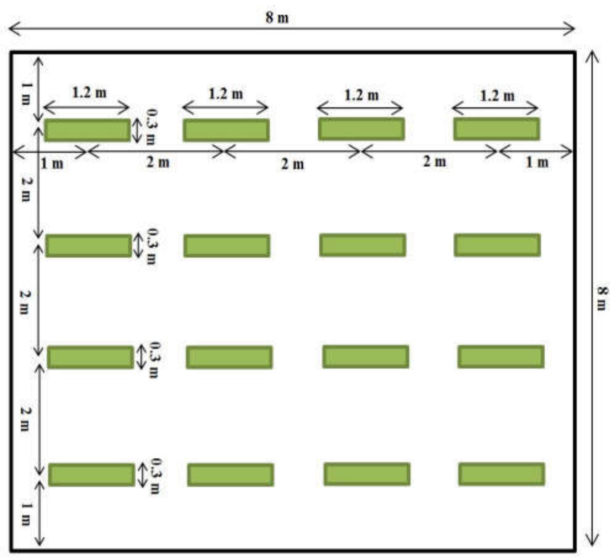

Figure 1. Location of LiFi AP

In this paper, we use simulation environment provided by IEEE TGbb to implement realistic simulation using VLC in Hospital Ward environment. We determine the number of rays going directly or reflecting

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off the object to the PD using the ray tracing tool of Zemax. It can calculate the detected power and path lengths for each ray. Then convert the data for use in matlab. These data have an information about the CIR for hospital ward. The CIR value is calculated as follows.

$$h(t) = \sum_{i=1}^{N_r} P_i\, \delta(t - \tau_i) \tag{1}$$

Where τ_i is the propagation time of the i th ray, P_i is the optical power of the i th ray, δ(t) is the Dirac delta function and N_r is the number of rays received at the detector.

The Hospital Ward environment is 8m x 8m x 3m. 16 LiFi APs are installed as shown in Figure 1. The half viewing angle of the LED is 54 ° and the power per each luminaire is 19W. [4]

2.2. Weighted Fuzzy Matching Algorithm

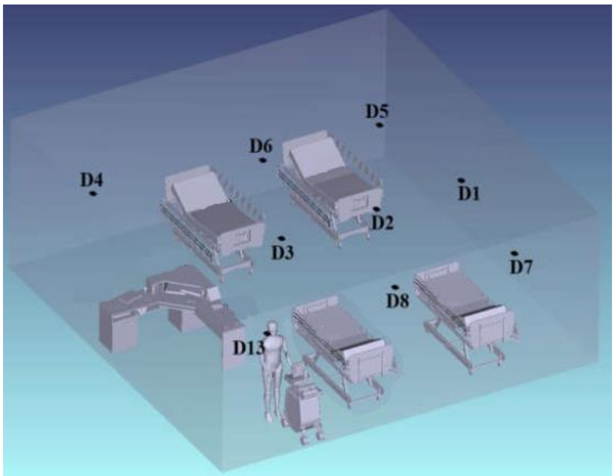

Figure 2. Location of LiFi Sample Points

To do Weighted Fuzzy Matching Algorithm, you must first create a fingerprinting map. The fingerprinting map is constructed by creating a grid of points in an indoor area. Grid points are spaced at regular intervals and displayed on the x-y coordinate plane. To create the fingerprint map, locate the sample point as shown in Figure 2 and measure the CIR value between each AP and the sample point through Equation 1.[5] Thus for the CIR-based location fingerprinting the overall offline database is defined as S^{CIR}, CIR matrix given by

$$S^{CIR} = \begin{bmatrix} h_1^1 & \cdots & h_1^m & \cdots & h_1^M \\ \vdots & & \vdots & & \vdots \\ h_n^1 & \cdots & h_n^m & \cdots & h_n^M \\ \vdots & & \vdots & & \vdots \\ h_N^1 & \cdots & h_N^m & \cdots & h_N^M \end{bmatrix} \tag{2}$$

Where h_n^m is denote CIR value between AP m and sample point n. The vector value between each AP m and Sample Point n is calculated. The vector value is defined as D, vector matrix given by

$$\mathrm{D} = \begin{bmatrix} d_1^1 & \cdots & d_1^m & \cdots & d_1^M \\ \vdots & & \vdots & & \vdots \\ d_n^1 & \cdots & d_n^m & \cdots & d_n^M \\ \vdots & & \vdots & & \vdots \\ d_N^1 & \cdots & d_N^m & \cdots & d_N^M \end{bmatrix} \tag{3}$$

Where d_n^m is denote vector value between AP m and sample point n.

The CIR value between the UE(User Equipment) k at an arbitrary position and the AP serving the UE is calculated to obtain $Z_k^{CIR} = [h_k^1, h_k^2, h_k^3, \ldots, h_k^M]$. The Euclidean distance is calculated by evaluating the correlation between Z_k^{CIR} and S^{CIR}. The correlation between the online fingerprints at location k and the offline fingerprint at location I for the jth AP is given by $\rho_{k,i}^j$, where $0 \leq \rho_{k,i}^j \leq 1$. The minimum distance is defined as;

$$d_{k,i} = \|p_{k,j} - I\| = \sqrt{\sum_{j=1}^{M} \left(\rho_{k,i}^j - 1\right)^2} \tag{4}$$

Thus, the result would be the Euclidean distance vector, $d_k = [d_{k,1}, d_{k,2}, \cdots d_{k,N}]$. The closeness degree is calculated from high to low, and choose four sample fingerprint vector that has the higher closeness degree with the node under testing. The selected sample fingerprint points are defined as $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ in close order. And the coordinates X0, Y0, Z0 of the UE is calculated as follows.

$$X_0 = \sum_{n=1}^{4} \beta_n X_n \tag{5}$$

$$Y_0 = \sum_{n=1}^{4} \beta_n Y_n \tag{6}$$

$$Z_0 = \sum_{n=1}^{4} \beta_n Z_n \tag{7}$$

β_i represents closeness degree weighted coefficient of the n-th sample point[5]

$$\beta_n = \frac{\alpha_n}{\alpha_{sum}}, \ \alpha_{sum} = \sum_{n=1}^{4} \alpha_n \tag{8}$$

3. Experiment

Table 1. Simulation Parameter

Parameter	Value	
	WiFi	LiFi
Environment	Hospital Ward	
Room Size	8m x 8m x 3m	
Number of repeated counts	10,000	
Number of AP	3	9
Number of Sample Point	9	9
Power per each AP	20W	19W

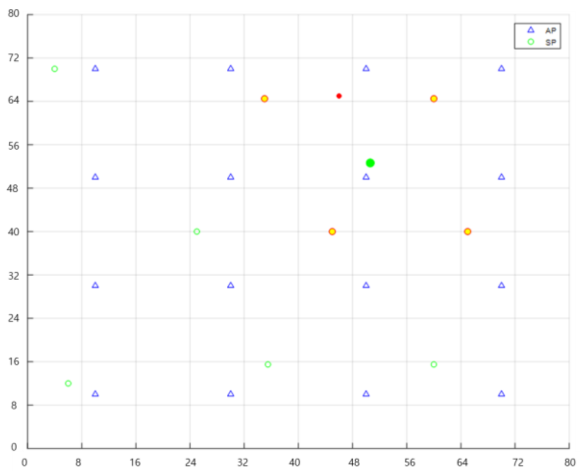

Figure 3. Location Estimation using LiFi

The simulation was conducted in the Hospital Ward environment provided by IEEE TGbb. The simulation parameter is shown as Table 1. The simulation is conducted in a space of 8m x 8m. 16 APs installed per lighting are installed at regular intervals. And in order to minimize the effect of offline fingerprinting, a relatively small number of 9 sample point positions is set. And measure the CIR value for the Sample Point in each AP. Then set up the fingerprinting database for the Sample Point. Then, in the on-line positioning step, the UE in the actual location coordinates indicated by the red dots has 16 APs measuring CIR values. Set four adjacent sample points, shown in yellow, as shown in Figure 3. A weighted Fuzzy Matching Algorithm is used to calculate the weights of adjacent sample points to derive green estimated position coordinates.

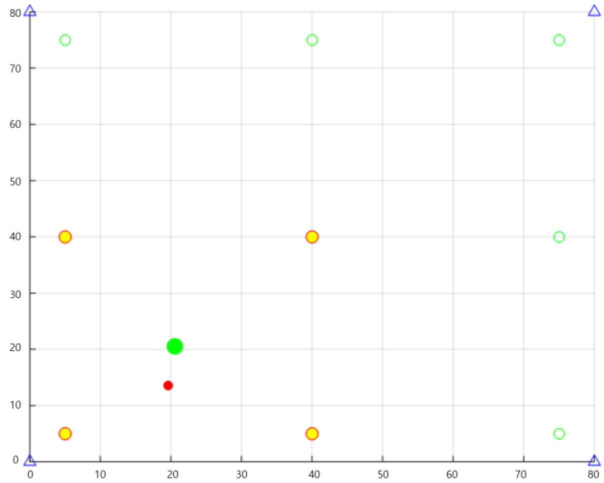

Figure 4. Location Estimation using WiFi

Figure 4 is a simulation of the location estimation of a UE when using WiFi in general. In the same size environment as LiFi, APs are installed at each corner. Like LiFi, nine sample points are set. And each RSS measures the RSSI value for the Sample Point. Then set up the fingerprinting database for the Sample Point. Each AP then measures the RSSI value between the UEs and then estimates the coordinates of the UEs using the Weighted Fuzzy Matching Algorithm. The error was measured by comparing the UE coordinates of the actual position with the UE coordinates of the estimated position.

In this paper, we performed 10,000 times with random placement of UE. And the average error of the UE coordinate was measured.

Table 2. Simulation Results

Parameter	Value	
	WiFi	LiFi
Average Error	2m	1.3m

As shown in Table 2, an average error of 2m occurred when estimating the location using WiFi. And if you estimate the location using LiFi, an error of 1.3m occurs, and you can see a 65% error reduction compared to WiFi.

4. Conclusion

In an outdoor environment, the location is estimated using a technology such as GPS, but these technologies are not suitable for indoor use. In addition, WiFi, which is mainly used for location estimation in indoor environments, requires multiple APs to estimate the exact location, and thus requires a lot of cost. However, when using LiFi to estimate the location, inexpensive installation of multiple APs can be inferred. Fingerprinting techniques used for location estimation require a lot of time and effort to measure CIR and RSSI values offline. But with LiFi, you can achieve higher accuracy than

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WiFi with fewer sample points. In addition, using the weighted fuzzy matching algorithm in addition to the existing fingerprinting algorithm, higher accuracy can be obtained even at the insufficient sample point. Later in the online positioning phase, the PSO and Kalman Filtering methods will be added to achieve higher accuracy.

Acknowledgments
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