Chapter

Averaging Indoor Localization System

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Abstract

This chapter aims at improving the accuracy of estimation the localization by using the RSS method to estimate the positions and take into account the effects of both LOS propagation. The proposed system is depending on developing a mathematical model for the noisy VLC positioning system. For improving the results, adopting the KF is combined with the proposed system, which is considered an optimal estimator. The performance of the proposed technique is determined by evaluating the positioning errors in a typical room. Also this chapter develops the accuracy of the positioning system by using different ideas with average techniques. The discussion of the results for averaging technique is displayed.

Keywords: RSS, KF, VLC, localization

1. Introduction

This chapter aims at improving the accuracy of estimation the localization by using the Received Signal Strength (RSS) method to estimate the positions and take into account the effects of both line of sight (LOS) and non-line of sight (NLoS) propagations. The proposed system is depending on developing a mathematical model for the noisy Visible light communication (VLC) positioning system. For improving the results, adopting the Kalman filter (KF) is combined with the proposed system, which is considered an optimal estimator. The performance of the proposed technique is determined by evaluating the positioning errors in a typical room. Also, this chapter develops the accuracy of the positioning system by using different ideas with average techniques.

The remaining of this chapter is organized as follows: Section 2 discusses the optical channel in indoor systems. Section 3 is devoted to explaining the methodology of localization using RSS techniques. A mathematical derivation for performance evaluation is developed in the same section as well. In Section 4, The proposed KF algorithm is presented with explaining its algorithm for estimation correction. There is an average technique aiming to use the average method as shown in Section 5. Using both effects of LOS and the first reflection of NLoS propagation is done in the average proposed system. Adopting KF with averaging is shown in Section 6. The discussion of the results for averaging technique is displayed in Section 7. Section 8 shows the comparison between the results with some recent references. Finally, the concluding remarks are given in Section 9.

2. Optical channel model

The characteristics of the channel modeling have been analyzed with the effects of the channel distortions in [1]. The power associated with the channel is separated into two factors, these being optical path loss (PL) and multipath dispersion. The PL is calculated from the knowledge of the receiver size, the transmitter beam divergence, and separation distance. However, a NLoS configuration (diffuse systems) mainly used in the indoor environment, uses reflections of the room surfaces and furniture. These reflections could be seen as unwanted signals or multi-path distortions which predict the PL more complex. The OW channel transfer function is defined by

$$H = H_{LoS} + H_{NLoS} \tag{1}$$

According to **Figure 1**, it describes H_{loS} as the contribution due to the LoS, which is independent of the modulation frequency and it depends on the distance between transmitter and receiver. In a VLC system, the direct current (DC) gain of a VLC channel is expressed by.

$$H^i_{\mathrm{LOS}} = \frac{m+1}{2\pi d_i^2}\cos^m(\phi_i)A_R\cos(\psi_i)T_s(\psi_i)g(\psi_i), \tag{2}$$

The received power therefore becomes

$$P_r = H_{LOS}.P_t, \tag{3}$$

where P_t is a transmitted power m is the Lambertian order, d_i is the distance between transmitter i and the receiver, ϕ_i is the irradiance angle, ψ_i is the incidence angle, $T_s(\cdot)$ and $g(\cdot)$ are the gains of the optical filter and concentrator at the receiver (assumed here as unity gain), and A_R is the detector effective area. Where the channel DC gain H_{NLOS} of the first reflection is shown as in the following equation related to **Figure 1**.

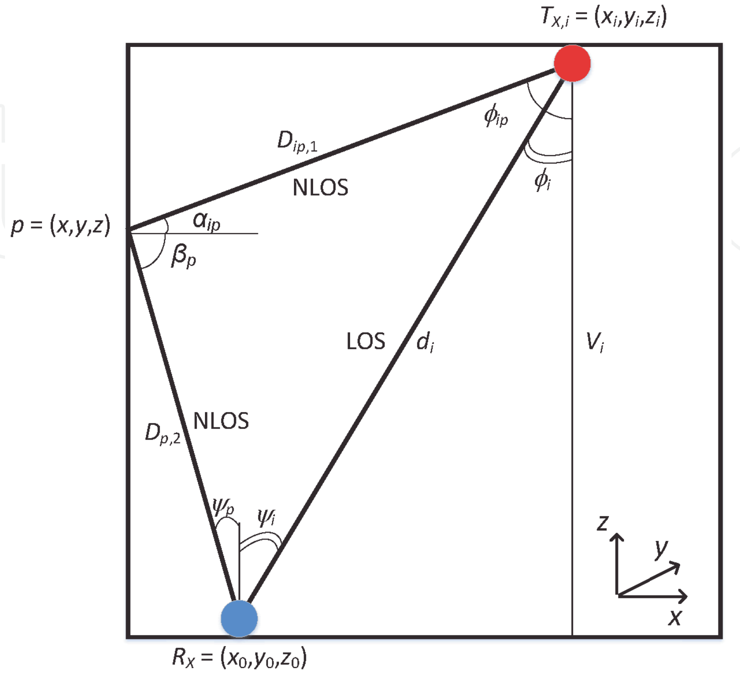

Figure 1.
The channel model of VLC system.

$$dH^{ip}_{\text{NLOS}} = \frac{m+1}{2\pi D^2_{ip,1} D^2_{p,2}} \cos^m\left(\phi_{ip}\right) \cos\left(\alpha_{ip}\right) \cdot dA_p \times \rho \cos\left(\beta_p\right) \cos\left(\psi_p\right) T_s\left(\psi_p\right) g\left(\psi_p\right) A_R, \tag{4}$$

where $D_{ip,1}$ is the distance between transmitter i and reflection point p, $D_{p,2}$ is the distance between reflection point p and receiver R_X, ϕ_{ip} and ψ_p are the NLoS irradiance and incidence angles with respect to point p, respectively, α_{ip} and β_p are the incidence and irradiance angles at reflection point p on the wall, respectively, ρ is the wall reflectivity, and dA_p represents the area of the reflection point on the wall.

The total NLoS channel gain for i th transmitter H^i_{NLOS} is given by collecting the reflections from the 4 walls [2]:

$$H^i_{\text{NLOS}} = \sum_{j=1}^{4} H^i_{\text{NLOS},wallj}, \tag{5}$$

where $H^i_{\text{NLOS},wallj}$ is the collection of reflections from transmitter i to wall j, and can be obtained by integrating (4) over (x, z) or (y, z) based on the wall location, such that

$$H^i_{\text{NLOS},wallj} = \iint\limits_{(x,z)\text{or}\,(y,z)} \frac{m+1}{2\pi D^2_{ip,1} D^2_{p,2}} \cos^m\left(\phi_{ip}\right) \cos\left(\alpha_{ip}\right) \rho \times \cos\left(\beta_p\right) \cos\left(\psi_p\right) T_s\left(\psi_p\right) g\left(\psi_p\right) A_R dA_p. \tag{6}$$

The determination of the parameters for the previous equation is as follows:

$$\begin{aligned} D_{ip,1} &= \sqrt{(T_{X,i} - p)(T_{X,i} - p)^T} \\ D_{p,2} &= \sqrt{(p - R_X)(p - R_X)^T}, \end{aligned} \tag{7}$$

where $()^T$ is the transpose operator for row vector a. By using triangle calculations, the angles $\phi_{ip}, \alpha_{ip}, \psi_p,$ and β_p can be found as follows:

$$\begin{aligned} \cos\left(\phi_{ip}\right) &= \frac{|z_i - z|}{D_{ip,1}}, \quad \alpha_{ip} = \frac{\pi}{2} - \phi_{ip}, \\ \cos\left(\psi_p\right) &= \frac{|z - z_0|}{D_{p,2}}, \quad \beta_p = \frac{\pi}{2} - \psi_p. \end{aligned} \tag{8}$$

The simulation of the power distribution is done for two cases, first case is using four transmitters which are distributed in different positions (1.25, 1.25, 3) m, (1.25, 3.75,3) m, (3.75, 1.25, 3) m, (3.75, 3.75, 3) m in room with size (5,5,3) m, as shown in **Figure 2**. Second case is using only one transmitter that is located in the center of the ceiling. This power distribution is shown in **Figure 3**. The simulation is done with using some parameters where $FOV = 70^o$ and assume the filter gain = 1, the number of LEDs by array 60x60. The concentrator gain = 1 where the active area of photo diode (PD) = $1cm^2$.

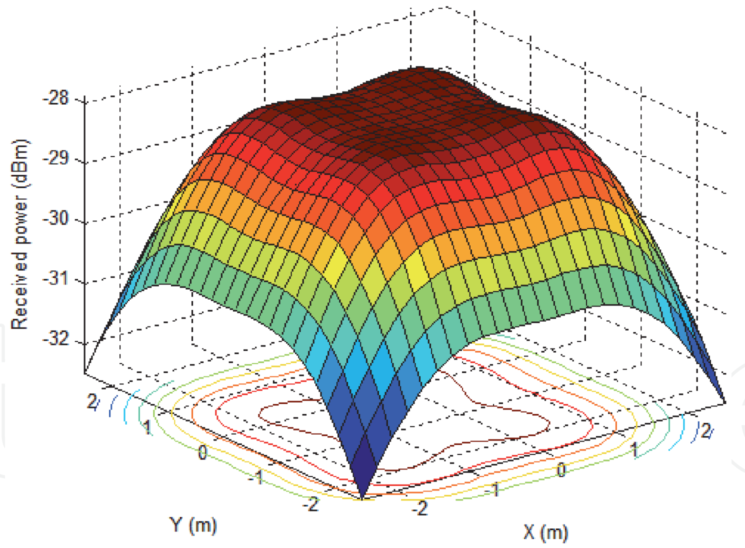

Figure 2.
The power distribution for 4 LEDs.

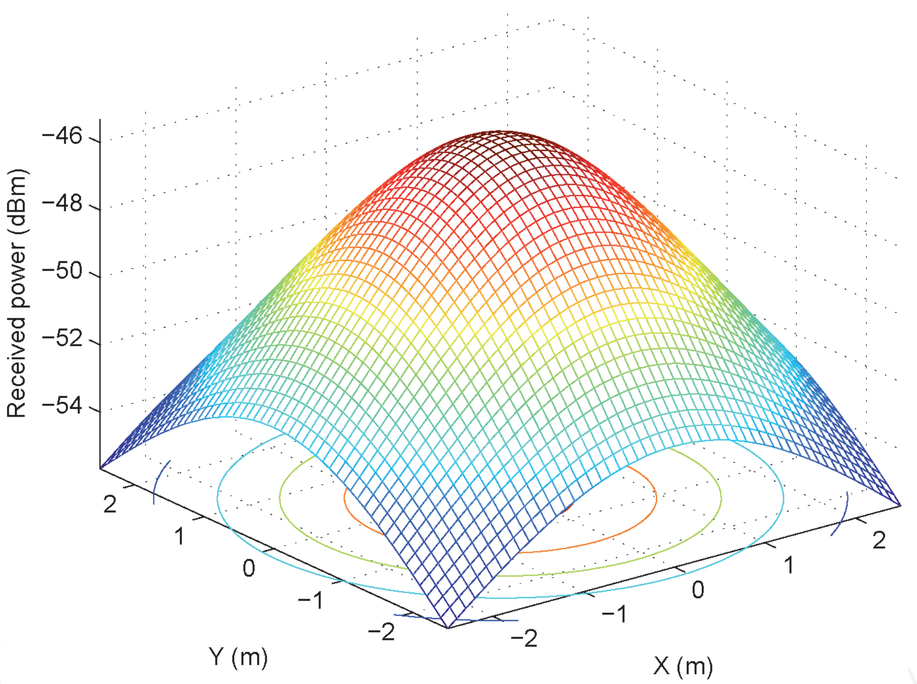

Figure 3.
The power distribution for one LED centered in the ceiling.

3. RSS mathematical analysis

The proposed technique depends on estimating the receiver position using RSS method, then further improving the acquired estimation by adopting the Kalman filtering algorithm. In the initial estimation, RSS technique is used taking into account the effect of LoS. Specifically, A mathematical model is developed for the noisy VLC positioning system and estimate both the angular and horizontal-distance errors. Because of the dependence of horizontal-distance error on the irradiance angle error. The performance of the proposed technique is determined by evaluating the positioning errors in a typical room. Also, the results are compared to that of the traditional RSS system. Depending on **Figure 1**; the analysis assumes that

$\psi_i = \phi_i$ for any $i \in \{1, 2, 3, 4\}$. Assume that the light emitted from each LED is distinguishable at the receiver. Accordingly, The index i is dropped from the developed equations.

If the transmitter and receiver are aligned together, then $\psi = \phi = 0, d = V$, where d is a direct distance between transmitter and receiver and V is the horizontal distance of the transmitter, using $T_s(\psi_i) = 1$, and $g(\psi_i) = 1$ as shown in **Figure 1**. In this case, the power of LoS can be approximated as the following:

$$P_{R0} = \frac{(m+1)A_R}{2\pi V^2} P_T. \tag{9}$$

In the general case ($\phi \neq 0$) as view in (2), and by using **Figure 1** where $\cos^2(\phi) = \frac{V^2}{d^2}$ and by multiplying the equation by $\frac{V^2}{V^2}$, then, the received power can be modeled as:

$$P_R = \cos^{m+3}(\phi) P_{R0}, \tag{10}$$

The last equation expresses the ideal system case, which means there is no noise affecting the system. From which:

$$\phi = \cos^{-1} \sqrt[k]{\frac{P_R}{P_{R0}}}, \tag{11}$$

where $k = m + 3$. In the previous works, P_{Ro} is known while here, P_{Ro} is not known exactly with noise power P_n. Assuming constant noise power in the room then the noise add to both the receiver power and irradiance angle. Neglecting the effect of NLoS (as it is very small), include the noise effect to (10) as follows:

$$P_R + P_n = \cos^{m+3}(\phi + \Delta\phi)(P_{R0} + P_n), \tag{12}$$

where P_n and $\Delta\phi$ are the receiver power and irradiance angle noises, respectively. Substituting ϕ from (11):

$$\Delta\phi = \cos^{-1} \sqrt[k]{\frac{P_R + P_n}{P_{R0} + P_n}} - \cos^{-1} \sqrt[k]{\frac{P_R}{P_{R0}}}. \tag{13}$$

From **Figure 1**, the horizontal distance without any noises is given by

$$d_L = V \tan(\phi). \tag{14}$$

In the case of a noisy channel, the horizontal-distance error Δd_L is estimated from:

$$d_L + \Delta d_L = V \tan(\phi + \Delta\phi). \tag{15}$$

The value of the horizontal-distance error Δd_L is used to determine the localization more accurate after calculating the position of the receiver by trilateration method as shown in the next section.

According to the RSS method, the positioning error is simply obtained from the distance errors. The positioning algorithm uses three maximum power levels to determine the location of the user [3]. Here, RSS algorithm is used to estimate (x_0, y_0), the position coordinates of the receiver. Let $(x_i, y_i), i \in \{1, 2, 3\}$, be the three coordinates of three transmitters. From Δd_L find the positioning estimate:

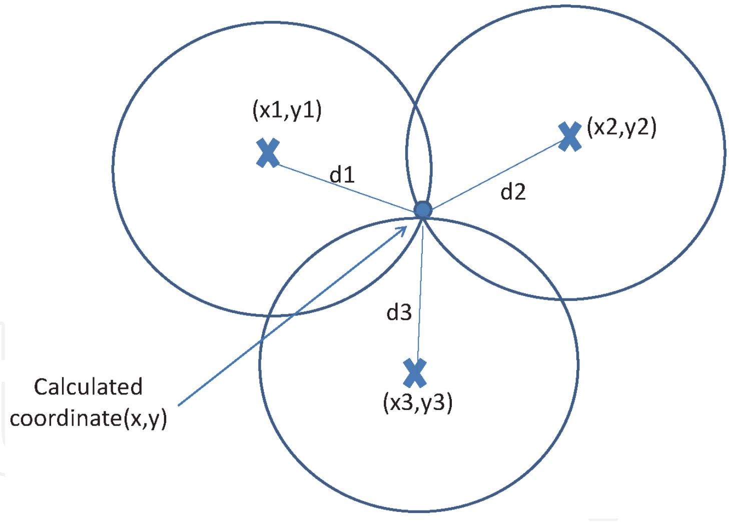

Figure 4.
A trilateration method for RSS to calculate the position of a receiver by using three transmitters.

$$(x_0 - x_i)^2 + (y_0 - y_i)^2 = \hat{d}_{L,i}^2, \tag{16}$$

where

$$\hat{d}_{L,i}^2 = d_L + \Delta d_L, \tag{17}$$

for any $i \in \{1, 2, 3\}$, where $d_{L,i}$ is the horizontal distance of the receiver from the transmitter i. This method can be clear as shown in **Figure 4**, where RSSI is received signal strength indicator.

4. Proposed KF algorithm

In this section, a KF algorithm is proposed to further improve the previous estimation (introduced in the last section) of the receiver position. Specifically, the estimation of the irradiance angle developed in the last section is further improved by adopting a KF algorithm.

The proposed system with KF is shown in **Figure 5** where the PD collects the received power and inserts it into the proposed system. The process of the proposed system is analyzing the mathematical equations to calculate the irradiance angle ϕ and the error of the irradiance angle $\Delta\phi$. Both of the two calculated values insert into the Kalman filtering process. The optimal value of the estimated irradiance angle is obtained after using the KF algorithm. The estimated irradiance angle inserted into the RSS process to calculate the estimated horizontal distance $\hat{d}$. The trilateration method has been applied to calculate the estimated position of the receiver by using the estimated horizontal distance $\hat{d}$. KF algorithm recursively

Figure 5.
The block diagram of the proposed system with KF.

estimates the state of variables in the system in two phases; prediction and measurement [4, 5].

4.1 Predict step

We denote the state vector by $x = (x_a, x_b)^T$, where x_a represents a measured angle, x_b is the error in the angle, and T is the transpose operator. Based on the estimate at iteration $k-1$, the state $x_{k-1|k-1}$. The next step k of the system dynamics $x_{k|k-1}$ is evaluated as:

$$x_{k|k-1} = F_k x_{k-1|k-1}, \tag{18}$$

where F_k is the state transition matrix. The corresponding state covariance matrix is given by:

$$P_{k|k-1} = F_k P_{k-1|k-1} F_k^T + Q_k, \tag{19}$$

where Q_k is the process noise covariance.

4.2 Measurement step

The updated state variable $x_{k|k}$ and updated state covariance matrix $P_{k|k}$ are given by

$$\begin{aligned} x_{k|k} &= x_{k|k-1} + K_k y_k \\ P_{k|k} &= (I - K_k H_k) P_{k|k-1}, \end{aligned} \tag{20}$$

respectively, where K_k is the Kalman gain, y_k is is the error vector, and H_k is is the observation model.

$$\begin{aligned} K_k &= P_{k|k-1} H_k^T S_k^{-1} \\ y_k &= z_k - H_k x_{k|k-1}. \end{aligned} \tag{21}$$

Here z denotes the measurement vector, given by:

$$z_k = H_k x_k + R_k \tag{22}$$

where R_k is the measurement noise matrix. Also S_k is the innovation matrix, which relates the covariance of state variables to measurement vector:

$$S_k = H_k P_{k|k-1} H_k^T + R_k. \tag{23}$$

Finally, after getting the estimated angle then recalculate the positioning error using equations developed in Section 3.

5. Proposed localization methodology using an averaging RSS technique

Second technique contains the averaging localization method and Kalman filtering with averaging schemes. For the averaging technique, the position of the receiver has been estimated by RSSI technique for multiple times (e.g., **N** samples) and the acquired estimations are averaged over all samples.

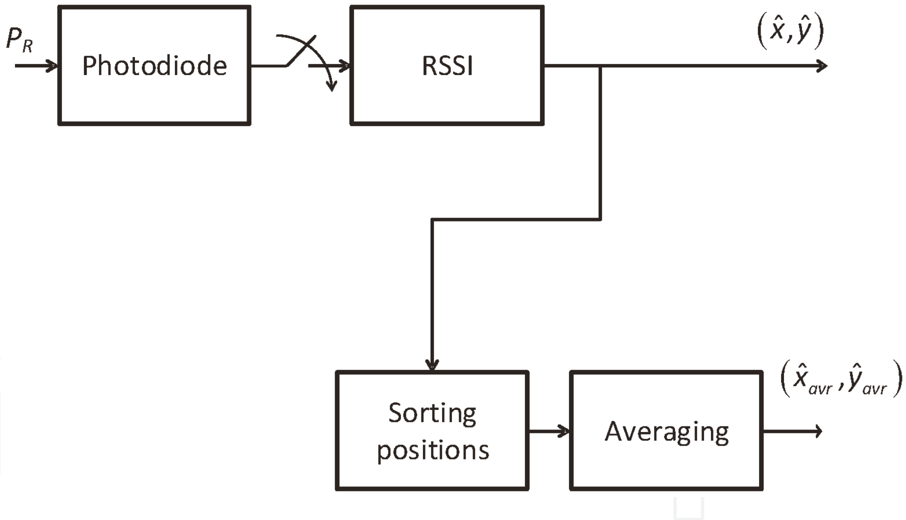

Figure 6.
Block diagram of proposed averaging positioning scheme.

To enhance the results of improving the localization, The algorithm of Kalman filtering has been adopted for estimation the received power over **N** samples, followed by using RSS technique on the average received power. These techniques have been analyzed mathematically, with respect to the effects of both LoS and first-reflection from NLoS propagation.

Typical room is considered for evaluating the positioning performances for proposed techniques and the results of them are compared with the traditional RSS system.

For determining the receiver location, the trilateration method is used with the RSS from three LEDs transmitters having the maximum received levels [3]. Our techniques depend on the average of estimated receiver position over a certain number of measurements to decrease the localization error. This decreasing in error gets at the cost of exceeding the system mathematical complexity. **Figure 6** shows a simple block diagram that demonstrates this approach.

5.1 RSS technique

Using (2), the received LoS power from transmitter $i \in \{1, 2, 3, 4\}$ can be written as:

$$P_{R,i} = \left(\frac{m+1}{2\pi d_i^2}\cos^{m+1}(\phi_i)A_R\right)P_{T,i}, \tag{24}$$

where $P_{T,i}$ is the transmitted power of i th LED. Here, assume that $\psi_i = \phi_i$, which is determined from **Figure 1** as:

$$\cos(\phi_i) = \frac{V}{d_i}, \tag{25}$$

where V is the vertical distance between transmitter and receiver, assumed constant. Accordingly, the distance between transmitter i and receiver can be evaluated as:

$$d_i = \sqrt[m+3]{\frac{(m+1)V^{m+1}A_R P_{T,i}}{2\pi P_{R,i}}}. \tag{26}$$

If consider the effect of NLOS as well, the total power collected at the receiver is obtained by modifying (24) to:

$$P_{R,i} = \left(H^i_{\text{LOS}} + H^i_{\text{NLOS}}\right) P_{T,i}. \tag{27}$$

5.2 Linear LS method

To estimate the receiver location, the linear LS estimation is commonly used. Let $(x_i, y_i), i \in \{1, 2, 3\}$, be the horizontal coordinates of transmitter i and $d_{L,i}$ be the horizontal distance of the receiver from transmitter i. The range equation can be written in the form:

$$(\hat{x} - x_i)^2 + (\hat{y} - y_i)^2 = d^2_{L,i}, \qquad i \in \{1, 2, 3\}, \tag{28}$$

where $(\hat{x}, \hat{y})$ is the estimated horizontal location of receiver. The last system of equations can be written in matrix form as:

$$A\hat{X} = B, \tag{29}$$

where

$$\begin{aligned} \hat{X} &= [\hat{x} \quad \hat{y}]^T \\ A &= \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \end{bmatrix} \\ B &= [b_{21} \quad b_{31}]^T. \end{aligned} \tag{30}$$

Here for any $m \in \{2, 3\}$,

$$b_{m1} \quad = (\hat{x} - x_1)(x_m - x_1) + (\hat{y} - y_1)(y_m - y_1). \tag{31}$$

The solution of (29) is:

$$\hat{X} = \left(A^T A\right)^{-1} A^T B. \tag{32}$$

5.3 Complexity analysis

The complexity of proposed averaging RSS technique can be analyzed by counting the number of mathematical operations required to solve the LS method once and then multiplying the resulting by the number of samples. Specifically, the total number of floating-point operations is $39N + 1$ flops, where N is the number of samples. That is, the complexity increases linearly with the number of samples.

6. Kalman filtering with averaging

KF estimates the states of a linear system from the noisy measurements then produces the estimation of unknown variables that aim to get more accurate than those which based on a single measurement value.

At this section, a KF algorithm is adapted to enhance the estimation performance of the receiver positioning system. In the first, KF estimates several samples of measured received powers. Then, the average of these estimated power values is

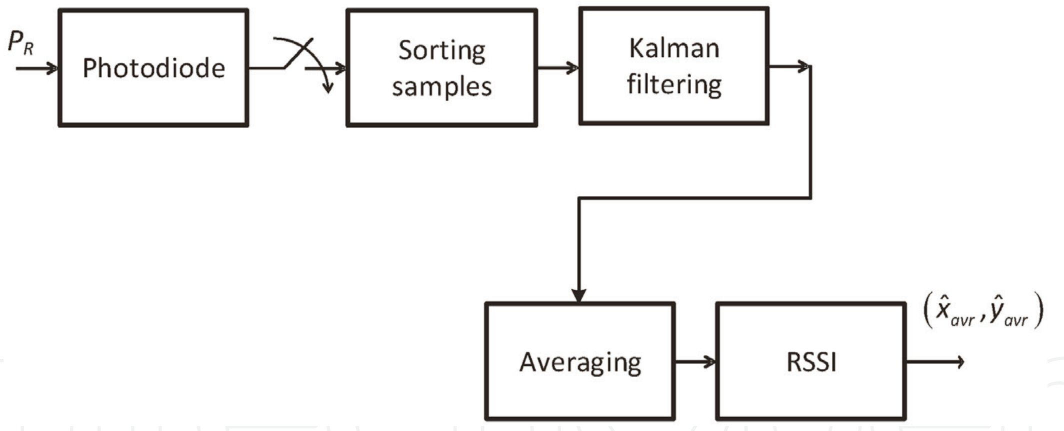

Figure 7.
Block diagram of proposed Kalman filtering technique.

evaluated. Using the output of KF which is the estimated average power, the position of the receiver can be calculated by using RSS technique. The block diagram of the proposed Kalman filtering with averaging technique is shown in **Figure 7**.

KF algorithm is shown in the previous chapter in Section 4 recursively estimates the state of variables in the system in two phases; prediction and measurement [4, 5]. We denote the state vector by x. This state vector represents measured received power and number of samples which are used in the process. Based on the estimate at iteration $k-1$, and have state $x_{k-1|k-1}$.

7. Simulation and discussion for averaging technique

In this section, The simulation results are presented and compared them to that of traditional systems. **Table 1** shows the main parameters used in the simulation.

In case of demonstrating the relation between the SNR and the average positioning error, **Figure 8** shows that using five different positions of the receiver and the average positioning error in a meter. This figure shows that the proposed system outperform the traditional RSS method by nearly 1 cm at SNR=10 dB while adopting KF decreases the error by 11.5 cm that means improvement by 52.27%.

Figures 9 and **10**, plot the true path with three different methods. The simulation is done at a FoV of 70° and an SNR of 20 dB. These figures are simulated as a plan view to show the estimation position of the receiver in the room. The proposed RSS technique achieves a tiny improvement while the proposed RSS with KF is the closest to the true path.

Parameter	Value
Room dimensions	$5 \times 5 \times 3$ m^3
Number of transmitters	4
Transmitted power	30 W
Locations of LEDs	(1.25, 1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), (3.75, 3.75, 3) m
FoV of photodetector	{70°}
The active area of the photodetector	1 cm^2

Table 1.
Main parameters in VLC.

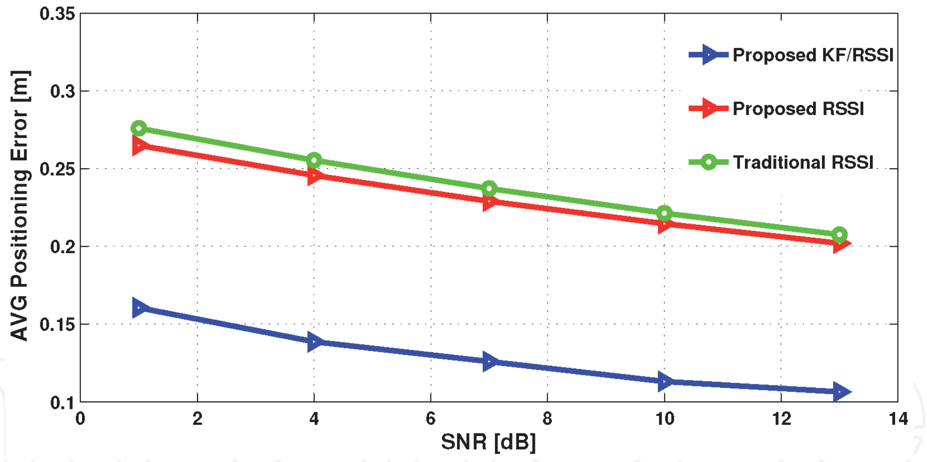

Figure 8.
The relation between average positioning error in meter with SNR for different positions.

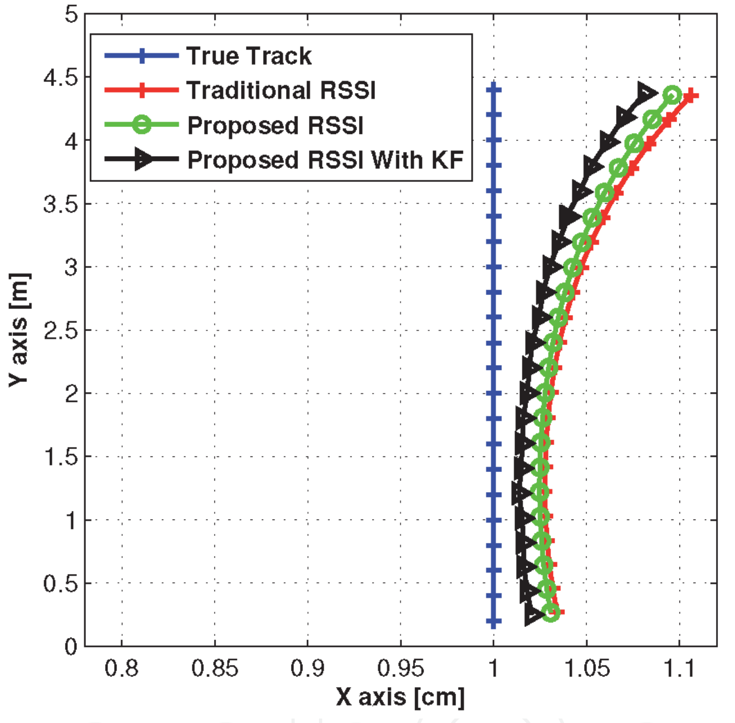

Figure 9.
Positioning error for traditional proposed, and KF correction RSS techniques at a FOV of 70° and an SNR of 20 dB for a y path.

The pedestrian is moving in random directions inside the room. In **Figure 11**, compare between three techniques: Traditional RSS, proposed RSS, and proposed RSS with Kalman filtering. The comparison is done at a FoV of 70° and an SNR of 20 dB. It is clear from the figure that adopting KF estimation further reduces the positioning error and provides an estimate that is very close to reality.

In the second technique, simulation results for the proposed system are presented and compared with that of traditional systems. The main parameters used in the simulations for the VLC link are listed in **Table 2**.

7.1 Positioning error

In the simulation, the performance measure is determined by the positioning error:

$$\varepsilon_{\text{position}} = \sqrt{(\hat{x} - x_0)^2 + (\hat{y} - y_0)^2}, \tag{33}$$

where (x_0, y_0) is the receiver horizontal location and $(\hat{x}, \hat{y})$ is its estimated location. **Figure 12** shows the average error in receiver positioning for different number of samples. It is clear that the error can be reduced to less than 10% of its maximum value by averaging over 50 samples. This reduction comes at the cost of

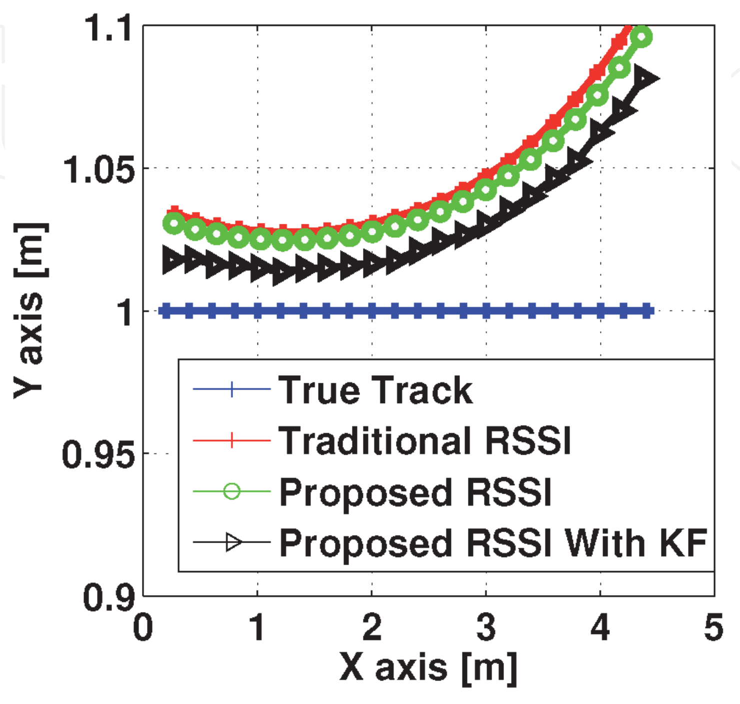

Figure 10.
Positioning error for traditional, proposed, and KF correction RSS techniques at FOV of 70° and an SNR of 20 dB for a x path.

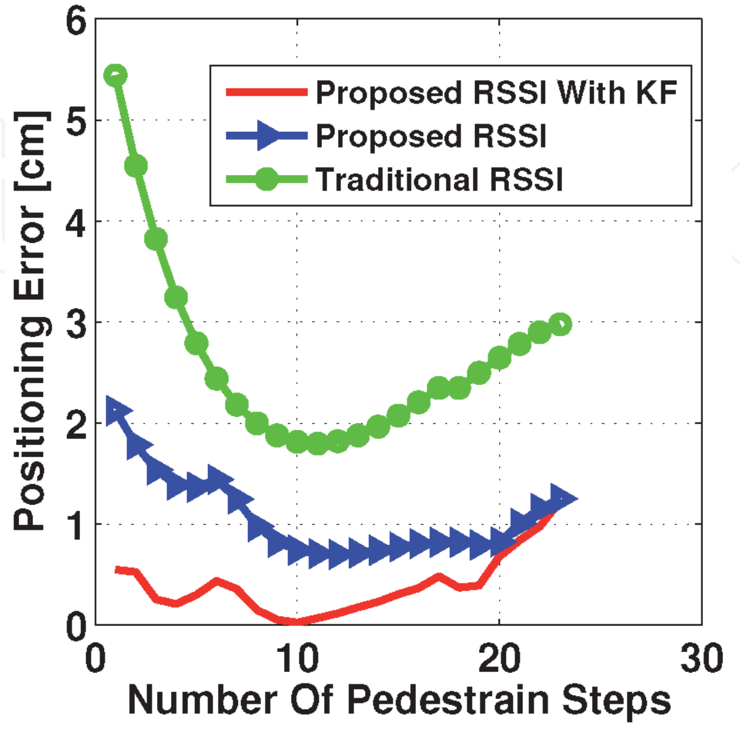

Figure 11.
Relation between positioning error and number of pedestrian steps at a FOV of 70° and an SNR of 20 dB.

Parameter	Value
Room dimensions	$5 \times 5 \times 3$ m^3
Number of transmitters	4
Total transmitted power	30 W
Locations of LEDs	(1.25, 1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), (3.75, 3.75, 3) m
FOV of photodetector	70°
SNR	20
Active area of photodetector	1 cm^2
Wall reflectivity ρ	0.8
Number of samples	50
Range of receiver in room	(1–3.5) m over both x, y axes

Table 2.
Simulation parameters.

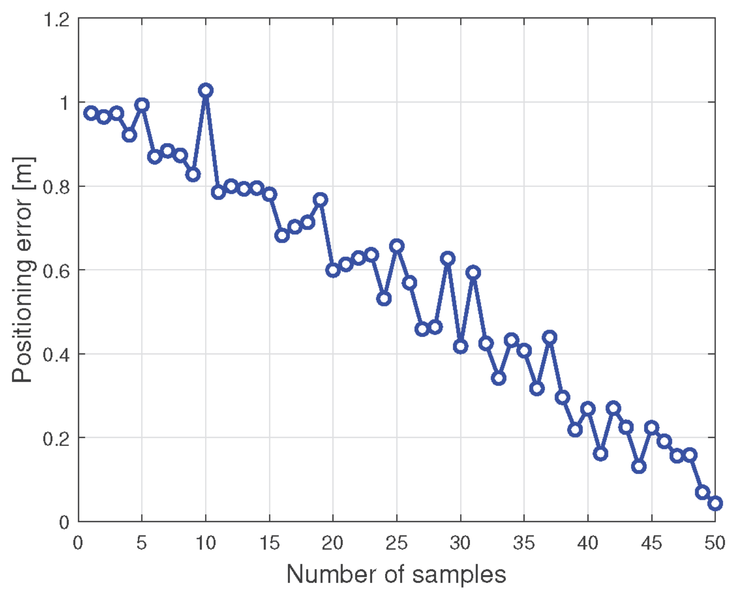

Figure 12.
Comparison between average positioning errors versus number of samples in averaging RSS technique.

increasing the mathematical complexity of the system as shown in **Figure 13**. The complexity is calculated according to the number of operations, which increases as the number of samples increases.

7.2 Averaging RSS and traditional RSS techniques

The RSS variations of the positioning error at every sample are shown in **Figure 13** for receiver position $(x_0, y_0) = (1, 1)$, considering the effect of LoS only. The positioning error using the proposed averaging RSS technique (with 100 samples) is plotted in same figure as well. The improvement using proposed technique is clear from the figure. The traditional RSS errors are more than 0.6 m (42.4%), where the error when employing the proposed averaging RSS is only 0.217 m (15.3%). That is, an improvement of about 27.1% is getting when adapting the proposed system. Both LoS and NLoS effects are studied for position of the receiver $(x_0, y_0) = (1, 1)$ as well and the results are plotted in **Figure 14**. Traditional RSS errors are more than 0.7 m (49.5%), where the errors when using proposed

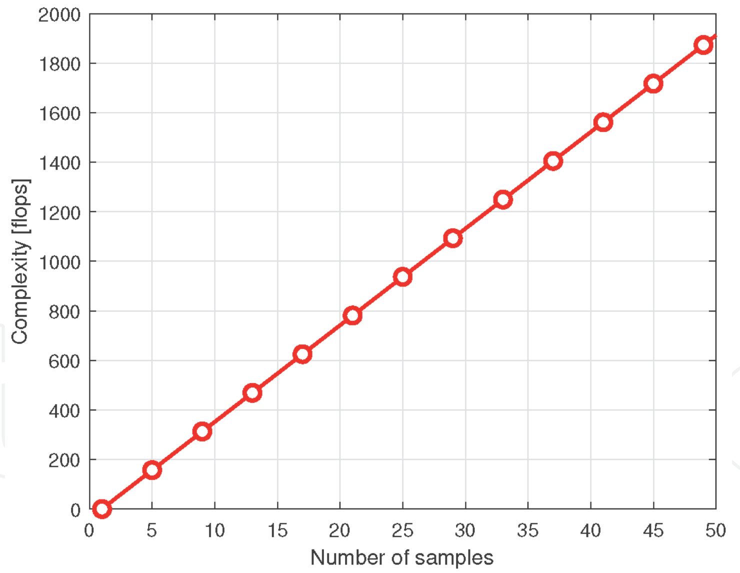

Figure 13.
Complexity of the averaging RSS method.

averaging RSS are only 0.255 m (18%). The improvement of nearly 31.5% is achievable by using the proposed scheme.

8. Kalman filtering, averaging RSS, and traditional RSS techniques

In this section, different comparisons are shown between the performance of three methods; The traditional RSS technique, proposed averaging RSS technique, and the proposed Kalman filtering with averaging. We use same values which given for the VLC link of **Table 2**.

8.1 LoS propagation

The effects of LoS only on two tracks' estimations for both x and y paths are presented in **Figures 14** and **15** for both x and y paths, respectively.

From the figures, both tracksâ€™ estimations are the nearest to the real one when employing the proposed techniques. Also, The results show that adopting KF estimation reduces the positioning error and improve the estimation. **Table 3** for three techniques summarizes the error and improving percentages.

8.2 Both LoS and NLoS propagations

The effect of both LOS and NLOS on Kalman filtering tracks' estimations for both x and y paths are presented in **Figures 16** and **17** for both x and y paths, respectively. It is clear that the track estimation gets slightly worse when including the effect of NLoS.

8.3 Kalman filtering response

The response for a random position estimation for the KF is shown in **Figure 18**. The filter input is a measured value of received power, while the filter output is the corresponding estimated value at different number of samples. The filter response (estimated value) is near to the actual value where the samples are greater than 11.

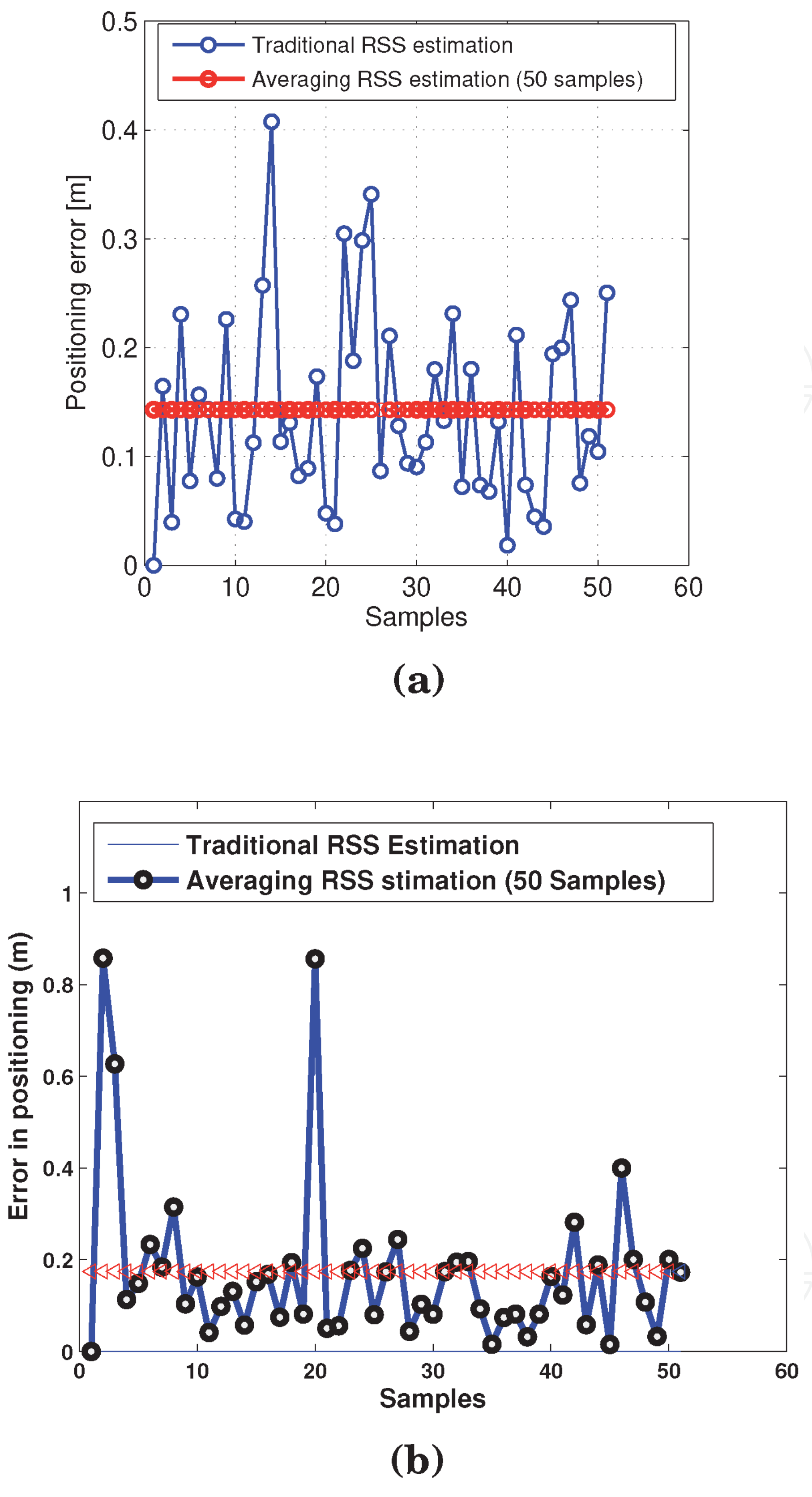

Figure 14.
Positioning error for both traditional RSS and averaging RSS techniques at position (1, 1), considering the effects: (a) LOS only, (b) both LOS and NLOS.

8.4 Position estimation accuracy comparison

As mentioned in the introduction, several techniques have been proposed for indoor localization based on VLC technology. In this section, a comparison is

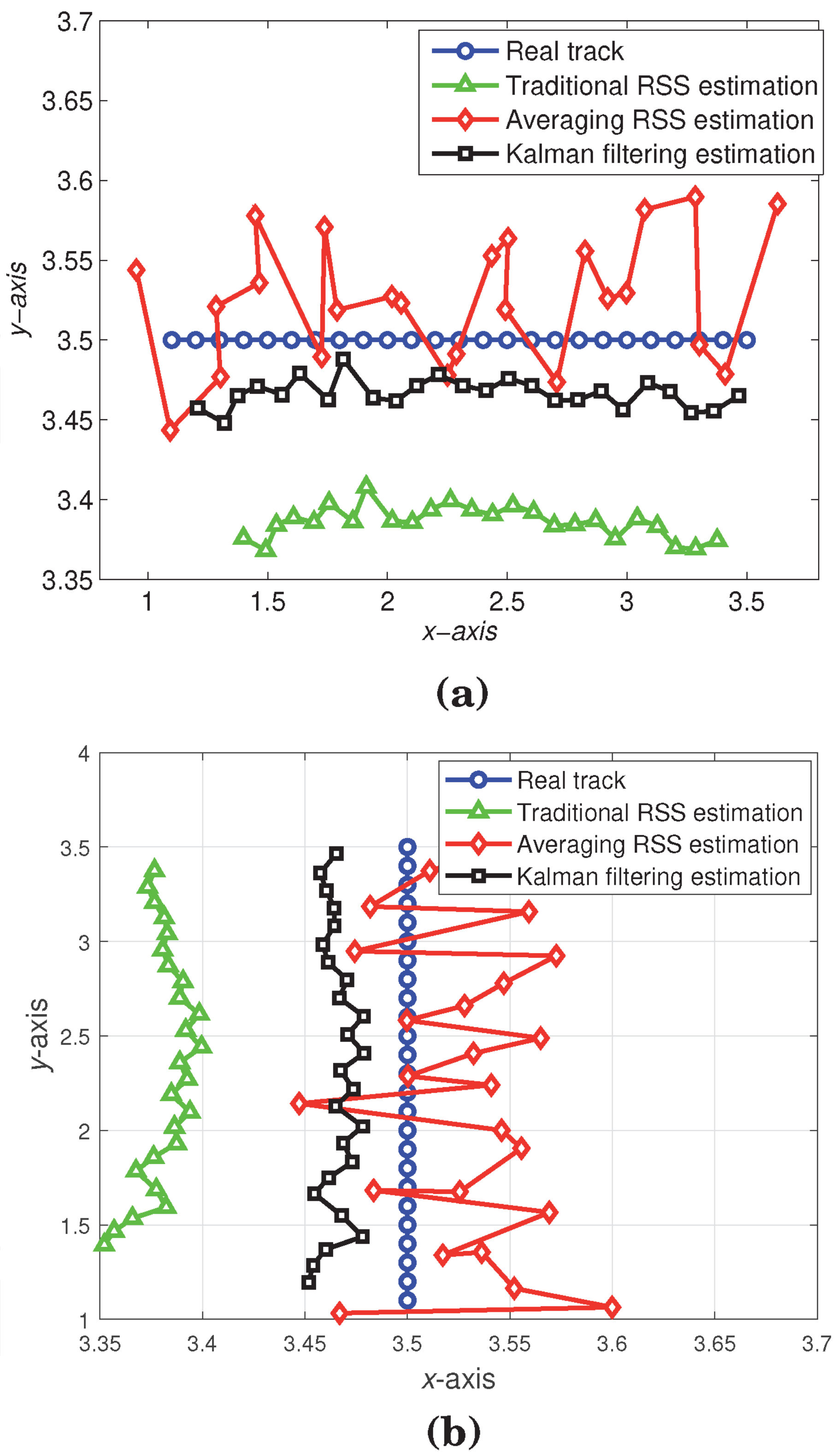

Figure 15.
Track estimations using traditional and proposed techniques for: (a) an x path, (b) an y path.

Localization method	Average positioning error	Percentage improvement
Traditional RSS	18 cm	—
Averaging RSS	12 cm	33.3%
Kalman filtering	5 cm	72.2%

Table 3.
Accuracy for different techniques.

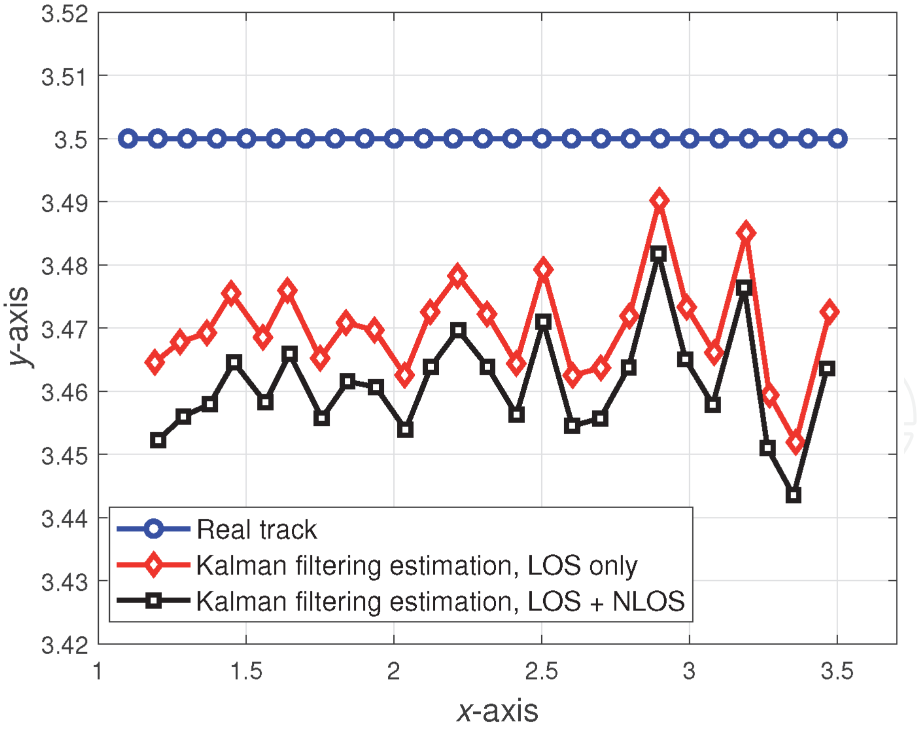

Figure 16.
Comparison between Kalman filtering track estimation for both LOS and NLOS propagations for an x path.

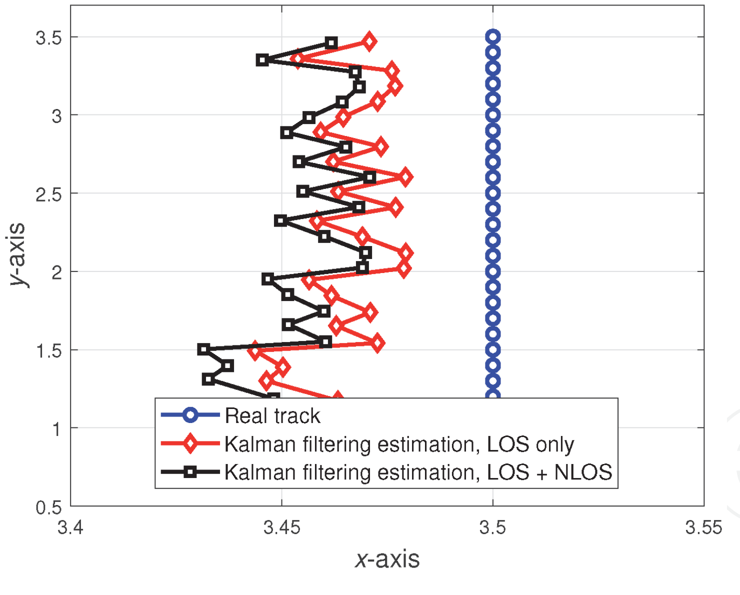

Figure 17.
Comparison between Kalman filtering track estimation for both LOS and NLOS propagations for an y path.

provided between the position estimation accuracy and that of previous works for same simulation parameters. The results of this comparison are summarized in **Table 4**.

It is clear from the **Table 3** that both proposed averaging RSS and Kalman filtering with averaging techniques achieve better accuracy than that proposed in [6–8]. Since the authors in [9, 10] have adopted Kalman filtering, they have better accuracy than the proposed averaging method. However, employing Kalman filtering with averaging gives a better accuracy.

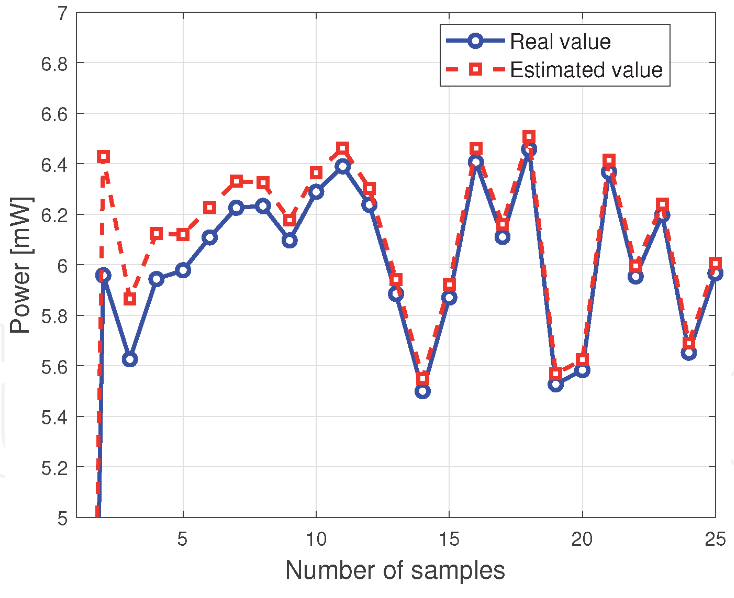

Figure 18.
Response of Kalman filtering technique.

Reference	Sys. parameters	Ref. acc.	Present work	Present work
			AVG sys. Acc.	KF acc.
[6]	LoS, FoV $= 80°$, $P_T = 10$ W, $A_R = 0.5$ cm^2, $(5, 5, 3)$ m^3	5 cm	3.7 cm	3.1 cm
[7]	LoS/NLoS, FoV $= 10$–$180°$, $P_T = 1.9$ W, $A_R = 0.81$ cm^2, $\rho = 60\%$, $(4, 4, 3.5)$ m^3	13.95 cm	9.1 cm	4.8 cm
[8]	LoS, FoV $= 85°$, $P_T = 1$ W, $A_R = 0.81$ cm^2, $(5, 4, 3)$ m^3	10 cm	6.17 cm	1.75 cm
[9]	LoS, FoV $= 80°$, $P_T = 17$ W, $A_R = 1$ cm^2, $(3.6, 3.26, 2.5)$ m^3	14.5 cm	17.4 cm	3.5 cm
[10]	LoS, FoV $= 25°$, $P_T = 17$ W, $A_R = 1$ cm^2, $(6, 6, 3)$ m^3	5 cm	11 cm	2.3 cm

Table 4.
Position estimation accuracy comparison.

9. Concluding remarks

First, the proposed techniques have been analyzed mathematically, taking into account the effects of LoS propagation. The positioning estimation accuracy of proposed techniques has been evaluated in a typical room. The results reveal that an improvement of about 52% in the average positioning error is achievable using the proposed technique with KF, when compared to that of the traditional RSS.

Secondly, both averaging and Kalman filtering by averaging schemes are adapted to improve the positioning system. Specifically, in the averaging technique, the receiver position has been determined by using the average of the samples of RSS estimations. The position is determined by RSS estimation of a Kalman filtered averaged multiple received power samples in the second proposed system, Kalman filtering with averaging algorithm.

Simulation results reveal that an improvement of about 33.3% in estimation accuracy is achievable when using the averaging scheme as compared to that of traditional RSS scheme. This improvement increases to 72.2% when adopting proposed Kalman filtering with averaging scheme.

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