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A HEURISTIC APPROACH TO INDOOR LOCALIZATION USING LIGHT EMITTING DIODES

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ABSTRACT

Widespread applications of location based services for indoor environments have created an opportunity for researchers to develop new techniques for accurate position estimation with less complexity. In this paper, we present a heuristic approach to localization by employing clustering for an indoor environment. Depending upon the number of light emitting diodes (LEDs) used as transmitter, level 1 clustering is achieved by simply comparing the signal strength for each combination of transmitter's light intensities at the receiver. For level 2 clustering, a new technique of clustering is proposed, named portion clustering, is applied to further partition the area where the object of interest can be located. From the simulation results, it can be observed that the location estimation up to 16 centimeters can be achieved for an indoor environment with the dimensions of $3 \times 3 \times 3\, m^3$ using LEDs.

Keywords: *Localization, Light Emitting Diode, Machine Learning, Clustering, Received Signal Strength*

1. INTRODUCTION

Localization, also known as positioning, is a process of determining the spatial position of an object or a person [1]. There are number of applications for localization such as navigation, home automation, intelligent transportation system, health monitoring, and location based services (LBSs) etc. LBSs, is a popular area of research nowadays because of its wide spread applications in daily life. Outdoor positioning systems are mainly dependent on global positioning system (GPS), however, it is not feasible to use GPS for indoor localization primarily because of meagre satellite coverage, signal diminution, electromagnetic (EM) interference, multipath effect and obstacles [2]. Therefore, there is a gap, which can be further investigated, leading towards the development of new techniques that can well suited for indoor localization and overcome the aforementioned shortcomings of GPS when viewed for indoor localization. For an indoor environment, visible light positioning system (VLPS) based on light emitting diodes (LEDs) is promising candidate which can overcome the limitations of GPS. LEDs are far superior when compared to traditional incandescent and fluorescent light sources as former one have a longer lifespan, high forbearance to humidity, high brightness, and energy efficiency etc. [3].

Various LED-based indoor positioning systems exist in literature which are based on received signal strength (RSS) [4], time difference of arrival (TDOA) [5], angle of arrival (AOA) [6], image sensors [7], correlation [8], fingerprinting [9], analytically solving Lambertian transmission equations [10] and so on. RSS requires the knowledge of properties of optical channels among transmitter, receiver and the optical power transmitted by each LED that is difficult to achieve. TDOA based systems require a precise delay control to adjust the initial phase. The AOA approach, which is an unsuited choice for radio frequency (RF), is a promising technique in visible light communication (VLC), requires multiple receivers for location estimation. Image sensor based localization systems have issues of light flickering in addition to complex and relatively expensive hardware. Correlation and fingerprinting

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techniques require an offline training stage and in case there is any change in indoor environment, then re-training is required.

The main purpose of this research is to introduce a simple and straightforward method to achieve indoor localization with least modification to existing lighting infrastructure. In this paper, we present a heuristic approach for indoor localization using LEDs and validate the proposed system using simulations. Furthermore, a new type of clustering named as portion clustering is introduced which is applied to the received signal in order to have an accurate location estimation. The rest of the paper is organized as follows. Section 2 introduces system modeling, transmitter design and the proposed algorithm. Section 3 describes the simulation parameters for performance evaluation. Section 4 discusses the results of the proposed algorithm for various scenarios and Section 5 concludes the paper.

2. SYSTEM MODELING, TRANSMITTER DESIGN AND PROPOSED ALGORITHM

Figure 1 in which four LEDs are placed on the ceiling can represent the overall system.

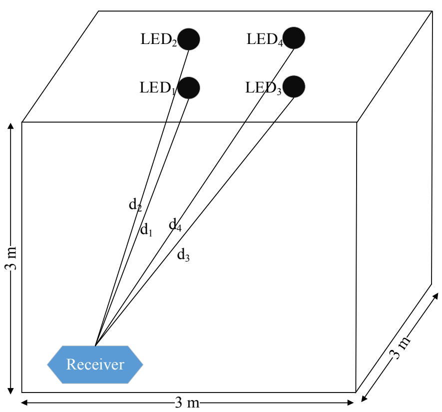

Figure 1: Elementary Units of Visible Light Positioning System

2.1 System Modeling

In order to establish a communication system, transmitter, channel and receiver are modeled. Light emitted from an LED follows a Lambert emission pattern that is governed by Eq. (1).

$$R(\phi) = \frac{n+1}{2\pi} P_T \cos^{n_l}(\phi) \qquad (1)$$

where P_T is the power transmitted from the LED, ϕ is the angle between the source orientation vector and the vector pointing from source to the receiver, n is the mode number of the radiation lobe which is $n = -\ln 2 / \ln(\cos \Phi_{1/2})$ where $\Phi_{1/2}$ is the LED view angle at half power. For our system, we use multiple LEDs i.e. $LED_i (i = 1,2,3...,k)$ and it is assumed that the receiver is facing vertically upwards toward the transmitter. Furthermore, for a typical VLC channel, the distance (d) between the transmitter and the receiver is quite large as compared to the photodiode detector area (A_R), which makes the received signal irradiance constant over the photodiode detector area. With these assumptions, the VLC channel impulse response $h(t)$ can be approximated as a scaled and delayed Dirac delta function from LED_i for $\theta_i \le FoV$ is given by Eq. (2).

$$h_i(t) = \left\{ \frac{n+1}{2\pi} \frac{\cos^n(\phi_i)\cos(\theta_i) A_R}{d_i^2} \delta(t - \frac{d_i}{c}) \right\} \qquad (2)$$

where θ_i is the angle between the receiver orientation vector and vector pointing from receiver to the source, FoV is the field of view of the receiver and c is the speed of light. The received signal can be expressed by Eq. (3).

$$P_R(t) = P_T \sum_{i=1}^{k} s_i(t) \otimes h_i(t) + \mathrm{n(t)} \qquad (3)$$

where $s(t)$ is the modulated signal and $\mathrm{n(t)}$ is the noise from the channel. In order to distinguish between the signals from each LED, time division multiplexing (TDM) is used and frame structure for one period is shown in Figure 2. At the end of each frame, the receiver will have the information about the received signal strength (RSS) from each LED. Based on the information received from the LEDs, the location of the object of interest is estimated by using a heuristic approach that will be discussed in Section 2.3.

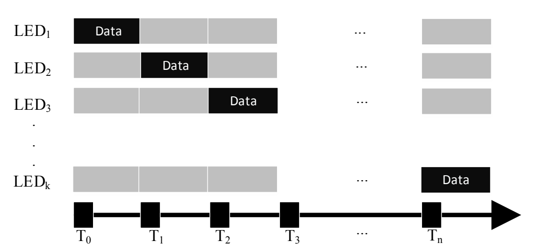

Figure 2: Frame Structure For K Transmitters

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2.2 Transmitter Design

In order to test our proposed algorithm, we placed the transmitters in various layouts i.e. triangular, symmetric square with uniform power from LEDs and symmetric square with non-uniform power from LEDs. The placement of LEDs are shown in Figure 3 where black stars represent the positions of the LED.

2.3 Proposed Localization Algorithm

Our proposed localization algorithm consists of two levels of clustering. The first level of clustering is through heuristic approach and the second level of clustering is through newly proposed clustering scheme. The key idea for the proposed algorithm is that the classification of the room can be done with respect to the maximum intensity of each LED for every location.

2.3.1 Level 1 clustering

We place the transmitters in various positions as shown in Figure 3. Depending upon the number of LEDs used, there will be $k!$ patterns in which the receiver can receive light from the LEDs and the 'greater than' condition is true. For instance, if there are four LEDs, then there will be certain areas where the intensities from the LEDs satisfy the following condition:

$$LED_{1_{Int}} > LED_{2_{Int}} > LED_{3_{Int}} > LED_{4_{Int}} \quad (4)$$

In addition to these $k!$ patterns, there will be $(k-1)!$ additional number of areas in which two LEDs will have the same distance (i.e. same intensity) and the remaining LEDs have different distances. Furthermore, there will be k number of areas where three LEDs have same distance from the receiver and other LED(s) will have different distances. Finally, there will be a single point on the surface where all the transmitters have an equal distance to the receiver. Therefore, if we have four LEDs, then in total there will be the following possible pattern as given by Eq. (5).

$$Total_{patt\_4LED} = k! + (k-1)! + k + 1 \quad (5)$$

However, when we consider symmetric placement of four LEDs then out of 24 conditions, there will be only 8 conditions which will be true thus reducing the number of portions for the next clustering and ultimately reducing the localization accuracy. There are two possible ways to overcome this issue. One is the asymmetric placement of LEDs i.e. LEDs are not placed at an equidistant from each other but in a random and planned fashion. Another way is to have non-uniform power emission with respect to each LED while keeping the symmetric placement. The first approach is not suitable as per its appearance is concerned, therefore, we consider non-uniform power emission to break the symmetric pattern. We can clearly see from Figure 3(c) that non-uniform power emission helps in avoiding the conditions where the receiver is receiving the same light from multiple LEDs. Thus by carefully selecting the power emitted from each LED can help creating $k!$ unique patterns of light.

2.3.2 Level 2 clustering

From level 1 clustering, it can be observed that the symmetric LEDs with non-uniform power give the maximum number of valid combinations in which the 'greater than' condition (i.e. signal strength of one transmitter is stronger as compared to others at a given location) is true. Then, for each valid combination, a portion clustering is applied. For a given received signal from k transmitters, the received signal will contain components of signal from each source. Based on the portion of each source contributing to the signal, clustering is done. From the readings of level 1 clustering, range is determined which is divided into p portions. For this study, p is taken to be 5. To have a better understanding of level 2 clustering i.e. the portion clustering, let's consider Figure 4.

Figure 4(a) is one of the 24 cases of level 1 clustering and for this specific case $LED_{4_{Int}} > LED_{1_{Int}} > LED_{3_{Int}} > LED_{2_{Int}}$ is true. The area in green color is the area where the intensity of LED4 is the brightest one and the intensity of LED2 is the weakest. Intensity of LED1 is less than LED4 and intensity of LED3 is less than LED1. Figure 4(b) shows how level 1 is portioned into 5 sub-portions based on the level of intensity of the LEDs. Following are the three steps which portion achieves clustering.

1. Data from the cluster level 1 is processed for level 2 clustering. Average weighted sum (AWS) of $k-1$ least bright LEDs for a specific region is calculated.
2. Average weighted sum is compared with the brightest LED at the specific level 1 cluster. Based on the range (the difference between the brightest intensity level and the AWS), data is further partitioned into p smaller portions.
3. For a given query LEDs reading; the trained clusters are used for position estimation

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assuming the object to be at the center of level 2 cluster.

3. SIMULATION PARAMETERS FOR PERFORMANCE EVALUATION

To validate the proposed algorithm, we tested it using simulation for various conditions as mentioned in Section 2.2. Room dimensions are taken to be 3 × 3 ×3 m^3 . Shadowing effect is not considering while simulating the environment and it is also assumed that there is no reflecting object present in the area of interest. For the first case (i.e. 3 LEDs arranged in triangular geometry) the LEDs were placed on the ceiling at fixed locations (0.8 m, 1 m, 3 m), (2.2 m, 1 m, 3 m), (1.5 m, 2.3m, 3 m). The reason for this selection is the uniform light intensity at the corners of the room. All the LEDs emit 12 W power. For the second and third case the LEDs are placed at (1 m, 1 m, 3 m), (1 m, 2m, 3 m), (2 m, 1m, 3 m), (2 m, 2 m, 3 m). For the second case, the power for all four LEDs is kept at 12 W, however, we choose LEDs with different power for the third case i.e. 11W, 11.5W, 12W and 12.5W. The LEDs are modulated by different addresses of [1 0 0], [0 1 0], [0 0 1] for case 1 and [1 0 0 0], [0 1 0 0], [0 0 1 0], [0 0 0 1] for case two and three, so that TDM can be applied. Each LED transmit data only in the time slot assigned to it that helps the receiver to differentiate the signals from each LEDs.

4. DISCUSSION AND RESULTS

4.1 Location Estimation Errors for Three Scenarios

We start the discussion with the results of the case when the transmitters are placed in a triangular geometry. With only 6 combinations at level 1 clustering, the level 2 clustering gives 30 portions in total for the given area of interest which results in significant errors. The average error for the location estimation is 38.73 cm. The results are shown in Figure 5.

For the second case, the first level of clustering gives 24 combinations but due to the symmetric placement in conjunction with uniform power emission from all the LEDs, only 8 combinations are unique on which level 2 clustering can be applied resulting in 40 unique portions corresponding to an area. The average position estimation error is 33.54 cm. The results are shown in Figure 6.

For the last case, four transmitters are used. They are placed in a symmetrical manner and transmitting different intensities. As the power emitted from each LED is of different intensity, level 1 clustering will yield 24 combinations. When level 2 clustering is applied on these 24 combinations, it will give 120 unique portions corresponding to an area. The average error for location estimation is 19.36 cm. The results are shown in Figure 7.

While plotting the error, the error limit value (i.e. the *z*-axis) for Figures 5, 6, 7 is kept in between 0 to 0.4, which gives a fair comparison for the accuracy for all three scenarios. It can be seen that the error is the least for case 3 and worst for case 1. Furthermore, the accuracy of the algorithm is better in the center of the room and poor at corners because the directionality of Lambert emission transmission. When the receiver is near the corner, the received intensity from the diagonal source can be considerably degraded and is susceptible to noise interferences.

4.2 Effect on Location Estimation by Varying Level 2 Portions

From the results, it is evident that when 4 LEDs are used with non-uniform light intensity, the location estimation error is the least, therefore, we further analyze the results for this case by varying the number of portions p in level 2 clustering. Initially p was taken to be 5 and for this section, we vary p from 2 to 7 and observe the effect on location estimation. Figure 8 is plotted against varying p and average location estimation error. From Figure 8, we can see that when the value of p increases, the accuracy of location estimation is improved.

4.3 Effect of Noise on Location Estimation

We evaluate the performance of the positioning algorithm under different noise level. When the area of the optical receiver is large then thermal noise can be ignored and noise is primarily associated with shot noise which can be modelled as Gaussian with power spectrum density (PSD) of $N_o = 2qI_{bg}$ where q is the charge on the electron and I_{bg} is the background light induced current. As the localization bandwidth requirements are very modest, therefore it is fair to assume a low speed data transmission communication system. Typically, the shot noise varies between -140 dbm W (direct sunlight) to -180 dbm W (artificial light only) [11]. Location estimation in the presence of noise is shown in Figure 9.

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When there is only artificial light sources in the field of view of the receiver, there is a minor effect on overall performance of the algorithm. Such light is not strong enough to disturb the symmetry of light distribution i.e. increase or decrease the light intensity of one source from one to another. However, in the presence of direct sunlight, the performance is significantly degraded.

5. CONCLUSION

Indoor localization is a popular area of research as there are many potential applications for indoor localization, which can be beneficial to us in everyday life. As GPS fails to provide accurate positioning so there is a need for the development of new techniques for indoor localization. In this paper, a heuristic approach for indoor localization using light emitting diodes is proposed. For three different scenarios, the LEDs are placed on the ceiling and based on the received signal strength from these LEDs at a given location, the room is partitioned. Furthermore, level 2 clustering is applied to narrow down the area for position estimation using the proposed portion clustering technique. We also analyzed the system for different number of portions at level 2 clustering as well as the impact of noise on localization performance. The limitation for this work are same as that of RSS based indoor localization i.e. whenever there is any change in the environment, database needs to be re-generated. It can be concluded that higher number of transmitters with non-uniform power emission and more portions at level 2 clustering gives the best location estimation for the proposed algorithm. From the results, it is evident that by using a simple heuristic approach, a good level of accuracy can be achieved keeping the algorithm complexity low. In this work, the author has explored RSS as a merit to create a database; however, it is worth investigation how this algorithm works when the database is created using AOA or TODA method.

REFRENCES:

[1]. Saadi, Muhammad, Thiti Sittivangkul, Yan Zhao, Lunchakorn Wuttisittikulkij, and Paramin Sangwongngam. "System demonstration for visible light communication using adaptive threshold detection for low data rate applications." IEEE International Conference on *Electron Devices and Solid State Circuit (EDSSC), 2012*, pp. 1-3.

[2]. Saadi, M., L. Wattisuttikulkij, Y. Zhao, and P. Sangwongngam. "Visible light communication: opportunities, challenges and channel models."International Journal of Electronics & Informatics" vol. 2, no. 1 (2013): 1-11.

[3]. Saadi, Muhammad, Ambar Bajpai, Yan Zhao, Paramin Sangwongngam, and Lunchakorn Wuttisittikulkij. "Design and Implementation of Secure and Reliable Communication using Optical Wireless Communication." Frequenz, vol. 68, no. 11-12 (2014): 501-509.

[4]. Jung, Soo-Yong, Seong Ro Lee, and Chang-Soo Park. "Indoor location awareness based on received signal strength ratio and time division multiplexing using light-emitting diode light." Optical Engineering, vol. 53, no. 1 (2014): 016106-016106.

[5]. Jung, Soo-Yong, Swook Hann, and Chang-Soo Park. "TDOA-based optical wireless indoor localization using LED ceiling lamps." IEEE Transaction on Consumer Electronics, vol. 57, no. 4 (2011): 1592-1597.

[6]. Yang, Se-Hoon, Hyun-Seung Kim, Yong-Hwan Son, and Sang-Kook Han. "Three-Dimensional Visible Light Indoor Localization Using AOA and RSS with Multiple Optical Receivers." Journal of Lightwave Technology, vol. 32, no. 14 (2014): 2480-2485.

[7]. Hossen, Md Sazzad, Youngil Park, and Ki-Doo Kim. "Performance improvement of indoor positioning using light-emitting diodes and an image sensor for light-emitting diode communication." Optical Engineering, vol. 54, no. 4 (2015): 045101-045101.

[8]. Jung, Soo-Yong, Swook Hann, Suyong Park, and Chang-Soo Park. "Optical wireless indoor positioning system using light emitting diode ceiling lights."Microwave and Optical Technology Letters, vol. 54, no. 7 (2012): 1622-1626.

[9]. Vongkulbhisal, Jayakorn, Bhume Chantaramolee, Yan Zhao, and Waleed S. Mohammed. "A fingerprinting-based indoor localization system using intensity modulation of light emitting diodes." Microwave and Optical Technology Letters, vol. 54, no. 5 (2012): 1218-1227.

[10]. Zhou, Zhou, Mohsen Kavehrad, and Peng Deng. "Indoor positioning algorithm using light-emitting diode visible light communications." Optical Engineering, vol 51, no. 8 (2012): 085009-1.

[11]. Wolf, Mike, and Dieter Kreb. "Short-range wireless infrared transmission: the link budget compared to RF." IEEE wireless communications, vol 10, no. 2 (2003): 8-14

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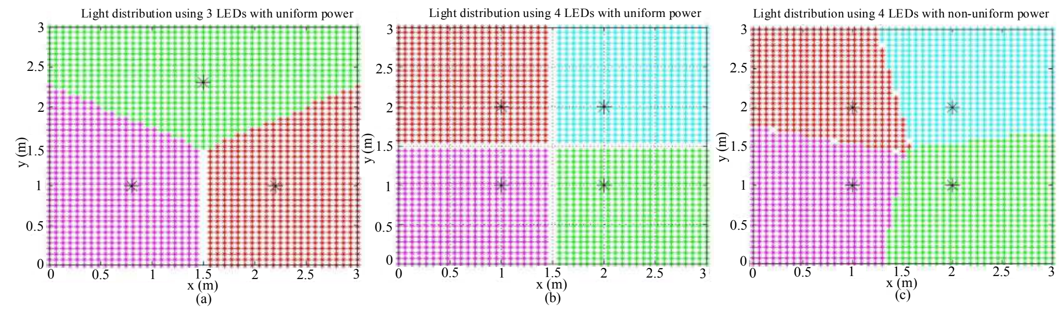

Figure 3: LED Placement With Their Footprints Based On The Maximum Intensity (A) 3 Leds In Triangular Geometry (B) 4 Leds In A Square Geometric With Uniform Power (C) 4 Leds In A Square Geometry With Non-Uniform Power With Respect To Each LED

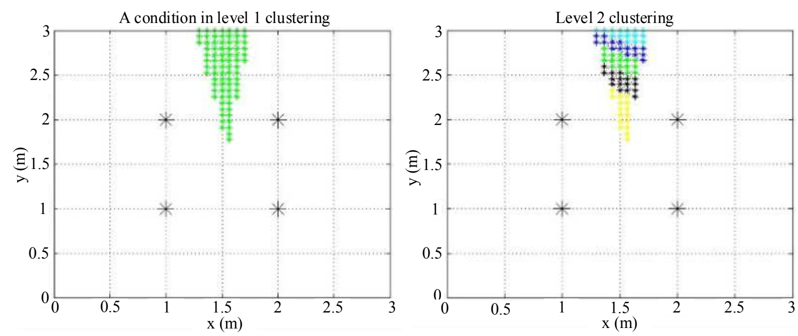

Figure 4 Clustering Levels (A). Level 1 Clustering (B). Level 2 Clustering

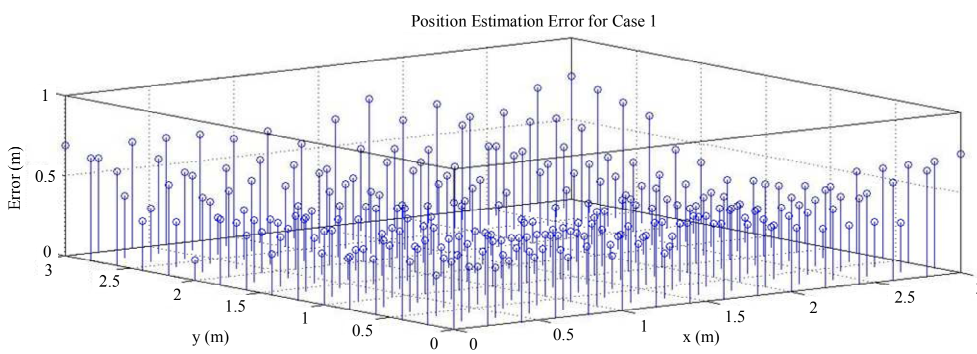

Figure 5: Plotting Error When 3 Leds Having Same Light Intensity

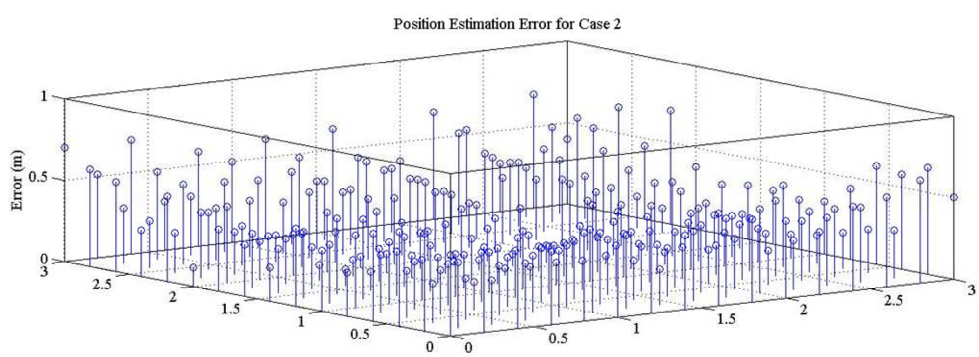

Figure 6: Plotting Error When 4 Leds Having Same Light Intensity

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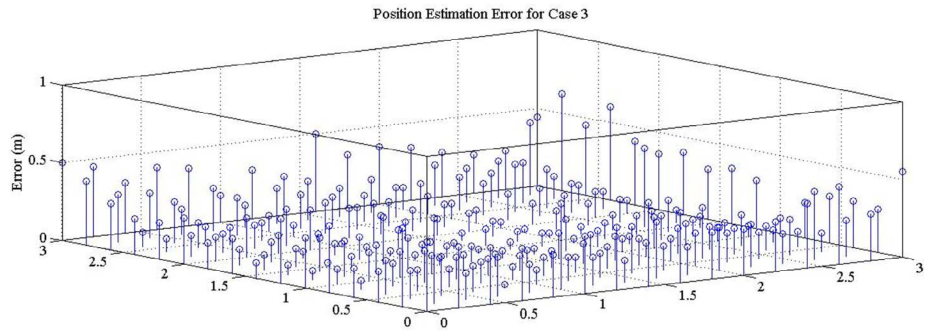

Figure 7: Plotting Error When 4 Leds Having Non-Uniform Light Intensity

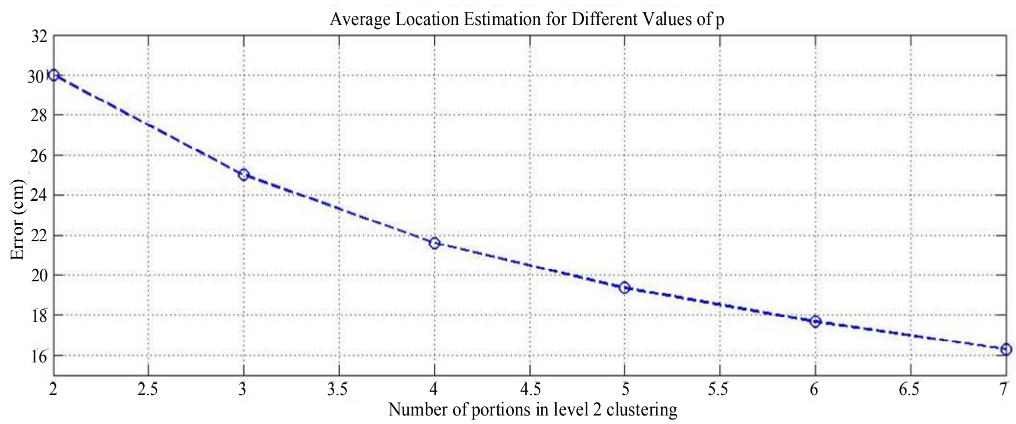

Figure 8: Average Location Estimation Error For Different Values Of P

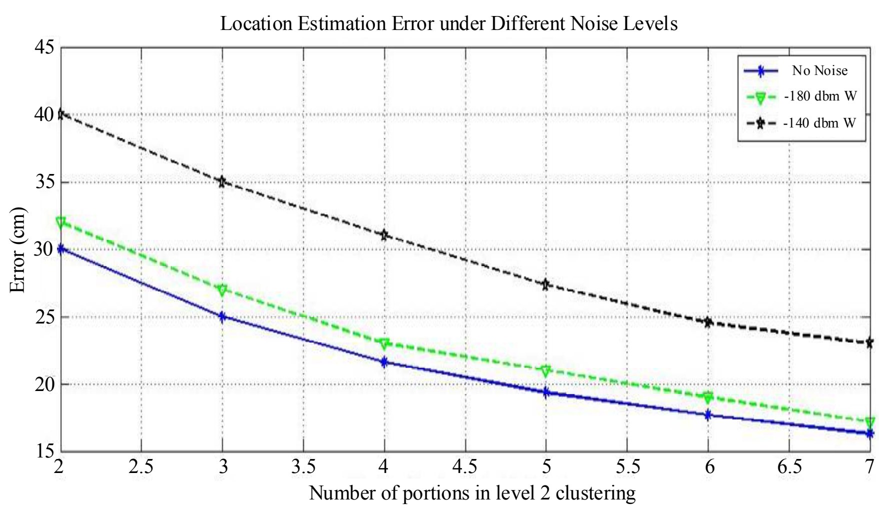

Figure 9: Effect Of Noise On Location Estimation