COMPARISON OF INDOOR POSITIONING TECHNIQUES USING VISIBLE LIGHT COMMUNICATION

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COMPARISON OF INDOOR POSITIONING TECHNIQUES USING VISIBLE LIGHT COMMUNICATION

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ABSTRACT

COMPARISON OF INDOOR POSITIONING TECHNIQUES USING VISIBLE LIGHT COMMUNICATION

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Visible light communication (VLC) is one of the most widely used indoor positioning technique. It has attracted wide attention in recent decades as it tries to integrate illumination with communication. In this research, the triangulation of the received signal strength (RSS) algorithm, based on indoor VLC positioning system, is utilized, where LED light is the transmitter and a photo detector is the receiver. The receiver detects the signal power from different paths including diffuse and direct path to calculate the distance between the transmitter and receiver. Then, the received power that reflected of each wall from the room reflections is analyzed on the receiver surface. To this end, the performance of linear least square (LLS) approach is evaluated by cumulative distribution function (CDF) of the positioning errors. To be more precise, the errors are estimated for all the locations over the room and compared with two different LED pattern of rooms. The simulation results show that the proposed system is capable of achieving a much higher positioning accuracy with lower complexity meanwhile the vertical distance between LEDs and receiver (Rx) surface is equal to 5 m for the first time, whereas in all previous works the vertical distance is lower .

Keywords: Light emitting diodes(LED); Visible Light Communication (VLC); Received Signal Strength (RSS); Line of Sight (LOS).

ÖZET

Görünür Işık İletişimi ile İç Mekân Konumlandırma Tekniklerinin Karşılaştırılması

AL-KHAZRAJI, Ali Adnan

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Görünür Işık Haberleşmesi (VLC) en çok kullanılan iç mekan konumlama tekniklerinden biridir. Işıklandırma kavramını haberleşme kavramı ile entegre etmeye çalışması nedeniyle son yıllarda dikkatleri üstüne çekmektedir. Bu araştırmada, LED ışığının verici ve foto detektörün de alıcı olarak kullanıldığı, iç mekan VLC konumlandırma sistemi tabanli alınan sinyal gücü ile nirengi algoritması kullanılmıştır. Alıcı, vericiye olan uzaklığını hesaplamak için, direk yol ve yayılım yolu (diffuse path) da dahil olmak üzere farklı yollardan gelen sinyal güçlerini saptar. Ardından, odanın her duvarından yansıyıp gelen güç sinyali alıcı yüzeyinde analiz edilmiştir. Bu amaçla, Lineer En Küçük Kareler (LLS) performansı konumlandırma hatalarının kümülatif yayılım fonksiyonu (CDF) ile değerlendirilmiştir. Daha açık belirtmek gerekirse, hatalar oda üzerindeki her konum için tahmin edilmiştir ve iki farklı LED konumu ile karşılaştırılmıştır. Simülasyon sonuçları önerilen sistemin konumlandırmada düşük kompleksite ile yüksek doğruluk sağlayabilme becerisine sahip olduğunu göstermiştir. Aynı zamanda, LED'ler ve alıcı arasındaki dikey mesafe (Rx) yüzeyi bu çalışmadan önceki bütün çalışmalarda daha düşük olmasına karşın, bu çalışmada bu değer 5 m'dir.

Anahtar Kelimeler: Işık Saçan Diyotlar(LED); Görünür Işık İletişimi (VLC); İçmekan Konumlandırması; alınan sinyal gücü (RSS); Görüş Hattı (LOS).

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LIST OF ABBREVIATIONS

AOA : Angle Of Arrival
CDF : Cumulative Distribution Function
FOV : Field of View
GPS : Global Positioning System
IMDD : Intensity Modulation Direct Detection
LBS : Location Based Services
LED : Light Emitting Diode
LLS : Linear Least Square
LOS : Line Of Sight
Wi-Fi : Wireless Fidelity
OOK : On Off Keying
PD : Photodetector
RF : Radio Frequency
RF-ID : Radio Frequency Identication
RSS : Received Signal Strength
NLOS : Non Line Of Sight
TDOA : Time Difference Of Arrival
TOA : Time Of Arrival
VLC : Visible Light Communication
VLP : Visible Light Positioning

CHAPTER ONE

INTRODUCTION

Localization techniques are methods that used for estimating target position which are the basic of navigation based services.

Determination of human being location is an ancient problem of humankind. The pioneers found their ways using the stars' locations. Location based services have seen a vast growth in last few decades. At present-day, the Global Positioning System (GPS) is used for localization of devices in. Despite providing a reliable operation on an outdoor environment, its use for indoor positioning is somehow difficult due to the fact that signals from GPS satellites can either be shadowed or be blocked inside buildings or in underground facilities. Thus, either the system returns erroneous position information or the information is not available at all. Due to this insufficiency, there is a need for alternative methods.

There is an increasing demand for precise indoor localization technologies and location based applications for under covered areas. There are a lot of applications that use indoor positioning techniques for inside building.

The big shopping malls and large compound buildings, it is sometimes from hard to locate the store that we are want. Therefore, under such conditions indoor positioning systems could assist us. Such problems can be encountered in large buildings, such as hospitals, libraries, airports, and so on. Navigating for the location of houses, railway stations, and airports is considerably an easier process, but rapid positioning is difficult when it comes to indoors to achieve the correct location by the Global Positioning System (GPS). The electromagnetic signals of GPS not infiltrate through buildings walls. Consequently, attempts to use GPS for inside buildings usually brings about a large amount of positioning error and sometimes result in conditions where connecting to the satellites is completely impossible. Under such conditions, the positioning accuracy of GPS is located in the order of several meters, which is unacceptably large for indoor scenarios. Therefore, the outdoor positioning technology cannot meet the requirements in the indoor environment. Further, positioning techniques must be used to facilitate Indoor Positioning System (IPS).

To avoid this situation, there are various indoor positioning technologies proposed such as Radio Frequency Identification (RFID) , Ultra-Wideband (UWB) and Wi-Fi . These technologies locate the position of an object. Nevertheless, additional units such as transmitting beacons tools in such practices. That leads the installation cost and maintenance would be so expensive. Also, numbers frequencies in the signals of radio frequency techniques forbidden to use in some distinct areas such hospitals, airports and shelters.

Visible Light Communication (VLC) has gained a great interest in the most recent decades due to the rapid developments in Light Emitting Diodes (LEDs). Efficiency, solidity and long life span of LEDs makes them a promising residential lighting equipment as well as an alternative cheap and fast data transfer equipment. Meanwhile ,the development of faster LED light brings opportunity for indoor based on localization. We can use the lights that already used for lighting the indoor also use for localization our self. Where, LED has property that easy to modulate so that we can use it in indoor communication plus the main purpose of it which is lighting.[1][2][3]

1.1 Related Works

Positioning systems used for obtaining user's location that depending on navigation services for localization .Indoor positioning applications need to be more precise for localizing rather than outdoor scenarios. Thus, the available techniques that used for communication nowadays such as Wifi, Radio frequency and Bluetooth [4][5][6], these techniques are used in indoor positioning systems to find the position of user indoor rather than GPS signals to enhance the accuracy of indoor positioning systems. Because the GPS positioning is inaccurate and mistaken for an indoor circumference because the atmosphere cased blocking and some attenuation to the signals of satellites. Indoor positioning systems use light emitting diodes (LEDs) have been widely used in nowadays. LEDs have a great advantages in the communication field, such that infrared LEDs, Laser diode and all kind of photo detectors and also in visible light communication (VLC) [11].

LED has paved the way for those indoor applications that use for positioning due to its huge bandwidth [12] safe to human eyes, secure transmission, and high rate of communication. VLC systems in transmission depend on line of sight so if anything interrupts the line of sight the transmission will cut so that any third party will be easily appear if he interrupt the connection between the transmitter and the receiver.

LEDs consume low power where it is quite energy efficient [13]. LEDs and photo detectors are very cheap component it is cost around dollar [14]. As these advantages. So, it is unsurprising that applying indoor positioning based on VLC, which has a great researches in industry recently to step into that field. There are a lot of methods and techniques used LEDs for localization in indoor and these studies are applied experimental and simulations .Indoor positioning based on visible light communication it uses light emitting diode for indoor positioning accuracy range around 0.1-0.5 m of the positioning error. While the others techniques such that WiFi around 5 m and Bluetooth accuracy around 3 m [15]. Nowadays there are a lot of articles using VLC based positioning published. Such that, in [14] the authors modeled and investigated the characteristics of VLC channel modes also several other VLC for indoor positioning. The study in [12] gives a good study as survey of VLC systems as well as algorithms to improve the performance of indoor all the positioning techniques that are available, where the survey focus on the difficulties that facing in indoor applications. None of previous studies illustrate the methods and techniques that are available for localization in indoor by using VLC localization techniques even though they mention the general IPS concept [14]. The work [16] investigated three methods that used for indoor positioning and compared their results including multipath reflections and synchronization. The article [17] proposed a tables for the available techniques based on positioning methods and concentrate on the errors of indoor positioning. The article [16], investigated the localization algorithms. But, the characteristic of VLC based positioning in terms of line of sight and the other VLC paths have not investigated. The work [18] focused on the localizing algorithms the author did not investigate about the characteristics of VLC and other parameters that depend on transmission between the transmitter and receiver such that field of view , half power semi angle and angle of incidence etc.

In the work [17], the author illustrates the all positioning techniques, but the author did not mention about channel noise and localization errors are not discussed. The state-of-the-art on IPS techniques focuses on the following methods that use for estimating the position of the target such as time of arrival (TOA), angle of arrival (AOA) time difference of arrival (TDOA), and received signal strength (RSS) and.

In [19], an author investigated the indoor positioning system by using time of arrival method is studied. The time was totally synchronized between the LEDs and the receiver. In the proposed system, the author used a normal LEDs for lighting with the same time it can be used for communication and determine the receiver position through TOA method. The photo diode that used for detection of transmitted signal from LED, it calculate the distance between the transmitter and the receiver. The author used a technique called Cramer-Rao bound and applied it on the TOA for indoor positioning is discussed in that paper, an error range of 2 to 6 cm found for the entire room where the theoretical accuracy computed by using the Cramer Rao bound. In [20,21], another system for indoor positioning used TDOA algorithm based on VLC was investigated. In the proposed system the author used four LED to send the information of its position and a single receiver contains a photo diode for receiving the signals from LED transmitters. The author used Time division multiplexing (TDM) technique to divide the received signals from different transmitters. After receiving a bunch of signals from the four LEDs, TDM used for separating the cods from the LEDs. An error of 3 cm found. In [22] a method same in [20,21] the author used a sinusoidal signal as the transmitted signal between the transmitter and the photo diode. The simulation result found the average error distance was 68.2 cm. Another technique used for indoor positioning which is angle of arrival. A system based on AOA used for indoor poisoning is studied in [23], the simulation results showed that an error of the accuracy is 0.1 m found for the system. Wearable devices used angle of arrival methods are presented in [24]. The author proposed a polarization based modulation, the authors found accuracy around 0.25 m when he applied the optimization of the positioning algorithm. A complex system used the technique of AOA in indoor positioning system is proposed in [25]. A three of photodetectors used in this system to receive the signals from multiple LED. The author used least-angle regression algorithm to obtain the incident angle. The simulation results found that the localizing error of the proposed method was around 5 cm. Received Signal Strength is another method for estimating the distance by using the power of the transmitted signals to estimate the distance from the LED transmitter and photo detector. For example [26] a system investigated the impact of the reflected light due to walls on the positioning errors of a VLC positioning system where the author used RSS, the distance between the receiver to the LED is by using the equation of the power for the received signal. The simulation is done by a room its dimension 5x5x3.5 the results of the root mean square error was 4 cm when the effect of NLOS not considered, while an error found of 80 cm when the reflected signals are into account. A VLC based positioning system using RSS was investigated in [27–30]. The visible light from three LED base stations installed on the ceiling of the room and the modulation that used for signals is Quadrature Phase Shift Keying (QPSK) each LED modulated with different frequencies. The experiment is applied in a box of 60 cmx60 cmx85 cm and errors that found in the box of 6 cm. In this research , to the best of our knowledge, this is the first study that utilized Linear Lest Square (LLS) in VLC based positioning. LLS is a low complexity technique that increases positioning accuracy. Therefore, we obtain a much higher accuracy respect to the previous studies.

1.2 Motivation

Visible light communication (VLC) is a technique that uses visible light signals as a medium for communication, recently the VLC uses LED lights for determining the location of targets in indoor with same time used for lighting and it has many advantages over others based positioning techniques. VLC uses the Light Emitting Diodes (LED) which is an interesting subject in wireless communications, due to the hug advantages of high luminous power that reach up to 110l m/W, LED light has long spin life around 50.000 hours and high data speed about up to 11 MHZ. The LED has a high frequency levels so the human eyes can detects these high switches. Thus, there are many techniques for LED modulation; LEDs can supply the illumination and communication at the same time. The light has an important property for situating the position of the targets in indoor scenario. Where, every color in the light has strength differ from each other with respect to the sources of lights, which can be detected by the photo diode and detectors in receiver devices. The other feature, light power is fixing at all the day. Hence, we can use from the lights that are already installed in indoor for locate our self.

Visible light positioning systems use in a lot of places such hospitals and airports these area are very sensitive to the RF signals. So it can be in these sensitive areas

probably because it does not produce RF interference between the lights. The emission angle of the light emitting diode is narrow, so that the light be more precise and hence can use for transmitting the data to receiver in a secure way. The power of VLC is focused on line of sight link which is consider the main link so the main power is transmitted through this link. We can use from the lights that already installed by doing some change in it to make it for both transmission and lighting.
Existing examinations uncover that high exactness can be accomplished with VLC based positioning. Next to these favorable circumstances, the primary inspiration for the expanding sum of investigate on VLC based situating is the possibility of LED gadgets and lighting systems getting to be ubiquitous,in near futur we could see lications depend on VLCmany app. With many features of LED, such as LED price is cheap, long life spin, environmentally friendly and great controllability. With the great developing in LEDs, the VLC uses LED light and this become the most important technique for future in wireless technologies. It is trusted that VLC is the perfect skill for empowering the Internet of Things (IoT). In the not so distant future, VLC base stations, which likewise fill in as lighting gadgets, may be installed all over the place, unfurling the capability of using them for an inescapable positioning framework. When LED lighting frameworks are introduced in all over the place, VLC based situating can give a consistent situating administration inside a lot bigger coverage than current strategies.[17] [18][31]

1.3 Aim of study

In this thesis, we propose VLC based IPS that uses received signal strength based on visible light communication RSS-VLC that can be used for indoor localization system. RSS triangulation model is simulated and evaluated for estimating the distances between the LED transmitters and a receiver plane, using the property of the signal attenuation in the VLC for LOS and NLOS links by using two scenarios of LED patterns. The evaluation of the proposed work is completed by investigating the impacts of different LED pattern as transmitters on a receiver plane. The accuracy parameters of the localization are done by calculating the best and worse receiver coordinates.

1.3 Thesis outline

- In chapter two, Visible Light Communications was briefly introduced .Next, the channel ,transmitter and receiver characteristics are analyzed. Then the existing indoor visible light positioning methods and common measurement of algorithms were discussed.

- In chapter three, the indoor localization method using received signal strength approach based on VLC was illustrated. A detailed review of the presented technique is provided and then a simulation for the proposed technique by using linear least square method was analyzed in details. Later , the results were discussed.

- Chapter four illustrates the conclusions and the future possibilities of this study.

CHAPTER TWO

LIGHT AND INDOOR POISONING

2.1 Visible Light Communication VLC

Visible Light Communication (VLC) is the umbrella term of all types that are available in the data communication applications, which depend on the optical signals that are limited to visible light.

The visible light frequency spectrum ranges from 430 THz to 770 THz, where wavelength ranges from 390 nm to 700 nm [32]. The most common source of visible light in nature is from the sunlight. Although, the spectrum of sunlight extends beyond the visible wavelength, the greater portion of its power is in the visible region [33].

Fig. 2.1 shows the Electromagnetic (EM) spectrum. The EM spectrum ranges from long waves with very low frequency to gamma rays with high frequency, and therefore covers the wavelengths for long waves ranging from several kilometers down to the length of gamma rays for an atom.

From Fig. 2.1, it can be seen that visible light is a small part of the complete EM spectrum. Another way to view the visible light is the colors it produces. The colors that are generated by the visible light within different and narrow frequency bands are called pure spectral colors. Table 2.1 shows the approximate spectral colors of the visible light.[34]

The utilization of these groups for communications purposes offers remarkable opportunities, which remain particularly unexplored so far.

In comparison to the radio frequency (RF) counterparts, Optical wireless communications OWC [35, 36] enjoys superior features such as ultra-high bandwidth, Different from radio waves radiating in all directions and penetrating through walls, interference between signals, the wavelengths od VLC can provide a huge bandwidth of hundreds of terahertz with unlicensed frequencies. VLC can provides a secure connection since if any third party interrupted the communication between the sender and receiver the connection will disconnect.

In OWC systems, modulation/demodulation is direct as there are no radios or antennas. In this way including more hubs is direct as no interference happens as in RF signals. VLC modules are built-in equipment and small, so it can easily embedded and implement to the structure of lighting.

VLC systems implementation are somehow simple compared with others methods. Instead of modeling a complete wireless communication, it can be reuse the omnipresent lighting framework, and there are a few extra units are included to the lighting systems.

In modern VLC systems, the optical transmitter (Tx) is conducted by light emitting diode (LED) and the optical receiver (Rx) by a PIN photo-detector (PD).

VLC systems take advantage of LEDs, which are turned on and off at a rapid rates with no detectable effects on the lighting yield and for human eye. The numerous use of unmistakable LEDs for enlightenment, information correspondence, and indoor restriction reasons for existing is a potential and vitality effective methodology and can set against how we will utilize lights in the following future.

VLC systems are applied for a lot of applications and communications including wireless access points, and vehicular networks. Not at all like infrared LED and laser including restricted optical power inside a tight shaft, lighting LED is a diffusive light source. Along these lines, it is inherently alright for some application situations with extensive discharged optical power .Since lighting LED does not produce radiation as radio recurrence or microwave gadgets, no conspicuous wellbeing risk is brought about to the earth and to the end clients. Security is an essential issue to RF correspondence since radio waves can infiltrate dividers, causing data leakage.

Since light can't infiltrate obscure items, VLC is restricted to an indoor, encased space with the goal that more secure correspondence connections can be guaranteed. The previously mentioned features help to yield different indoor and open air VLC applications.

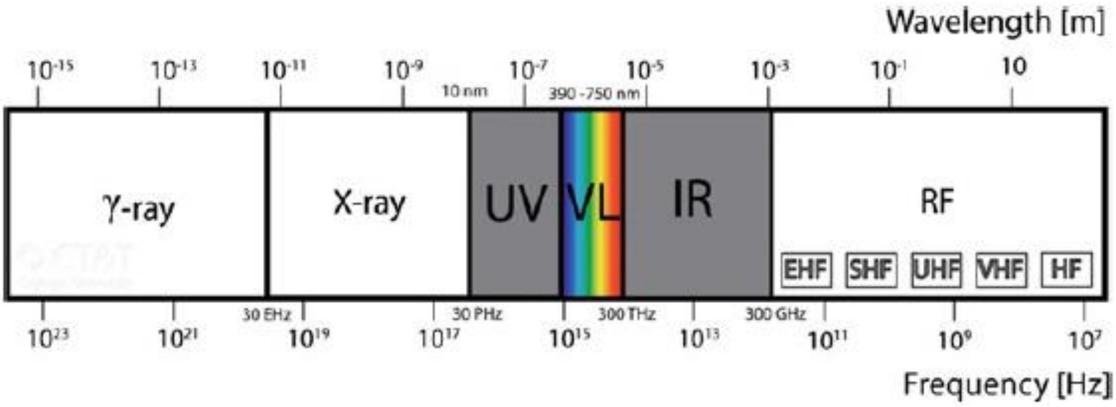


Figure 2.1: Electromagnetic spectrum [34].

Table 2.1: Approximate spectral colors of visible light [34].

Color	Wavelength	Frequency
violet	380–450 nm	668–789 THz
blue	450–495 nm	606–668 THz
green	495–570 nm	526–606 THz
yellow	570–590 nm	508–526 THz
orange	590–620 nm	484–508 THz
red	620–750 nm	400–484 THz

2.2 Optical Source – Light emitting Diode

The VLC system uses LED as a transmitter and photodiode as a receiver where it uses the visible light as a medium LEDs have enormous advantages such as low power consuming, has a high energy density, and reliability.

In the last years LEDs have gained a great development. The efficiency now could reach more than 100 lm/W. The LED is a nature of solid-state lighting source, which generates light via solid-state electroluminescence. LEDs are manufactured to generate light across a huge range of wavelengths. Currently, the light spectrum can modulated and transmitted through LEDs.

Nowadays, the demand for LEDs lights are increased. The LEDs related to VLC where the colors of LEDs are white an use forso it c illumination and communication. Nevertheless, LEDs colors can transmit information through VLC and users in the environment can be lighted and using this information .

Brightness is an essential parameter since it is firmly identified with the transmitted vitality. The higher the brilliance, the more vitality transmitted. To depict the light brightness seen by human eyes, otherworldly radiant proficiency work V (λ) was defined by the International Commission on Illumination, that shows that the human visual framework is more delicate to the light with center wavelengths compared to either short or long wavelengths. The apparent light power is estimated as glowing flux, as shown by [37].

$$\Phi = K_m \int_{380}^{780} V(\lambda)\Phi_e(\lambda)d(\lambda) \qquad (2.1)$$

Where Km is a 683 lm/W and P(λ) is the power spectral distribution. So, the luminous intensity can found as:

$$I = {d\Phi}/{d\Omega} \qquad (2.2)$$

where Ω is the spatial angle.

Since LEDs are particular semiconductor gadgets that radiate ambiguous light when driven by current, the data to be passed on is normally tweaked into the instantaneous optical intensity of the LEDs.

In indoor VLC frameworks, the splendor of LED light ought to be diminished for the convenience of brightening. An illuminance dimension of 300 lux (lumen per square meter) is favored for perusing and composing purposes, though 30 lux is adequate for computer tasks.

Another normal for LED is the LED half point control, the edge at which the optical control lessens to half. In the event that this esteem is too little (under 10/15 degrees), the light would be excessively confined and this would make the accepting excessively restricted; meanwhile if this esteem is too huge (more prominent than 75/80 degree) the light will be excessively widespread and the power gotten will be too little.[38]

2.3 Photodetectors and Photodetection Techniques :

2.3.1 Photodetectors:

A photodetectors are utilized such an optical receiver for transferring the optical signal into the electrical signal by visible light communication. A photodiode produces a photocurrent with amplitude IPD in response to an incident optical power Pr, in an around linear manner especially, when the photodiode is work in photoconductive mode, in another word as reverse bias mode :

$$R = \frac{Ipd}{Pr} \qquad (2.3)$$

The general structure of the photodiode is the equivalent as the LED, the thing that matters is in the inclination extremity. The reason is that the photodiode working depends on the consumption zone: the bigger the exhaustion zone is, the bigger the photograph indicator affectability is. The exhaustion zone measurement is relative to the reverse photodiode voltage bias beginning from V = 0; at V = 0 the consumption zone measurement depends on the manufacture procedure. Moreover, if an excessively bigger inclination is connected the diode goes in to breakdown district and never again fills in as it ought to be.

Photodiodes are utilized in numerous fields of regular day by day life. For example, sun based power panels, radiation locators, cellphone cameras, and so on. For VLC frameworks there are a few features of photodiode that make them especially reasonable, for example, has the an extraordinary ability for time reaction, essential to get and dissect the flag this amount appear to what extent the photodiode utilizes to break down the flag. It is exceptionally monetary and has low estimating where is critical on the grounds that a beneficiary can be made of a few photodiodes. Wide wavelength extend which must reach be at any rate equivalent to unmistakable light wavelength go (450 nm to 850 nm). The Field of vision (FOV) should be greater than 25/35 degrees if it is larger than these value an error it could raise up due to multipath reflections from the objects.[2]

2.3.2 Modulation and Photodetection Schemes:

The aim of photodetection is to recover the information modulated on the transmitted optical signals from the received signals. Usually, the information are modulated on the frequency, phase or the intensity of the transmitted optical signals. Currently, intensity-modulation and direct detection (IM/DD) is widely used in VLC system.

In the IM/DD scheme, only the intensity of the optical signal radiated from an LED is modulated to convey the information. The transmitted information is related to the variation of the intensity of the transmitted optical radiation.

IM/DD is also known as the envelope detection, and therefore the oscillator is not needed in the detection. The IM/DD is a very simple detection scheme and therefore is widely adopted in optical receiver as shown in fig.2.3. The phase cannot be viewed as on the grounds that the transmitted light isn't sound. Consequently, if the identifier is hitting by an approaching optical radiation with Pr normal power one can evaluate the electric photocurrent created by locator through this:

$$I = R\,Pr \qquad (2.4)$$

IM/DD is utilized, we display the optical channel as a straight framework at the dimension of the instantaneous optical power. We indicate the quick optical forces at the transmitter output and photodiode contribution with p(t) and prx(t), where prx(t) as follow in equation:

$$Prx = P(t) * g_{ch}(t) \quad (2.5)$$

$$Y(t) = Prx(t) + n(t) \quad (2.6)$$

The term $g_{ch}(t)$denotes the channel response, n(t) is the AWGN and * is the convolution.

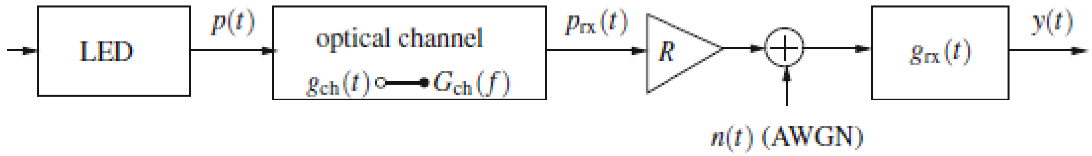


Fig. 2.2 The channel between the LED and the photodiode of VLC system using IM/DD

The instantaneous power from the transmitter can be modulated as a time continuous from LED output and the photodetector input as shown in Fig 2.2. [2][37][38][39][40]

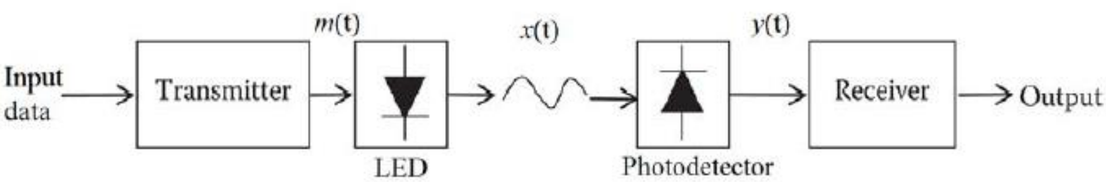


Fig.2.3 Illustrative diagram of VLC system using IM/DD.

2.4 Propagation links

The propagation links can be classified into two categories, line of sight (LOS) link and non-line-of-sight (NLOS) link or sometimes diffuse.

Since the intensity of the LOS way is the essential and the intensity of the reflected ways is much lower, a LOS remote framework more often than not has a higher power effectiveness. At the point when the LOS way is hindered by moving articles or impediment in the way, the framework performance will quickly disintegrated. Along these lines, causing to correspondence interference. While for a NLOS remote framework, the lights diffused by the transmitter are reflected by the surfaces of the roof or dividers inside a room.

Contrasted with the LOS connect situations, multi way spread enhances the heartiness of the NLOS interface based VLC frameworks. Notwithstanding when hindrances exist between the transmitter and the collector, the signs through reflected ways can in any case be detected.

Considering the directional of the transmitter and the beneficiary, the VLC propagation connections could be likewise ordered into three classes: coordinated connection, non-directed connection and half breed link.

For the coordinated connection, the transmitter and the collector straightforwardly point to one another with narrow semiangle and field of view (FOV). Hence, the coordinated connection based framework has a high power efficiency.

While in the non-coordinated connection, both the transmitter and the recipient have wide semiangles for simplicity of use.

Concerning the half breed interface, the transmitter and the beneficiary have diverse directional (narrow semiangle transmitter in blend with wide FOV collector or wide semiangle transmitter in mix with restricted FOV recipient). The orders of these spread connections are appeared in Fig. 2.4.

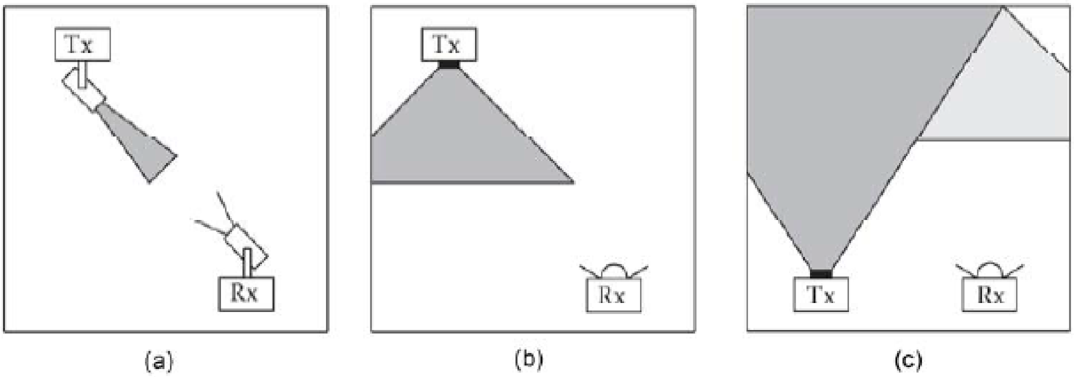


Figure 2.4: VLC configuration: (a) LOS, (b) NLOS, (c) Hybrid . [37], where Tx represents the transmitter and Rx represents the receiver.

In customary radio recurrence interchanges, multi way engendering could cause the variety of the extent of the got electromagnetic flags and between symbol obstruction. Paradoxically, VLC is typically free from multi way blurring on the grounds that the physical discovery zone of the photodiode is a lot bigger than the square wavelength of the light.[41][42]

2.4.1 LOS link:

For indoor directed line of sight (LOS) and nondirected LOS schemes, there exists a directed LOS of VLC path between the LED and the photodiode. The LED is represented light source and photodetector is used to collect signals and converts as photocurrent as shown in figure 2.5. For the light source, assuming that the LED lighting has a Lambertian radiation pattern, the distribution of radiation intensity R(ϕ) is given by [38]

$$R(\phi)\begin{cases}\frac{m+1}{2\pi\, d^2}\ \cos^m(\phi)\ ,\ 0\leq\ \phi\leq \pi/2\\ \\ 0 \qquad\qquad\qquad ,\ \ \phi>\pi/2\end{cases} \tag{2.7}$$

Where *m* is the Lambertian order which is given by :

$$m = -ln\,2 \,/\, ln\,(cos\,\psi_{1/2}) \qquad (2.8)$$

$\psi_{1/2}$, is the half power angle of the transmitter, ϕ is the angle of irradiance with respect to the transmitter axis, and d is the distance between a LED and a receiver. For the receiver, assuming the photodetector has an active area *A*, where the optical signals that emitted from LED reach on the detector surface with angle *Ψ*, area of the detector is can be given as:

$$A(\psi) = \begin{cases} A\cos(\psi) & ,0 \le \psi \le \pi/2 \\ 0 \;, & \psi > \pi/2 \end{cases} \qquad (2.9)$$

To increase the effective area that collect the signals, concentrator is used in the receiver. The gain of the concentrator *g*(*Ψ*) is given by [43]

$$g(\psi) = \begin{cases} \frac{n^2}{sin^2(\Psi_c)} & ,0 \le \psi \le \Psi_c \\ 0 \;, & 0 \ge \Psi_c \end{cases} \qquad (2.10)$$

Where n denotes the refractive index and ΨC denotes the width of the field of vision at a receiver.

Then the channel DC gain of the LOS optical link from the LED to the photodetector can be model as [43][44]

$$H(0)\begin{cases}\frac{(m+1)A}{2\pi\,Dd^2}\ \cos^m(\phi)\ \ T_s(\psi)g(\psi)\cos(\psi)\,, & 0\le\ \psi\le\Psi_c\\ \\ 0 & ,\quad \psi>\Psi_c\end{cases}\qquad(2.11)$$

where *A* is the physical area of the detector in a PD, *Dd* is the distance between a transmitter and a receiver, ψ is the angle of incidence, ϕ is the angle of irradiance, *Ts(*ψ*)* is the gain of an optical filter, and *g(*ψ*)* is the gain of an optical concentrator. Ψ*C* denotes the width of the field of vision at a receiver.

The average received optical power *Pr* that photodetector collects is given by:

$$\mathrm{Pr} = H(0)Pt \qquad (2.12)$$

2.4.2 NLOS link :

For indoor NLOS and diffuse schemes, a nondirected path of the optical channel among the LED and the optical receiver. The optical channel is affected by factors, room dimension, arrangement of walls and the furniture, the walls or ceilling reflectivity. Therefore, from hard to specify the kind of channel, that effect on VLC links between the transmitter and the receiver. Here, we consider reflections from the walls, which is a relatively simple case. For the receiver, the average received optical power is given by:

$$Pr = \sum^{LEDs}\{P_t\ H_d(0) + \int_{walls} P_t\ dH_{ref}(0)\ \} \qquad (2.13)$$

Where *Hd*(0) is the channel DC gain of directed path, and *Href*(0) represents reflected paths.

The first reflected signal from the reflection surfaces has the big effect on the direct path of the optical signal, the channel DC gain of the NLOS signal is given by:[43][44]

$$dH(0)\begin{cases}\frac{(m+1)A}{2\,\pi^2\ D_1^2\,D_2^2}\ \rho\ dA_{wall}\cos^m(\phi r)\ \ T_s(\psi)g(\psi)\cos(\alpha)\ \cos(\beta)\cos(\psi r)\,, & 0\le\ \psi\le\Psi_c\\ 0 & ,\quad \psi>\Psi_c\end{cases}\qquad(2.14)$$

Where *D1* is the distance between transmitter and the reflective surface, *D2* is the distance between the reflection surface and the photodetector. ρ is the reflectance factor, *dAwall* is a reflective surface, ϕ is angle of irradiance to a reflective surface , α is the angle of irradiance to a reflective surface, β is the angle of irradiance to the photo detector, and ψ is angle of incidence as shown in Fig 2.5.

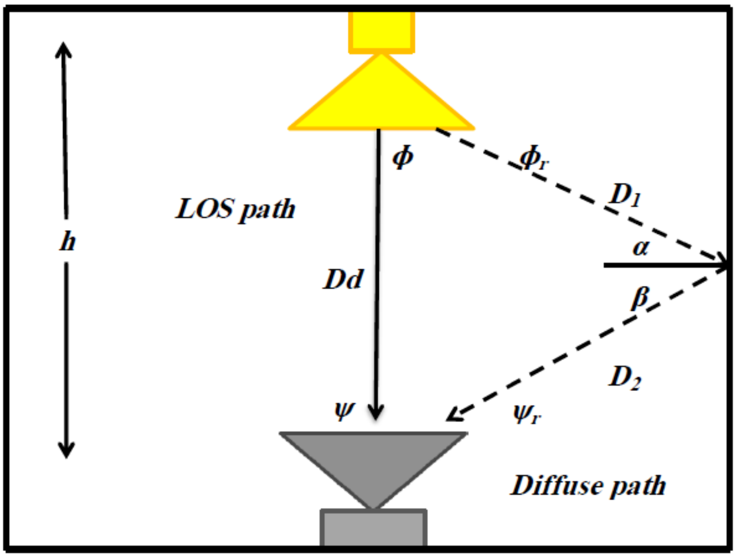


Fig. 2.5. VLC paths between the LED and Photodetecor.

2.5 Noise

If a message needs to be send through a medium, one thing should take into account that the messages that reaches to the receiver side suffer from variations. Generally, the variations could effect in the communication and it could cause a bad connection between the transmitter and receiver.

These components and varieties that happen in transmission medium are examined and demonstrated in the clamor hypothesis. In general each sort of clamor pursues a stochastic law and commonly this can be similar to as a distribution.

The background noise happens because of the vibe factor, for example, the sun or the sky luminosity. This commotion, as a rule, relies upon the force of the external source. The intensity depends generally on wavelength spectrum.

Thermal noise happens due to the thermal agitation and it can be considered white Gaussian noise. In electrical devices, the current that produced from particles of electrons, the temperature effects on the movement of those electrons. [45][46]

2.6 Indoor Localization Based on Visible Light Communication

Positioning or localization is the process of getting the most accurate location of a target. The expanding computational limit of mobile devices such as cell phones and tablets has formed an opportunity for indoor positioning techniques.

If we enter a shopping mall and we do not know where the shop we will be heading to is, we can easily benefit from the same technology we will see the lighting fixtures. The advances in VLC make it one of the best candidates for finding the key to location-based problems.

The installation cost of VLC is lower than Wi-Fi or RF-ID methods. The target market for visible light positioning (VLP) consists of areas where a large number of people and items are available. The purpose of VLP is to attain the accurate location of the target, just like a Global Positioning System (GPS). Large warehouses, museums, shopping malls, hospitals and conference halls normally they are areas where people need to position them self the most in it.

GPS is the best solution for outdoor positioning so far, but the radio waves of GPS are subject to multipath effects because radio waves reflect from humans or other kind of obstacles.

The precise of GPS is also another concern, for an indoor area an inaccuracy of a couple of meters is big. However, indoor VLP signals do not suffer from power loss, unless there is an obstacle blocking the in their ways.

Bandwidth is also another problem for communication purposes. Visible light users do not compete for bandwidth like in Wi-Fi. The light waves cannot penetrate through solid materials generally, which makes VLC a reliable and safe network medium. Therefore, there will be no interference with neighboring rooms. Since there is no interference and there are less multipath effects, VLP systems give more precise results than those of other techniques.[47][48]

2.6.1 Triangulation

This technique utilizes the geometric of triangles to find the target position. Triangulation can devise into two categories, lateration and angulation.

Lateration is a method to find the location of target by estimating the distance from multiple points. In all the VLC based situating frameworks proposed up until this point, the reference focuses are light sources (transmitters) and optical recipient is pre-situated with the objective.

Angulation, measures the angle between several points. Then the position is found by finding the intersection of the lines.[49][54]

A. TOA

Time of Arrival (TOA) localization method is a method that involves calculation of the duration of time required to move to the receiver from the source. The visible light signal travels from the source and to the receiver. Therefore, it must be ensured that the receiver and the source are accurately synchronized to provide that the information entailing the Time of Arrival is accurately measured. The separation between the target and base station is computed as guaranteed by time, which the flag uses to be in contact at the base station. At the point when the distance between a device and three references are predefined, the area of the target are accomplished. Assume that the engendering time between the portable device and the ith base station is ti, and the spread speed is v. Then the distances si between the target and base station are found as $v * ti$. It is supposed that the coordinates of the target and base station are ($X0$, $Y0$) and (Xi, Yi) respectively. as shown in the equation[49][50]:

$$\sqrt{(x_i - x_o)^2 + (y_i - y_o)^2} = s_i, \quad \text{i=1,2..3} \qquad (2.15)$$

where i is refers to base stations. Then it can draw three circles with radius the distance si. Ideally, the intersections of these three circles are the receiver in as shown in Figure 2.6.

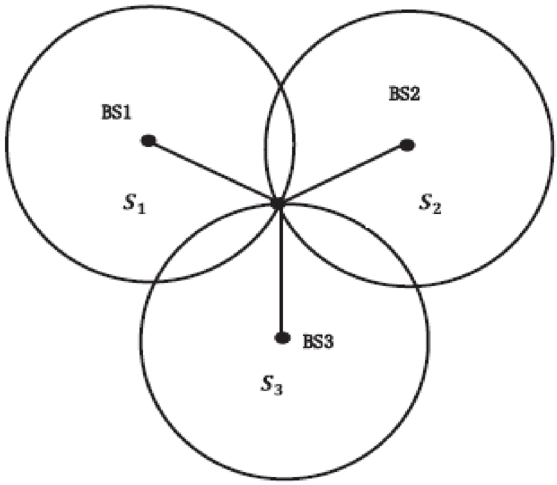


Fig. 2.6. Positioning based on TOA.

This technique depend on the devices for computing the distance especially, the time must be perfectly synchronize thus led to more costly.

B. TDOA

Time Difference of Arrival is another scheme used for indoor localization while using in VLC. TDOA technique analyses the differences in time during which the visible light indicator lands at the various computing entities. The source must be located on a hyperboloid for every TDOA dimension having a constant array variance in amid the two calculating units.

The measurements are then obtained using many duos of allusion points with known settings. The advantage of using this indoor localization method in VLC is the fact that it does not require a coordinated time source.

TDOA strategy estimates the engendering time distinction between the portable device and base stations, at that point changes over it into the separation by duplicating the speed of proliferation. At that point we can accomplish the situation of the portable customer utilizing the hyperbolic situating strategy. As Figure 2.7 shows, the separations contrast between the base station BS1 and BS2. It must be guaranteed that the cell phone must lie in the hyperbola whose centers are the two base stations and the central length is the distance distinction s12(the strong line in

Figure 2.7). In the meantime, another hyperbola can be drawn whose centers are the BS1 and BS3, and the central length is their distance distinction s13 (the specked line in Figure 2.7). At that point, the crossing point of the two hyperbolas is the situation of the portable customer. It is supposed that the coordinates of the target and the base station are (*x0, y0*) and (*x1, y1*) respectively. Then, we use the equation as shown[51].

$$s1i = \left\{\sqrt{(x1 - xo)^2 + (y1 - yo)^2} - \sqrt{(xi - xo)^2 + (yi - yo)^2}\right\}, \text{ i = 2,3} \quad (2.16)$$

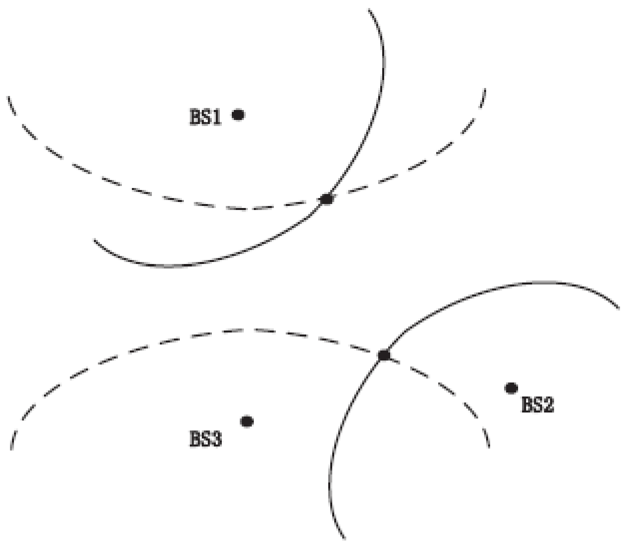


Fig. 2.7. Positioning based on TDOA.

Equation 2.16 demonstrates two solutions with respect to the two intersections of the hyperbola. The difference between TOA and TDOA is the later less effected with surrounding objects so that it is give a great positioning accuracy.[17]

C. AOA

The Angle of Arrival technique is a method that involves scheming of the slant at which the visible light indicator reaches the receiver from the source. Fundamentally, this expanse is a line that comprises of an edge with the receiver. AOA carries out the location process to the angle of incident between the transmitter and the receiver. It needs at least two transmitted beacons. By using the properties of geometric the intersected angels of two or more line intersections are the location of the target, as shown in Figure 2.8.

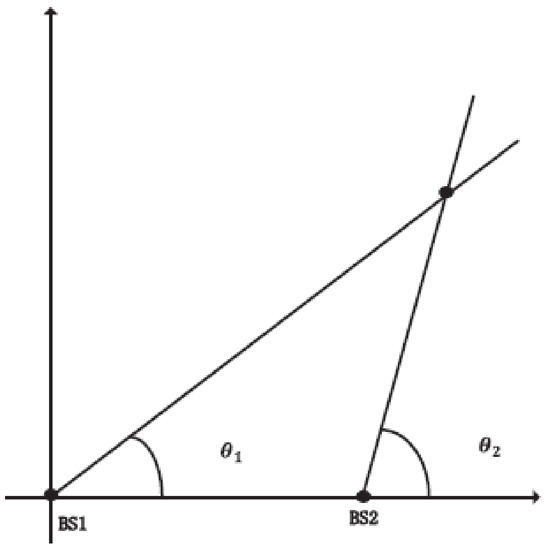


Fig. 2.8. AOA for positioning.

Supposing the angles between the lines of the transmitted signals and the target, namely BS1 and BS2, are denoted by $\theta 1$ and $\theta 2$ respectively. The position of the target is (*x0*, *y0*), and the location of the transmitted signals is (*xi*, *yi*). As shown in the equation:

$$tan\,\theta i = (yi - y0) / (xi - x0), i = 1,2 \qquad (2.17)$$

AOA is to a great degree helpless against the outside condition, and its situating exactness is lower than TOA. Something else, the situating precision of AOA will diminish when the physical separation between the cell phone and base station increments. Meanwhile, AOA needs the additional hardware which grows the expense. AOA isn't sensitive to the power and arrangement uneven characters of the signal framework. Likewise there are three factors that can impact on the exactness of AOA-based situating, which are deliberate mistakes, rakish accuracy, and geometry on position uncertainty.[49][51]

D. RSS

The The received signal strength (RSS) methods that can compute the distance of the target receiver from some LEDs through measuring the attenuation of strength of optical signals emitted by LEDs, as shown in Figure 2.5.

RSS methods calculate the signal path loss through the propagation. Theoretical and empirical models are used to translate the difference between the transmitted signal strength and the received signal strength into a range estimate as in equation 2.7. RSS methods overcome the obvious limits of TOA and TDOA methods. However, it is needed to establish the accurate channel model and parameters to measure the path loss of the transmitted signal. In addition, as the indoor environment changes, the channel model and parameters may also change. In general, compared to TOA and TDOA methods, the RSS methods are widely used for VLC based indoor localization.[52]

2.6.2 Indoor Localization techniques conclusion

The indoor localization method using VLC is a method that has become one of the world's most preferred indoor localization techniques. It has some advantages as compared to other localization methods such as RF.

It can be installed cheaply as it utilizes illuminating systems with very few adjustments being applied. In addition to that, we can use the visible light in many of places where the other techniques for localization forbidden to use. Finally, the VLC positioning technique is quite motivating shortly due to the increasing number of lighting systems and the Lighting Emitting Diodes devices.

CHAPTER THREE

INDOOR LOCALIZATION BASED ON VLC

Indoor position based on visible light technique is a novel localization technology with a highly positioning performance. In this chapter, we first illustrate and analyze an RSS-VLC localization system based on the propagation links of visible light in term of LOS and NLOS triangulation model. The proposed system is simulated and estimated using two types of scenarios to estimate the distance from multiple LED patterns. Then we investigated the lights illumination of each scenario including the diffuse reflection of visible light. Furthermore, the distance is estimated by using the output electrical power of the photodetector to measure the distance between the LED and the receiver plane. Next we investigate the process of effects of different LEDs pattern as transmitters and receiver plane and determining the best and worst coordinates of the localization accuracy on the receiver plane.

In the last section, we explore the Linear least square LLS analysis for RSS-based localization using VLC, where the LLS relates the localization error to the measurement error, which is an important and effective factor to evaluate the localization accuracy in RSS localization. Furthermore, we illustrated the relationship between power intensity to the distance that affect on positioning accuracy for RSS-based indoor localization using VLC, then analyze two localization scenarios with different of LED grid patterns, quantize the impact of LED grid patterns on the position error of the mobile receiver, and present the simulation results.

3.1 RSS based positioning:

In the proposed system, the trilateration method of the RSS is used, and the trilateration needs at least three transmitted signals are required to compute the receiver position [53]. RSS technique has been widely used for indoor positioning systems and visible light systems due to its enormous advantage.

The RSS exploit the characteristics of the transmitted light, where the intensities of the RSS are easy to measure by using a single photodetector. Thus, no extra devices and hardware required. Typically, the gotten flag power pursues the channel show, which implies that the force of the transmitted flag is diminished as the separation between transmitter and collector increments. In light of this model, numerous calculations and procedures can be connected for LED positioning frameworks, for example trilateration and fingerprinting, there are many publication papers that verifying and investigated for these methods.

In this part, a system used three LEDs as transmitters is introduced for illustration of the trilateration method. As soon as the receiver or photodetector detect the power of the transmitted signals, each separation from the comparing transmitter is ascertained and hovers with the radii of figured separations can be drawn. The area of the beneficiary would then be able to be determined by ascertaining the crossing point purpose of these circles, as shown in Figure 3.1.[54]

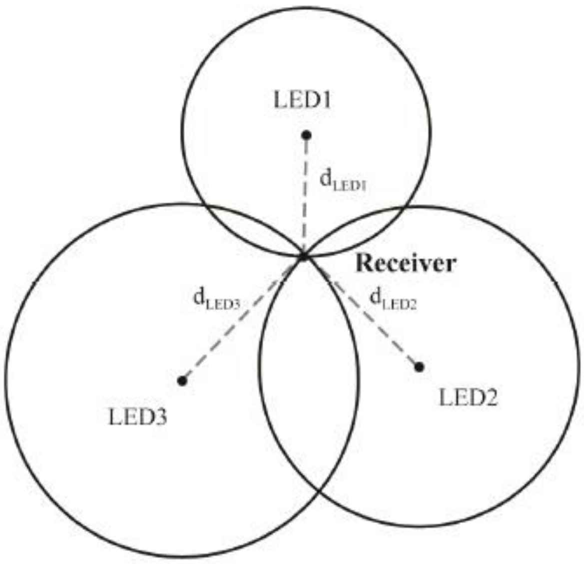


Fig.3.1 Trilateration

In the proposed system, the RSS data of gotten signal is utilized to appraise the collector's separations from transmitters on the roof room, after which the beneficiary will be situated by triangulation strategy. In optical wireless communication systems, the most feasible method of communication is Intensity Modulation with Direct Detection (IM/DD) for optical carrier. Intensity modulation (direct modulation) is performed by varying the drive current of a light emitting diode (LED) or laser diode (LD). At the receiver, direct detection is completed by using photodiodes to generate an electric current proportional to the incident optical power.

The common modulation schemes used for IM/DD are On Off Keying (OOK) in IM, the intensity or power of the emitted radiation is varied. Variations in intensity level are depending on the received digital data and modulation that used in channels. Where binary 1 and 0 are transmitted by switching an LED ON and OFF respectively in a very high frequency. The intensity of the light emitted from the LEDs can be changed by varying either the voltage across it or current through it. Thus, the LED lights are transmitting its own data that modulated by using On Off Keying (OOK) modulation.

The intensity modulation and direct detection (IM/DD) technique is used in this research to design an indoor positioning system by using VLC. The IM/DD strategy is generally applied in VLC because of lower complexity of implementation, where no special tools required and low cost receiver of the photo diode. Variety in the power of LED light that emitted is transfer to current variation by using the photodetector. Instead, the DD strategy is utilized, where intensity variations are detected by a photo sensitive device (PDs). Thus, the modulated signal is demodulate at a receiver.[2][37][40]

3.2 Background

RSS systems are the most well-known and are described by simplicity and low cost due to a large portion of the current devices that are available have the ability to measure the RSS values [47]. The RSS method needs an awareness of the optical channel for VLC properties, and the intensity of the transmitted optical power to obtain the target location.

Moreover, the received signal strength (RSS) is commonly used to get the location coordinates of different targets. A system with RSS method utilized for indoor positioning has been illustrated in [29], the simulation was applied in a room and average accuray error of 2.4 cm was achieved. In [55], the RSS based localizing algorithm combined with a maximum likelihood estimator has been implemented to enhance the performance of a positioning system. But, only a line-of-sight (LOS) channel was considered. However, in practical scenarios, the diffuse reflection has effect on the distribution of a visible light signal [56],[57] and causes retrogression of the performance of an indoor positioning system based on RSS algorithm. The author in [3], a system investigated the impact of the reflected light due to walls on the positioning errors of a VLC positioning system where the author used RSS, the distance between the receiver to the LED is by using the equation of the power for the received signal. The simulation is done by a room its dimension 5x5x3.5 the results of the root mean square error was 4 cm when the effect of NLOS not considered , while an error found of 80 cm when the reflected signals are into account. In [59], the OFDM method was joint with RSS for location technique, and the accuracy of positioning error of the entire scenario was decreased around 4 times. As already mentioned, majority of the published investigations showed that LOS path used for simple analysis and implementation. But, in reality, there are lights reflected by different walls and objects which are called non line of sight (NLOS) that exist between the transmitter and receiver surface [60][56].

This is due to the performance of a VLC system drastically appears with the encompassing condition [56]. This conduct has an extraordinary effect on RSS system due to the range estimation is straightforwardly identified with the received signal. So, neglecting the NLOS will cause large positioning errors, and the accuracy is extremely lessened. A couple of studies have examined RSS by using VLC positioning systems with diffuse link. In [61], the author used a method called Cramer Rao bound the accuracy is estimated restriction to the RSS technique. The author utilized the circle show amid examination and assumed that the channel gain was level under a recurrence of 10 MHz. They inferred that the effects of multi way reflections on the CRB could be deserted when the balance speed was littler than the channel cutoff recurrence.

3.3 Proposed Model

3.3.1 Fundamentals of LED light

LEDs have two basic properties, first one is luminous intensity which is luminance flux per solid angle, it expresses the directionality of the energy radiated and brightness of luminaires.

Second property is the transmitted power, which refers to the total energy that emitted from a luminaire. The luminous intensity is given as:

$$I = {}^{d\Phi}/_{d\Omega} \qquad (3.1)$$

Where Ω is the spatial angle, and Φ is the luminous flux, which can be given from the energy flux Φ_e as:

$$\Phi = K_m \int_{380}^{780} V(\lambda)\Phi_e(\lambda)d(\lambda) \qquad (3.2)$$

Where V(λ) is the standard luminosity curve, K_m is the maximum visibility, and the maximum visibility is about 683 lm/W at λ = 555 nm.[40][2]

3.3.2 Illuminance of LED light

The distribution of illuminance at a desk level surface will be discussed. The illuminance tells that the radiation power that falls on to an area. Assuming that, LEDs blub has a lambertian radiation pattern, then the luminous intensity as a function in ϕ is given by [26][62] :

$$I(\phi) = I(0)\cos^m(\phi) \qquad (3.3)$$

Where, I(0) is the center luminance intensity, ϕ Angle of irradiance with respect to the axis normal to the transmission surface, *m* is the order of Lambertian emission and is given by the semi-angle at half illuminance of an LED $\psi_{1/2}$ as :

$$m = -ln\, 2 \,/\, ln\, (cos\, \psi_{1/2}) \quad (3.4)$$

Relating to transmitter semiangle $\psi_{1/2}$. In practice, semiangle at half power can be adjusted using some optics, therefore m varies with divergence angle of lambertian beam, where semiangle is an important parameter in VLC since it determines the transmitter coverage area, where increasing *m* increasing the directionality.

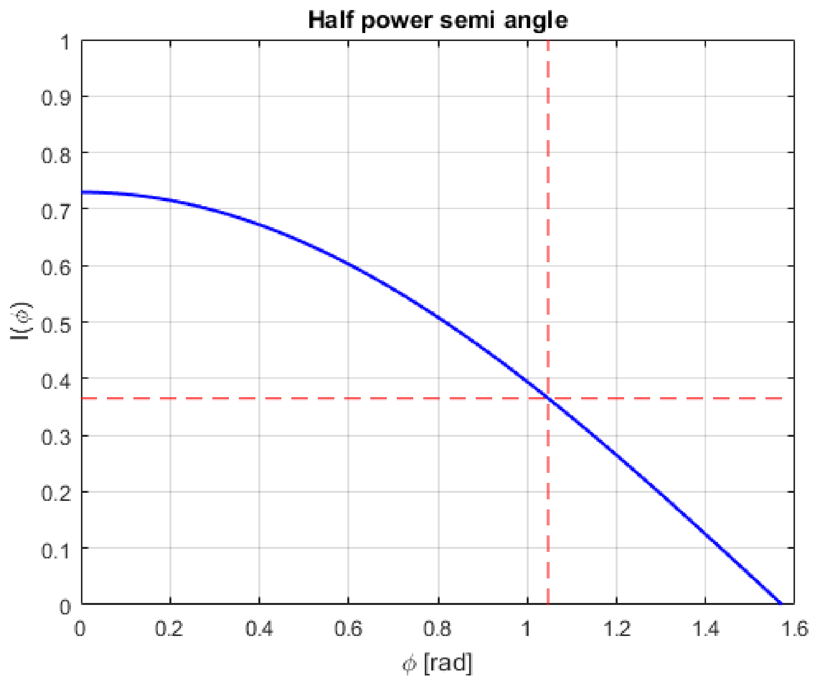


Fig.3.2 Semi-angle at half power at 60 drgree

Fig3.2 shows the power of transmission at different angle, where X axis angle in radius, and Y axis the angular current density.

A horizontal illuminance Ihor at a point (x, y) on receiver's plan is given by:

$$I_{hor} = I(0)\frac{\cos^m(\phi)}{Dd^2}\cos(\psi) \qquad (3.5)$$

$$I_{hor} = \frac{I(\phi)}{Dd^2}\cos(\psi) \qquad (3.6)$$

Where ϕ is the angle of irradiance, ψ is the angle of incidence, and Dd is the distance between an LED and a detector’s surface.

We have examined the illumination distribution through the entire room for two scenarios first one scenario 1 LEDs at corner of the room, and the other one scenario 2 LEDs at center of the room.

The simulation parameters are shown in Table 3.1. Figure 3.3 shows the horizontal illuminance distribution results at receiver side.

According to the ISO standard [40], it can be said that both scenarios are sufficiently illuminated across all positions of the entire room as the analysis shows illuminance for the LED lights when at corner (scenario 1) of 160 to 187 lux. And for the second scenario LED lights at center (scenario 2) of the room shows of 161 to 360 lux. Which are sufficient for both lighting and communication.

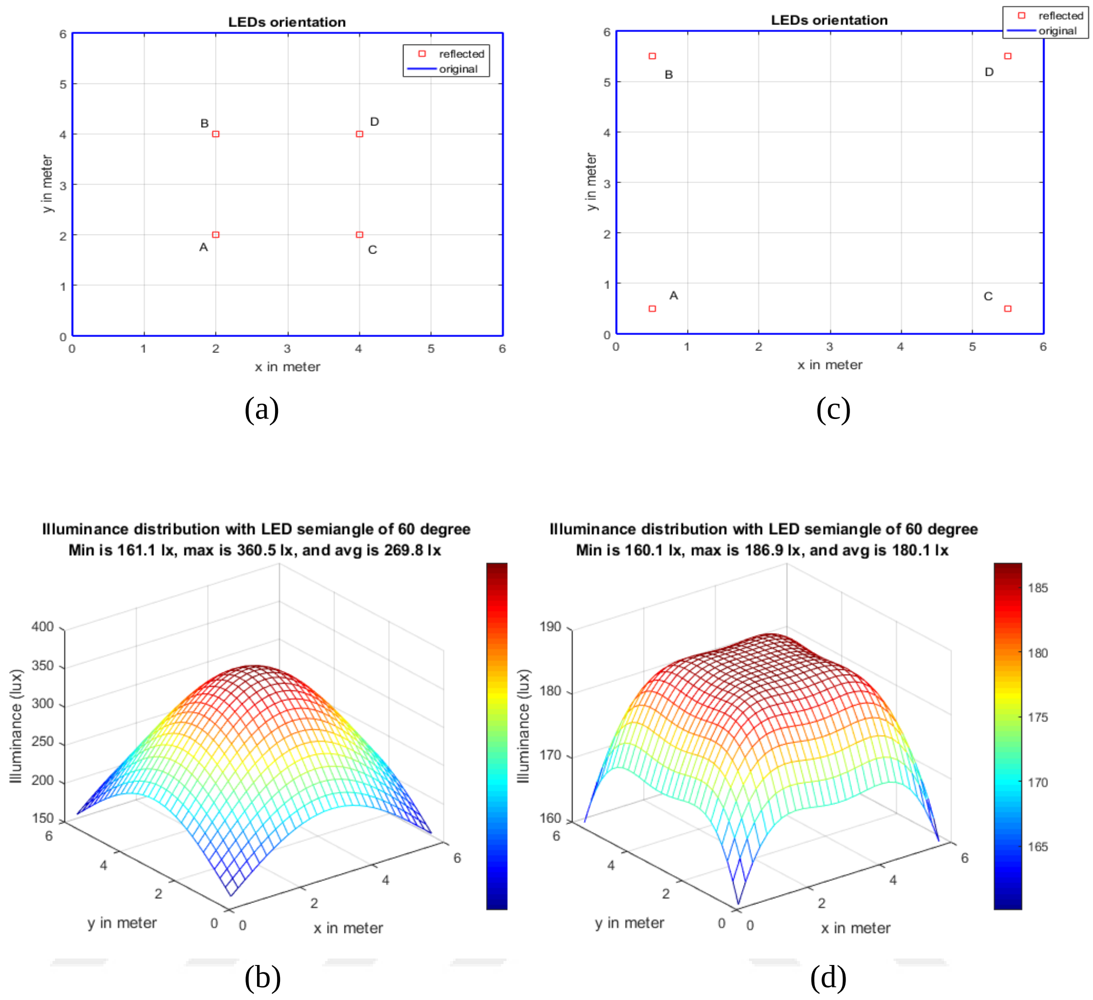


Figure 3.3 shows the LED patterns of the room for (a) scenario 2 (c) scenario 1 and horizontal illuminance distribution results at receiver side for (b) scenario 2 (d) scenario 1.

3.3.3 Distance estimation :

Let the normal axis of LED transmitter and the receiver Rx be a parallel, so the total received power could be written as shown in Fig.2.5.

$$Pr = \sum^{LEDs}\{P_t\, H_d(0) + \int_{walls} P_t\, dH_{ref}(0)\,\} \qquad (3.7)$$

We can easily calculate the rx power from all 4 LEDs including the diffuse paths. By defining R as the receiver responsivity, so that the output of electrical power from photodetector can be obtained by :

$$P_{ele} = (R\, Pr)^2 \quad (3.8)$$

The output electrical power from the photodetector is written as:

$$P_{ele} = \frac{(R\, P_t\, (m+1) A\, T_s(\psi) g(\psi)\, h^{m+1})^2}{4\pi^2\, Dd^{2m+6}} \quad (3.9)$$

The distance between LED and photodiode can be obtained

$$Dd_{est} = \sqrt[2m+6]{\frac{(R\, P_t\, (m+1) A\, T_s(\psi) g(\psi)\, h^{m+1})^2}{4\pi^2\, P_{ele}}} \quad (3.10)$$

Where *h* is the distance between the transmitter and photodetector. Where the total received power *Pelec* normally, come from diffuse path and direct links. Thus, an error turn up in the calculation of *Ddest* when taking into account only the direct path of VLC. Therefore, the total received power for both links can be obtained analytically.

It ought to be seen that just the first reflection from the four dividers is viewed as in this research.

Moreover, the noise power N at the receivers is considered as the Gaussian noises which are caused by photodiode. These factors are closely related to the environment, also have a role to effect on the total power [63] [61]

$$N = \sigma^2_{thermal} + \sigma^2_{shot} \quad (3.11)$$

Where $\sigma^2_{thermal}$ is the thermal noise variance, and σ^2_{shot} is the shot noise variance. Therefore, because of the fluctuations in Pelec (photon fluctuations).

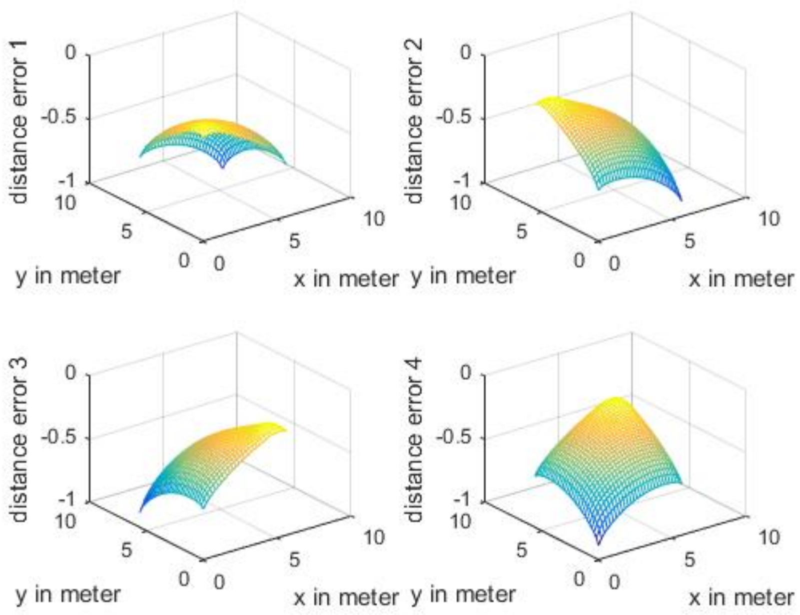
Hence, the ideal photo detector is effected by the quantum nature of light so the noise is generated from this take the name photon fluctuations, where the photon fluctuations noise is a noise that available in all detectors.

To evaluate the VLC performance, the positioning accuracy is utilized which is usually represented by Positioning Error (PE).

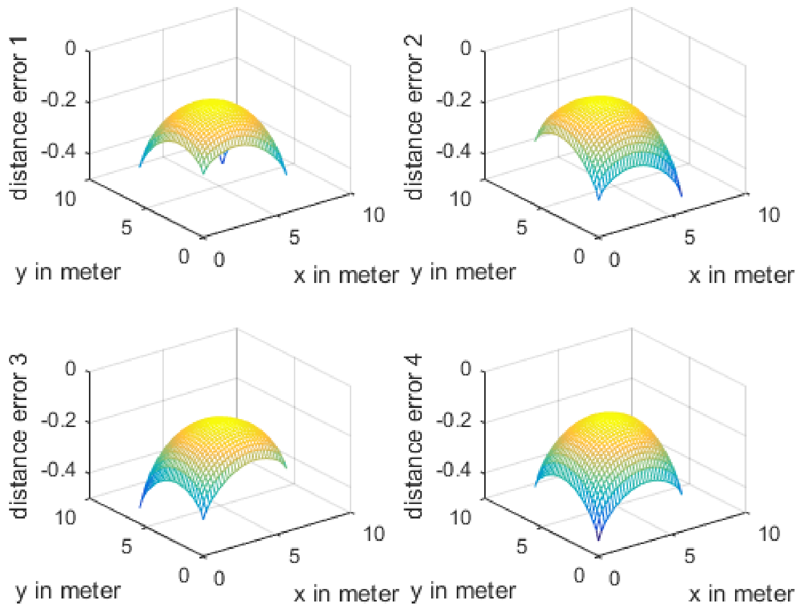
So we get dest instead of Dd where dest is the evaluated direct separation between the transmitter and recipient producing into accounts the results of commotion and the NLOS part of the channel.

So we try in this research to get dest close to Dd by limiting the impacts of commotion and NLOS control. So the distance error is the error between the real distance and the estimated one. That can also be negative when the estimated distance is smaller than the actual distance Fig. 3.4 shows the distance error for the proposed model when there are reflections at each point of the room.[1][63]

$$D_{error} = D_{est} - D_d \tag{3.12}$$



(a)



(b)

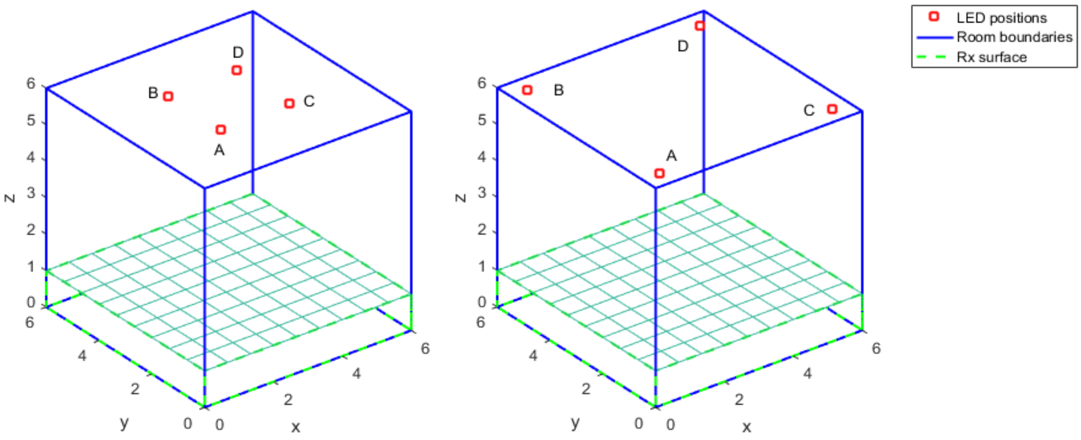
Fig. 3.4 Distance error from each led when there is reflections at each point of the room for (a) at corner (scenario 1) and (b) at center (scenario 2).

3.4 Geometry and simulation :

We consider two patterns of indoor localization scenarios using VLC. In scenario 1, the room dimension $L \times W \times H$ is 6×6×6 m^3, empty room, , and four LED lights are located at the four corners of the ceiling respectively, they work together as access points at height of 6 m, as shown in Fig.3.5. The position of four LED lamps in scenario 1 are denoted by A(0.5,0.5,6), B(0.5,5.5,6), C(5.5,0.5,6),and D(5.5,5.5,6).

In scenario 2, the room dimension $L \times W \times H$ is still 6×6×6 m^3, also empty room, and four LED lamps are located in the central area of the ceiling, as shown in Fig.3.5. The positions of four LED lamps in scenario 2 are denoted by A(2, 2, 6), B(2, 4, 6), C(4, 2, 6), and D(4, 4, 6).

The walls are made from plaster with 0.1 reflectivity where multiple reflections occur between them. The simulation parameters for LED and photo detector (PD) are provided in Table 3.1.



(a) (b)

Fig.3.5 LED lights pattern at(a) center (b) at corner

TABLE 3.1. Simulation parameters of the VLC system.

Parameters	**value**
Room dimensions	6×6×6 m^3
Table height	1 m
Semi angle at half power $\psi_{1/2}$	60^o
Number of LEDs	3600 (60×60)
LED transmitted power	1 W
Lambertian mode (m)	1
Reflection coefficient	0.1
Photodetector area	1 cm^2
Modulation bandwidth (W_B)	640 KHz
Modulation depth (ηook)	12.5 %
Field of view Ψ_c	70^o
Receiver responsivity	0.4 A/lux
Concentrator gain	1
Center luminous intensity	0.73 cd
Filter gain	1

3.5 The total received power :

The total received power at each point of Rx position should be taken in account not only direct path is consider , but also the power of reflected light by walls are considered .The relations between optical received power (Pr) and optical transmitted power (Pt) could be expressed as:

$$Pr = \sum^{LEDs}\{P_t\, H_d(0) + \int_{walls} P_t\, dH_{ref}(0)\} \qquad (3.7)$$

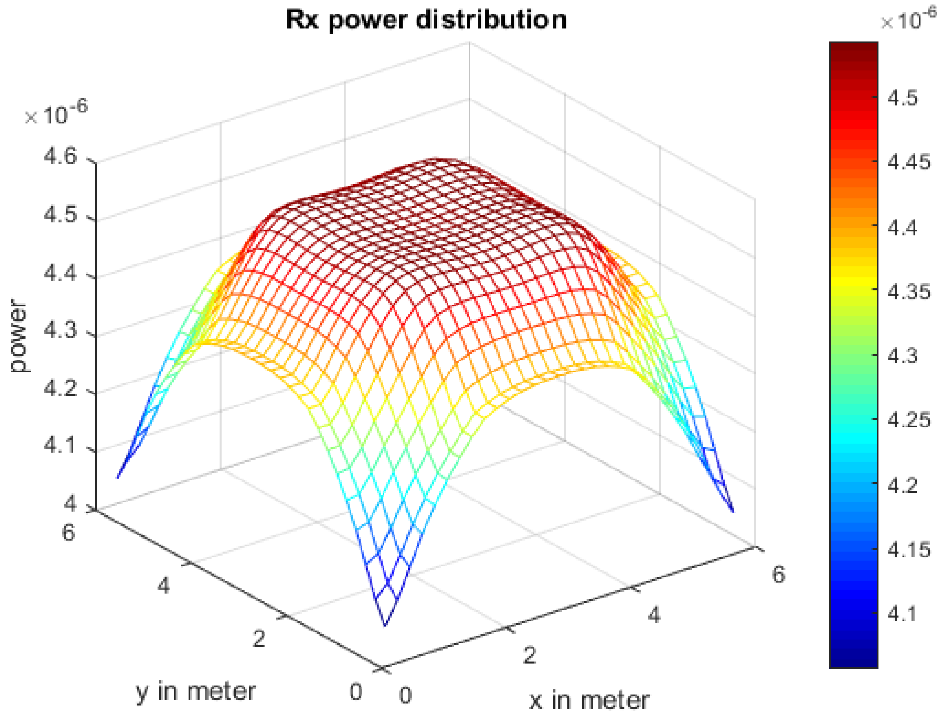


Figure 3.6.a :the distribution of the total received power of light when LED lights in the corner.

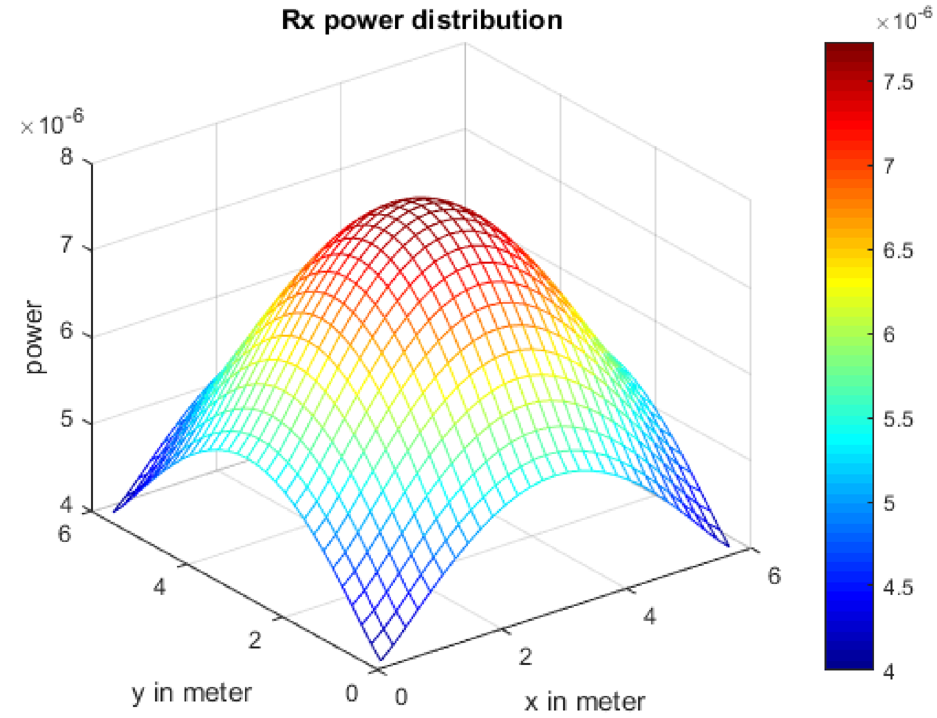


Figure 3.6.b :the distribution of the total received power of light when LED lights in the center.

Figure 3.6 shows the distribution of the total received power of light from LED lights for both scenarios.

From this figure, the received power when LEDs pattern at corner is 4.06×10^{-6} to 4.55×10^{-6} W in all the entire room. Meanwhile, the received power when LEDs pattern at the center is 4×10^{-6} to 7.72×10^{-6} W in all entire the room.

The presented simulation room's dimension is 6 m^3, so the distance between the LED transmitter and Photo detector receiver roles a function with the receiver power, where the closer to the transmitter the higher intensity of light that received by photo diode also the NLOS and reflectivity of walls might effected.

We consider that there is a reflection from only LED to each wall from the four walls, but numerically result, we taken into account the effect of each LED in computing the received power therefore we included the both gains of LOS and NLOS.

3.6 Received signal strength NLOS:

Since RSS information is applied to estimate the distance, power intensity distribution might affect on positioning accuracy.

The received power is inversely proportional to the distance, which is in correspondence with the power attenuation shown in Eq. (3.7). However, the power intensity is high at the edge and corner area near the transmitter side for the first reflections as shown in Fig.3.7.

The reflected powers, the intensity is slightly higher in corner and edges area for scenario 1 when LED lights at corner, while the intensity of the reflected powers distribution becomes more uniform for the scenario 2 when LED lights at center.

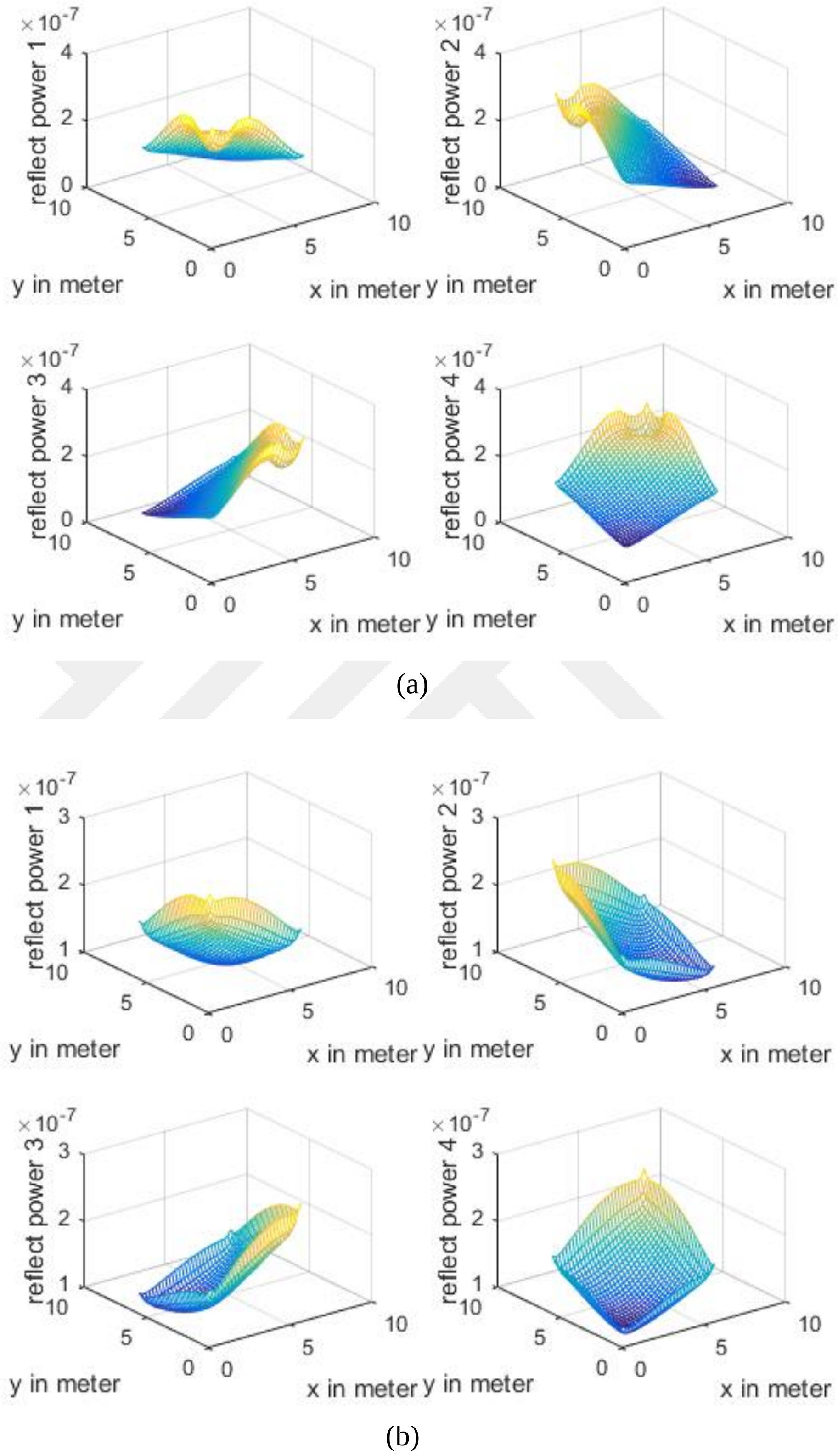


Fig. 3.7. Reflected power from each LED at each point of the room for (a) at corner (scenario 1) and (b) at center (scenario 2).

3.7 Linear Least Square Approach

To find the target location by estimating the distances from Rx and at least three Txs by using the trilateration process as shown:

$$(X_R - X_1)^2 + (Y_R - Y_1)^2 + (Z_R - Z_1)^2 = Dest_1^2$$
$$(X_R - X_2)^2 + (Y_R - Y_2)^2 + (Z_R - Z_2)^2 = Dest_2^2 \qquad (3.13)$$
$$(X_R - X_3)^2 + (Y_R - Y_3)^2 + (Z_R - Z_3)^2 = Dest_3^2$$

Let (xi, yi, zi) be the coordinates of the ith LED luminaire,(xR, yR, zR) are the locations of the target positions, and desti are the measured distance between the receiver and the transmitter LED. Since all the transmitters are placed at the certain height so that ($Z_1 = Z_2 = Z_3$).

By solving the above equations and subtract from each other and simplify them into three matrix as shown in the form equation.

$$A\ X = B \qquad (3.14)$$

Where X matrix is the coordinate of the target that want to estimate its position , B matrix represent the observations data that taken from transmitters, A matrix acts as characteristics of the LED observations such that i-th row of A characterizes i-th sensor.

$$A = \begin{bmatrix} X_2 - X_1 & Y_2 - Y_1 \\ X_3 - X_1 & Y_3 - Y_1 \end{bmatrix} \qquad (3.15)$$

$$X = \begin{bmatrix} X_R \\ Y_R \end{bmatrix} \qquad (3.16)$$

$$B = 1/2 \begin{bmatrix} D_{est1}^2 - D_{est2}^2 + X_2^2 + Y_2^2 - X_1^2 - Y_1^2 \\ D_{est1}^2 - D_{est3}^2 + X_3^2 + Y_3^2 - X_1^2 - Y_1^2 \end{bmatrix} \qquad (3.17)$$

This is the basic form can solved by:

$$X = (\,A^T\ \ A)^{-1}\,A^T B \tag{3.18}$$

For estimating the target position, the distance found from Txs , LLS can be employed to define X that minimize r :

$$r = \|A\,X - B\| \tag{3.19}$$

Where r is the residual.

LLS is eligible to provide a good solution due to its ability to convert nonlinear equations into linear, and since we had small number of LEDs so LLS will provide more reliable estimation.[64]

3.8 Positioning Accuracy Analysis:

We evaluate the LLS algorithm to the proposed system in terms of localization accuracy on a receiver surface and compare two scenarios of LEDs light room. First, tables shows the statistical about the maximum and minimum of the received power and location accuracy at the receiver plane ,then the poisoning error distribution at the entire room for the both scenarios, and the histogram of the location errors, at the end the cumulative distribution function for the localization error.

The positioning performance of the receiver plane is considering the multipath reflections for all the entire room for the both cases. The LEDs laid at the corners of the rectangular ceiling which the positioning error is relatively high due to reflections.

As positioning errors of most points increase, the reflections impair the system performance significantly. As expected, the positioning error at scenario 2 is less than scenario 1 since the reflections at the center are not as intense as those at the corner.

Fig. 3.8 illustrates the distribution of localization error in meter around entire room for both scenarios using linear least square technique. We can notice that at the center of the room the localization errors are minimum and become high gradually as we move to the walls.

We could conclude that because the reflections near the walls are higher than those at the center of the room.

Figure 3.9 shows the histogram for localization error. It illustrates that most of the errors are less 0.6 m in the case of the scenario 2, but they are distributed till 1m in the case of the scenario 1.

Fig. 3.10 where the cumulative distribution function (CDF) of localization errors (e) are plotted against positioning accuracy (Ac).

CDF is defined as the probability that random positioning error e takes on a value less than or equal to the positioning accuracy Ac, i.e

$CDF_e(A\,c) = P\,(e \leq A\,c).$

For the proposed LLS algorithm, the location errors about 85% CDF are less than 80 cm for scenario 1. Meanwhile, the location errors of 85% CDF are less than 40 cm for scenario 2.

The results verified that the proposed LLS method for localization is valuable and functional to estimate the position of the target at receiver plane through RSS technique by using visible light positioning system. Table 3.2 show maximum and minimum for error positioning and received power for a certain coordinates.

Table 3.2 : maximum and minimum for error positioning and received power with coordinates at (a) LED A, (b) LED B, (c) LED C, (d) LED D.

(a)

	Scenario 1 LED A located (2, 2, 6) m	Scenario 2 LED A located (0.5, 0.5, 6) m
Max.error positioning (m) Coordinate(x,y,z) m	1.3 (0.2 ,0.2 ,1)	0.8 (0.2, 0.2, 1)
Min.error positioning (m) Coordinate(x,y,z) m	0.02 (3, 2.8 ,1)	0.009 (3 , 2.8, 1)
Max. received power(w) Coordinate(x,y,z) m	4.54×10^{-6} (2 , 2.4, 1)	7.74×10^{-6} (3, 3, 1)
Min. received power(w) Coordinate(x,y,z) m	4.06×10^{-6} (0.2, 0.2, 1)	4×10^{-6} (0.2, 0.2, 1)

(b)

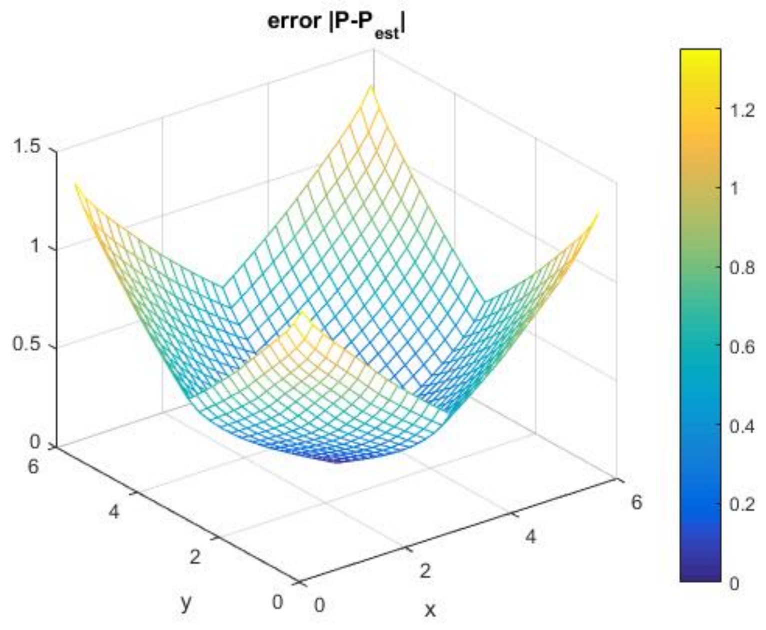
	Scenario 1 LED B located (2, 4, 6) m	Scenario 2 LED B located (0.5, 5, 6) m
Max.error positioning (m) Coordinate(x,y,z) m	1.3 (0.2 ,5.8 ,1)	0.8 (0.2, 5.8, 1)
Min.error positioning (m) Coordinate(x,y,z) m	0.02 (3, 3.2 ,1)	0.009 (3 , 3.2, 1)
Max. received power(w) Coordinate(x,y,z) m	4.54×10^{-6} (2.2 , 4.2, 1)	7.74×10^{-6} (3, 3, 1)
Min. received power(w) Coordinate(x,y,z) m	4.06×10^{-6} (0.2, 5.8, 1)	4×10^{-6} (0.2, 5.8, 1)

(c)

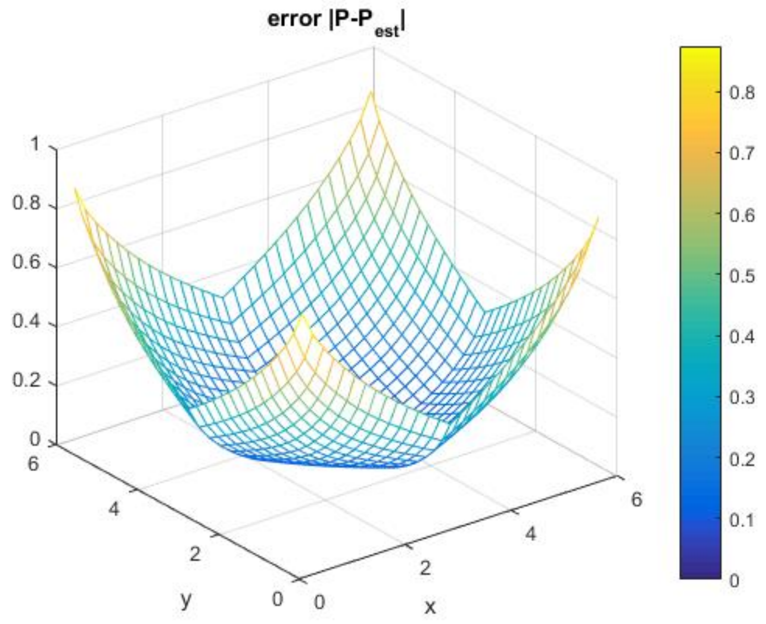
	Scenario 1 LED C located (4, 2, 6) m	Scenario 2 LED C located (5.5, 0.5, 6) m
Max.error positioning (m) Coordinate(x,y,z) m	1.3 (5.8 ,0.2 ,1)	0.8 (5.8, 0.2, 1)
Min.error positioning (m) Coordinate(x,y,z) m	0.02 (3.2, 3 ,1)	0.009 (3.2 , 3, 1)
Max. received power(w) Coordinate(x,y,z) m	4.54×10^{-6} (3.8 , 1.8, 1)	7.74×10^{-6} (3, 3, 1)
Min. received power(w) Coordinate(x,y,z) m	4.06×10^{-6} (5.8, 0.2, 1)	4×10^{-6} (5.8, 0.2, 1)

(d)

	Scenario 1 LED D located (4, 4, 6) m	Scenario 2 LED D located (5.5, 5.5, 6) m
Max.error positioning (m) Coordinate(x,y,z) m	1.3 (5.8 ,5.8 ,1)	0.8 (5.8, 5.8, 1)
Min.error positioning (m) Coordinate(x,y,z) m	0.02 (3.2, 3 ,1)	0.009 (3.2 , 3, 1)
Max. received power(w) Coordinate(x,y,z) m	4.54×10^{-6} (4.2 , 4.2, 1)	7.74×10^{-6} (3, 3, 1)
Min. received power(w) Coordinate(x,y,z) m	4.06×10^{-6} (5.8, 5.8, 1)	4×10^{-6} (5.8, 5.8, 1)

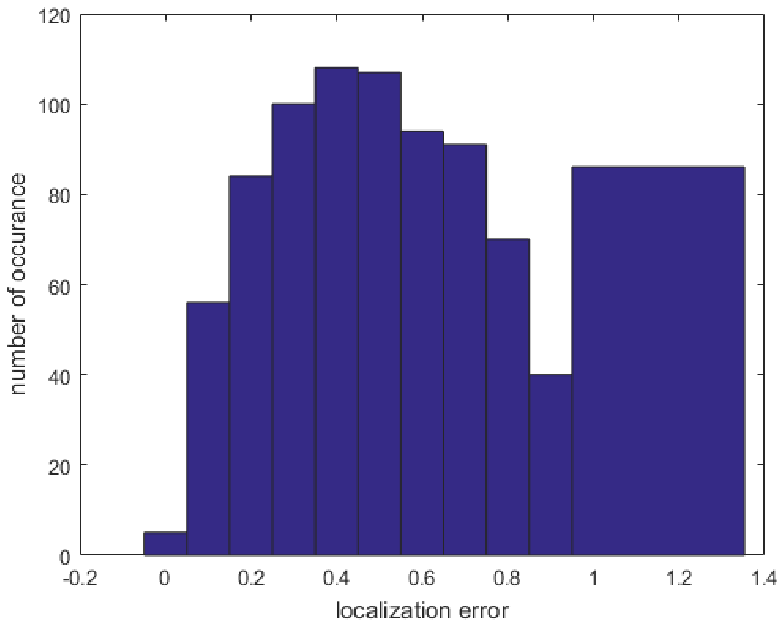


(a)

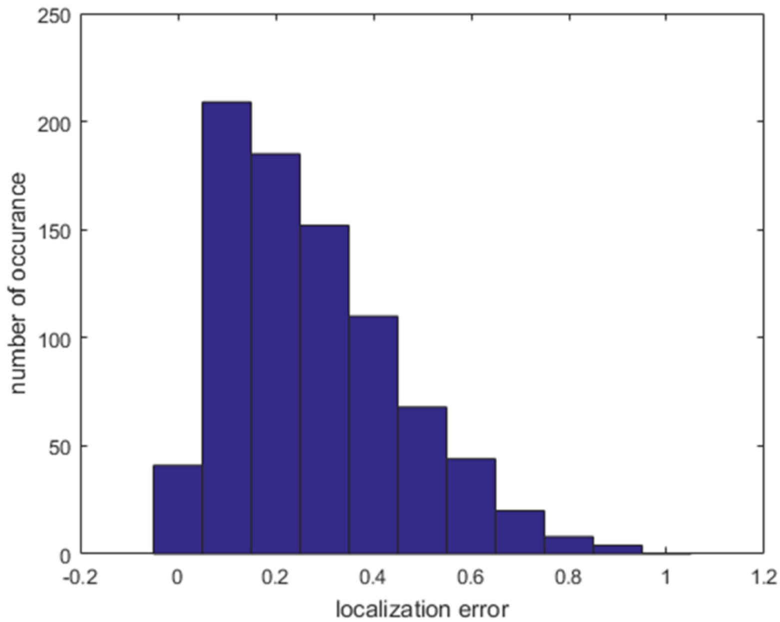


(b)

Fig 3.8 Positioning error in (a) scenario 1 (b) scenario 2

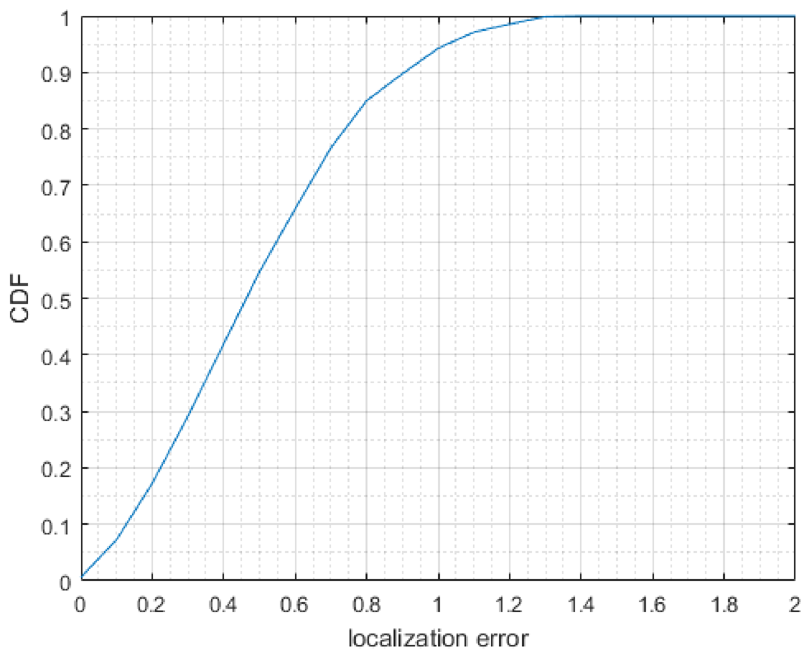


(a)

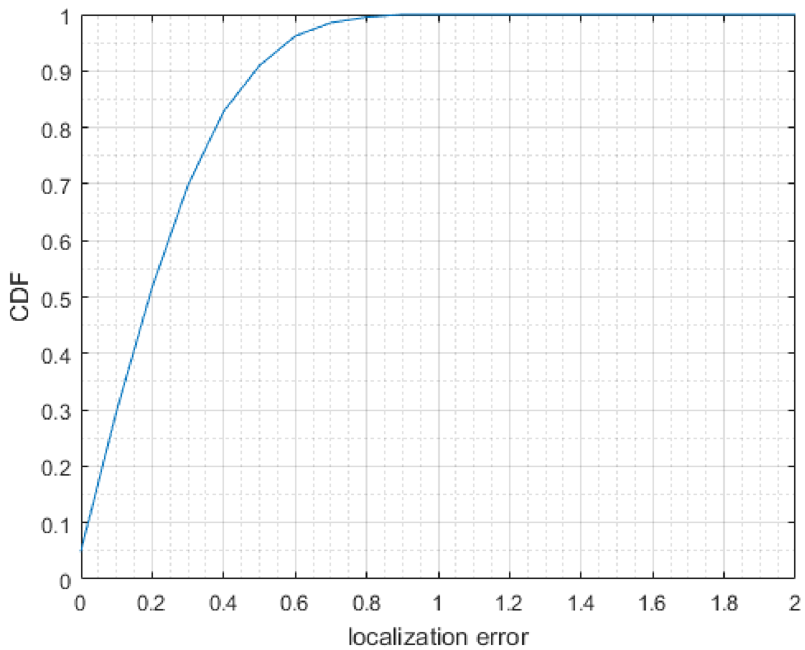


(b)

Figure 3.9 histogram of localization error in (a) scenario 1 (b) scenario 2



(a)



(b)

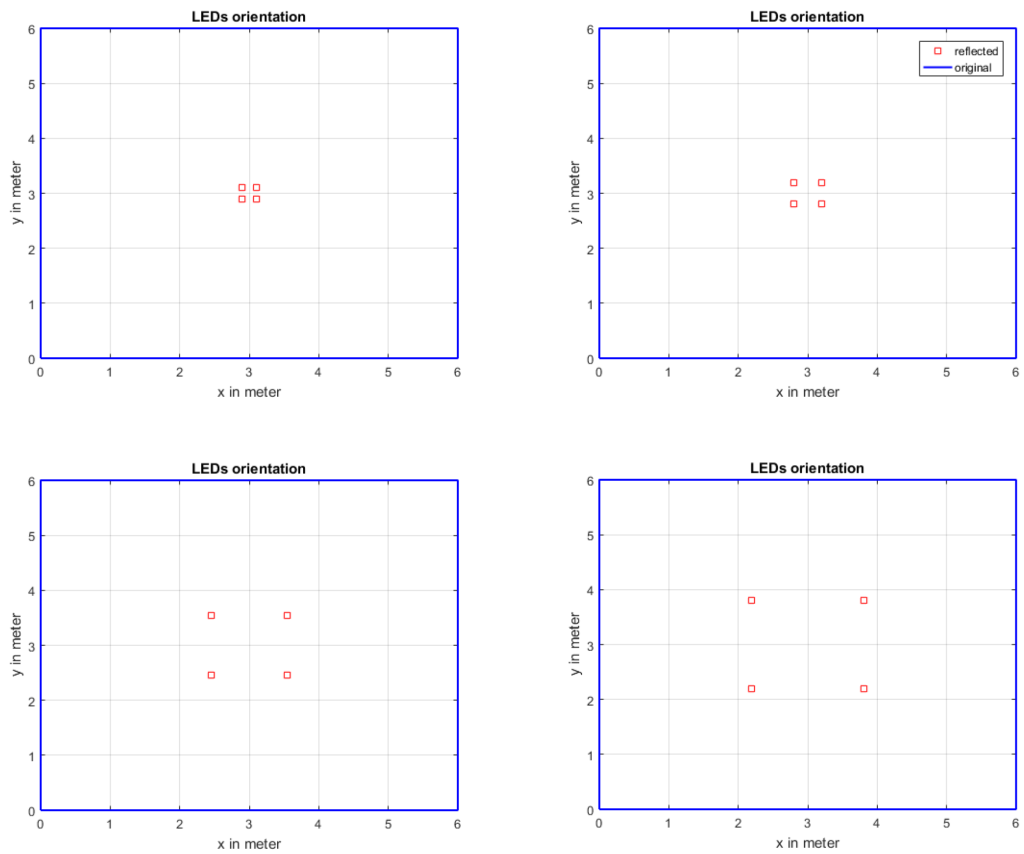
Fig.3.10 CDF of positioning errors (a) scenario 1 (b) scenario 2

3.9 Extended simulation:

In this section, the effects of the LEDs position on the localization error for overall VLC links in term of directed path and diffused path discussed for the same simulated room 6 m^3 with the receiver's height 1 m. Next, standard deviation and mean localization error were used for the evaluation of performance.

3.9.1 LEDs positions:

To investigate and estimate the variations of the localization errors for all the four LEDs possibilities to be located on the ceiling room by diagonal line starting from the center and gradually moving away to the corners area. Each step between LED positions is around $0.3\sqrt{2}$ along the diagonals of the ceiling room (6 m width and 6 m length) as shown in Fig 3.11.



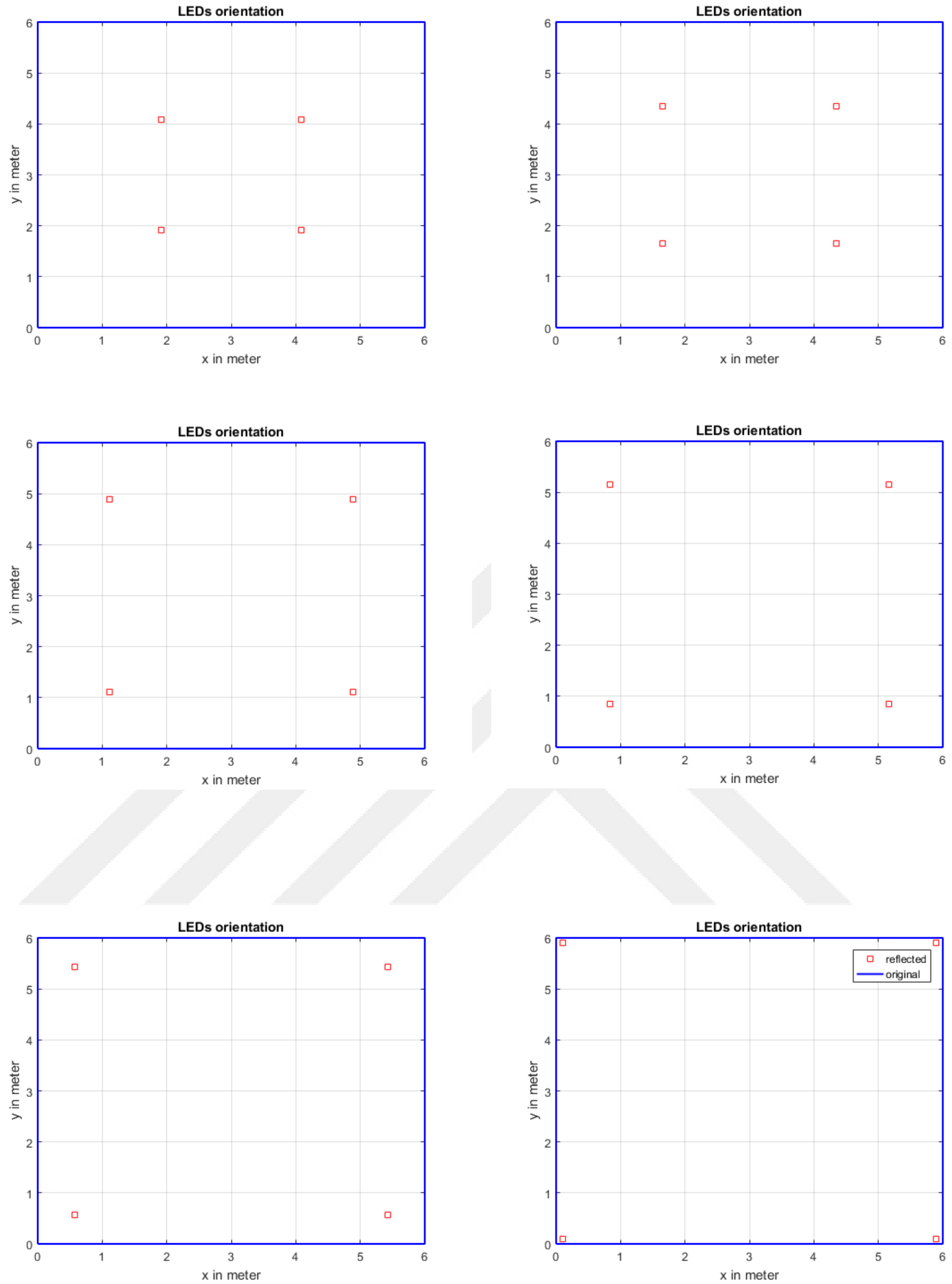


Fig. 3.11 shows the LEDs movements from the center to the corners

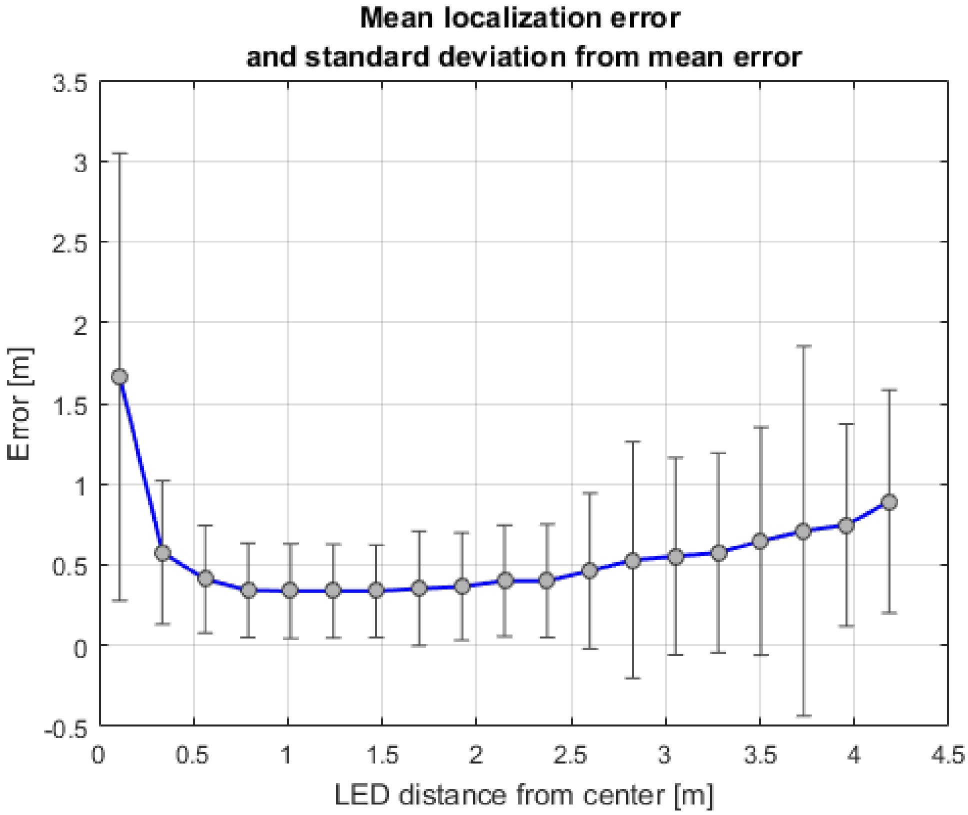


Figure 3.12 standard deviation and mean localization error

Figure 3.12 shows the steps of the LED positions, the distance between each diagonal movement of LED is $0.1\sqrt{2}$ from the center to the corners of room and the signal to noise ratio is 25 dB. We can notice that the first step of the mean localization error has a high value of error due to the close positions of the transmitters, which are used as anchor nodes. However, the mean localization error is around 30 cm when the LEDs pattern located at (2.62, 2.62) m. Thus, the position accuracy is not greatly affected by the reflection signal. Meanwhile, after this point towards the corners the mean positioning error increases gradually. The maximum value of the mean is around 80 cm, when the LEDs are located around (0.2, 0.2) m due to the excessive amount of reflections.

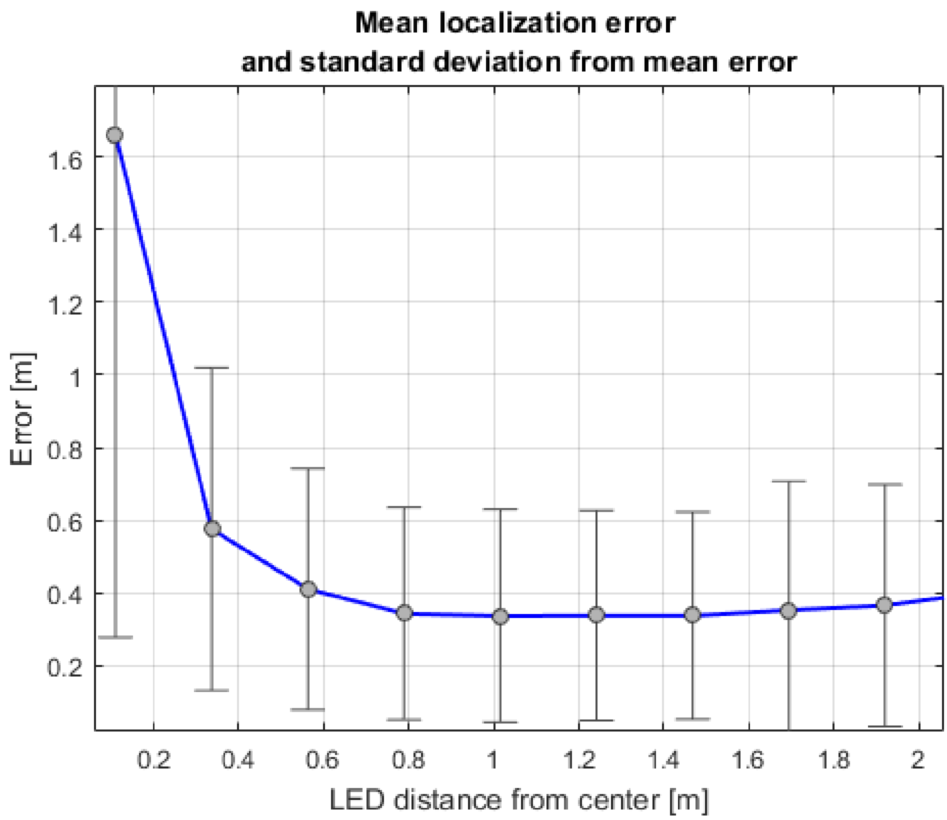


Figure 3.13 standard deviation and mean localization error for 20 steps

To find the optimum LED placement, we run the simulation in smaller step size. Figure 3.13 shows the diagonal movment of LED positions closley by 0.1 $\sqrt{2}$ from the center to the corners. We see that the minimum average error is 0.337 m which is optained when LEDs are positioned 0.5 $\sqrt{2}$ m away from the center of the diagonals. As we move away from this points towards the corners, the adverse aeffects of the reflected paths decrease accuracy. As move move from this point towards the center, the accuracy drops since anchor points are located too close for effective triangulation.

CHAPTER FOUR

CONCLUSIONS AND FUTURE WORK

4.1 Conclusions

In this research, we have investigated for the visible light communication system by considering direct propagation (LoS) and non direct propagation (N-LoS) including the reflection from walls, models are investigated for a typical room with different LED patterns. Equations of the received power of both different models are applied to calculate and simulate the received power at the receiver plane. We next investigate and evaluate the designs of indoor VLC links.

A light positioning system with multipath reflections is considered for a 6 m^3 room. The received power intensity distributions are calculated and positioning errors have been estimated and compared with two scenarios. Considering that the bad positioning accuracy in the corner and edge is caused by the noise and the impact of multipath due to the reflections several approaches will be explored in the future. In addition, by expanding the coverage area of the LEDs with a suitable pattern design, the positioning error can be diminished.

4.2 Future work

Indoor positioning via visible light communications (VLC) is a promising technology and is evolving with an increasing number of endeavors from researchers around the world.

Future work will be focused on analysis of the effect of the angle of incidence, the angle of radiation, the dimension of the room on RSS analysis for more complex indoor environment. We do not have an exact model for the noise in the system. A further investigation of the noise sources in the room circumference is possible.

Another possible study is to investigate positioning algorithms making utilization of estimations in areas other than VLC to provide more accurate and robust positioning services. Comparison of VLC positioning precision based on different algorithms is planned.

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