

NLoS-VICINITY: A Non-Line of Sight Approach for Visible Light Communication based INdoor PosITioning SYstem

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Abstract—In recent years with the rapid development of wireless communication technologies, positioning the person inside a building and providing various indoor location-based services have gradually penetrated in our daily life. Radio frequency (RF) based positioning techniques such as Radio Frequency Identification (RFID), Bluetooth and Wi-Fi plays a major role in indoors as GPS is unreliable in interior spaces because of the attenuation faced by the satellite signals. But RF based solutions require additional devices to position the user which in-turn increases the infrastructure cost. Among the optical Wireless Communication (OWC) technologies, Visible Light Communication (VLC) can be an alternative to RF based positioning with little modification in existing lighting infrastructure. VLC combines illumination and communication thereby saving energy and cost. Unlike RF based positioning systems, VLC based positioning requires Line of Sight (LoS) to establish communication between transmitter and receiver which may create user discomfort. A novel user comfort enabled solution using Non-line of Sight approach has been developed to position the user in an indoor environment using VLC. This paper explains the challenges existing in LoS based positioning approach, our proposed system and presents the results of experimental analysis.

Keywords— Indoor Positioning System (IPS), Optical Camera Communication (OCC), Optical Wireless Communication (OWC), Non-Line of Sight (N-LoS), Visible Light Communication (VLC)

I. INTRODUCTION

With the increase in the use of smart phones, location-based services attract the attention of a great pool of users. Accurate location provisioning is a key for providing location-based services. GPS provides precise location in outdoor environment whereas it remains arduous for indoors. Due to the multipath fading and interference generated from other wireless devices, GPS provides poor coverage inside buildings [1]. Existing indoor positioning technologies use Wi-Fi, RFID, and Bluetooth Low Energy (BLE). These technologies determine the relative position between them, by moving targets and communication of the fixed unit and then obtain the actual locations of targets [2]. These RF based positioning solutions, requires installation of additional devices that lead

to a significant increase in the cost for infrastructure, maintenance, and management. Positioning systems based on Light Emitting Diodes (LEDs) emerged in recent years, which leverages visible light signal instead of RF [3]. VLC combines illumination and communication and data is transmitted using visible light. Once LED lighting systems are installed everywhere, VLC based positioning can provide a seamless positioning service within much larger coverage than current techniques [4]. VLC based positioning systems can be installed inexpensively because existing lighting infrastructure with little modification can act as a VLC Transmitter.

VLC based indoor positioning can be used in public places such as airports, railway stations, museums and malls to assist public to reach their destinations. This is especially useful for first time visitors. It can also be used in malls for smart advertising, where merchants can deliver their advertisements and coupons to potential customers as they enter the mall, promote personalized shopping experience and analyse customer purchase behaviour.

VLC based positioning system consists of a transmitter and a receiver. Transmitters are LED lights with control circuit fitted on the ceilings. By switching on and off the LEDs at high speeds, 1's and 0's can be transmitted. This switching can be so fast that it cannot be perceived by human eyes. Data to be transmitted is modulated using several modulation techniques. Transmitters are always located on the ceilings, so it is much easier to reduce the negative effect of environmental interferences on data reception than RF-based systems, whose accuracy always degrades in practice due to various interferences such as the multipath effect [5]. Receiver can be a photodiode (PD) or an image sensor. Receiver only senses the light lobes within its field of view.

Different VLC based positioning approaches such as triangulation, fingerprinting, dead-reckoning and proximity are discussed in [1]-[8].

Triangulation method described in [3] determines the absolute position. In this method, time of arrival (TOA), time difference of arrival (TDOA), and received signal strength (RSS) are used to estimate the position based on the distances measured from the transmitters to the receiver. Angle of arrival (AOA) measures the angles relative to multiple LEDs

to determine the position of the receiver. TOA and TDOA are not feasible for real-time implementation because of difficulty in measuring the time difference as well as the need for perfect synchronization between the transmitter and receiver. AOA method is used for image sensor based receiver. For photodiode based receiver, AOA and RSS based methods are used. AOA positioning is more accurate in PD based receiver than camera based receiver.

The fingerprinting approach described in [8] estimates the relative position by matching real-time measurement parameters with the pre-measured location-based data. This approach is sensitive to the environment where features of the measured data changes with the locations.

Dead-reckoning is a fusion positioning method ([8]-[11]), that uses additional sensors such as accelerometer, gyroscope to estimate the relative position. This approach is susceptible to the accumulative positioning error therefore it cannot provide long-term positioning accuracy.

In proximity method, location of the mobile device is determined based on the signal from a single LED base station with a unique identification code. This approach cannot give absolute or relative positions but can provide only proximity location information.

A lot of research ([12]-[15]) has been carried out in photodiode based receivers. Photodiode is a semiconductor device that converts incident light into electric current. For signal detection, RSS information of received signals can be easily obtained to estimate the distance.

In [12], a pluggable photo detector based receiver device has been developed. It can be plugged into Android mobile through an audio jack. Normal user can receive the transmitted data whereas admin user can change the value of transmission. The developed application allows for indoor navigation, showing the position received from the lamp in a map.

VLC based indoor positioning system that can be employed in the future smart supermarket has been implemented in [13]. A detection algorithm and a simple ID exchange protocol with error detection and correction between the LED and mobile user has been developed as a part of the above research.

A general framework is presented in [14] for multi-photodiode device positioning by exploiting relative positions, as well as the received signal strength indications, of the multiple PDs. Location accuracy in the order of centimetres can be achieved according to realistic tested results.

A novel NLOS-aware localization algorithm, namely Enhanced Fingerprinting-aided RSS-TL (EFP-RSS-TL) [15] has been developed to improve the localization accuracy for the corner regions of a room by eliminating the Non-Line of Sight (NLOS) impact while keeping the same high accuracy for the room center. This is achieved by leveraging a RSS fingerprint database which records the line-of-sight (LOS) light power ratios beforehand.

For VLC based indoor positioning, the user needs to carry an additional device if photo detector is used as receiver. As part of OWC, optical camera communications (OCC) have become very attractive, considering recent developments in

cameras and the use of fitted cameras in smart devices [16]. Image sensors in smart phones can be used as a receiver. The image sensor can be of two types: global shutter and rolling shutter. In global shutter cameras, the entire frame is exposed at one time; therefore, it captures either the ON or OFF state of an LED. In rolling shutter cameras, the image is captured using row-by-row exposure [20]. For a fixed frame rate, the camera exposure time needs to be adjusted to cope with the LED's ON-OFF status and capture a black and white striped image.

Several works have been carried out using image sensor in smart phone as receiver. In [17], LED lamps act as anchor and smart phone act as a target device. Trilateration approach is used to locate a device. Binary Frequency Shift Keying (BFSK) and channel hopping are adopted to enable reliable location beaconing from multiple, uncoordinated light sources over the shared optical medium.

Authors of [18] implemented a non-flickering VLC transmitter, an OCC rolling shutter receiver and implemented photogrammetric mechanism for distance estimation. VLC link using mobile-phone camera with data rate higher than frame rate of the Complementary Metal Oxide Semiconductor (CMOS) image sensor has been demonstrated in [19].

Most of the research work carried out in positioning the user in an indoor environment through VLC is based on line of sight approach. The proposed system uses proximity based approach where each light transmits a unique ID that is received by rear camera of smart phone using NLOS approach. Uniqueness of the proposed system is as follows

- Identify the position of the user based on NLOS approach (capture the reflected image from floor) using rear camera
- Developed indigenous decoding algorithm with a smaller footprint
- Developed smart LED down light as VLC transmitter to transmit a 12 bit unique ID

Rest of the paper is organized as follows. Challenges in existing VLC based indoor positioning system and our proposed system are discussed in Section 2 and 3 respectively. Performance analysis done to measure the accuracy of the system for different distances and mobile holding positions under single and multiple light sources are discussed in Section 4. Section 5 explains the conclusion and future work.

II. CHALLENGES IN EXISTING VLC BASED INDOOR POSITIONING SYSTEM

Conventionally, front camera of the smart phone is researcher's choice for receiving the data in VLC based Indoor Positioning System using LOS approach. Though this LOS approach aids the user in positioning in indoor environment there do exists few challenges. Some of the challenges of existing system are mentioned below:

A. Line of Sight

Unlike the RF based communication system, Visible Light Communication requires LOS to establish communication

between the transmitter and receiver. This mechanism of LOS approach creates user discomfort.

B. Rolling Shutter Support

For VLC Receiver, capturing images using smart phone camera needs the support of rolling shutter feature. Support for this feature for front camera is very minimal in commercially available smart phones. Most of the commercially available smart phone's rear camera supports for rolling shutter effect. Use of rear camera is user friendly compared to the usage of front camera in a mobile application.

C. Packet Size Limitations

Using LoS approach, packet size is limited based on the number of stripes received. Number of stripes decides the maximum addressable lights. Capturing the entire packet in a single frame using LoS approach depends on the distance between transmitter and receiver, modulation frequency and diameter of light as described in [20].

Number of stripes captured in a frame

- Decreases with increase in distance between transmitter and receiver
 - *Limitation:* Packet size is fixed as distance between the transmitter and receiver cannot be changed
- Increases with increase in modulation frequency
 - *Limitation:* Commercially available smart phone camera can support only up to 1.5 KHz so modulation frequency cannot be increased further.
- Increase in diameter of light
 - *Limitation:* In compliance to standard dimensions diameter of light cannot be changed.

Above limitations are addressed with our NLOS approach

D. Higher Footprint Libraries

Conventionally researchers use smart phone camera to capture the data as video streams where data is spread across multiple frames. These data are processed using standard image processing libraries of higher footprint (hundreds of MB). This in-turn increases the memory footprint and the processing time. To overcome this, an indigenous decoding algorithm with smaller footprint (few KB) has been developed.

E. Camera Settings

Camera settings play a major role when using smart phone based receivers. Exposure as described in [21] is a critical element that determines what is actually recorded on a camera's image sensor. International Standards Organisation (ISO) sensitivity, aperture, and shutter speed are the three adjustable elements that control the exposure. Determining a proper camera control settings and arriving at an empirical value for capturing data stripes has been evolved and implemented in our proposed solution.

III. PROPOSED SYSTEM

To overcome the constraints of rolling shutter support, packet size limitations and user discomfort using LOS

approach, a NLOS approach (capture reflected image from floor using rear camera) to receive the data has been proposed.

Fig 1 depicts the proposed VLC based Indoor Positioning System. Smart LED down light fitted in the ceilings acts as a VLC Transmitter and smart phone carried by the user acts as a VLC Receiver.

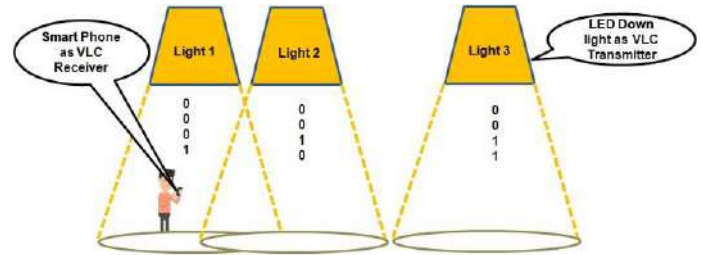


Figure 1. Proposed VLC based Indoor Positioning System

Overall flow of proposed system has been depicted in Fig 2. Each VLC transmitter is programmed to transmit a unique ID that is not visible to the human eye. Transmitted unique ID will be received as black and white stripes by rear camera of smart phone through a mobile App using Non-Line of Sight (Reflected image from floor is captured) approach. Sample images captured using NLOS approach is shown in Fig 3.

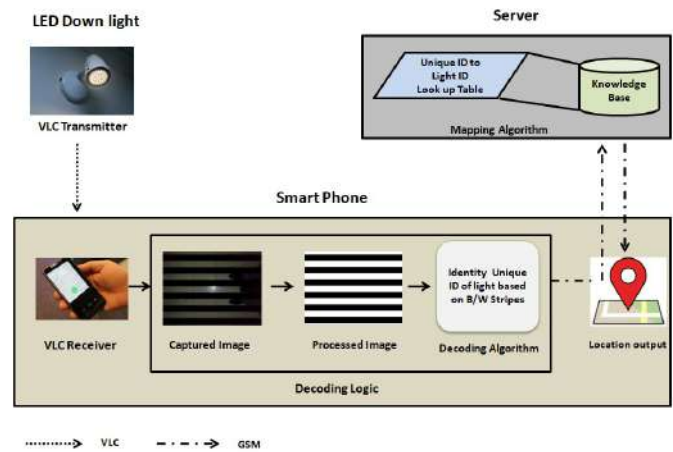


Figure 2. Overall Flow of Proposed System

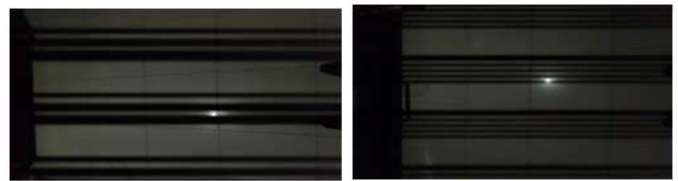


Figure 3. Sample images captured using NLOS Approach

Decoding logic running in the mobile App processes the captured image and decodes the unique ID. Upon detection of the unique ID, mobile app will communicate with server via GSM/Wi-Fi to fetch the user position. Based on the received unique ID, the algorithm running in the server provides the exact position of user and the services associated with it. Mobile App after receiving the information from server

displays the user location on a map and also pops the associated services.

A. VLC Transmitter

Smart LED down light is designed and developed to act as a VLC Transmitter. Each VLC transmitter as in Fig 4 consists of microcontroller, LED driver, power supply and LED down light.

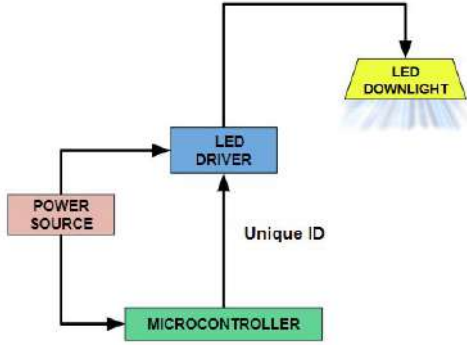


Figure 4. Internals of VLC Transmitter

Specifications of designed Transmitter are shown in Table 1. Electrical and mechanical modules of the transmitter has been designed and developed in-house.

TABLE 1. VLC TRANSMITTER SPECIFICATIONS

Parameter	Value
Luminous Flux	1710 lm
Power	12.6 W
Angle	70°
Illumination Diameter	6.8 cm
Control Module	Yes

Developed Transmitter with the control module is shown in Fig 5.

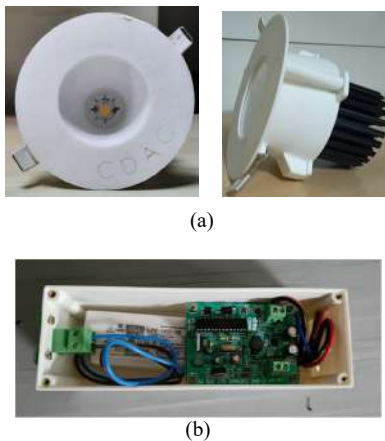


Figure 5. VLC Transmitter- (a) Front View (L), Side View (R), (b) Control Module

Fig 6 depicts the packet structure of proposed system. 12 bit unique ID with 1 start bit and 1 stop bit modulated using On-Off keying (OOK) modulation and Manchester encoding (as per IEEE 802.3) are generated using control module. Using the proposed system 4096 lights can be addressed.

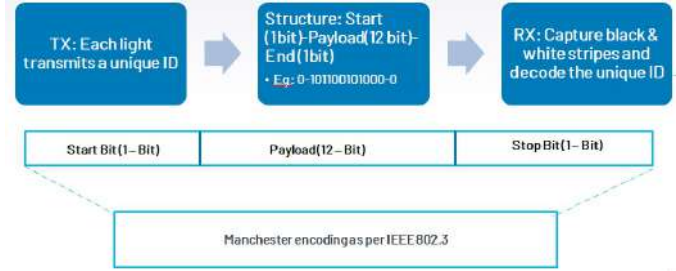


Figure 6. Packet Structure

Unique ID generated by the microcontroller will be fed to the LED down light through LED driver and is transmitted using visible light communication.

B. VLC Receiver

Rear camera of smart phone is used as VLC Receiver. Configuration details of the smart phone used for experimentation is depicted in Table 2

TABLE 2. VLC RECEIVER CONFIGURATION

Rolling Shutter Support	Yes
Android OS Version	11
Rear Camera	64 MP

Rear camera is accessed through a mobile App and empirical value has been set for capturing the data stripes using NLOS approach. Captured image is then processed by the indigenously developed decoding logic. Process flow of decoding algorithm is shown in Fig 7.

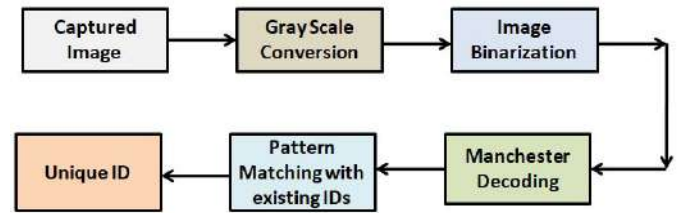


Figure 7. Decoding Algorithm – Process Flow

Captured and processed image for Unique ID - 707 is shown in Fig 8.



Figure 8. Captured Image (L) and Processed Image (R) for unique ID 707

Steps followed for decoding the captured image are illustrated below:

1. Capture the image using rear camera
2. Sample the image by width and height
3. Take pixel from each sample and calculate RGB value
4. Do gray scale conversion using RGB
5. Compute the threshold value for binary conversion
6. Compare the gray scale pixel values against the threshold. BLACK & WHITE binary image is obtained by the end of this step
 - a. If pixel value < threshold: convert the pixel into BLACK
 - b. If pixel value > threshold: convert the pixel into WHITE
7. From the binary image, compute the stream of 1's and 0's based on the Unique ID pattern and captured frame size
8. Perform Manchester decoding
9. Compare the bit pattern with the pattern of known Unique IDs used in an infrastructure
 - a. If pattern matches, give unique ID and EXIT the process
 - b. If pattern mismatch occurs, then go to step 1

Footprint of developed indigenous decoding algorithm is 20 KB (approx) and overall size of the receiver App is 7.3 MB (approx) with a processing time of about 6 sec (approx).

C. Installation Setup of VLC Transmitters

Five Transmitters (L1 to L5) are installed in lab premises at C-DAC Chennai as shown in Fig 9. Unique IDs and services associated with it are shown in Table 3. L5 is installed at the entrance of lab and L1 to L4 are installed inside the lab. Floor to ceiling height is 8.5 feet. L1 and L2 are 6 feet apart whereas L2 and L3 are 8 feet apart.

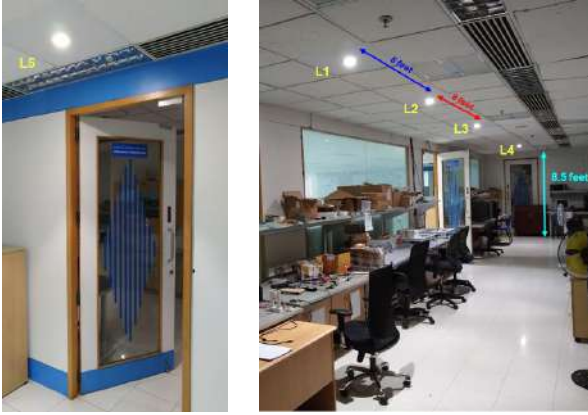


Figure 9. Installation setup

TABLE 3. UNIQUE IDs AND ITS ASSOCIATED SERVICES

Light	Unique ID	Service Associated
L1	3450	Soldering zone
L2	213	3D printing zone
L3	707	VLC testing zone
L4	1731	HPC Facility
L5	2575	Ubicomp Lab

D. Server Application

Steps involved in server side application are as follows

- Add Unique IDs of the lights (transmitter) and different services
- Upload floor plan and building name. Using a mobile app the building name will be updated which will be then visible in the configuration page.
- Mark the light installation points on the map
- Map the light IDs against their locations and the associated services available to those locations

Upon request from the receiver mobile app, server sends the location and services associated with the unique ID via GSM/Wi-Fi. Fig 10 depicts the snapshot of Server Application.

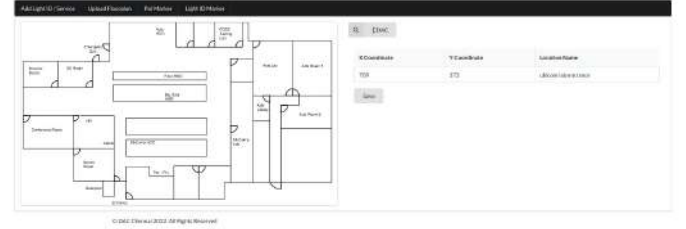


Figure 10. Server Application

Mobile app after retrieving the location is shown in Fig 11.



Figure 11. Display location on Receiver Mobile App

IV. EXPERIMENTAL ANALYSIS

Each transmitter has a coverage area of 12 feet. Experiments have been performed to analyze the accuracy of the proposed system under single and multiple light sources. Performance of the system under different coloured surfaces was also analysed.

A. Analysis under Single light source

Experiments have been performed to analyze the accuracy of system under different distances and different mobile holding positions. Experimental setup of single light source is shown in Fig 12.

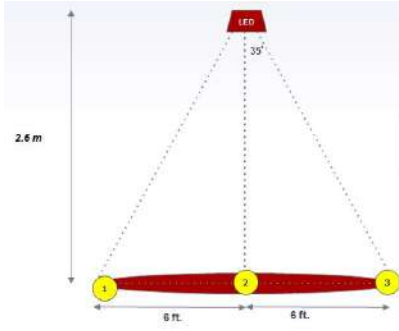


Figure 12. Experimental setup of Single Light Source

1) Analysis under Different Distances: Conducted experiments for every 0.5 feet from centre (0 feet at pt. 2) to end (6 feet at pt. 3). Results of the analysis are shown in Fig 13. Results shows that system is 90% accurate at 0 feet and 70% accurate at 2.6 feet.

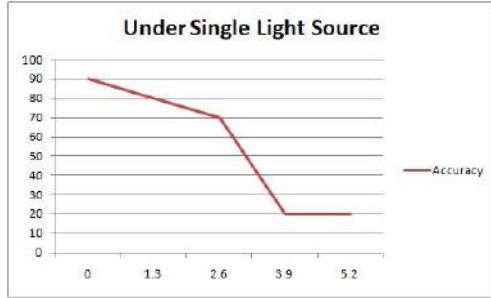


Figure 13. Accuracy (%) vs. Distance (ft) for Single Light Source

2) Analysis under Different Mobile Holding Positions: As the proposed system uses NLOS approach at the receiver, performance of the system is analysed for different mobile holding positions viz. horizontal to floor and slightly tilted mobile holding angle (i.e. casual mobile holding angle). Using 12 bit unique ID transmission, proposed system can address 4096 lights. Total of 163 unique IDs from ID number 25 to ID number 4096 (in steps of 25) has been taken for analysis. For each ID 3 to 4 attempts has been experimented. Out of 1138 test cases, 913 cases are positive and 225 are negative. Total test accuracy is 80.22%. Accuracy obtained for horizontal to floor position and slightly tilted mobile holding angle positions are 79.5% and 80.95% respectively. Results shows that NLOS approach is user friendly and can achieve up to 80% accuracy.

B. Analysis under Multiple Light Sources

Two Smart LED down lights (ID: 213 and ID: 707) are installed in ceiling with a distance of 8 ft (centre to centre) in the lab. A single light has coverage of 6 ft on either side. As depicted in Fig 14 point of interest for doing the performance analysis will be pt. 2, 3, 4, and 5.

Starting from the LED down light ID: 707, pt. 5 performance has been checked at every 0.5 ft towards ID: 213, pt. 2. And the same process has been repeated from pt. 2 to pt. 5. Results obtained are shown in Fig 15.

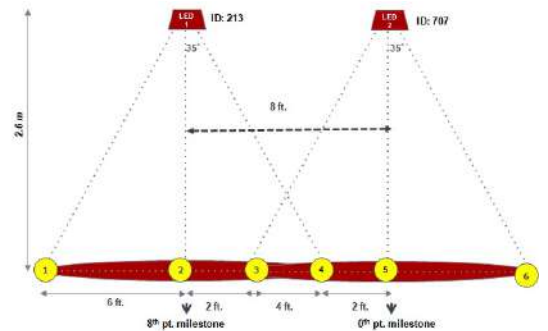


Figure 14. Experimental setup of Two Light Sources

Results obtained are as follows:

- At pt. 2 and pt.5: Accuracy is 80% to 100% from centre of the light up to 1 ft
- At pt.3 and pt.4: Up to 2 ft region on either side of the light from the centre, Unique IDs are detected with minimum accuracy of 60%

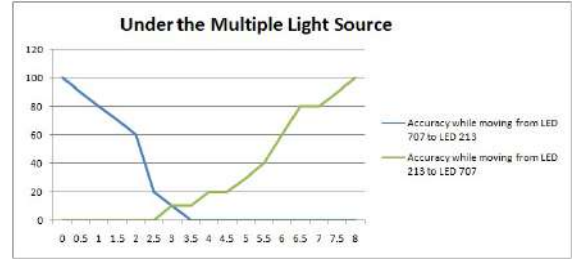


Figure 15. Accuracy (%) vs. Distance (ft) for Multiple Light Source

- Area between pt.3 and pt.4: Accuracy drastically drops after 2 ft. Unique IDs detection were not successful in this region.

C. Analysis under different coloured floors

As the receiver captures the reflected image from floor, experiments have been performed under different coloured floors. Receiver was able to decode the unique ID in presence of standard colour mats such as red, blue and wooden floors.

V. CONCLUSION AND FUTURE WORK

A novel user comfort enabled solution using Non-Line of Sight (NLOS) approach has been developed to position the user in an indoor environment using VLC. We have developed an LED down light as transmitter and an indigenous decoding algorithm with a smaller footprint (20KB). The proposed system uses proximity-based approach where each light transmits a unique ID (12 bit) that is received by the rear camera of smart phone through a mobile App using NLOS. The proposed system can address 4096 lights using 12 bit unique ID transmission, thereby making it suitable for use in larger space like malls. The system has been installed and tested in C-DAC premises. Performance of the system has been analysed under single and multiple light sources and were able to achieve accuracy up to 2 feet coverage with 80% and 60% respectively. For casual mobile handling position

accuracy is found to be 80.95% which indicates that the proposed solution is flexible and easy to use. Also, Receiver was able to decode the unique ID in presence of standard colour mats such as red, blue and wooden floors. In future, we would like to improve the accuracy of the system by adding sensor fusion techniques

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