Visible Light Communication Based Indoor Positioning System

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Abstract **– Indoor positioning dependent on visible light correspondence (VLC) innovation has turned into a well-known research subject as of late. In this work, a comprehensive state-of-the-art survey of positioning with the help of Visible Light Communication, as well as the main concepts and challenges related to this emergent area are presented. In addition, standardization of the technology, applications, as well as challenges for practical implementation and commercialization are reviewed.**

Keywords **– positioning system, visible light commination, light fidelity**

1. Introduction

Energy efficient lighting option is gaining tremendous support; governments around the globe are taking measures to curb the use of incandescent and fluorescent lighting bulbs. The prominent energy efficient lighting option is the use of LEDs, and the prediction is that the LEDs will be the only contender in the market in the near future [1]. The primary function of the LED is to provide illumination; however same LED light could be used as a medium of communication termed as Visible Light Communication (VLC). The VLC is an emerging wireless technology, which works on the idea of providing communication and illumination at the same time.

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The idea of using the LED as a source of wireless communication medium is quite fascinating and has tremendous potential to work on it [2].

The LED light could be deployed for illumination as well as a source of communication in range of visible light spectrum. The applications of LED light to serve both purposes will be many because of the many good attributes of visible light. For example, has bigger spectrum compared to radio waves, relatively no adverse effect on Human health, less power consumption and which all makes this technology suitable for future development and deployment.

Li-Fi is one of those practical implementations of the VLC based wireless communication. The Li-Fi is abbreviation for Light Fidelity introduced by Harald Haas in 2011. RF devices are always remain prone to radio interferences from other radio waves. The common example of RF interference is experienced with aircraft navigational instruments. The Li-Fi could be deployed in the areas that are sensitive to electromagnetic radiation. IoT is another major area of application of the Li-Fi, because it has the capacity to support up to 10 Gbps of data which is more than 200 times more than the super-fast broadband [3], [4]. For Vehicle-to-Vehicle (V2V) communication application scenario, a high speed VLC system like Li-Fi could deploy to improve the overall safety and security features in automobile by enabling exchange of safety messages between them. [5]. The advantage here is that vehicle lights and traffic light infrastructure could be used to vehicular communication [6]. The VLC has an advantage over RF when we talk about underwater communication, because of good conductivity of RF waves in sea, they don't propagate well on the sea bed. However, specially designed Un-Tethered Remotely Operated Vehicle (UTROV) is another application of the VLC in underwater communication. VLC has tremendous application scope in the places like hospitals, where we have electromagnetic wave sensitive areas such as the MRI scanner rooms. There is evidence that these medical facilities are susceptible to RF waves from other devices. The VLC will not interfere with this equipment. Other applications include Information displaying signboard, visible light ID system, sound communication and wireless local area network.

2. VLC Based Localization: Indoor Positioning System (IPS)

The VLC based IPS is considered as the highest potential alternative when we have discrepancies faced by the GPS system in indoor environment and with the RF communication systems which are highly prone to electromagnetic interference and multi-path fading. The VLC positioning system could be deployed in Indoor/outdoor environment, but has more demand in indoor navigation systems, places like hospitals, buildings, campuses, malls, community centers and metropolitan areas [7].

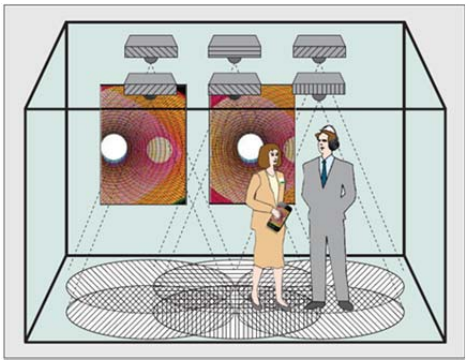

Figure 1. Two uses of visible light positioning in an art gallery [24]

The benefits of using VLC based IPS are many and a few are listed below:

1. Visible light positioning can be used in Radio Frequency sensitive areas, like hospitals. The MRI sensors have documented interference with the RF devices.
2. The VLC based positioning can be used in other RF-inappropriate areas including underwater, and underground mining fields.
3. The RF signals are more subjected to multipath propagation losses than the VLC signals, thus making the VLC positioning systems more reliable and predictable.
4. The main motivation behind using visible light as an indoor positioning is the increasing popularity of the LED lights. The LED light is being considered as the only contender in providing illumination in the future due to its many positive advantages including being environmentally friendly, cost-effectiveness, and controllability.
5. The VLC could be employed as the technique for enabling the Internet of Things (IoT), because of its candidacy as the future wireless technology.
6. Currently a number of researchers are working on different aspects of the VLC due to its potential of having larger coverage area once the LED lightening is found everywhere as the source of light.

3. Alternative Solutions for IPS and their Limitations

To exploit indoor position system, there are quite a number of methods that are on the table.

Global position system (GPS) does not work in indoor environment, because of the attenuation faced by the satellite signals due to thick walls. To overcome this shortcomes, several methods including cooperative localization, along with dead reckoning, finger printing and network beacon, [8] are being proposed to carry out investigation. Different technologies are being employed to find which works better in indoor environment such as Ultra-wide band, wireless local area network, Radio Frequency identification, Bluetooth and the cellular system. [9].

The common research area is also Wi-Fi based position system. The Wi-Fi has become a common requirement for internet access [10]. A number of position characteristics are available in the Wi-Fi network, but the most favorable one is the Received Signal Strength (RSS). The RSS is characterized by the attenuation of radio signals during propagation. And reading the RSSI signal is compatible with the existing infrastructure. However, accuracy and robustness of the RSSI based positioning system is still fundamental problem [10]. The accuracy of localization could be improved with additional number of Wi-Fi devices, at least three devices are required to get the appropriate accuracy. The addition number of WiFi devices are required to improved coverage in the case of shadowing of RF signal due to large objects in the coverage area. Addition number of WiFi devices will be helpful in the sudden or rapid movement of subjects. [11].

There is another approach through which the indoor localization problem could be catered, namely through wireless sensor network, where efficient and less power consuming integrated sensor nodes work in ad-hoc fashion, gather the data and send it over the network to a central unit [12]. Localization methods in wireless sensor networks are categorized according to the below mentioned flow chart.

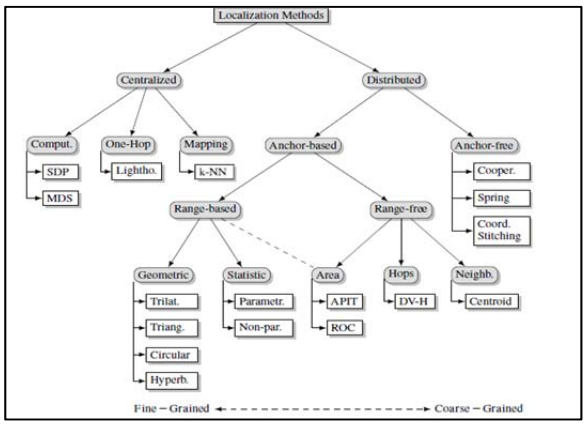

Figure 2. Location methods overview [12]

The method of localization in any IPS could be divided in two groups; one is structured on distance estimation and the second one is mapping based localization. Distance estimation process is further divided into two sub stages. The first stage is employing certain technique to estimate distance; there are a number of techniques that could be used for distance estimation such as Received Signal Strength Indicator (RSSI), Time of Arrival (TOA), Time distance of Arrival (TDOA) or Angle of Arrival Technique (AOA) [13]. The second stage is based on localization (position) calculation method based on the results obtained from distance estimation in the first stage. The localization calculation methods which can be used are trilateral, maximum likelihood or min-max method [13]. The second group, the Mapping based localization, works on the values of measured RSSI Values with the pre-stored RSSI database. The RSSI based localization methods have an advantage in terms of low cost, low power and accessibility. However, the uncertainty in the RSSI values leads to inaccuracy in the distance estimation and localization.

4. Working Principle of VLC Based Indoor Positioning System (IPS)

The VLC based Positioning systems uses VLC signals transmitted from a LED serves as a base station to find the position of the mobile device. The mobile device, which is equipped with a built-in camera, or a photo diode, reads the signal from the LED which contains its ID or any form of identification information. As shown in Figure 1., the LED lamp primarily used for shedding light in certain indoor vicinity, would also transmit the positioning signal. The positioning signal must accompany with the ID of the LED lamps. Each ID will be associated with each LED lamp installed on certain location. The information of IDs and LED placement must be required prior to positioning estimation. This database will be made available to the mobile devices. The basic scenario of localization in the VLC would remain same. However, there are many techniques that could be adopted or researched to achieve the optimum positioning of the mobile device in different scenarios. There are multiple criteria on which Position systems can be scaled or classified. The criteria's under discussion are based on the usage of algorithms for location calculation. Which include: Proximity, Triangulation - TOA, TDOA, RSS, AOA, RSSI, RSSR finger printing and vision analysis, etc.

As per the ISO/IEC 18305:2016, for Localization and Tracking Systems (LTSs), the application scenarios of the LTS are very diverse and have tremendous potential to become the multi-billion-dollar industry by 2020. Apart from its growth potential, there is still a lack of standardized Test and Evaluation (T&E) procedures for all the application scenarios for LTSs. The ISO/IEC 18305:2016 is the only standardized T&E of LTSs which is being developed to help government agencies to set the minimum performance requirement for various application of LTSs. This document will help the government agencies to infuse a requirement for coal mining operator to locate every miner with the 5 m range during normal mining operation and with 100 m range in case of any catastrophic accident in the mine. There is a possibility that one T&E standard may be applicable to different scenarios such as an explosion or roof collapse. But minimum performance requirement of any LTS varies from one application to another. One section of the LTSs is location-based services (LBS) which includes personal navigation, fleet management, and asset tracking in factories/warehouses / hospitals.

5. Accuracy Prediction of VLC Based IPS

The Targeted Localization accuracy of VLC based IPS has a significant reliance on the type of algorithm used for positioning. All the relevant positioning techniques used for different approaches for indoor positioning can be adopted for the VLC based indoor position. The VLC indoor positioning techniques can be classified into five groups; proximity, fingerprinting, triangulation, vision analysis, and dead reckoning. Precision and accuracy are the highly investigated topic in the literature. There is still not a single agreement.

The VLC based IPS have the capability to provide resolution for a few centimeters, when compared with its counter parts which is less than any of the other. The accuracy of an indoor positioning system, is also depending on the application scenario it is being deployed and also on the dimension of the object under investigation. The calculation of the accuracy depends on the amount of error present in the localization. The smaller the error, the more accurate the system would be. After investigating the proposed systems for the VLC based IPS in the literature, it can be concluded that the accuracy of the VLC based IPS can be classified into two categories; experimentally achieved results and simulation achieved results.

In the literature, more extraction is being carried out for simulation results and positioning error has been reduced to few millimeters (1-2 mm) by computer simulation, and the most accurate proposed system [14] is accurate for up to (4 cm) experimentally. However, the system [14] is providing the localization when the relative position of the photodiodes (PDs) is already known and has been assisted with multiple-PDs terminals, which is a different case when compared with the actual positioning where the coordinates of the receiving

nodes are not known in advance [15]. There is still quite a difference in simulated acquired results and experimentally observed accuracy because of the multiple adverse effect present in the environment, most likely the multipath effect. The practically implemented VLC based IPS systems include Eplison, Luxapose, LIPS and PIXEL [15].

Table 1. Comparison among different techniques

VLC based IPS	Practical/ Experimental Accuracy	Mathematical Algorithm	Sensor Assistance
Eplison [16]	0.4 m, 0.7 m and 0.8 m	Triangulation - RSS	Light sensor
Luxapose [17]	0.1 m	Triangulation - AOA	Image sensor and Accelerometer
LIPS [18]	0.4 m	Triangulation - RSS	Light sensor
PIXEL [19]	0.25 m	Triangulation – AOA	Image Sensor

6. Dependency of Localization Accuracy

Localization Accuracy of positioning system depends on many different aspects. However, it is being noted that in most of the research work, the achieved localization accuracy in the result of different experimentation is either not being reported by the researcher in his/her work. Sometimes the theoretical assumptions are being taken into consideration which are not similar with other researcher work or different experimental scenarios are used, in that case too, the reported accuracy cannot be compared. cannot be compared. The different aspect on which localization accuracy depends are listed and discussed below:

A. Ambient light noise

Ambient light noise refers to the degradation of signal from VLC due to the presence of light from Sun. There are still many open questions in this regard. Currently available Photodiodes (PD) are completely non-observant to the LED in the presence of direct sunlight.

B. Time measurement

The localization accuracy calculation requires greater amount of understanding because of the nature of the system, in the VLC systems we are dealing with the speed of light, there is a little miscalculation which can lead to greater deviation from the actual result.

C. Mobility

The performance of the VLC systems in a mobile environment is also susceptible to bit rate provided. Accuracy would increase with higher bit rate, however, to accommodate high rate which modulation scheme will be appropriate, is still under investigation.

The dependency of localization accuracy list also depends on achieving higher level of synchronization between the LED base stations and the receiver. Flickering issue might occur due to the modulation of light at low frequencies [20].

7. Research Challenges

In the recent development towards IPSs, the VLC based IPS has always been the center of discussion. Scientist and researchers all around the globe are working and a lot of work has already been done in this regard, many research problems have already been sorted out in a very short span of time. However, there are still many open issues in this field which are still very less investigated and need in-depth probation [15], which includes;

A. Inter-cell interference

There is a substantial possibility that the VLC based IPSs will be subjected to inter-cell interference. The usage of same frequency band by the adjacent lightening cell will instigate this problem. Different carrier allocation techniques are being adopted and proposed to mitigate the inter-cell interference, which turns out to be as trade-off schemes [21]. The fast and reliable data transmission through the VLC and reliable multiplexing techniques along with the extended capabilities in multi-source lightening scenarios requires further investigation and an open issue.

B. Multi-path reflection

The accuracy of the VLC based IPS is highly dependent on the multi-path reflection. In a normal indoor scenario, the error probability is higher on the corners and edges and accuracy reduces significantly. Mitigating multi-path reflection is very necessary for the VLC bases IPSs. In [22], a comparison is being done with and without the multi-path effect. However, the results are not satisfactory because the percentage error is quite high. In this paper, calibration technique is being adopted to minimize the multi-path effect. A more decent calibration technique could further reduce the percentage error to acceptable limits.

C. Minimization of calculation time

The basic procedure of estimating the position of an object requires certain general steps which include data collection, running positioning algorithms and

other procedures to minimize the positioning error which costs time. A system model which can provide real time positioning for the application and navigation services would be a preferred choice.

Other research challenges include, energy efficiency, receiver design, mobility.

The necessity to introduce the new mathematical model for the VLC based IPSs is prominent and compulsive, because of many open and realistic issues which are needed to be addressed. The absolute positioning algorithms, such as triangulation and vision analysis, and relative positioning algorithms, such as finger printing and proximity methods have their own advantages and disadvantages.

Finger printing is a relative positioning algorithm, where the preparation of offline database is time consuming and requires precision. However, finger printing is more accurate than the proximity method. On the other hand, the triangulation methods, AOA, TOA, TDOA and RSS and vision analysis provide the absolute positioning with more accuracy than their relative positioning counterparts [20]. If we compare the triangulation methods with each other, we will find out that each of them has its own capabilities and certain limitation. AOA, with respect to implementation perspective is more expensive and has more complicated hardware implementation than any other. Implementation of the RSS is simple; it uses single photodiode as a receiver which is less hardware cost. The RSS works better when the receiver is positioned horizontally near the LED, and the distant positioning introduces inaccuracies in the result. The TOA has simple mechanism, but the TOA and the TDOA require very precise time calculation. A new mathematical approach is required to be proposed which can combine the advantage of different individual algorithms and minimize the limitation associated with. The combined TOA-RSS and AOA-RSS based algorithms are much recent approaches in this regard [15].

8. Research Objectives

- Visible light communication is a new field; a lot of research in many different aspects needs to be done to bring it to its maturity. The first question that usually arises while dealing with the VLC based positioning systems is that the usage of techniques adopted for wireless positioning could be employed here or not. The techniques that are being exploited to deal with wireless positioning can be classified into three groups, triangulation (using trigonometry and geometrical approaches), scene analysis also referred as Finger printing (using the RSSI) and proximity [23]. These approaches have been employed for the VLC based positioning but require further investigation.
- Currently the VLC based positioning system requires support from wireless network to complete its operation. A complete independent VLC based position system is required to be developed, which will not leverage on other solutions to maximize the system's performance [23].
- There are so many areas which are still not or very less investigated related to the VLC based positioning systems for example which modulation scheme will be appropriate, what would be frequency of Identification messages transmitted by the LED lamp, how the interferences between different light sources transmitting signals will be managed [24]. There is room to test the previously adopted techniques and also to introduce new approaches and methods.
- Currently the research related to the VLC based positioning system is going on by keeping some idealistic approaches, for example the object has very restricted movement or there is no object in the vicinity of the subject or with less reflective or diffusive elements. However, in real scenarios the movement of the object is quite rapid and there is always a possibility of large number of obstacles and people in the surrounding which is still a point very less investigated [25].

9. End User Application Scenario

Indoor positioning has become requirement for certain equipment, applications and living beings. Indoor localization has gained significant importance over the last several years and has been a point of research since then [10].

The struggle to find an accurate and reliable indoor positioning system is always being a part of research over the last decade. The end user application scenario is highly associated with the increased usage of the LED based lightening systems. In the VLC, the LEDs are being turned on and off so rapidly that they can transmit information but without being observed by the human eye, in other words, there wouldn't be an impact on illumination. Installation of lightening system is basic requirement of any building; consider this lightening associated with the digital address lightening interface, where each luminaire/LED has its own unique identifier and auto-discovery feature. This unique identifier is transmitted by LED through VLC, detected by the smartphone or other handheld device, which in turn processes the information presented through the VLC and respond.

The VLC based positioning system could have a direct impact over the customers' preference if placed in the retail. The retail segment is fast growing and

relies on the quickly changing market trends. The main concern of business is to identify the customer behavior and have accurate information about the movement pattern in the stores. This will lead to more in-depth customer centric business model. Once the positioning system in place, customers with the help of handheld device, mainly cellphone, receive the information about their possible point of interest and would be informed about the current promotion along the path of their shopping spree in the store. There is a strong support to the VLC based positioning system from some big names in the industry including Philips, QUALCOMM.

Energy efficient and highly productive working environment is also a major advantage of the VLC based positioning and lightening system. Provisioning of lightening system with positioning would provide control feature, consider an office environment which is equipped with the finest details of concentration of the people in different parts of the office and be aware of the amount of the lightening required. User would be able to locate other colleague, information desks, and meeting rooms. A more advanced VLC based positioning would be able to provide valid credentials to use certain facilities in the office environment for example printer, documentation room etc.

Advance featured VLC based positioning system could also be employed in providing reliability to self-drive vehicle in an indoor environment of an industry or warehouse, self-driven robotic units working in correlation between warehouse sections and loading and unloading bay. The VLC based positioning system can also be deployed in places including hospitals and medical clinics and rest houses, where the human life is being taken care of and the patients are being monitored.[26]

10. Research Publication Statistics on the Topic VLC Based IPS in Leading IEEE Journals

Apart from the Visible light communication based Indoor positioning system, there are 35 Journal Papers published on the subject of the VLC in different IEEE transactions between the years 2013 and 2018. [27]

Table 1. Research Publication Statistics

Journal	No. of Paper published in Last 5 years	Year published	Recognition	Journal Rank
IEEE Journal on Selected Areas in Communications	1	2018	Top 10 IEEE Journals based on impact factor	8
IEEE Wireless Communications	1	2015		6
IEEE Transactions on Consumer Electronics	1	2012	IEEE Transactions	
IEEE Transactions On Instrumentation And Measurement	1	2017		
IEEE Communications Surveys and Tutorials	1	2017	Top 10 IEEE journals in Telecommunications by Eigen factor Score	9
Journal of Light wave Technology	4	2016, 2014, 2017, 2017		8

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