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Citation: Mahmoodi, Khadijeh Ali, Gholami, Asghar and Ghassemlooy, Zabih (2020) Impact of Number of LEDs on An Optical Camera Communication Based Indoor Positioning System. In: 2020 3rd West Asian Symposium on Optical and Millimeter-wave Wireless Communication (WASOWC). Institute of Electrical and Electronics Engineers Inc., Piscataway, NJ, pp. 1-4. ISBN 9781728186924, 9781728186917

Published by: Institute of Electrical and Electronics Engineers Inc.

URL: https://doi.org/10.1109/WASOWC49739.2020.9410069 <https://doi.org/10.1109/WASOWC49739.2020.9410069>

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Investigation of the Impact of Number of LEDs on An OCC based Indoor Positioning System

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***Abstract*—Optical camera communications (OCCs) technology, which utilizes lighting infrastructure for both illumination and data transmission and camera as the receiver, recently has drawn a lot of attention and luckily it can be used for indoor positioning as well. We consider an indoor environment with a number of light emitting diodes (LEDs) lighting access points for positioning and estimate the location using the view angles between LEDs' images mapped onto the image plane. The impact of the number of LEDs, which are varied from 3 to 9, on the positioning accuracy is investigated theoretically and validated experimentally. We show that increasing the number of LEDs has a significant effect on the performance of the OCC-based indoor positioning systems (IPSs).**

Keywords— Indoor positioning, Optical camera communication, LEDs.

I. INTRODUCTION

Nowadays, positioning in outdoor environments is widely achieved using the highly-established global positioning system (GPS). However, in indoor environments GPS signals are extremely weakened and cannot be used for an accurate indoor positioning. Presently, other technologies for indoor positioning systems (IPSs) has been proposed to overcome the drawbacks of the GPS in indoor environments. IPSs are used in applications such as location tracking, robot movement control, medical surveillance, work safety, smart manufacturing places, etc. [1,2].

Most existing IPSs are based on the radio-frequency (RF) technology [2] such as using Bluetooth, Wi-Fi, Cellular networks, sound-waves [3], [4], infrared radiation [5], visible lights [6], [7], or a combination of them [8], [9]. The RF-based IPSs have problems such as high implementation cost, long response time, and low accuracy. Sound-based IPSs can achieve higher accuracy, but the ambient noise level needs to be low, which is inappropriate in most indoor applications.

Recently, optical camera communications (OCC) as part of the emerging visible light communications [10] has drawn high attentions to be used as an alternative method for IPSs, which relies on using the light emitting diodes (LEDs)-based lighting fixtures in indoor environments, offering low cost, simplicity and a high level of accuracy (in order of centimeters) [1,5,11,12,13]. Table I, shows the pros and cons of OCC-based IPSs over other technologies [14]. It shows that IPSs which take advantages of OCC have higher accuracy and the implementation cost is lower that other technologies.

TABLE I Comparison of the most important IPS technologies

IPS Technology	**Advantages**	**Disadvantages**	**Accuracy**
Wi-Fi	Low cost	Low accuracy, high implementation cost	1-5 m
Bluetooth	Low cost and low power consumption	Low accuracy	1-5 m
Cellular networks	Widely covered scope	Low accuracy	2.5-20 m
Ultrasound	Good accuracy	Low accuracy in noisy environments	0.01-1 m
OCC	Low cost, low complexity, high accuracy	High power consumption, low data rate	3-40 cm

In the OCC technology, an image sensor (IS) is used as the receiver (Rx) in place of photodiodes (PDs). OCC-based Rxs (i.e., cameras) are less expensive and are available in smart devices, which can be effectively utilized for IPS. Although OCC does not support high capacity link connectivity due to the camera limitation, it can be employed in low data rate applications such as IPS. In OCC, the data rate can be varied from 500 bps as investigated in [15] to 10 kbps as indicated in [16] depending on the camera's type and its sample rate, communication distance, and modulation scheme. A typical camera has a frame rate of 30 fps and it can increase to 200 fpm in more advanced ones. In rolling shutter cameras, multiple LED states (i.e., on and off states) can be obtained at the same time in a single frame, meaning the response time can be very low depending on the type of the camera. In OCC-based IPSs, the world coordinates of LEDs are sent through the OCC link and image processing methods are used to determine the image coordinates of the LEDs in the image plane using geometric information, which can be based on different schemes, the world coordinates of the camera is estimated.

In [13], a camera as the Rx, an inclinometer and a magnetometer as the additional sensors and 3 LEDs as the Txs were used for estimation of a two-dimensional (2-D) indoor positioning with an accuracy of about 33 cm, which is considerably low compared with other IPSs. In [17], using two LEDs as the Txs and by employing the relationships between geometrical specifications of LEDs in the image and world coordinates the 2-D coordinates of the camera was estimated. The maximum positioning error (PE) reported was 6.5 cm, which is very low. In [18], the 3-D coordinates of the Rx with an IS and a gyroscope while having 4 LEDs was estimated, whereas in [7] a single LED as the Tx, an image sensor, a gyroscope and a PD were utilized to estimate the 3-D coordinates of the Rx with PEs of 8 and 10 cm, respectively.

In this paper, we employ the same approach as was reported in [19], and capture the view angles (VAs) between a pair of LEDs and used it for 3-D IS-based IPS with no use of additional auxiliary equipment. We show that, increasing the number of LEDs will lower the PE because of a higher number of LEDs being captured in the image plane as well as a large set of VAs between LEDs for 3-D based positioning (i.e., increased number of error functions to be solved).

The rest of the paper is organized as follow. In section II the simulation as well as the experimental system models are introduced. Section III presents the results, and finally, section IV concludes the paper.

II. SYSTEM MODEL

A. Simulation model

In order to explore the effect of number of LEDs on the performance of the IPS system, first of all, an OCC-based IPS is simulated by applying the same process reported in our previous work [19]. The simulation system model with 3-D coordinates illustrated in Fig. 1, and the proposed approach is best illustrated using the flow chart depicted in Fig. 2. Indeed, LEDs are used as the Txs, which are fixed on the ceiling, and the Rx is a camera. The images of LEDs are mapped onto the image plane using the camera lens. Having adopted the same approach as in [19], we determine the Rx's location using the VAs, where VA is the angle viewed between two LEDs from the center of the camera lens, see Fig. 2. Note, α is the view angle between LEDs 1 and 2 as shown in Fig. 2.

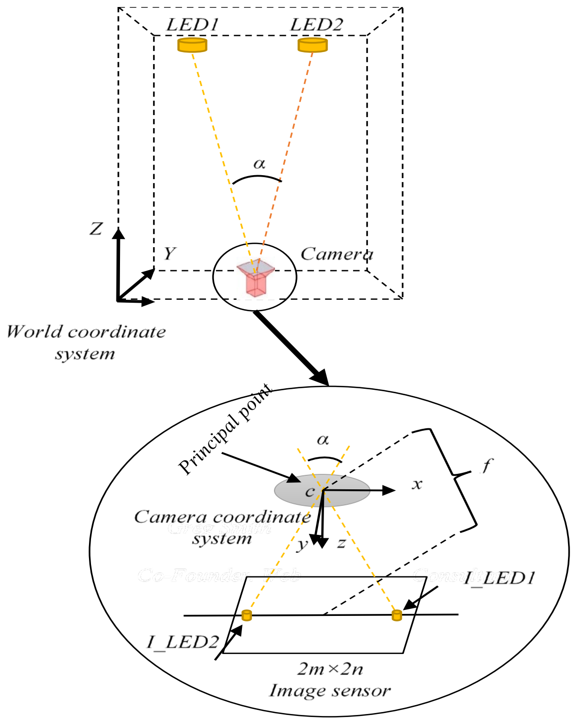


Fig.1 system model of the proposed OCC-based IPS

Using the law of cosines, the view angle between 2 LEDs in this image plane is calculated. Considering this fact that the view angle between LEDs in the real world is the same as view angle between them in the image plane and reusing law of cosines, the location where the image is taken can be calculated as presented in [19].

In general, both the world and camera coordinate systems are related by a set of physical parameters including (i) the focal length of the lens; (ii) the size of the pixels; (iii) the position of the principal point (i.e., the center of the lens); and (iv) the position and orientation of the camera. In IPS, two parameters are needed in order to simulate a camera, which are (i) extrinsic, which define the location and orientation of the camera coordinate system with respect to a known real world coordinate system; and (ii) intrinsic, which link pixel coordinates of an image point to the corresponding coordinates in the camera coordinate system [20].

Using the key parameters given in Table II, we have carried out simulation in MATLAB, where the LEDs were mounted on the ceiling of the room and a camera was used to capture the image of LEDs in specific positions on the floor level.

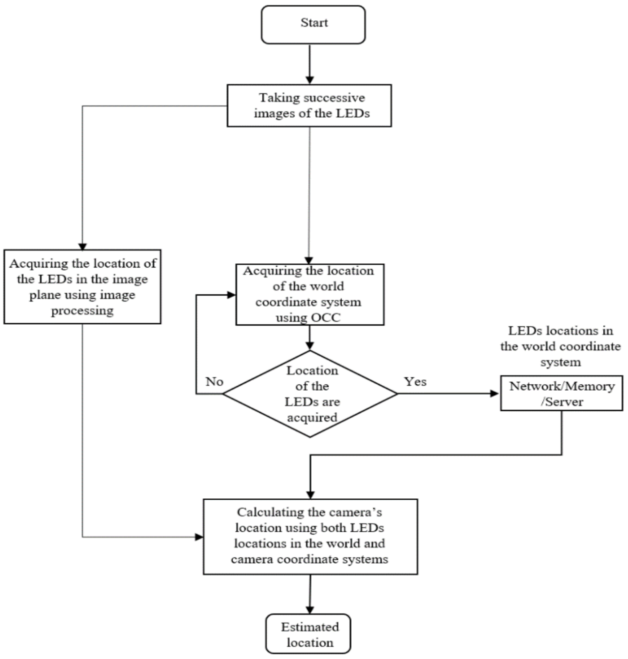


Fig. 2 Flow chart of the Proposed OCC-based IPS

TABLE II Simulation and experimental system parameters

Parameter	value
Room size	200×200×200 cm^3 (in simulation) & 146×206×248.5 cm^3 (in experimental)
No. of LEDs	9
Camera model	SM-J730GM
Image sensor resolution	3096×4128 (pixels)
Image sensor size	18.7×14 (mm^2)
Pixel size	0.006 mm×0.003 mm
Focal length	3 (mm)
Principal point	1548×2064 (pixels)

B. Experimental model

In order to verify the simulation results with regards to the relationship between the number of LEDs and the accuracy of the positioning system, we have carried out an experimental evaluation of IPS as depicted in Fig. 3. Here, we used 9 LEDs as the Txs located on the ceiling at a height of 248.5 cm and a front camera of a smart phone as the Rx. 16 locations marked on the floor level were used to capture images of the LEDs using the camera, see Fig. 3. The system parameters are shown in Table II.

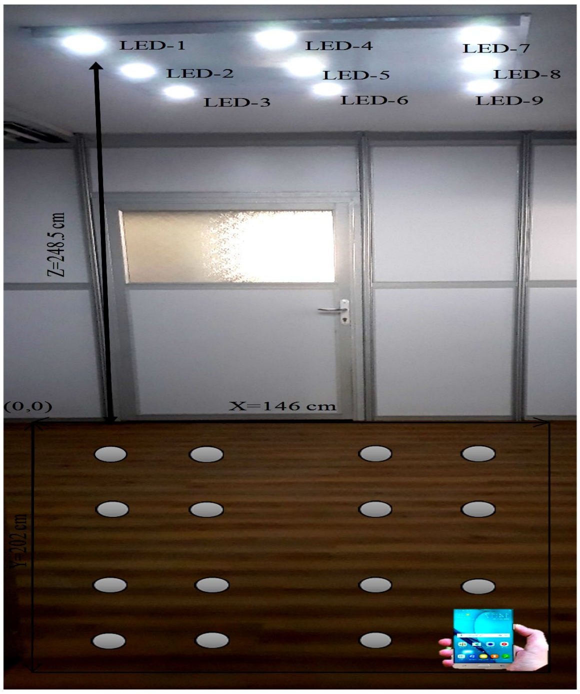


Fig. 3 Experimental setup

III. RESULTS

In order to investigate the effect of number of LEDs captured by the camera on the performance of the IS-based IPS we first determine the camera matrix parameters for the image of Txs being fixed at a specific location.

Next, we mapped the 3-D world scene onto the image plane following the same approach as in [20]. Based on the positions of LEDs and the captured images of the LEDs at a specific location on the floor level, we determined the VAs between LEDs' images. Note that, the VAs based approach can be treated as an optimization problem with 3 variables. This optimization problem can be solved using the well - known imperialist competitive algorithm inspired by the imperialist competition, which is a socio-political fact. The algorithm starts with some initial randomly distributed populations, which are called countries. At the end, a single component remaines which is the most powerful country that is, in fact, the solution of the positioning problem [19].

To evaluate the performance of an IPS, we use PE, which is given by

$$PE = \sqrt{(x-x_e)^2 + (y-y_e)^2 + (z-z_e)^2} \qquad (1)$$

where (x, y, z) and (x_e, y_e, z_e) are the coordinates of reference and estimated points, respectively.

The distribution of PE within the room is illustrated in Fig. 4. As shown, there is almost no PE at the center of the room but it is significantly higher (i.e., > 50 mm) at the corners. This is due to the camera capturing images of a reduced number of LEDs.

The root mean square error (RMSE) for the *x* coordinate with 16 sample points is given by

$$RMSE_x = \left(\frac{\sum_{i=1}^{16} (x-x_e)^2}{16} \right)^{1/2} \qquad (2)$$

where x and x_e are reference and estimated points, respectively. Equation (2) can also be used to calculate the $RMSE$ for the *y* and *z* coordinates as well. Fig. 5(a) illustrates the impact of the number of LEDs captured by the camera on the performance of the proposed OCC-based IPS. It Also shows the total $RMSE$ in black for comparison. Note, the PE is determined using (1). The $RMSE$ of 5.5 cm for 3 LEDs is reduced to almost zero for higher numbers of LED (i.e., > 6).

Next, we evaluated the predicted results as illustrated in Fig. 4 by means of experimental investigation using the set up shown in Fig. 3 and the parameters given in Table II. Fig. 5(b) depicts the $RMSE$ as a function of LED numbers for the three coordinates.

Table. III, compares the PE of the proposed scheme with other recently published OCC-based IPS methods. In [1] and [13], 3-D positioning was reported using at least 3 LEDs and with the positioning methods of angle difference of arrival (ADOA) and geometric information respectively. In [5], [7], 2-D positioning schemes based on a minimum of 3 and 1 LEDs were reported, which in the former trilateration algorithm was used and in the later a hybrid method of received signal strength (RSS) and angle of arrival (AOA) was utilized. In this work, with no use of any additional sensors, the view angles between LEDs in the image plane, which is the key parameter, is used to optimally estimate the 3-D position. The PE of almost zero is obtained by using 9 LEDs in the simulation and an accuracy of 6.2 cm is achieved by using the same number of LEDs in the experiment.

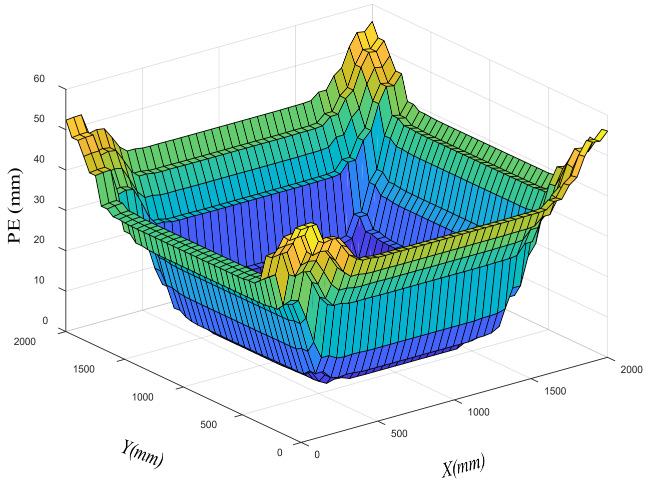
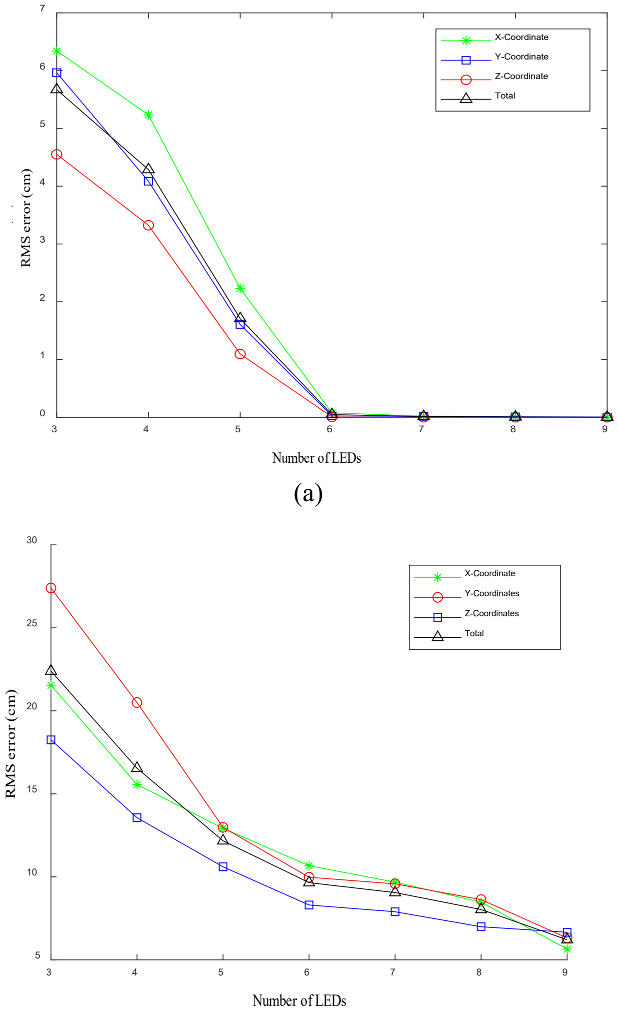


Fig. 4 Distribution of the PE within the room



(a)

(b)

Fig. 5 Impact of the number of LEDs on the performance of the proposed IPS: (a) simulation, and (b) experimental

TABLE III Comparison of OCC-based IPS

Ref.	**LEDs**	**Positioning type**	**Additional sensors**	**PE (cm)**	
[1]	3	3D	No	3.20	
[5]	3	2D	No	5	
[7]	1	2D	Gyroscope	10	
[13]	3	3D	Inclinometer, Magnetometer	33	
[17]	4	3D	Gyroscope	9	
Our work	3-9	3D	No	Depends on the number of LEDs captured	
				Simulation	Experiment
				5.5 (No. of LEDs=3) ~0 (No. of LEDs>6)	22.5 (No. of LEDs=3), 6.2 (No. of LEDs=9)

IV. CONCLUSIONS

In this paper, we investigated a camera-based indoor positioning system by determining the view angle between LEDs' images, which is the key parameter in the proposed scheme. The effect of number of LEDs on the performance of the positioning system was investigated both theoretically and experimentally. We showed that, the number of LEDs captured per image, which are varied from 3 to 9, affected the estimated location by significantly improving (i.e., reducing) the positioning error.

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