Two-Dimensional Indoor Visible Light Positioning Using Smartphone Image Sensor

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ABSTRACT

A simplified two-dimensional high-resolution indoor visible light positioning using smartphone image sensor is proposed in this paper. The smartphone can obtain the real coordinate of LED luminaires by the unique identification of each LED luminaires and identify its location using a captured still image. Experimental results demonstrated that the proposed two-dimensional indoor visible light positioning using smartphone image sensor achieves the maximum positioning errors of x- axis and y-axis were within 2.27 cm and 3.87 cm, respectively, under a hexahedron positioning space with 100 cm height.

INTRODUCTION

Significance of indoor positioning is becoming widely recognized for location-based services (LBS) applications owing to People spend 80-90% of their time indoors [1]-[3]. Indoor navigation and surveillance system can be achieved by accurate indoor positioning for many LBS business, including retail, data collection, and medical care. In extensive exhibitions, crowded transfer stations, broad street mall, highly precise positioning system is very helpful for guidance.

In this paper, we propose and demonstrate a visible light positioning (VLP) system using complementary metal-oxide semiconductor (CMOS) image sensor embedded in smartphone. A prototype will be implemented to demonstrate and evaluate the effectiveness of the proposed simplified two-dimensional VLP method.

OPERATING PRINCIPLE

The visible light positioning (VLP) system using smartphone image sensor is shown in Fig. 1, consisting of two light emitting diode (LED) luminaires L_1 and L_2 installed on the ceiling and a smartphone C. Each of LED luminaires is assigned with a unique identification (UID) indicating its system coordinate, *i.e.*, $(x_i, y_i, z_i), i = 1, 2$. The ID information associated to LED luminaires can be transmitted to smartphone via image-based visible light communications. When C received IDs associated to L_1 and L_2, it is aware of its rough position. More accurate positioning can be estimated by using the images of L_1 and L_2 taken by smartphone camera and the center coordinate of image sensor I_c. The images of L_1 and L_2 are I_1 and I_2 with image coordinates (ix_i, iy_i), $i = 1, 2$, and the image coordinates of I_c is (ix_c, iy_c). In [4], as shown in Fig. 1, the distance $h_1$between the ceiling and C was calculated by w_1/w_2, where w_1 denotes the distance between L_1 and L_2 while w_2 represents the distance between I_1 and I_2 with the assumption of an given distance h_2 between optical lens and image sensor. When h_1 is available, the system coordinate (x_s, y_s, z_s) of C was obtained by using the pixel distances among I_1 or I_2 and I_c.

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THE PROPOSED POSITIONING ALGORITHM

The positioning method proposed in [4] was under the assumption of h_2 is available. However, h_2 is a specified parameter of the camera module, and might be different from one smartphone to another. Moreover, position information is mainly used to drive the location based service in a two-dimensional space. Hence, the 3-D coordinates of the positioning system in Fig. 1 can be projected onto the two-dimensional xy-plane by viewing the positioning system from the top down as shown in Fig. 2. Notably, the center of the image sensor and the position of the smartphone are viewed as the same point and can be represented as (ix_c, iy_c) in image sensor coordinate system and (x_s, y_s) in the environment coordinate system. Based on the geometric relation shown in Fig. 2, id_x and id_y can be calculated and the

$$\begin{aligned} x_s &= (ic_x - ix_1) \times \frac{w_1}{w_2} + x_1 \\ y_s &= (ic_y - iy_1) \times \frac{w_1}{w_2} + y_1 \end{aligned} \tag{1}$$

EXPERIMENT, RESULTS AND DISCUSSION

A. Transmitter

Each of LED luminaries was implemented using a single white phosphor-LED(FD-10W-S45) that was driven at ~1050mA (~10V) with neatly 1000 lm output power. The positioning system adopts the Arduino Mega 2560 microcontroller board to implement the transmission of the UID assigned to each of LED luminaries through UART serial ports. Hence, each of C can be modulated to generate its UID in the format of on-off keying (OOK) signaling.

B. Receiver

The white light is emitted from each of LED luminaries and perceived by the embedded CMOS sensor of the ASUS Zenfone 3 smartphone, which has a resolution and frame rate of 480 × 640 and 30 frames per second, respectively. By taking the still image and converting the taken image to grayscale format, the smartphone can process to demodulate the UIDs of LED luminaries. In the grayscale image, the grayscale value is averaged row by row and a vertical column pixel will be selected for the data demodulation. To overcome the blooming effect of the CMOS sensor, a second-order polynomial fitting for each averaged row pixel is adopted [5]. Based on the threshold value given by the second-order polynomial fitting function, the averaged row grayscale values can be demodulated to logic values and retrieve the UIDs of LED luminaires.

C. Experiment Setup Condition

The experiment was conducted in the setup condition describe as follows. Two LED luminaires L_1 and L_2 are installed on the ceiling in $(30, 30, 100)$ and $(60, 30, 100)$, respectively. The smartphone was placed at the xy-plane below the plane of two LED luminaires, i.e., the distance between the xy-plane and the ceiling is 100 cm. The coordinates of the smartphone placed at different fixed positions are estimated to demonstrate the performance measure of the proposed indoor visible light positioning using smartphone image sensor.

D. Results

Fig. 3 shows the experimental results of the proposed positioning method under the condition of the axis of LED luminaires and the smartphone image sensor are the same. In Fig. 3, black square makers are coordinates of the LED luminaires, the dark circle makers are the fixed positions of the smartphone, and light grey rhombus makers are the estimated positions by the proposed positioning method. The maximum positioning errors in x- and y-axis were 1.81 cm and 2.88 cm, respectively.

Fig. 4 presents the calculated positions of the smartphone under the conditions of the coordinate axis are rotated by 45°, 135°, 225°, and 315°, respectively, relative to the coordinate axis of the LED luminaires. The results showed that the maximum positioning errors of x- and y-axis were within 2.27 cm and 3.87 cm, respectively.

CONCLUSIONS

Without using the information of the distance between optical kens and image sensor, a simplified two-dimensional indoor visible light positioning using smartphone image sensor was presented in this paper. The proposed positioning system was successfully implemented, including the transmission of UIDs of LED luminaires and execution of the image signal processing of estimating the smartphone position. Experimental results demonstrate that precise positioning with position error within 40 mm is achieved under a hexahedron positioning space with 100 cm height.

REFERENCES

[1] K. Kalliola, “Bring navigation indoors – the way we live next 2008,” Nokia, 23 Sep. 2008.

[2] P. Davidson and R. Piché, “A Survey of Selected Indoor Positioning Methods for Smartphones,” *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 1347-1370, 2017.

[3] J. Luo, L. Fan and H. Li, “Indoor Positioning Systems Based on Visible Light Communication: State of the Art,” in IEEE Communications Surveys & Tutorials, vol. 19, no. 4, pp. 2871-2893, 2017.

[4] J. Kim, S. Yang, Y. Son, and S. Han, “High-resolution indoor positioning using light emitting diode visible light and camera image sensor,” *IET Optoelectronics*, vol. 10, no. 5, pp. 184-192, 2016.

[5] C.-W. Chow, C.-Y. Chen, and S.-H. Chen, “Enhancement of Signal Performance in LED Visible Light Communications Using Mobile Phone Camera,” *IEEE Photonics Journal*, vol. 7, no. 5, Oct. 2015.

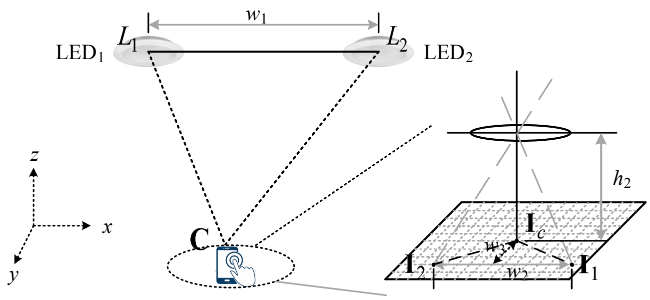

Fig. 1 Illustration of the proposed VLP.

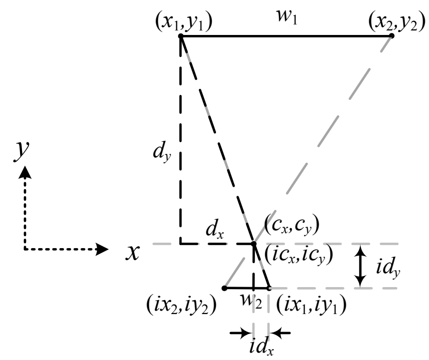

Fig. 2 Coordinate system of camera image sensor.

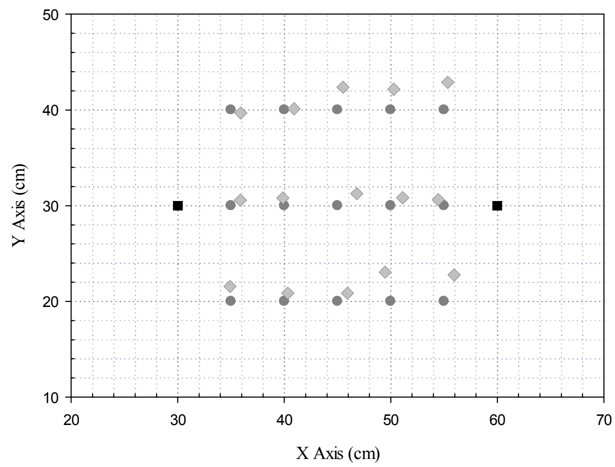

Fig. 3 The experimental results on the same coordinate axis.

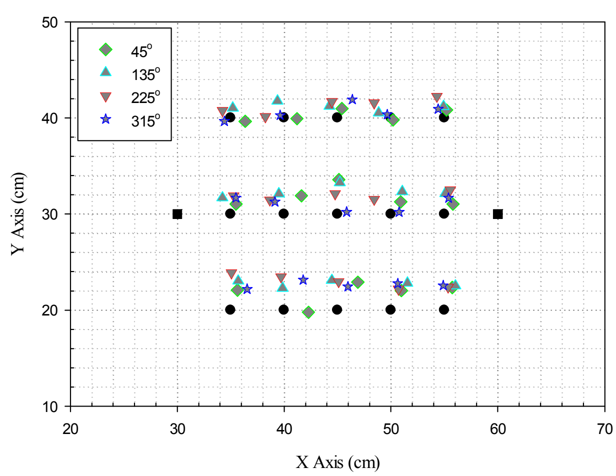

Fig. 4 The experimental results with smartphone rotation.