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RefRec: Indoor Positioning Using a Camera Recording Floor Reflections of Lights

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Overview

Indoor positioning system using LEDs and a smartphone

1. LED modulated with unique frequency
2. A camera capturing <u>floor reflections</u>

six-degrees-of-freedom mobile attitude estimation

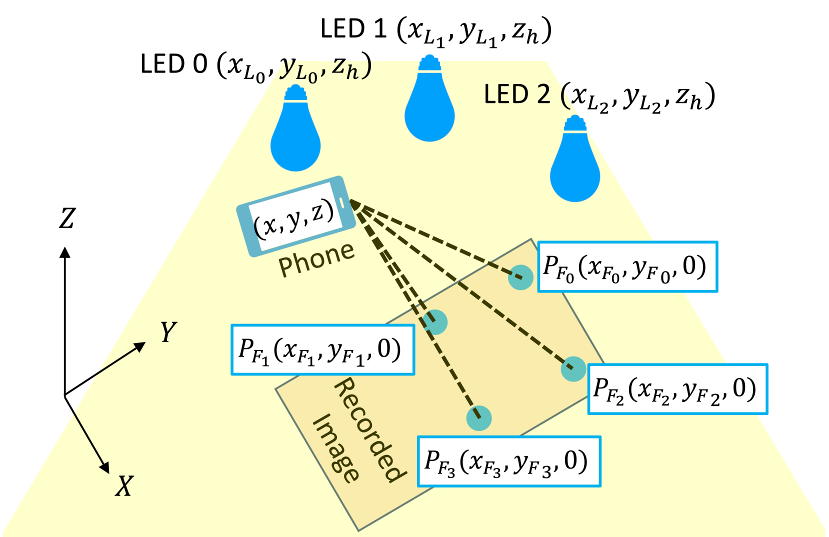


Fig. System overview

$(x_{L_k}, y_{L_k}, z_{L_k})$: Known position of LED k

P_{F_i} : Any position on the recorded image

(x, y, z) : Unknown position of the mobile

Background

Increased demand

for indoor localization technique

ubiquitous infrastructure

Smartphone

- Medical care
- Advertising
- Manufacturing
- Sales

and so on

How to localize the smartphone ?

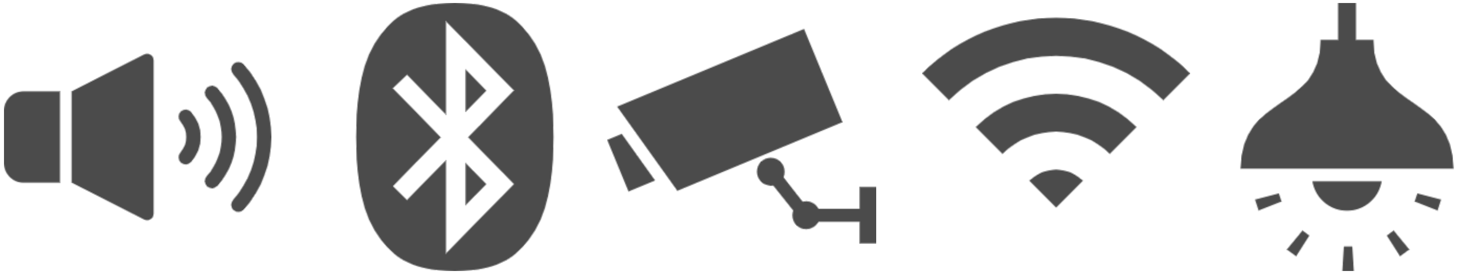


Fig. Ubiquitous infrastructures for indoor positioning system

Visible Light Positioning (VLP)

Efficiency

Accuracy

Cost

Fig. Smart light system proposed by Philips lighting

https://www.usa.lighting.philips.com/systems/lighting-systems/indoor-positioning

PhotoDiode (PD) ?
Camera ?

PD on the mobile:
<u>Not sensitive</u>
to receive the signal

We use a CAMERA

Existing problem and our purpose

Conventional: Directly detection

- ➢ Lack of camera function
  - Too dark to take other objects
- ➢ Lack of the signal
  - High ceiling or narrow LED space

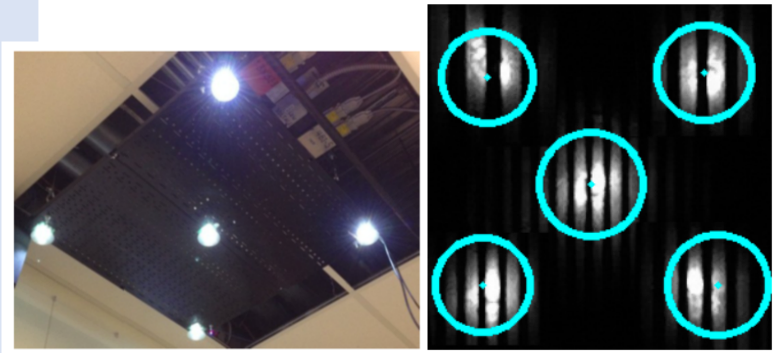


Fig. Detection LEDs directly [4]

Proposal: Detection Reflections

- ➢ Entire lighting on the floor
  - LED can be detected everywhere on the floor

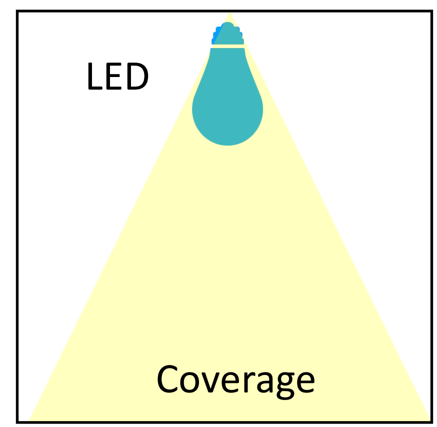


Fig. Coverage of positioning using reflections

[4] Ye-Sheng Kuo, et al.. Luxapose: Indoor positioning with mobile phones and visible light. MobiCom 2014

Proposal principle

Distance from LED can be estimated by the intensity on the floor

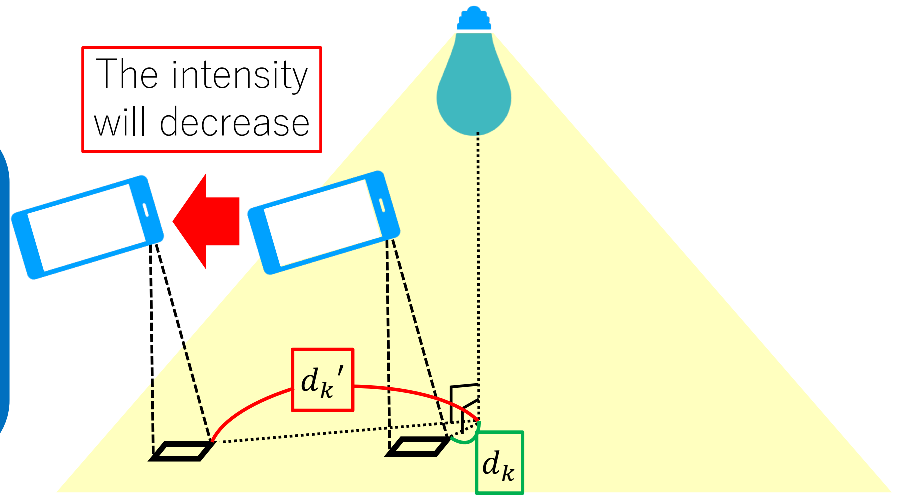


Fig. Attenuation of the reflections by the distance

Each LED are modulated with an orthogonal unique frequency sine wave to identify

※Frequency means blinking rate

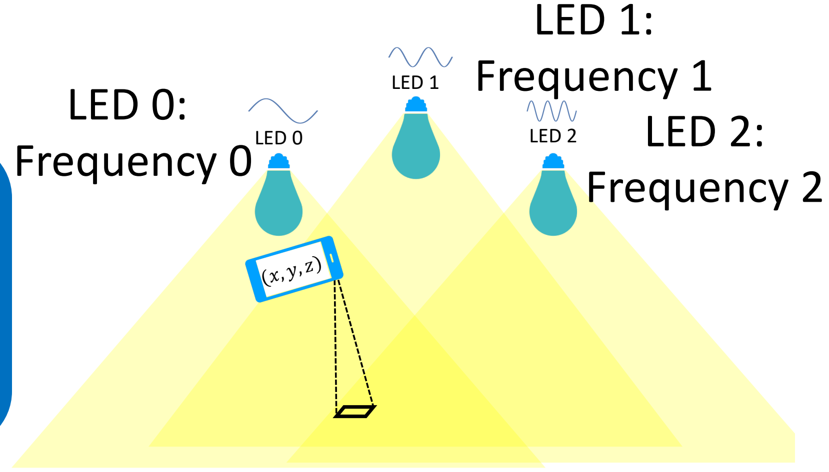


Fig. Each LED and allocation of frequencies

Three step for positioning

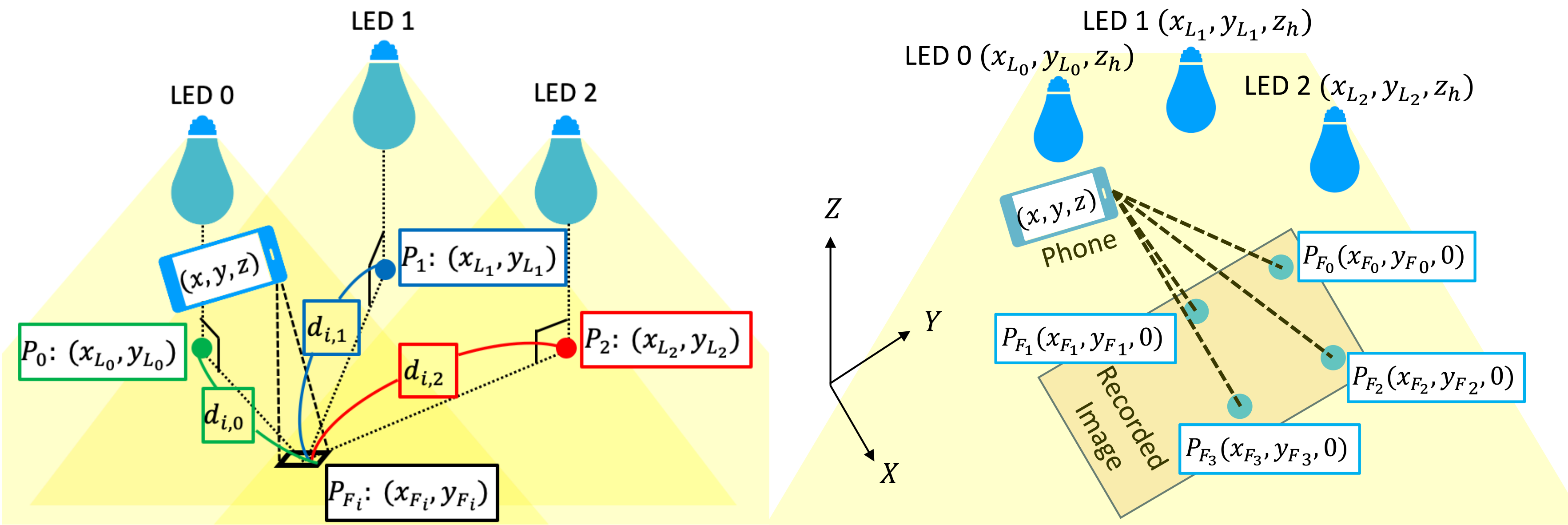


Fig. System overview

1. *Distance $d_{i,k}$ between the light source and the recorded floor*
2. *Position on the floor P_{F_i} recorded by the camera*
3. *Position and attitude of the camera*

1: *Distance d_k between the light source and the recorded floor*

Model about distance d_k VS amplitude spectrum β_k

→approximated by a hyperbolic secant distribution

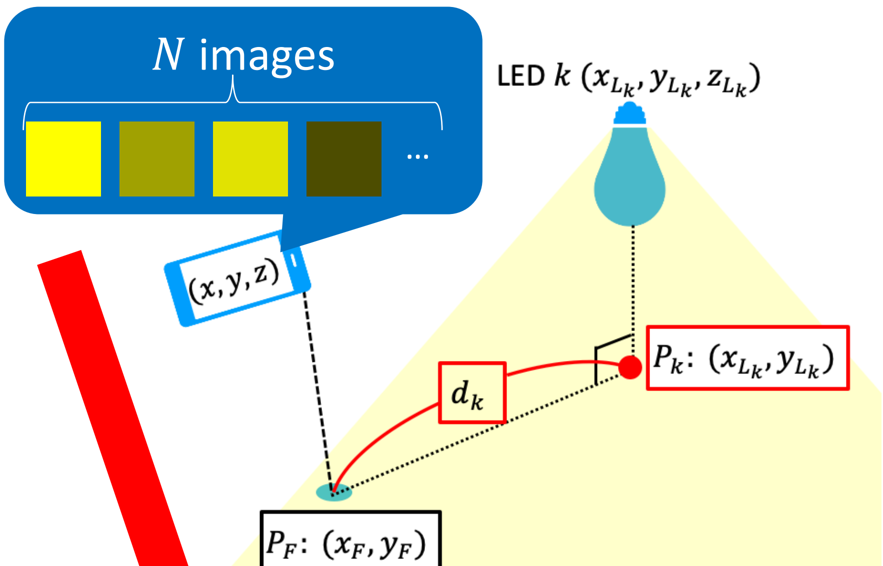


Fig. The camera capturing N images

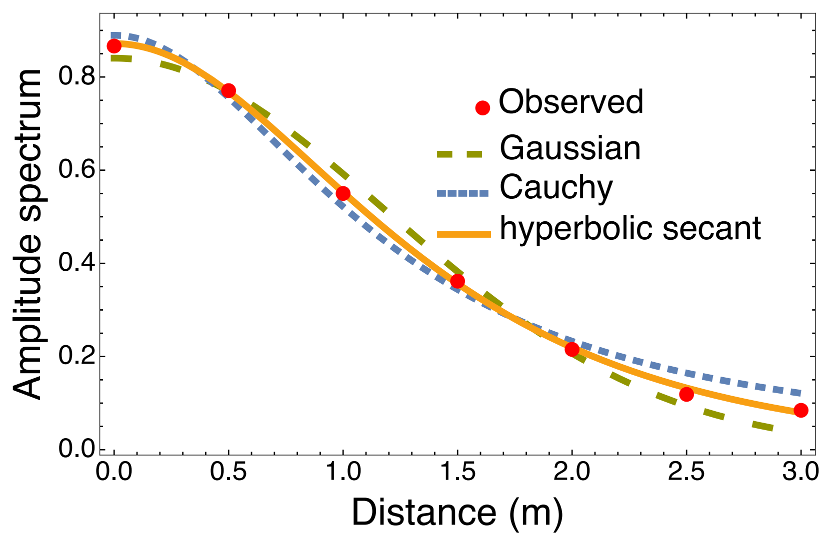


Fig. Amplitude spectrum $|\beta_k|$ VS distance d_k

Fourier transform

$$|\beta_k| = \frac{C}{e^{\frac{\pi}{2}\sigma d_k} + e^{-\frac{\pi}{2}\sigma d_k}}$$

σ : radiation characteristic of the LED
C : the transmission efficiency
β_k: amplitude spectrum

2. *Position on the floor* $P_F = (x_F, y_F)$ *recorded by the camera*

Trilateration using more and over three d_k

$$\begin{cases} \sqrt{(x_F - x_0)^2 + (y_F - y_0)^2} = d_0 \\ \sqrt{(x_F - x_1)^2 + (y_F - y_1)^2} = d_1 \\ \sqrt{(x_F - x_2)^2 + (y_F - y_2)^2} = d_2 \end{cases}$$

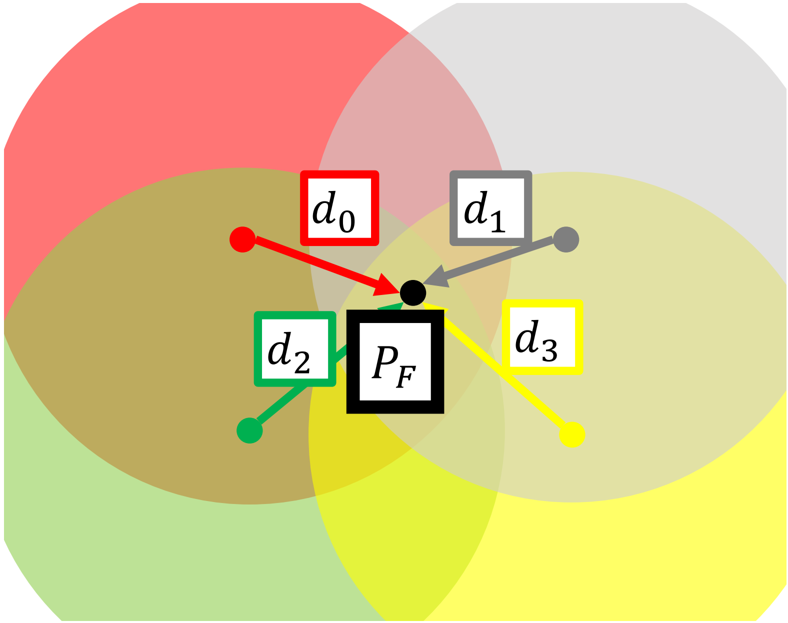


Fig. P_F captured be the camera and distance d_k from each LED

If over three LEDs are used, it should be solved as an optimization problem

3. *Position and attitude of the camera*

six-degrees-of-freedom mobile attitude estimation from Angle of Arrival using P_F

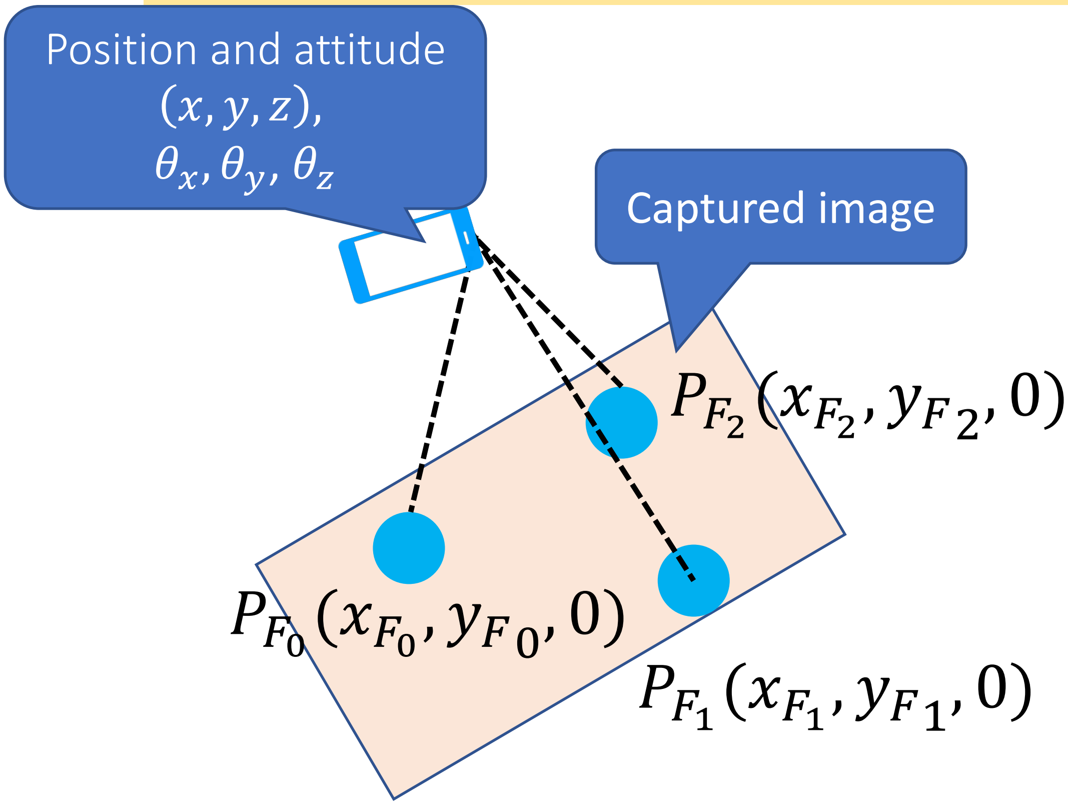


Fig. Camera position and Angle of Arrival of P_F

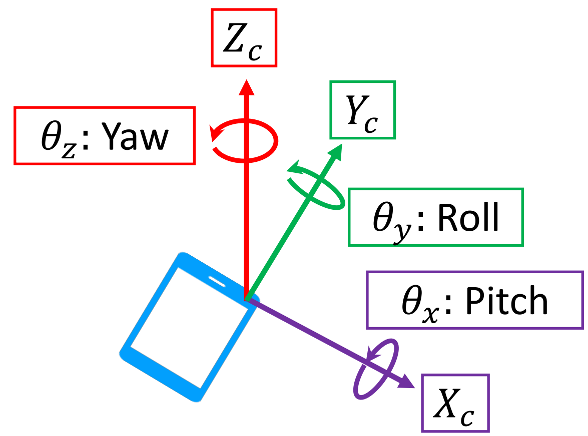


Fig. Definition of camera attitude

Minimize the traditional camera matrix [21]

$$\mathrm{Min}\|\mathbf{A}[\mathrm{R}|t]P - sp_s\|_2$$

[21] G. Bradski and A. Kaehler, Learning OpenCV: Computer vision with the OpenCV library. " O'Reilly Media, Inc.", 2008.

Experimental environment

Camera

- iPhone 7: 50fps
- Sutter speed: 1/500 second
- ISO value: 500
- 32 × 32 Pixel at each P_F
- Fixed with a tripod
- Any other object was removed
- Recording 100 images at each measurement

LED

- Four LEDs are mounted
- 36V (about 3000lm)
- Modulated at 101, 106, 113, and 120Hz sinusoidal

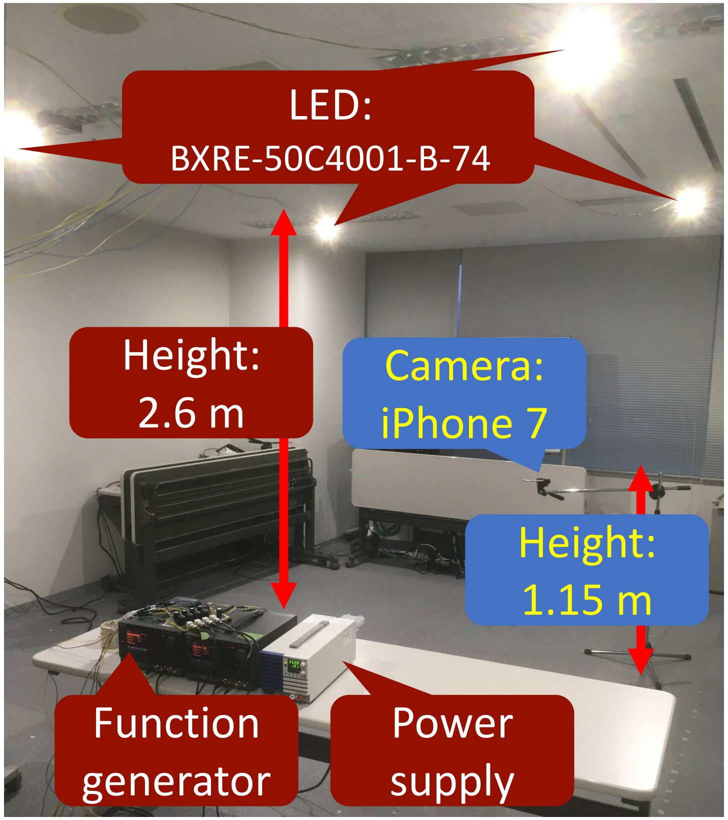


Fig. Experimental environments

Two estimation experiments

Position of P_F captured by the camera

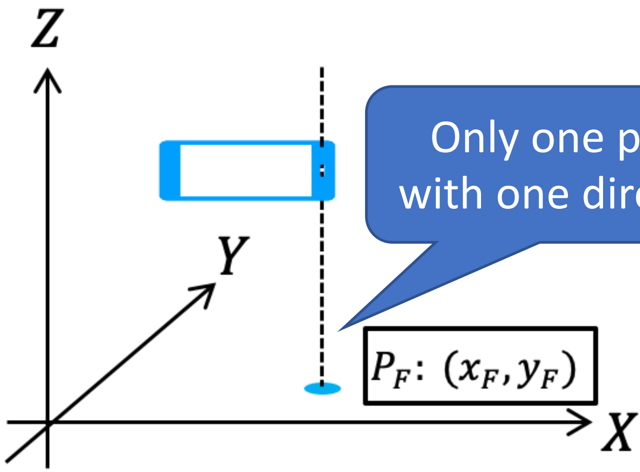


Fig. P_F captured by the camera

Camera

- Horizontal fixed with a tripod

Recording

- 80 measurement points in 4.0 m square area
- Measurement at each point

six-degrees-of-freedom mobile attitude

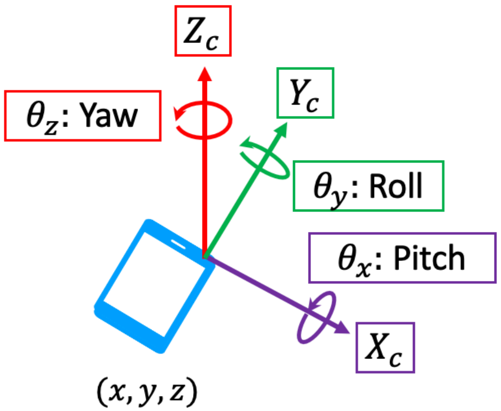


Fig. six-degrees-of-freedom mobile attitude

Fig. Nine P_F using estimation

Camera

- Each angle was changed by 10 degrees with tripod

Recording

- One measurement points (x, y, z) = (1.0, 0.5, 1.15)

Estimated Position of P_F

Less than 0.42 m at the 90th percentile error

- Potential for applications requiring high-accuracy

Large error on the outside

- Implied Limitation

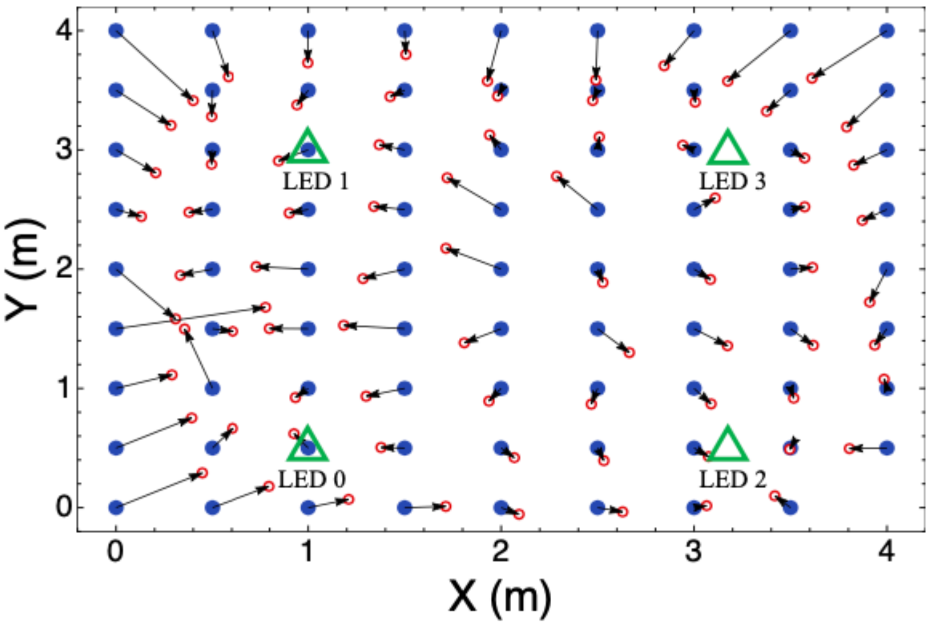


Fig. LED arrangement, P_F measurement points, and estimated positions

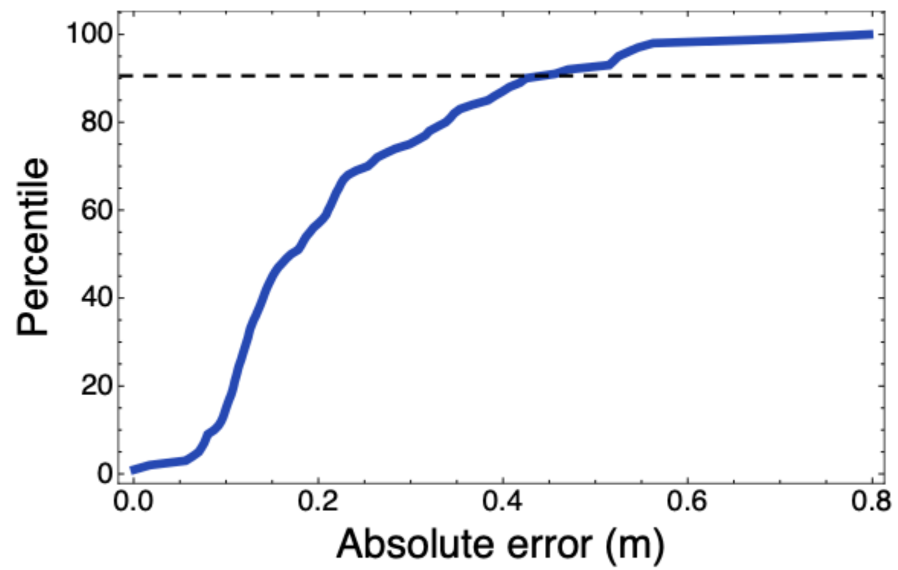
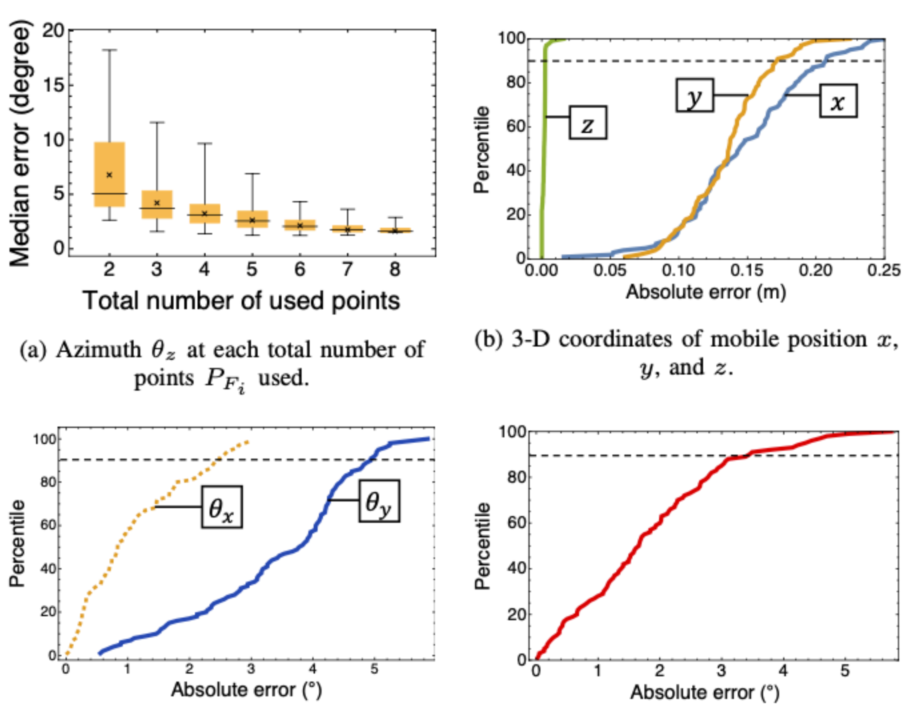


Fig. CDF of absolute errors of estimated P_F positions

Estimated six-degrees-of-freedom mobile attitude

Means of 90th percentile absolute rotation error were 5.69◦, 5.78◦, and 3.96◦ for the roll, pitch, and yaw

- Potential for applications using direction like a indoor navigation



(a) Azimuth θ_z at each total number of points P_{F_i} used.

(b) 3-D coordinates of mobile position x, y, and z.

(c) Pitch θ_x and roll θ_y.

(d) Azimuth (yaw) θ_z.

Fig. Estimated absolute errors about six degrees-of-freedom using nine P_{F_i} s at $(\theta_x, \theta_y, \theta_z) = (0,0,\pi/4)$.

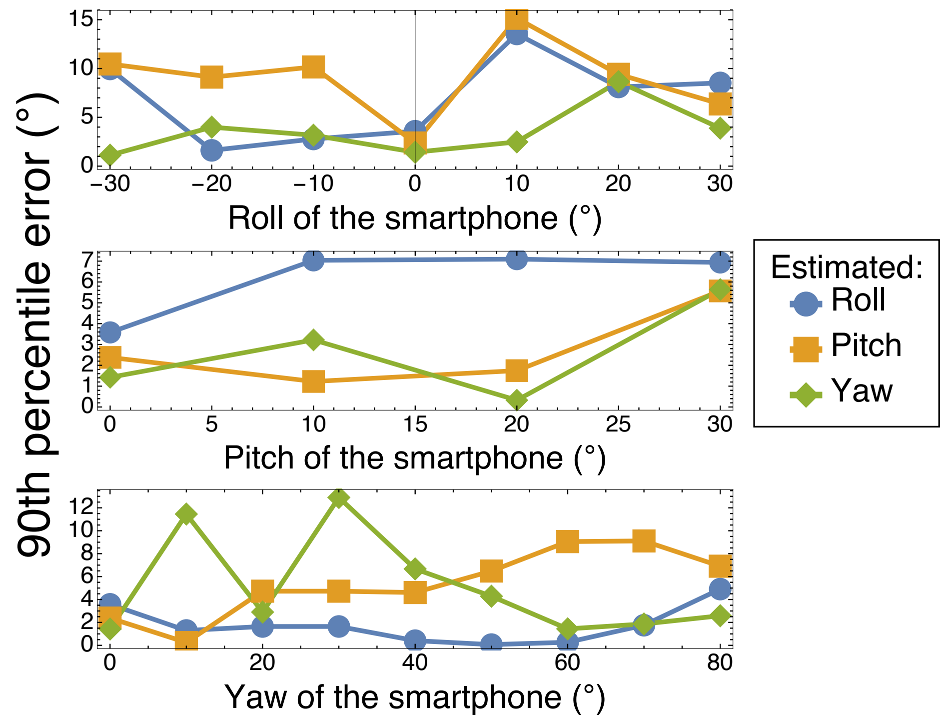


Fig. 90th percentile absolute rotation error at each posture of the smartphone.

Comparison, limitation, and future work

TABLE I. COMPARISON WITH EXISTING VLP METHODS USING LED.

	Epsilon [7]	Luxapose [4]	PIXEL [8]	Rajagopal [5]	Nakazawa [9]	Our proposal
Accuracy of position	∼0.4m	∼0.1m	∼0.3m	N/A	∼0.1m	∼0.27m
Accuracy of rotation	N/A	$\sim 3^\circ$	N/A	N/A	N/A	$\sim 5.78^\circ$
Method	Model	AoA	Polarized	PRR	Model	RSS
Coverage	5.0 m×8.0 m	1.0 m×1.0 m	2.4 m×1.8 m	3.9 m×8.0 m	1.0 m×2.4 m	4.0 m×4.0 m
Facing	Ceiling	Ceiling	Ceiling	Floor	Ceiling and floor	Floor
Distortion	No	Yes	No	Yes	Yes	No
Extra	PD	No	Filter	No	No	No
Number of LEDs	5	5	8	4	2	4
Resolution	N/A	7712×5360	120×160	1280×720	3280×2460 1472×1104	32×32×9

Smallest resolution, larger coverage, and less limitation of the receiver

Some factors cause the error

- Tilt of the smartphone
- Obstacles (shadow, object, human, and so on)

Requirement for improvement about robustness

[7] L. Li, et al.. Epsilon: A visible light based positioning system. NSDI 2014
[4] Ye-Sheng Kuo, et al.. Luxapose: Indoor positioning with mobile phones and visible light. MobiCom 2014
[8] Yang, Zhice, et al.. Wearables can afford: Light-weight indoor positioning with visible light. MobiSys 2018
[5] N. Rajagopal, et al.. Visual light landmarks for mobile devices, IPSN 2014
[9] Y. Nakazawa, et al.. Precise in- door localization method using dual-facing cameras on a smart device via visible light communication, IEICE Trans. Fundamentals, 2017.