Underwater Communication Using Visible Light

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April 9th, 2018

Outline

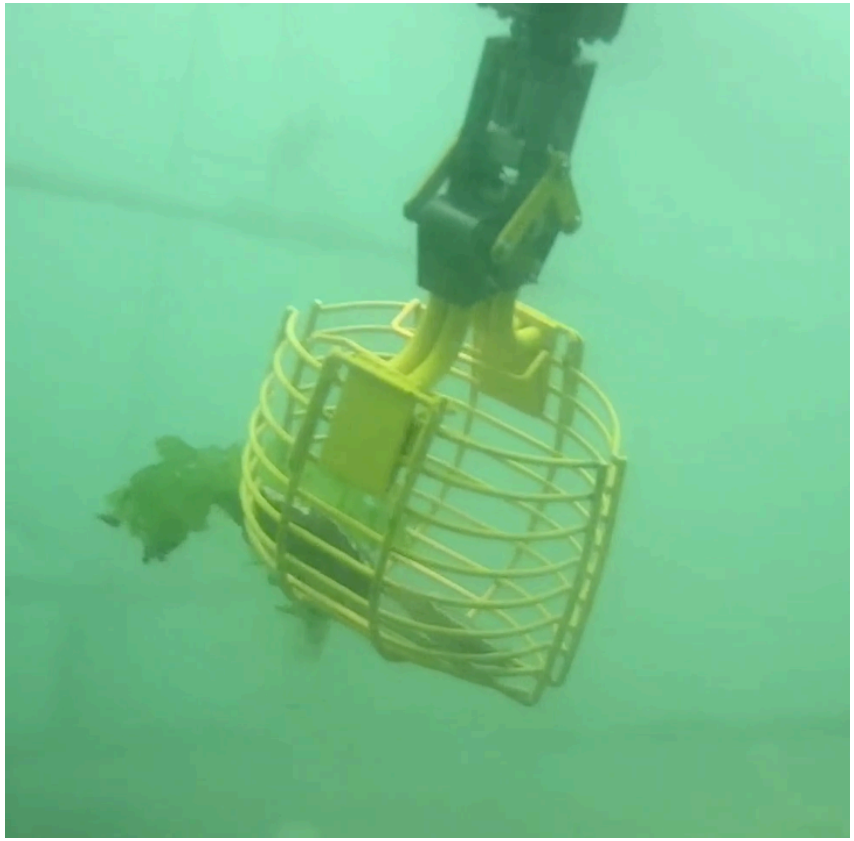
- Problem Formulation
- Related Work
- Idea
- Question and Answer

Problem Formulation

- High demand for underwater communication
  - Worker: Exchanging work progress

Problem Formulation

- High demand for underwater communication
  - Workers: Exchanging work progress
  - Machine: Knowing location and direction



Problem Formulation

- Gesture, Pipeline
  - Short distance, less information
- Wired Cable
  - Limited by complex underwater geography
- Wi-Fi
  - Extremely strong fading (transmission distance: around 0.7m)

Where light can reach, it can communicate.

–Visible Light Communication

Visible Light Communication

- Using visible light with the frequency between 400 and 800 THz (780-375 nm)
- Speed: 50 Gbps by the end of 2015
- Range: Up to 2 km (low rate)
- Components: Sensors (photodiodes or cameras) and Light Sources.

Hardware

- Transmitter
  - LED
- Receiver
  - Photodiode: BPW34, PD333, BPV10, etc.
  - Camera: Phone
- Entire prototype costs around 200 yuan ($30)

A Supplement, Not a Substitute

- Advantages
  - Fast
  - Cheap
- Disadvantages
  - Downwards only
  - Dying in the sun
  - Susceptible to interference

Related Work

- Xinyu Zhang, University of California San Diego.
  - Indoor Localization (Mobicom’17, Mobisys’17, Mobicom’16)
  - Privacy Protection (Mobicom’17)
- Nan Chi, Fudan University.
  - Increasing Speed
- Peking University
  - IoT Application (Mobicom’17)
- National Taiwan University, National Chiao Tung University
  - Localization (Mobisys’17)

Pulsar: Towards Ubiquitous Visible Light Localization

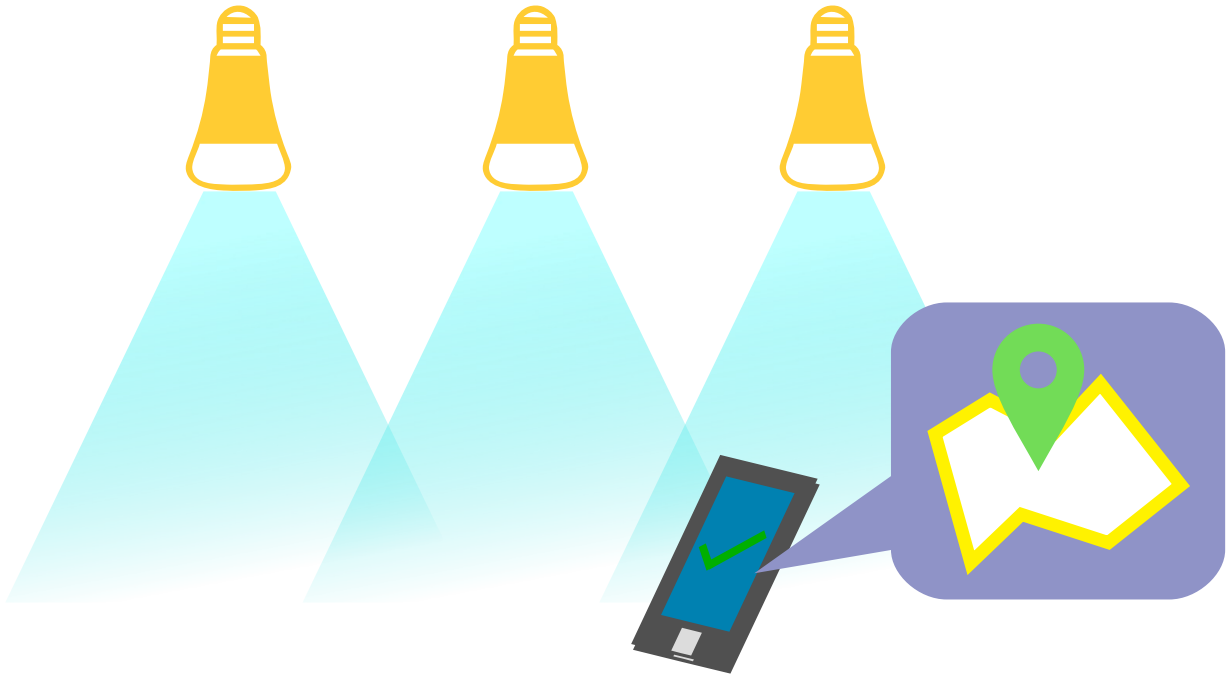
Chi Zhang, Xinyu Zhang

MobiCom'17

WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

UC San Diego

Visible Light Localization

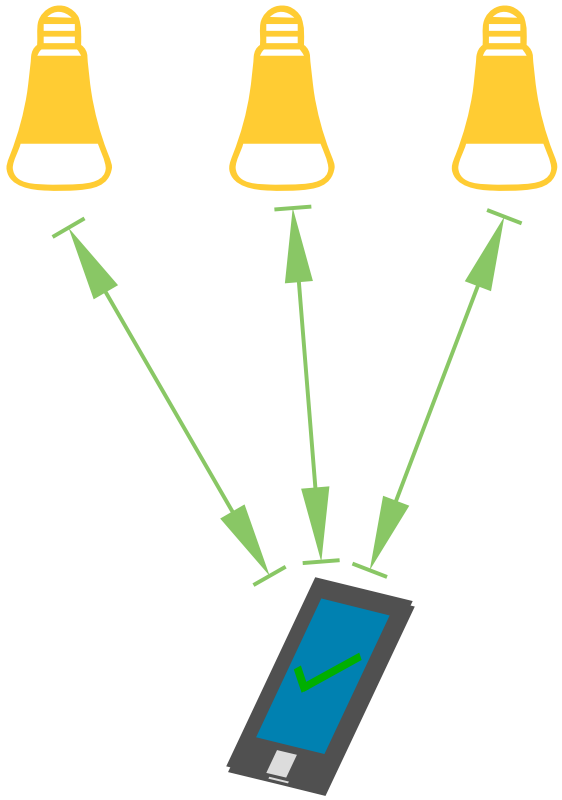


Accurate

Robust

Existing Solutions

- Photodiodes
  - Compact
  - Low-power
  - RSS Propagation Modeling

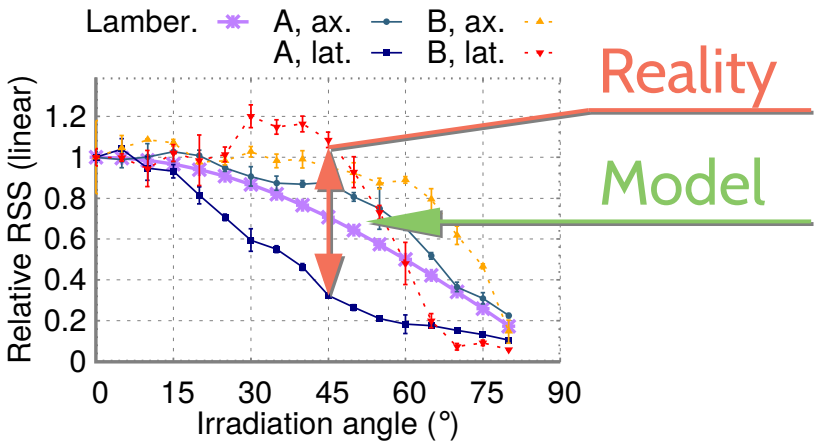


Existing Solutions

- **Photodiodes**

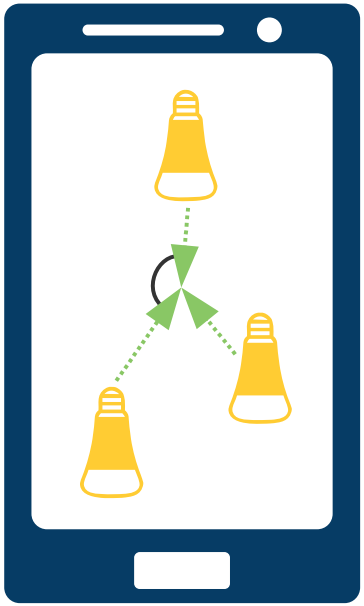
  Channel Model is **Unrealistic** for Fixtures

  Partial Shadowing and Blockage **Breaks** Model



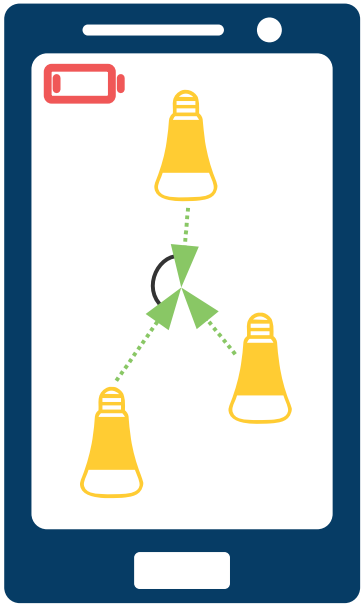
Existing Solutions

- Cameras
  - Accurate
  - Robust
  - Triangulation with Photogrammetry

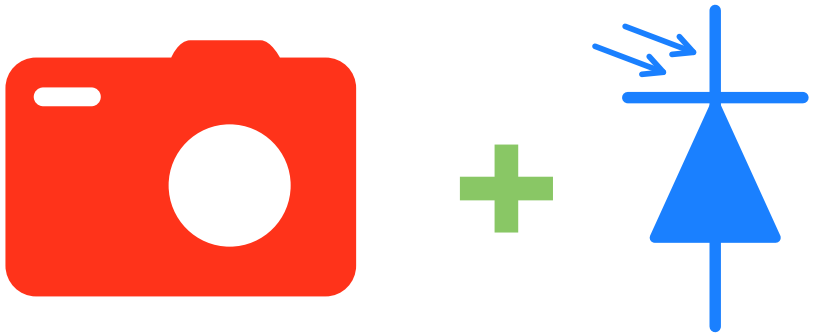


Existing Solutions

- Cameras
  - Narrow Field of View
  - High Energy Consumption
  - Long Latency

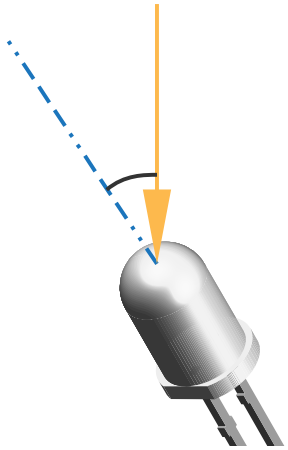


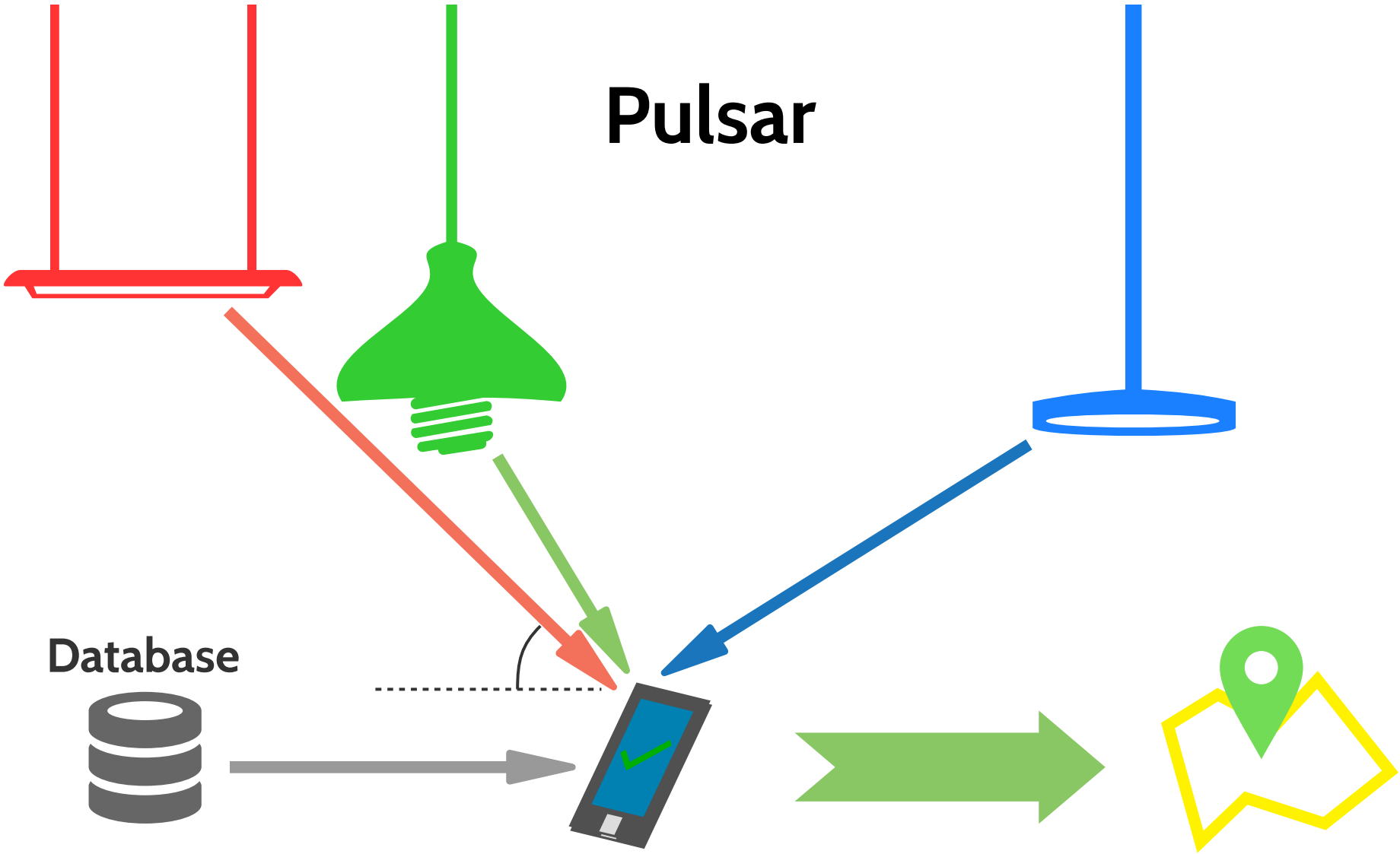
Achieve Accurate and Low-power Localization



Achieve Accurate and Low-power Localization

Sense Angle of Arrival with Photodiodes

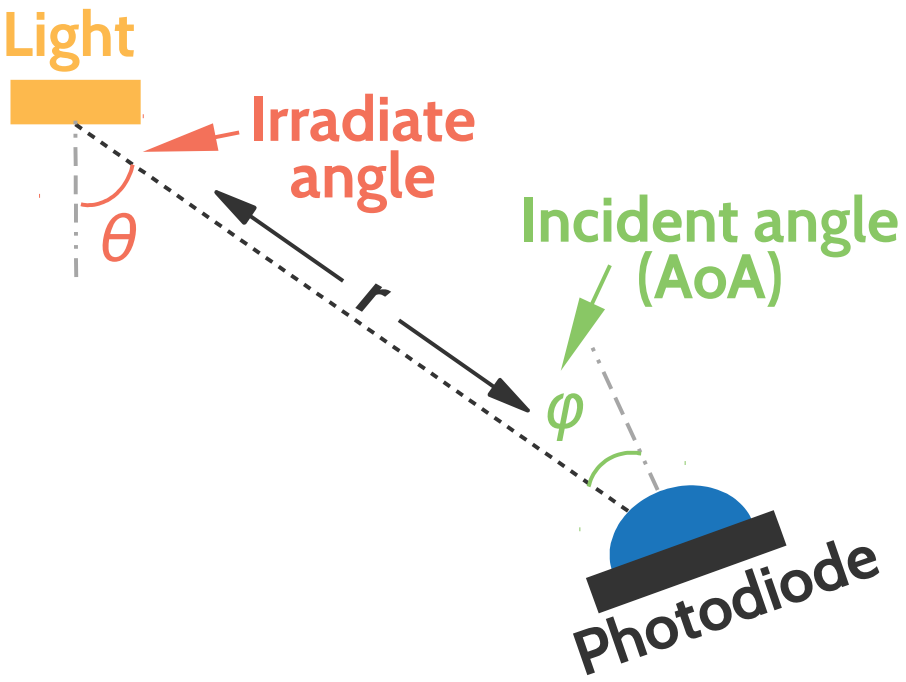



Pulsar
Database

Sensing AoA with Photodiodes

- Review **Channel Model**

$$\text{RSS} = P_t\, A_t(\theta)\, \alpha(r)\, A_r(\varphi)$$



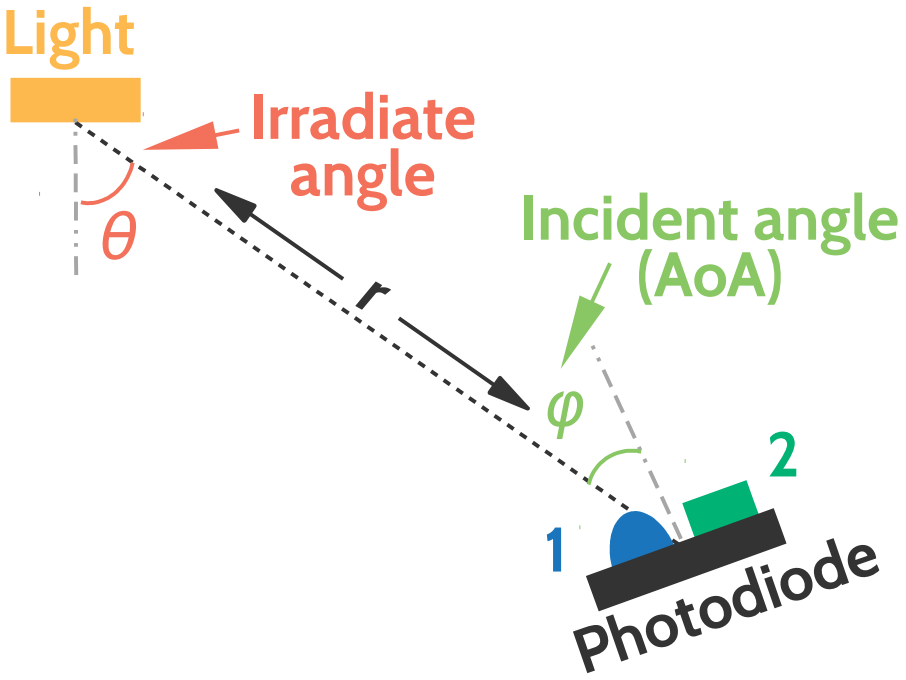
Sensing AoA with Photodiodes

Review Channel Model

$$\text{RSS} = P_t\, A_t(\theta)\, \alpha(r)\, A_r(\varphi)$$

$$\text{RSS}_1 = P_t\, A_{t1}(\theta_1)\, \alpha(r_1)\, A_{r1}(\varphi_1)$$

$$\text{RSS}_2 = P_t\, A_{t2}(\theta_2)\, \alpha(r_2)\, A_{r2}(\varphi_2)$$



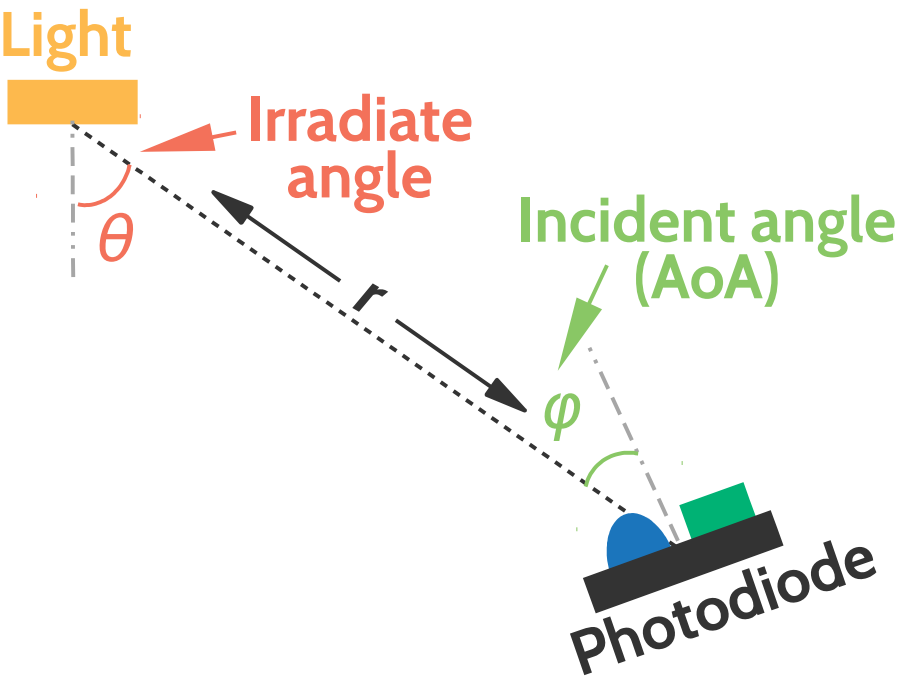
Sensing AoA with Photodiodes

- Review **Channel Model**

$$RSS_1 = P_t A_{t1}(\theta_1)\,\alpha(r_1)\,A_{r1}(\varphi_1)$$
$$RSS_2 = P_t A_{t2}(\theta_2)\,\alpha(r_2)\,A_{r2}(\varphi_2)$$

Co-located → Same

Different

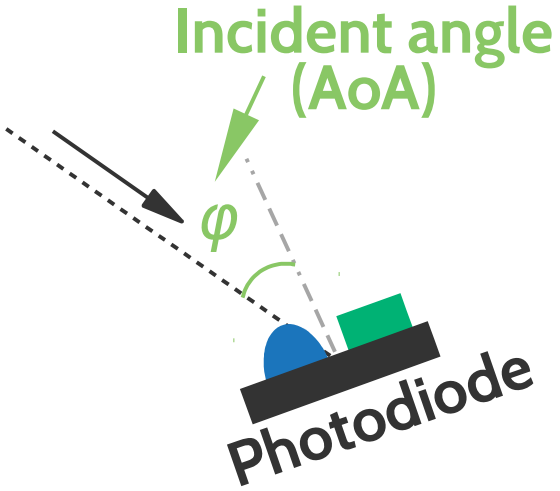


Sensing AoA with Photodiodes

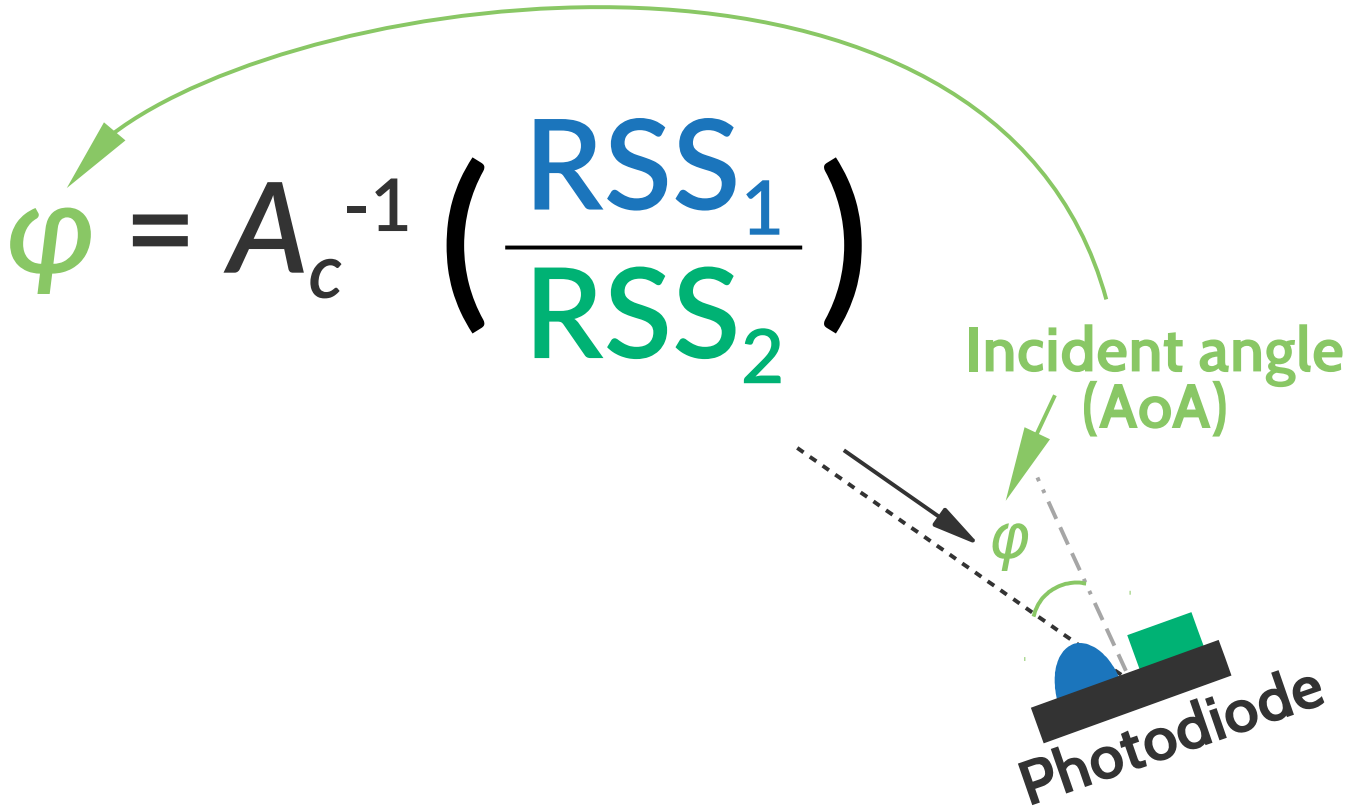
Assumptions on light are gone!

$$\frac{RSS_1}{RSS_2} = \frac{A_{r1}(\varphi_1)}{A_{r2}(\varphi_2)} = A_c(\varphi)$$

Fixed once manufactured



Sensing AoA with Photodiodes

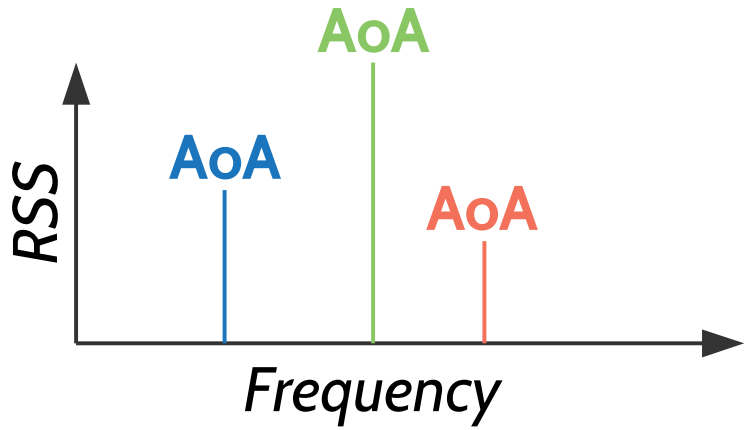


Sensing AoA with Photodiodes

$$\varphi(f) = A_c^{-1}\left[\frac{RSS_1(f)}{RSS_2(f)}\right]$$

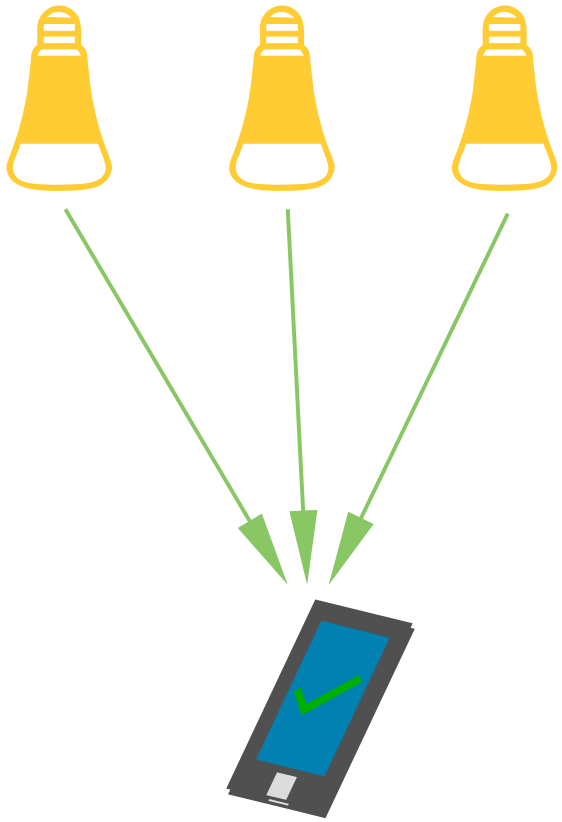
RSS at each frequency

AoA at each frequency



Light Extraction

Triangulation: >= 3 lights required

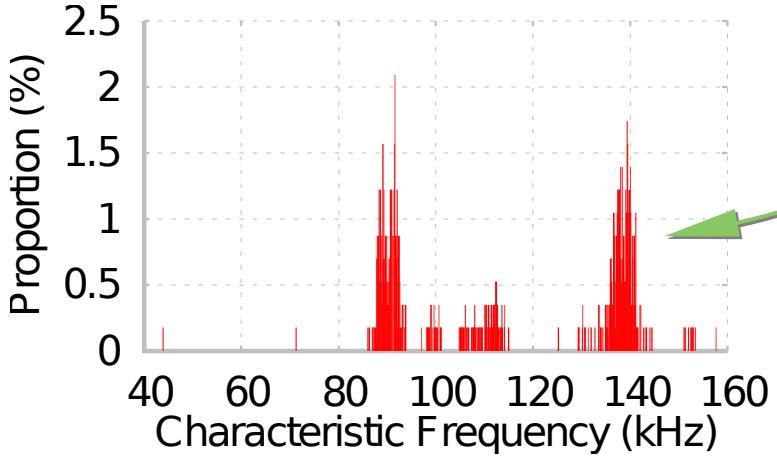


Light Extraction

Triangulation: >= 3 lights required

Separate from spectrum:

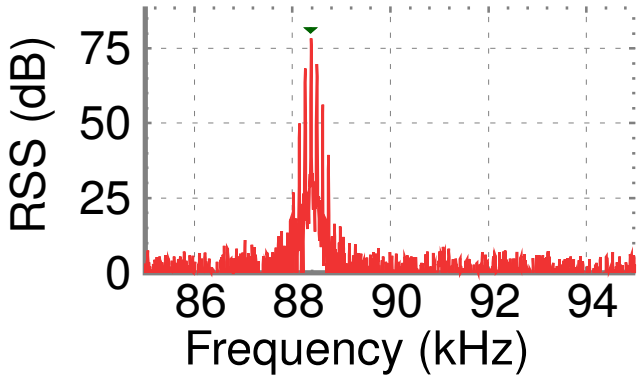
Leverage diversity in **Characteristic Frequency**



(LiTell, MobiCom'16)

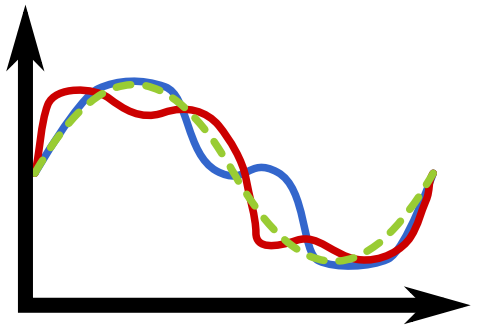
Light Extraction

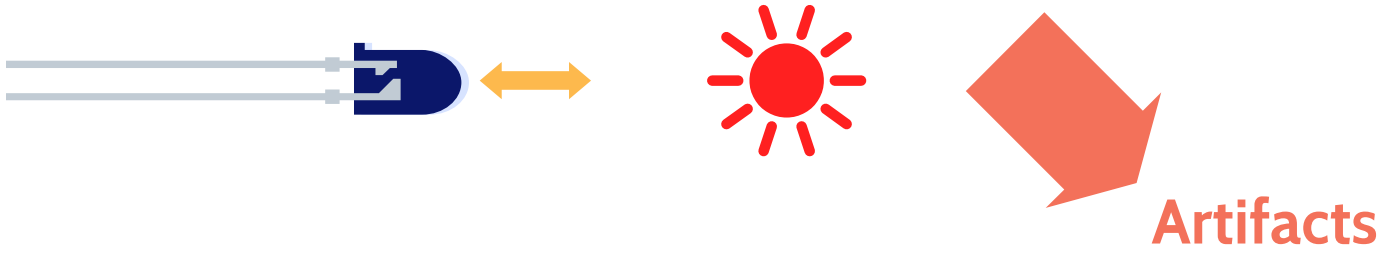
🔍 Spurious peaks!



Light Extraction

- **Causes:**
  - Powerline harmonics
  - User motion





Light Extraction

- **Causes:**
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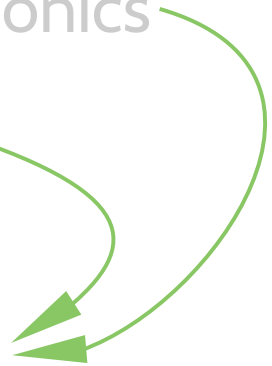
  - User motion
- **Observe:**
  - AoA unaffected
  - Same AoA = from the Same Light



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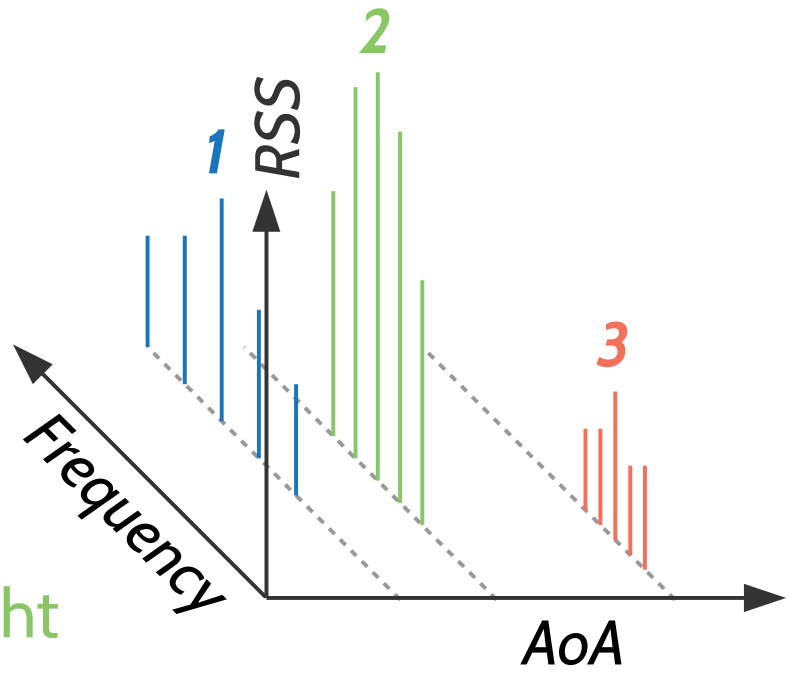


Separate by AoA Clusters

Light Identification

- **Frequency to ID:**
  - Match individual lights = poor accuracy

Light Identification

- **Frequency to ID:**
  - Match individual lights = poor accuracy
- **Observe:**
  - Correct match likely in ones with lowest freq error
  - Lights in Field-of-View are close to each other

Light Identification

- **Solution:**
  - Identify by whole group of lights
  - Each frequency = 2~3 candidate ID

  ✅ Tightly-packed group with low freq error

Localization

Triangulation:

- 3D coordinates from 3 vector equations
- >= 4 lights: solves orientation

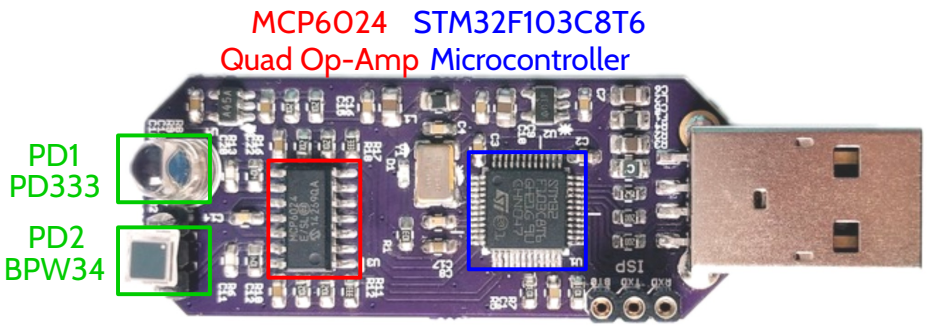
Light Registration

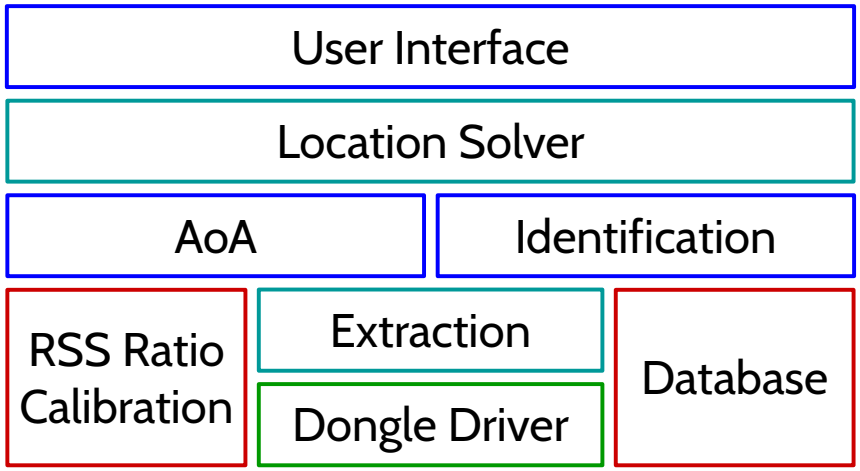
- **Registration is hard work**
  - Even **smart bulbs** do not know their **own locations**!

Light Registration

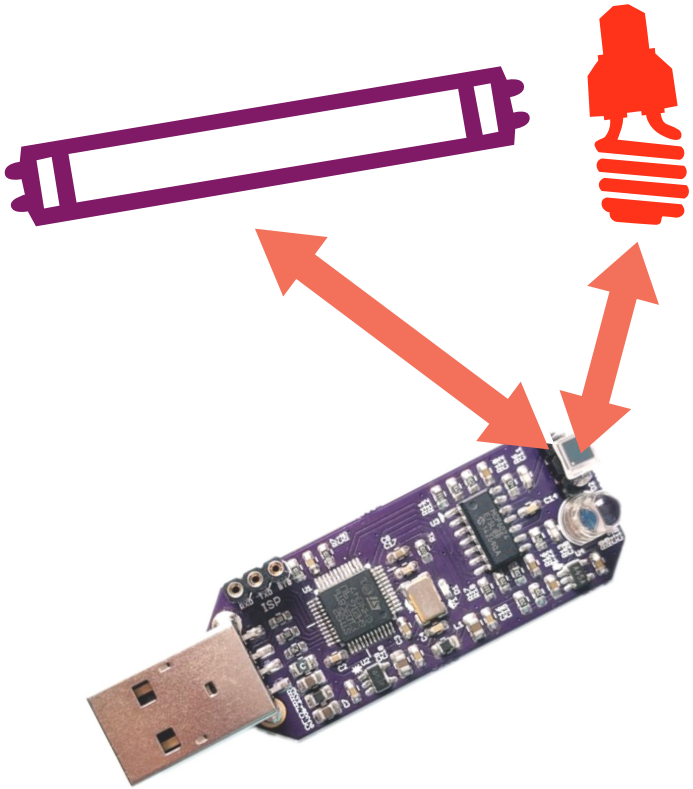
- Registration is hard work
  - Even **smart bulb** does not know its **own location**!
- **Motion tracking with Tango**
  - Record relative location during survey
  - Map to absolute location on map
  - ✅ Eliminates complicated measurements

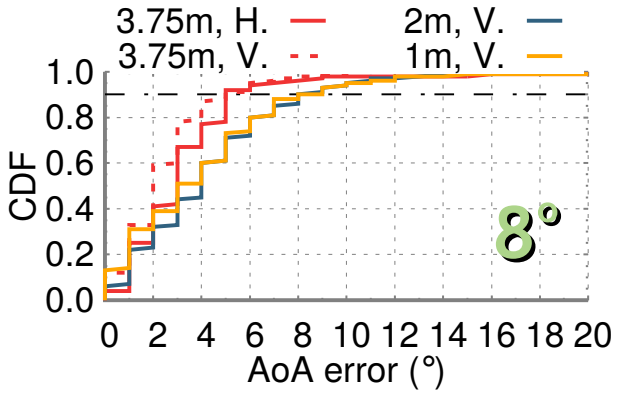
Implementation

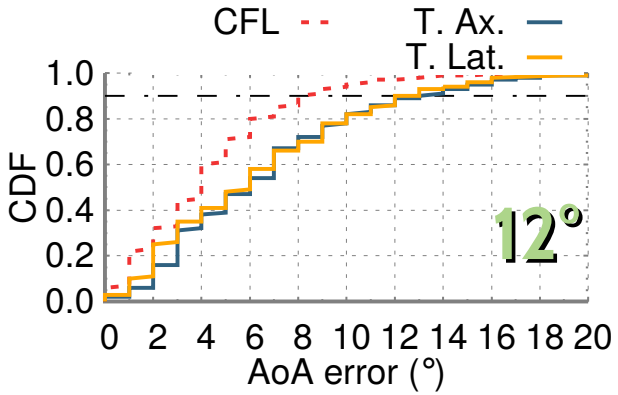




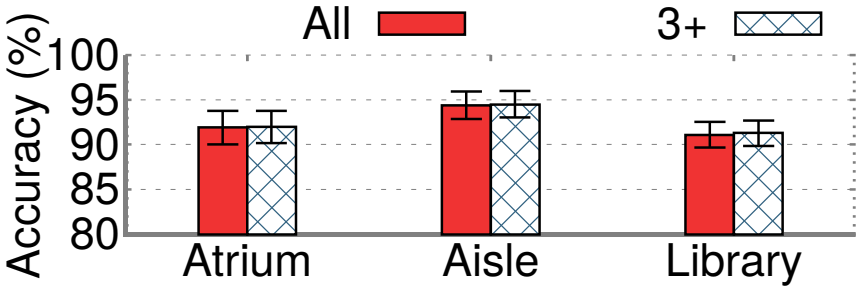
Accuracy of AoA Sensing



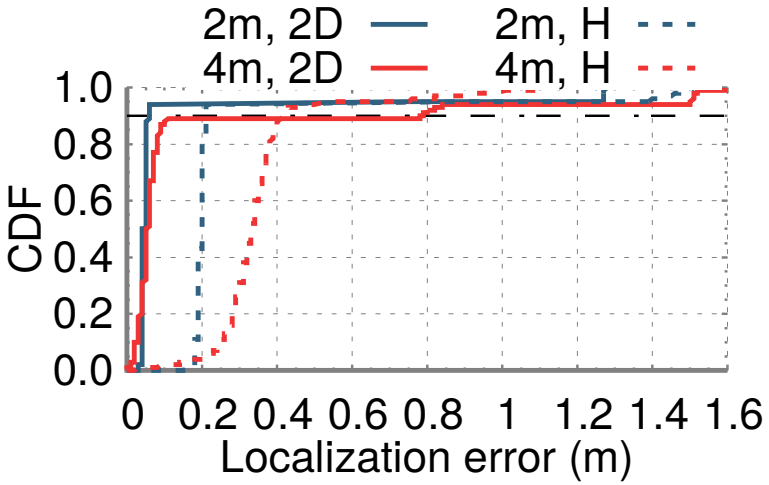


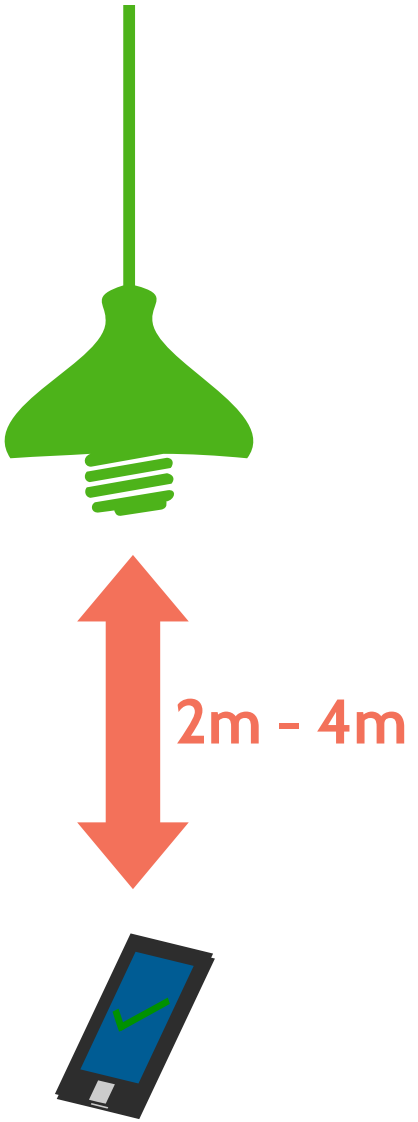


Identification

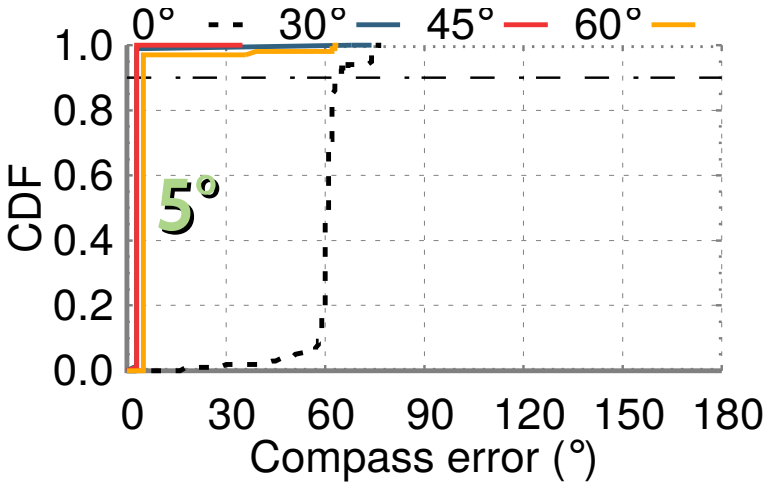


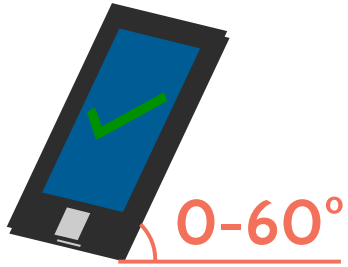
Localization



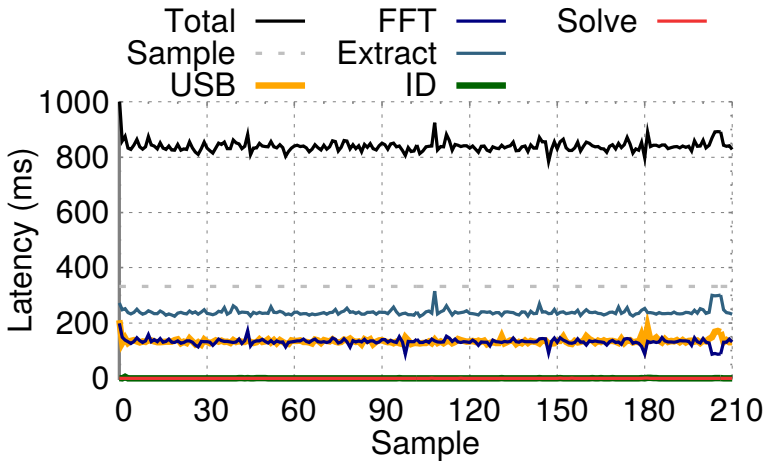


Orientation



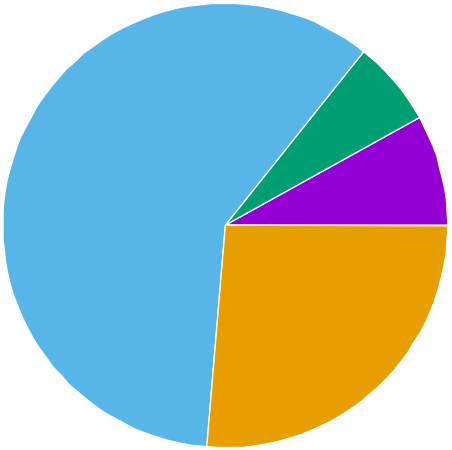


Latency


Total
Sample
USB
FFT
Extract
ID
Solve
1000
800
600
400
200
0
Latency (ms)
0
30
60
90
120
150
180
210
Sample


50%

Energy



Dongle
150 mW
8.1%

USB Loss
116 mW
6.2%

Idling
1105 mW
59.4%

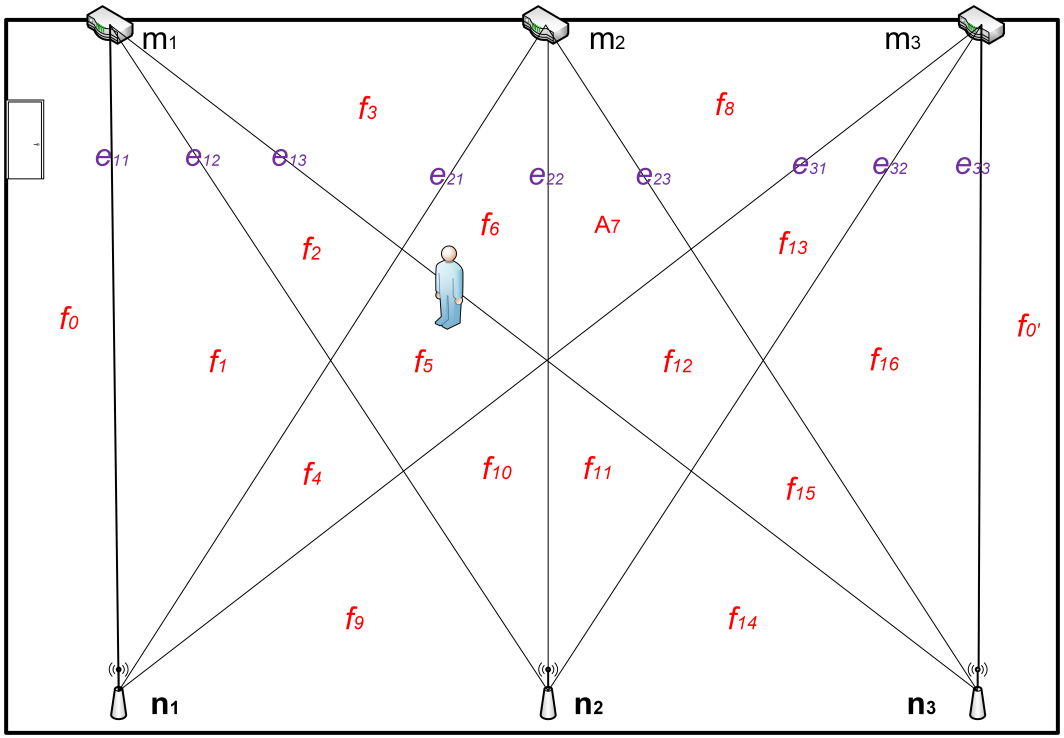
Processing
489 mW
26.3%

63% Power

82% Energy per Location

Idea

- Feature of Line of Sight (LoS)
- Tracking —> Coarse-grained Localization —> Fine-grained Localization
- Simple, Fast and Energy Efficient



Question and Answer

- For this slides, please scan the QR code and visit my blog.

- For paper and slides mentioned in my talk, please visit the homepage of the author.

  - Zhang C, Zhang X. Pulsar: Towards Ubiquitous Visible Light Localization[C]//Proceedings of the 23rd Annual International Conference on Mobile Computing and Networking. ACM, 2017: 208-221.

  - http://dword1511.info/me/