LiTell: Robust Indoor Localization Using Unmodified Light Fixtures

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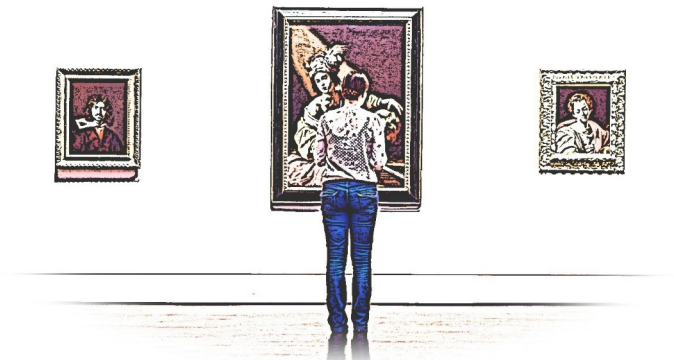
MobiCom'16

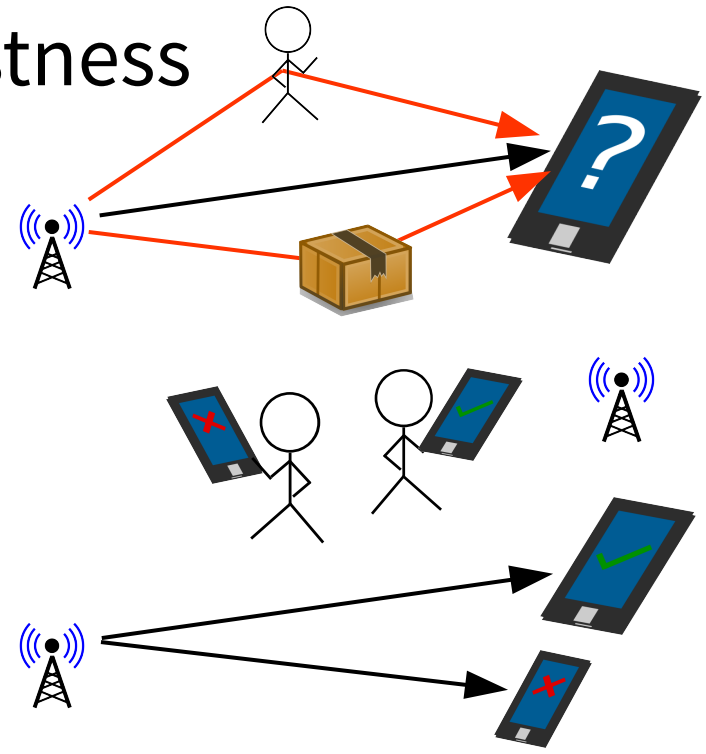
Indoor Localization: Enabling Technology



RF-based Localization

Multiple factors compromise robustness

- Multipath propagation
- Environmental dynamics
- Device heterogeneity



Visible Light Localization

- LoS propagation: **robust, multipath-free**
- Densely deployed landmarks: **high accuracy**

  Existing works show **10cm** to **1m** accuracy[1]

[1] Y.-S. Kuo, et al., “Luxapose”, MobiCom'14; L. Li, et al, “Epsilon”, NSDI'14

Deployment Challenges

LED beacons needs **extra circuits**

Adds to **manufacturing cost**

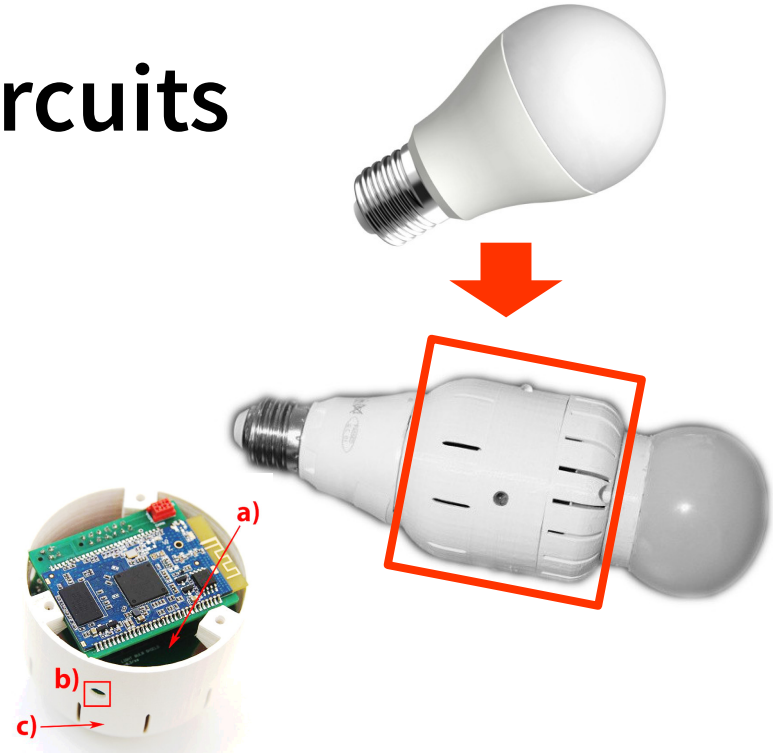
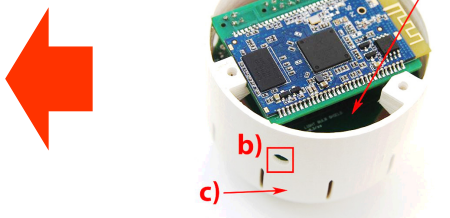


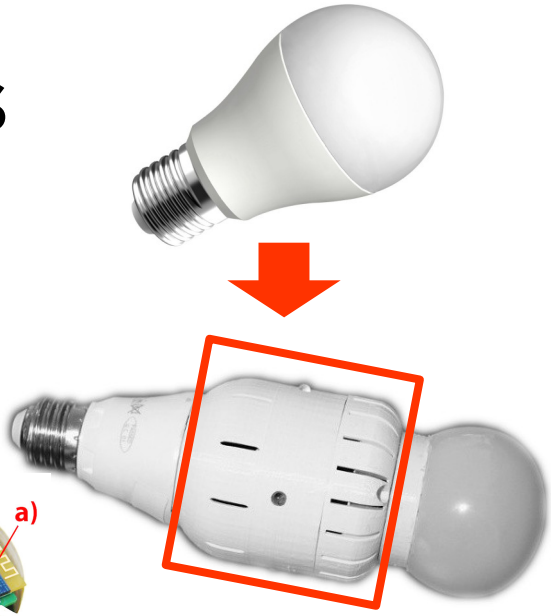
Image of lights: S. Schmid, et al. “Linux Light Bulbs”, VLCS'15

Deployment Challenges

LED beacons needs **extra circuits**

- Adds to **manufacturing cost**
- Huge **retrofitting effort**





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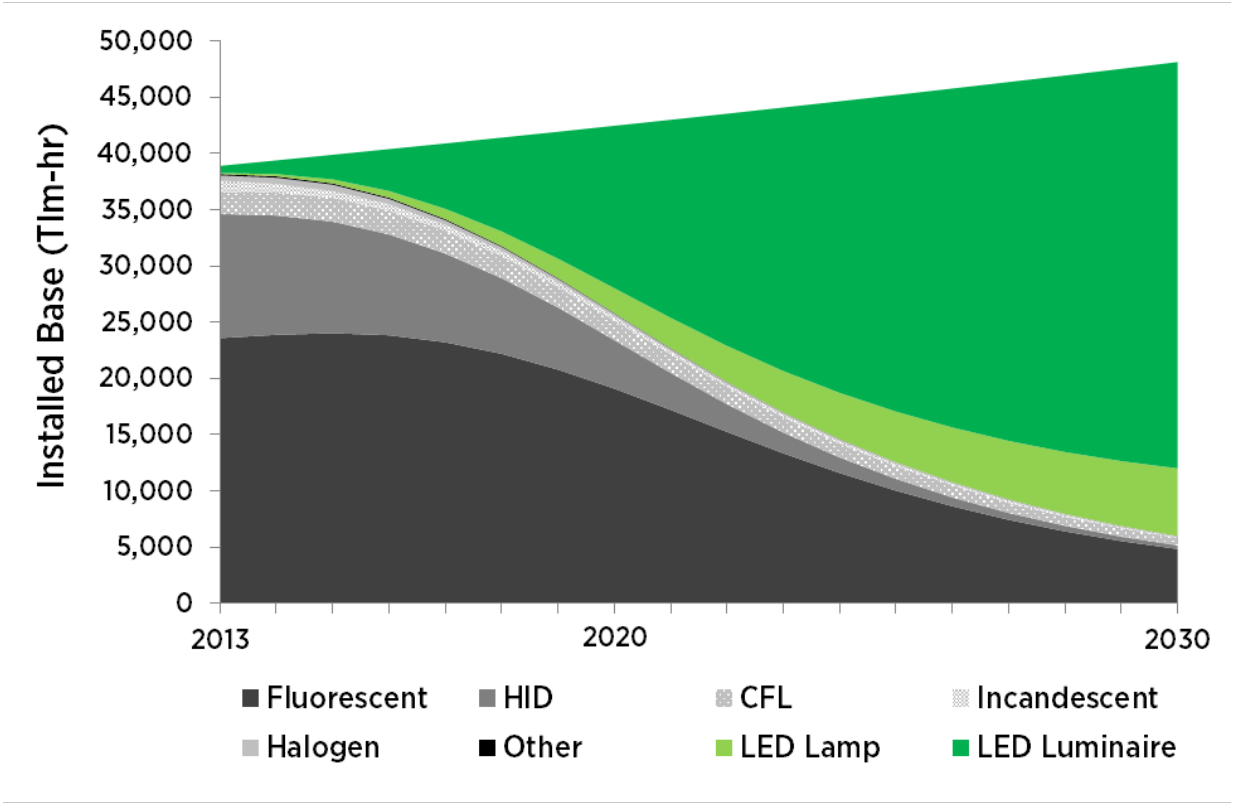

Source:
US DoE

LiTell

- Landmark: **unmodified fluorescent light fixtures**
- Sensor: **smartphone cameras**
- **Zero** retrofitting cost!

Localization Using Incumbent Lights

Fluorescent light driver operates at **high frequency**

This frequency is reflected in the **light emission**

It is unique due to manufacturing variations,

hence we call it "characteristic frequency" (CF)

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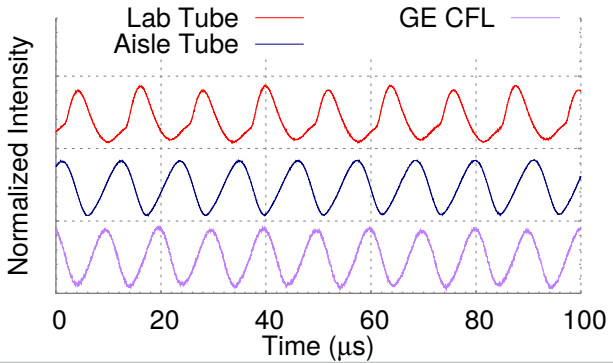
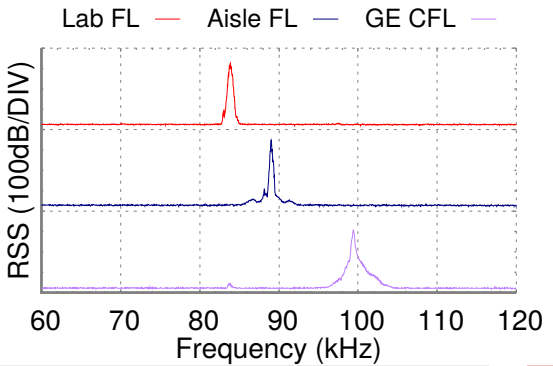
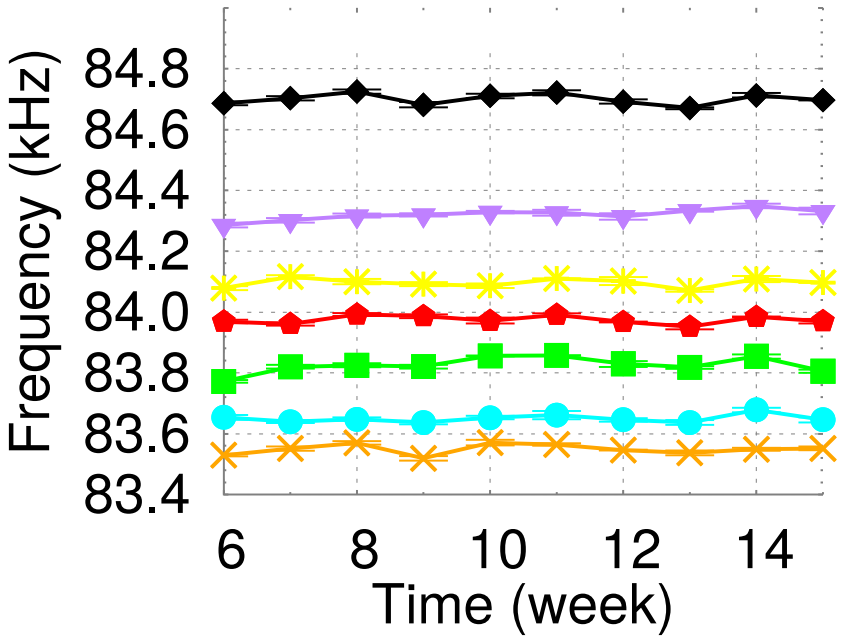


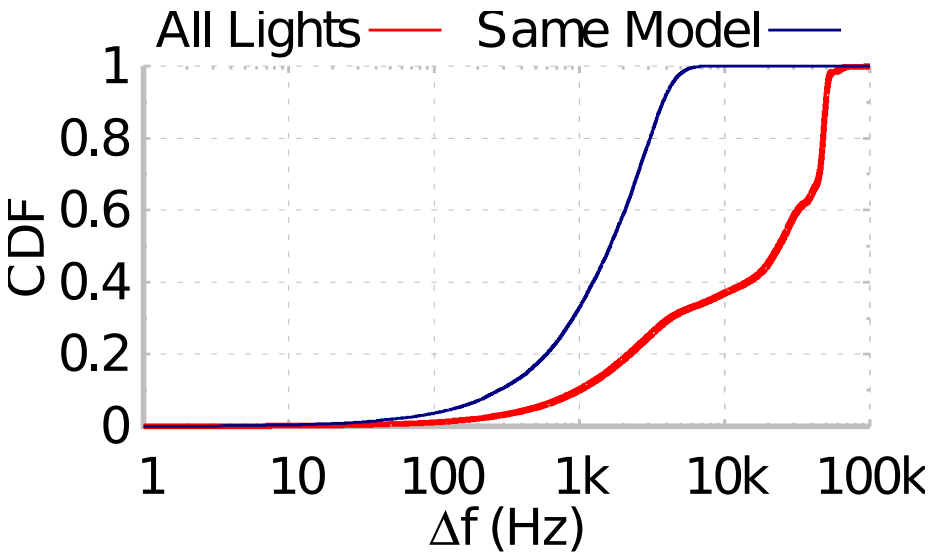


Characteristic Frequency (CF)

7 lights in our lab



500 lights in an office building



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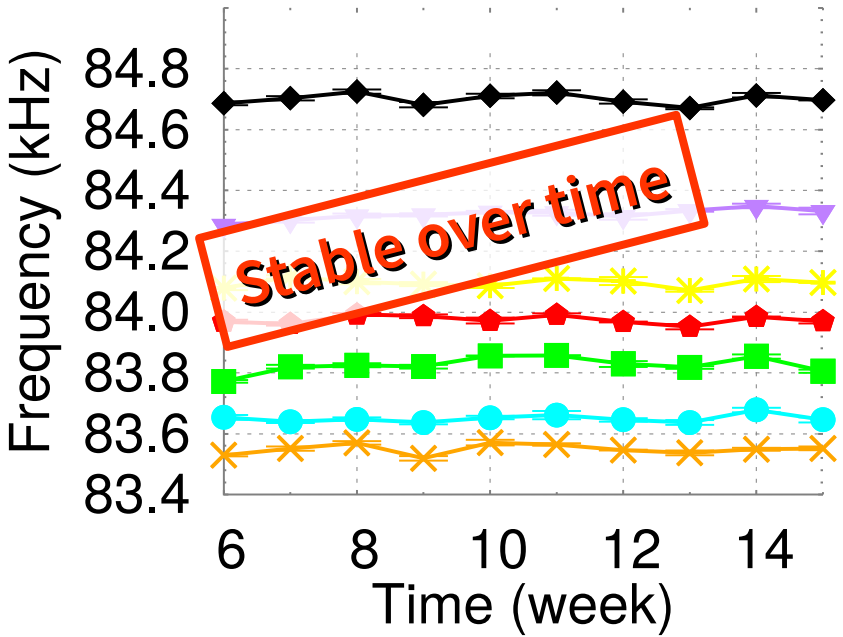

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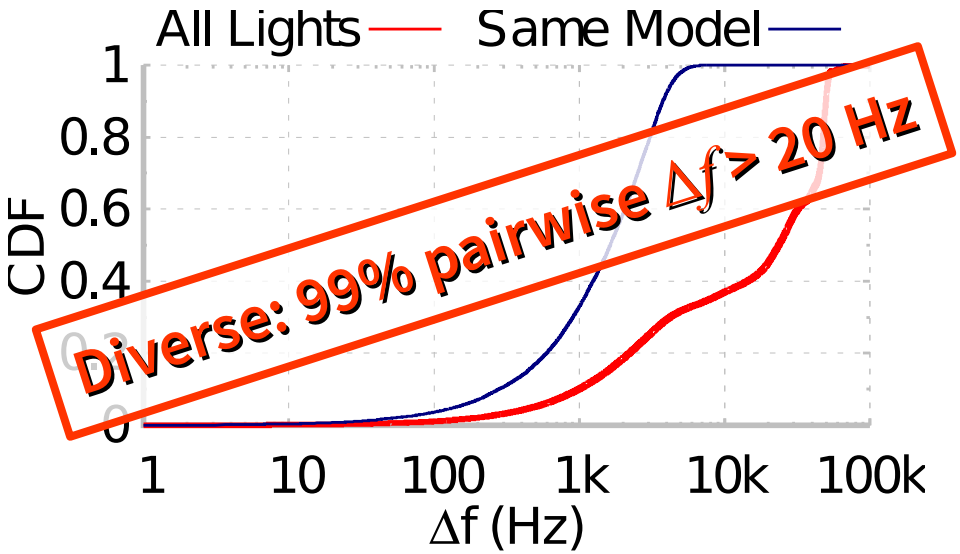


Capturing CF on Phones

COTS phones do not have **high speed light sensors.**

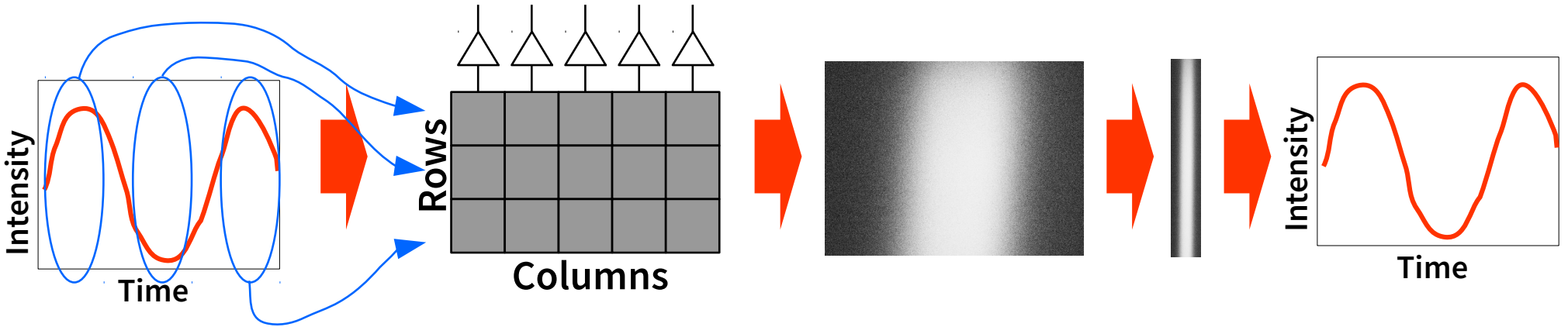
Instead, we can use **cameras**.

Key Challenges:

- **Low sampling rate**
- **Low SNR**

Sampling CF

Rolling shutter: a primer

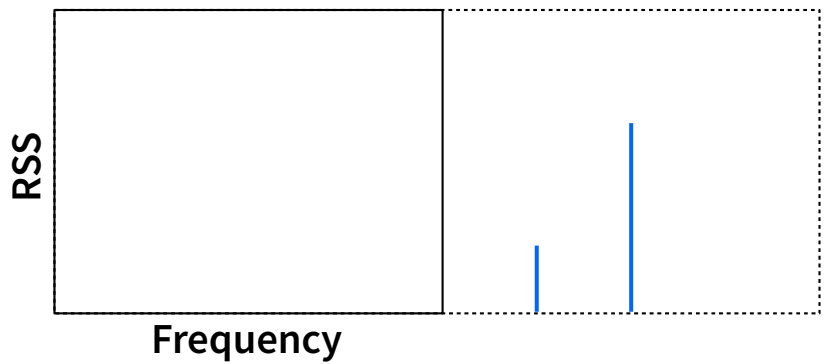


Key benefits: higher sampling rate, reliable timing

Sampling CF

Typical smartphone has sampling rate of **56 ~ 105 kHz**

CFs are around **80 ~ 100 kHz**, need Nyquist sampling rate **> 200 kHz**



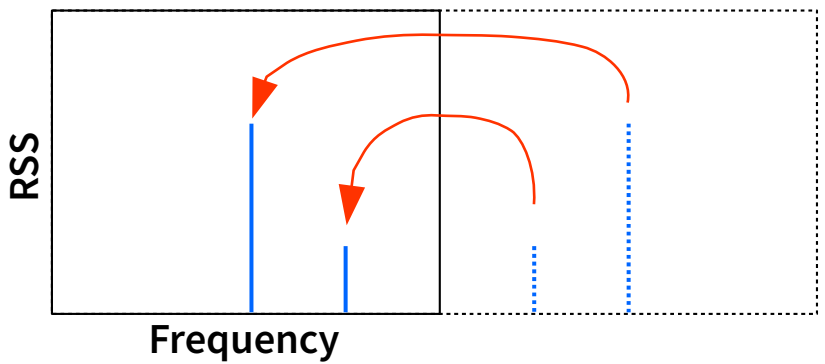
Sampling CF

Typical smartphone has sampling rate of **56 ~ 105 kHz**

CFs are around **80 ~ 100 kHz**, need Nyquist sampling rate **> 200 kHz**

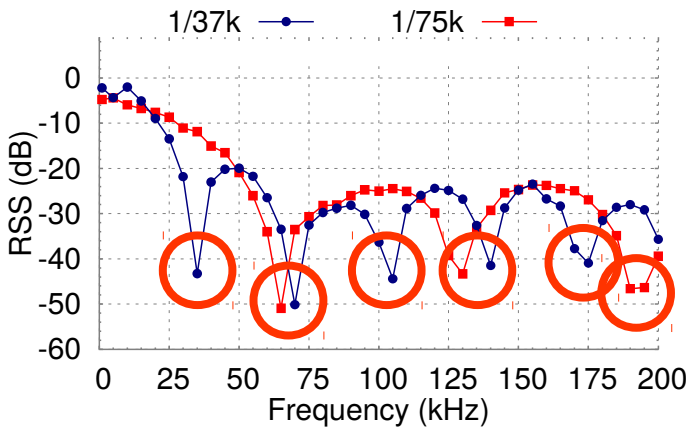
Observation: **CF is extremely sparse**

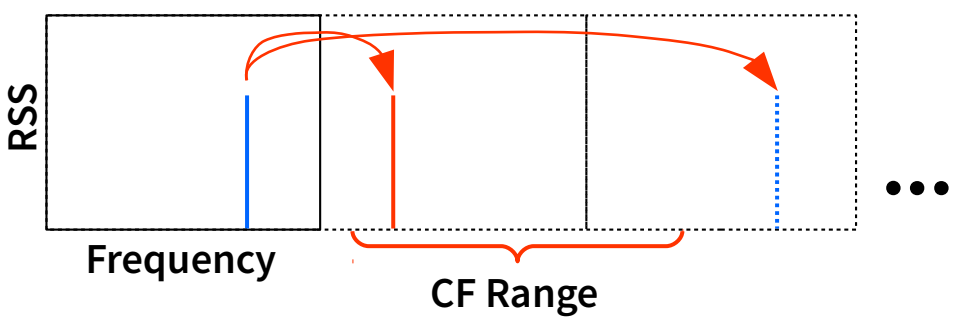
Solution: **leverage aliasing effect**
(If the analog bandwidth suffices!)



Sampling CF

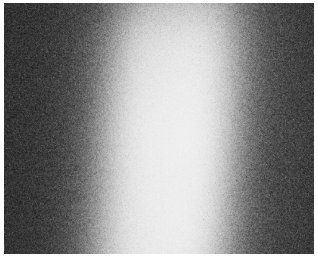
- Camera's analog bandwidth: up to **200 kHz**
- **Adaptive exposure** to avoid notches
- **De-aliasing** mechanism to disambiguate CF

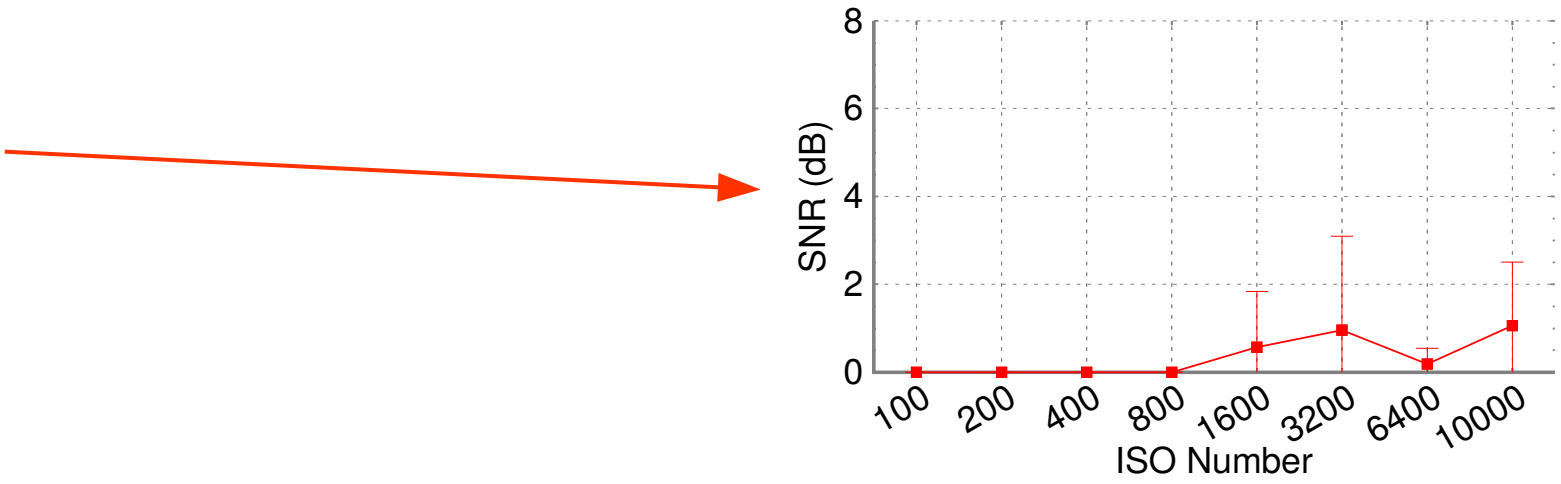




Boosting SNR

Noise from **dark areas** / **ambient sunlight** reduces SNR.

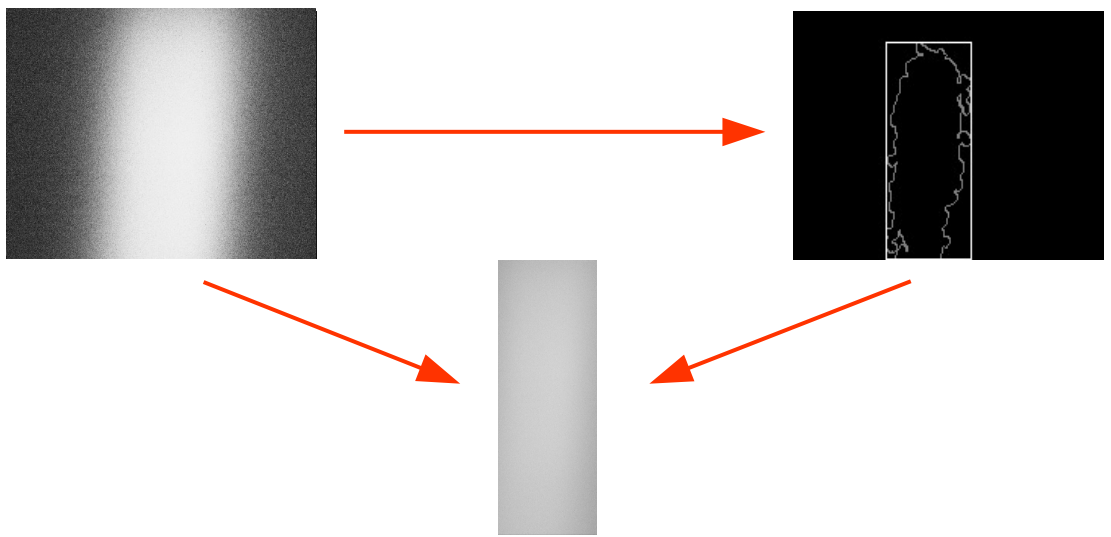


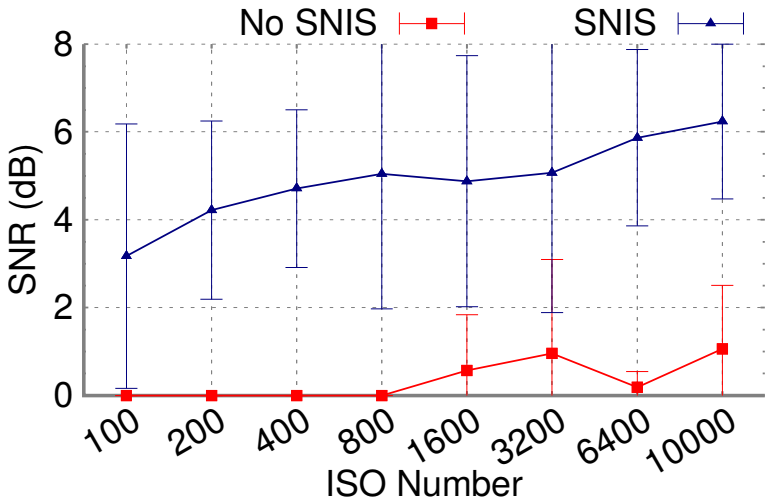


Boosting SNR

Noise from **dark areas** / **ambient light** reduces SNR.

SNIS: fast spatial noise removal tailored for lights

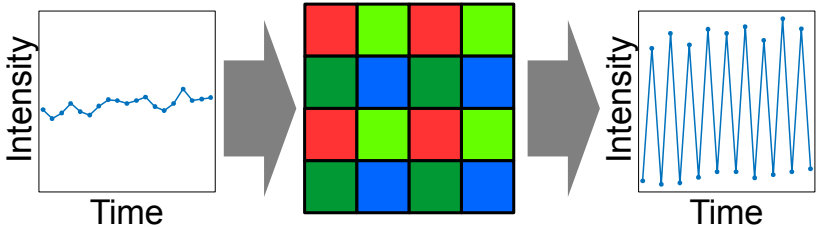




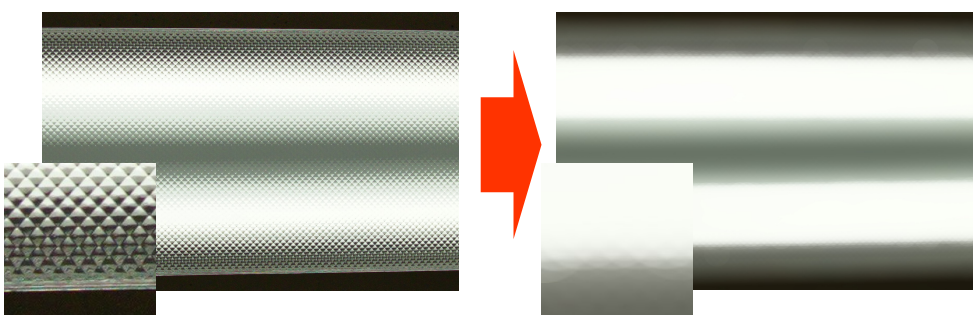
Boosting SNR

Artifacts:

- **Interleaving:** from camera



- **Spatial patterns:** from light cover

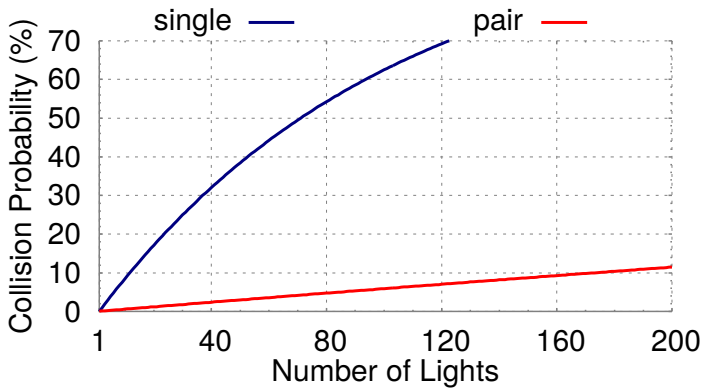


Localization

Identifying individual lights:

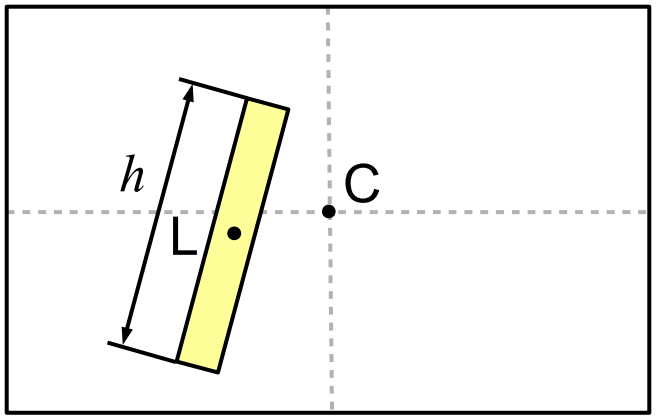
collision rate grows as more lights are added in database

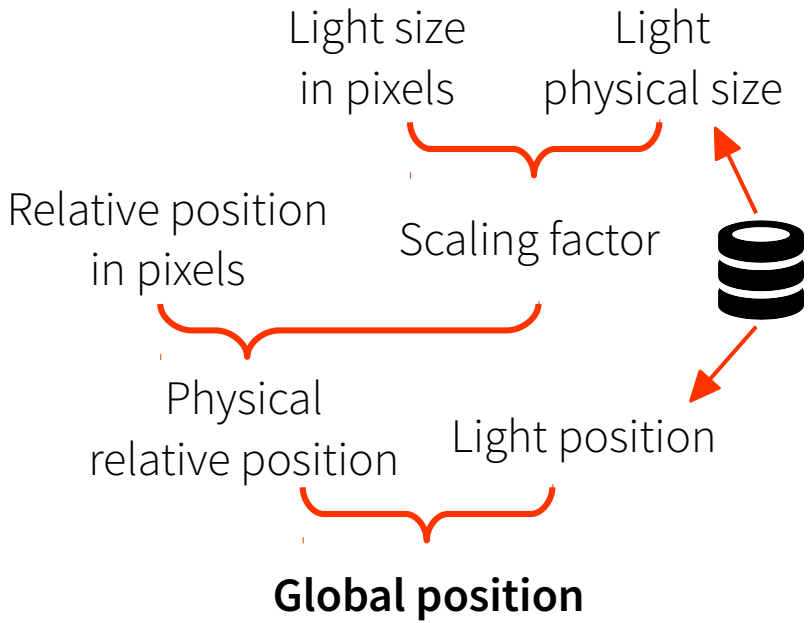
Error control mechanism: **using pairs of consecutive lights**



Localization with Respect to a Specific Light

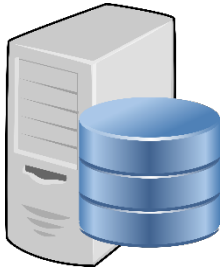
Observation: **images are scaled from physical structure**





Implementation

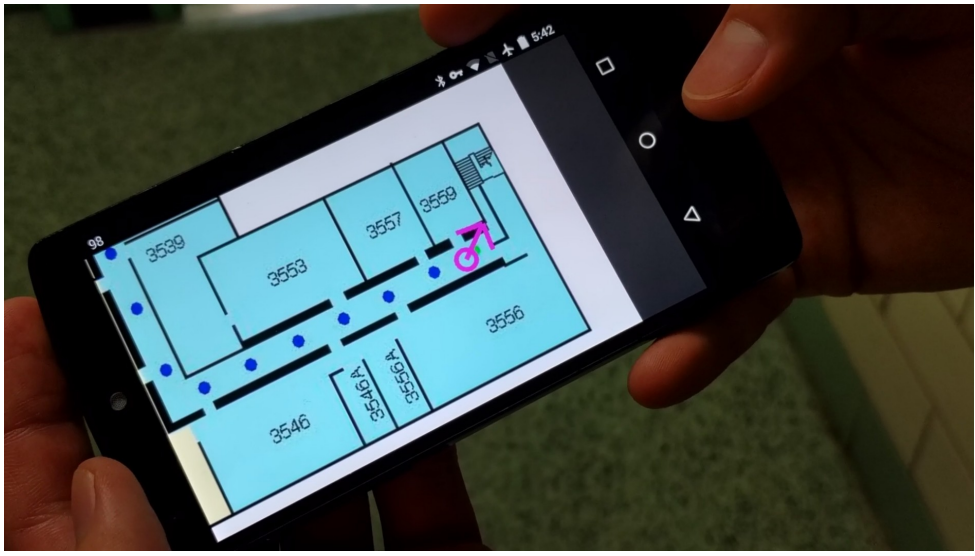
LiTell Server



Send ceiling light samples

Return current location

LiTell Android App



Experimental Evaluation

- Robustness
- Accuracy
- User study

Robustness

Distance: up to 2m with typical smartphone camera

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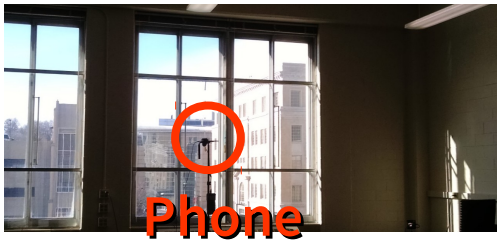
Ambient light: works by the window with direct sun light

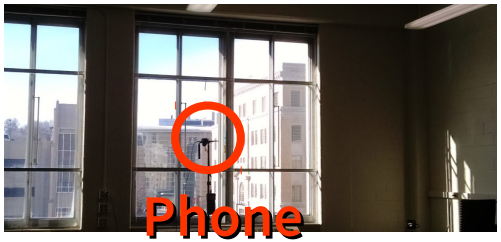


Robustness

Distance: up to 2m with typical smartphone camera

Ambient light: works by the window with direct sun light

User behavior: unaffected by normal pose and walking

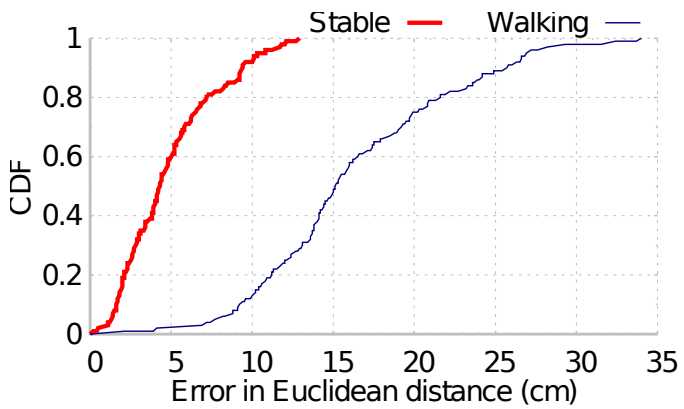


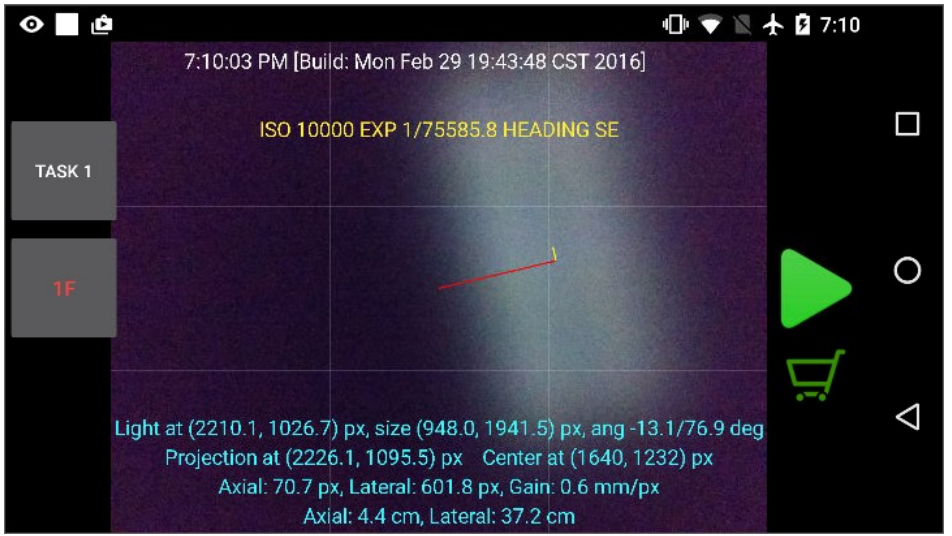
Light Identification Accuracy

Landmark Identification: **90.3%** accuracy in typical places

Localization Precision

Localization w.r.t. each light: 10cm in ideal case, ~**25cm** when walking

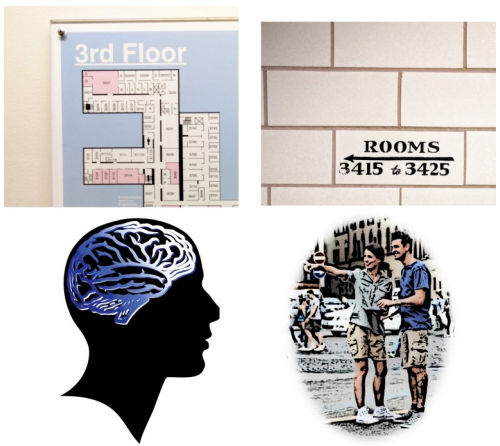




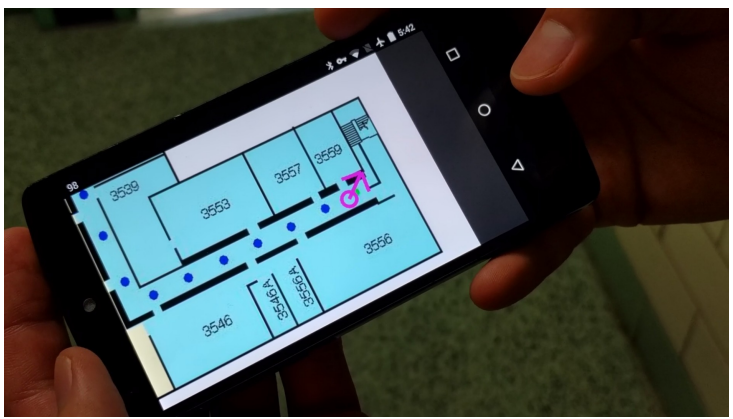
User Study

1 office building, 2 floors, 6 targets, 10 volunteers.

Find room by number.



Control Group



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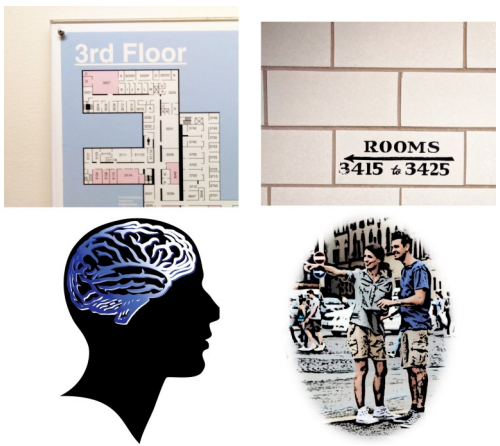

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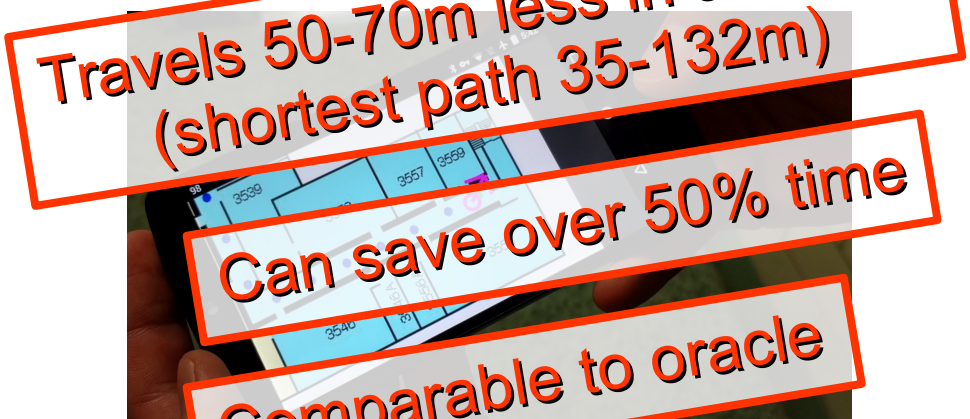
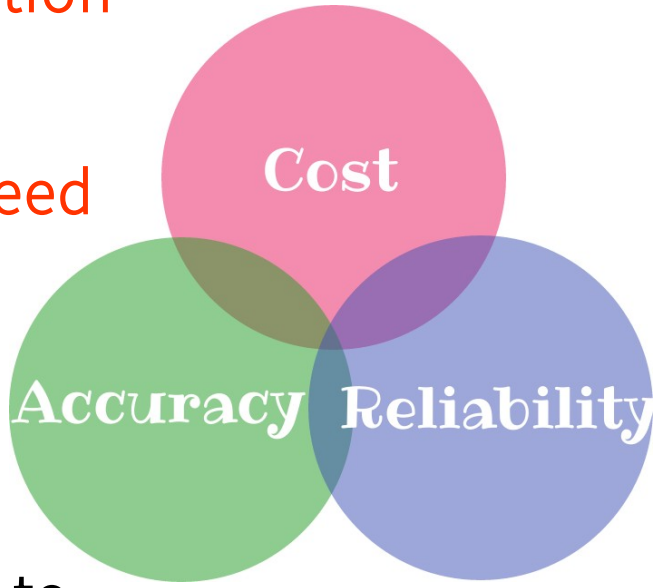


LiTell Group

Conclusion

- LiTell uses fluorescent lights as zero-cost location landmarks
- LiTell turns smartphone cameras into high speed light sensors
- Deterministic visible light channel assures LiTell's accuracy and robustness
- LiTell brings accurate visible light localization to today's buildings



Thanks!