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Smartphone Positioning and 3D Mapping Indoors

Ruizhi Chen

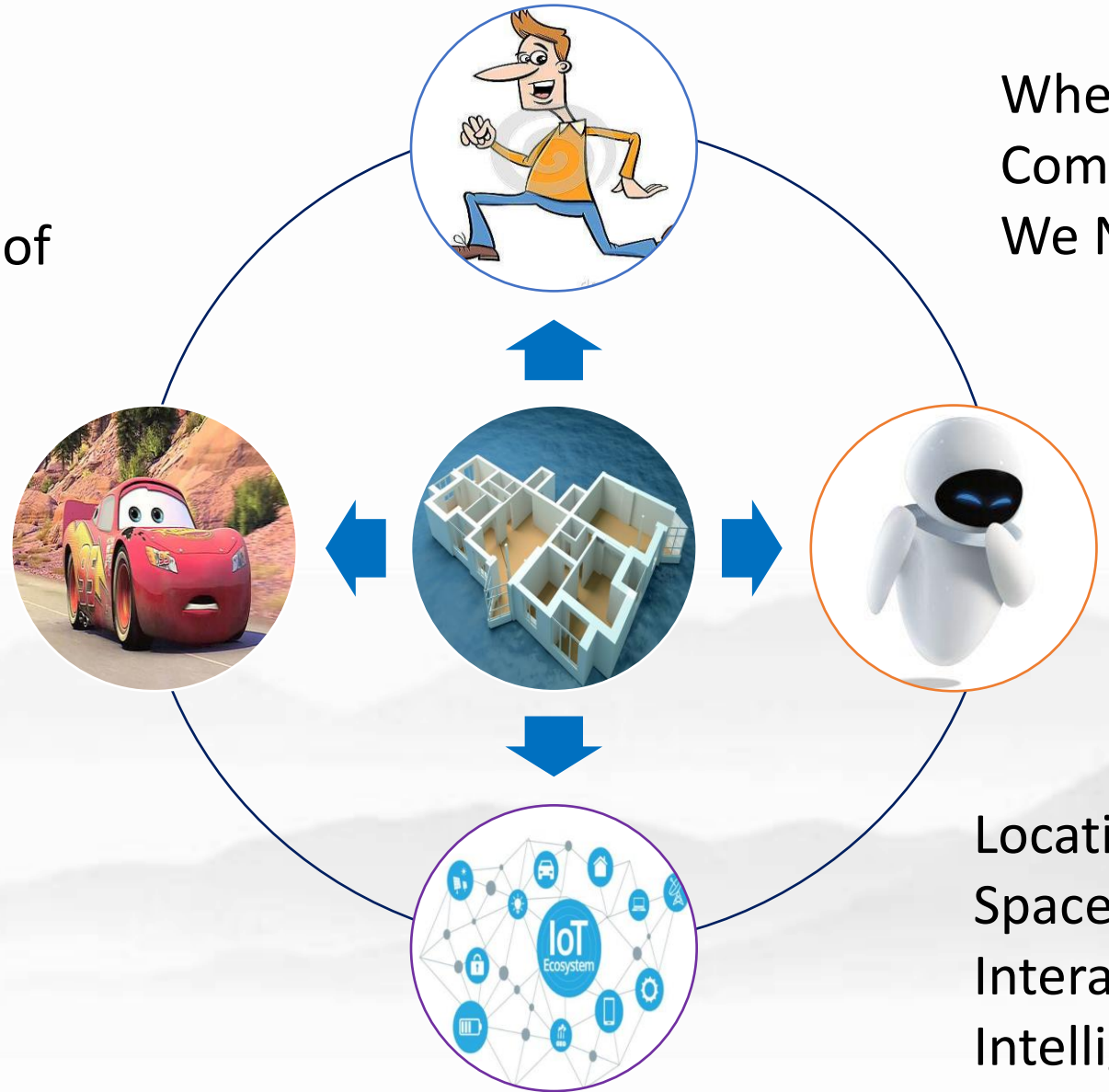
Wuhan University

Oct. 4, 2018, Delft

Adding a Smart LIFE to 3D

People spend 80% of their time indoors

When People Communicates to a Robot, We Need Locations

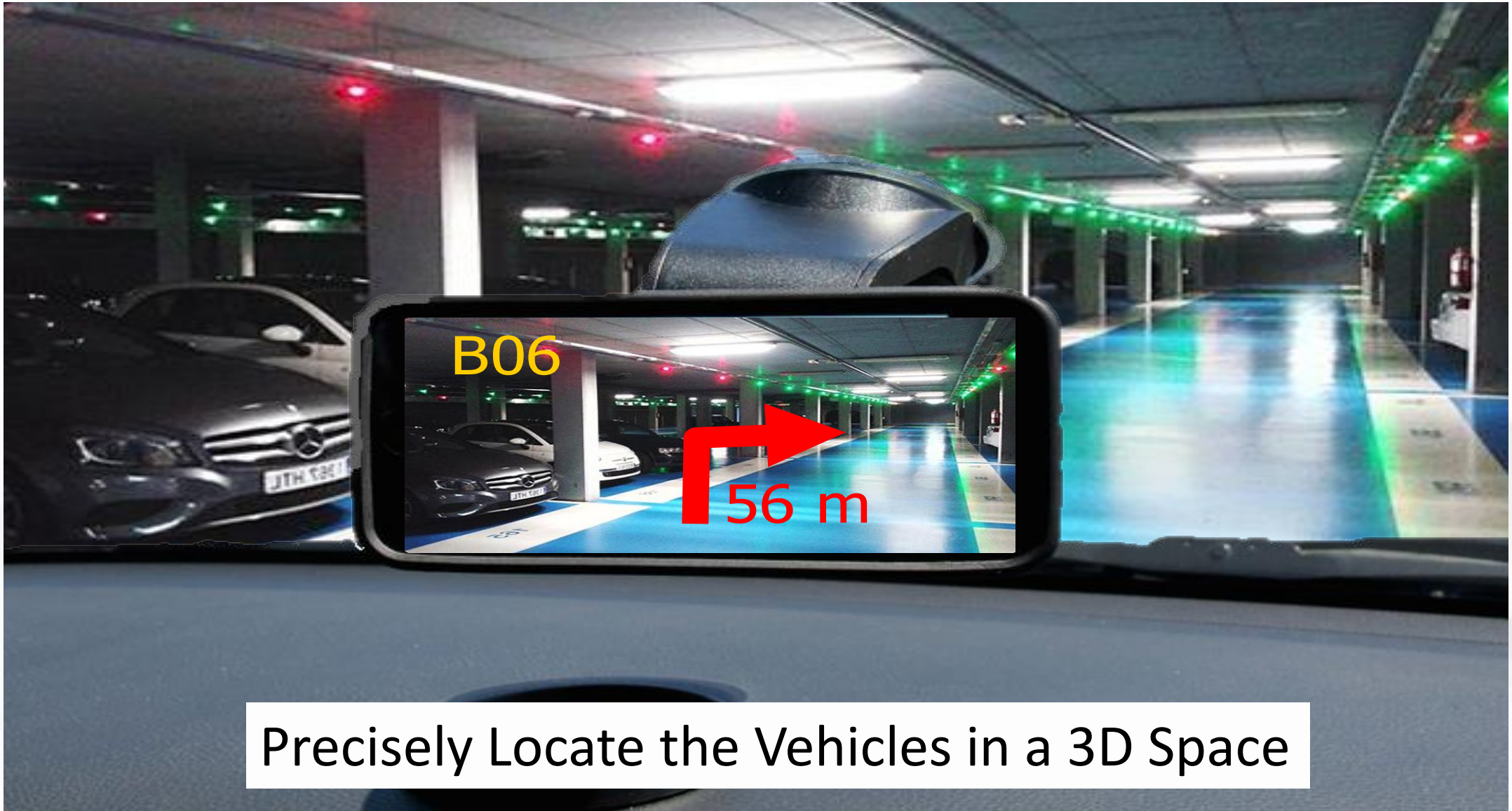


Locating Actors Living in 3D Space will Facilitate Smart Interactions and Enable Intelligent Applications

Mixed Reality Games in 3D Spaces

Interaction between a virtual object and a human

Autonomous Driving for Underground Parking



Precisely Locate the Vehicles in a 3D Space

Precision Marketing

Interaction between human and goods

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Contents

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Your Phone Knows Where You Are

“Where am I？”

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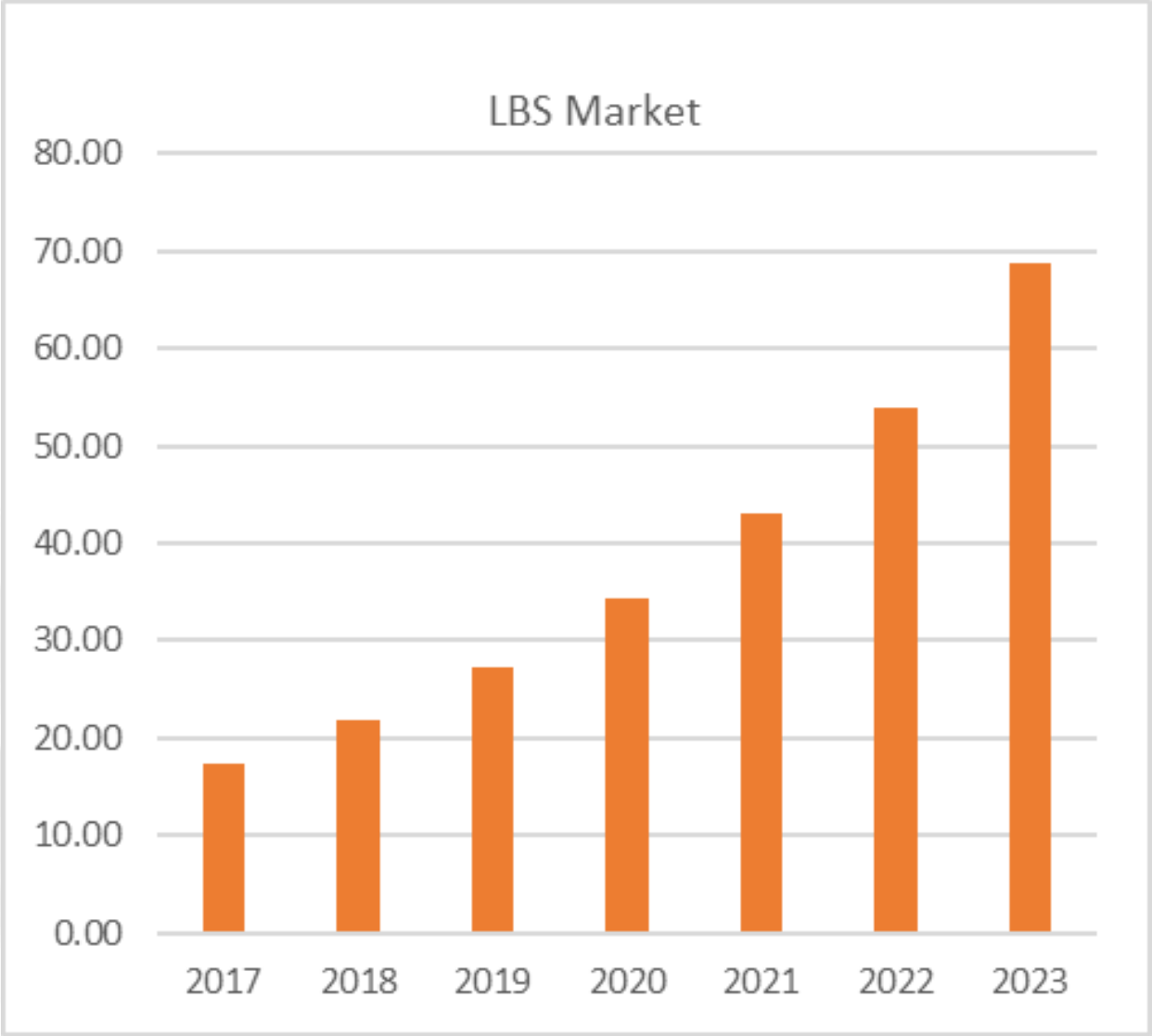
The Market Size of LBS and RTLS

The Location-Based Services (LBS) and Real-Time Location Systems (RTLS) market size was valued at USD 17.38 billion in 2017 and is projected to reach USD 68.85 billion by 2023, at a Compound Annual Growth Rate (CAGR) of 25.4% during the forecast period. The base year considered for the study is 2017 and the forecast period is from 2018 to 2023.



MarketsandMarkets™
https://www.marketsandmarkets.com/Market-Reports/location-based-service-market-96994431.html

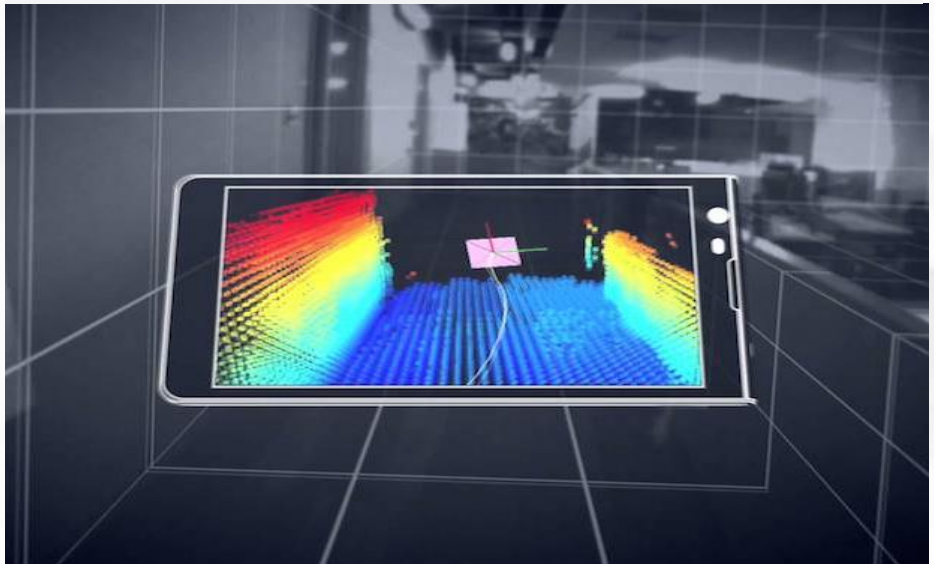
Challenges for Indoor Positioning

Complex topology

Complex radio environment

Complex human motion patterns

Visual Positioning Service – A Google Core Technology



Google

iBeacon – An Apple Technology

iBeacon

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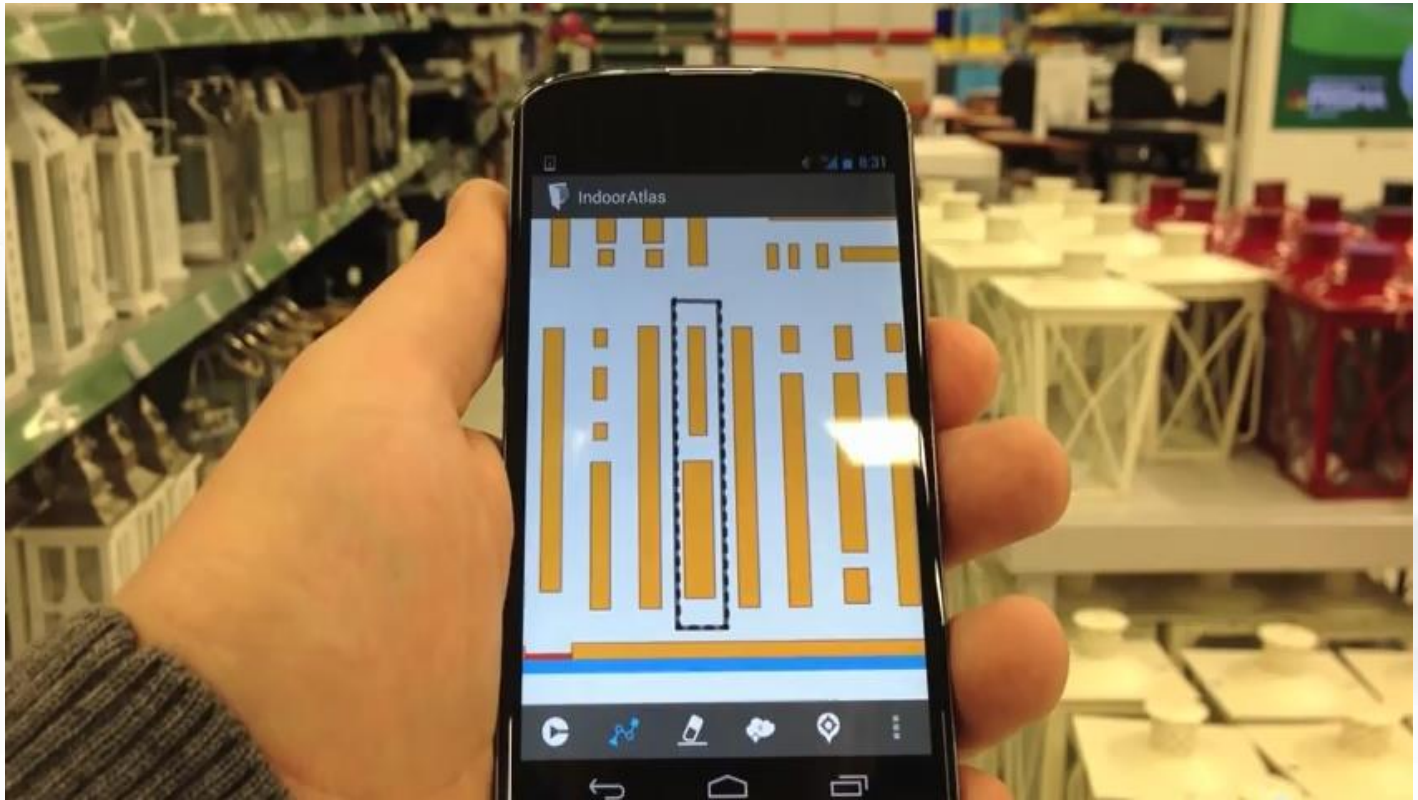
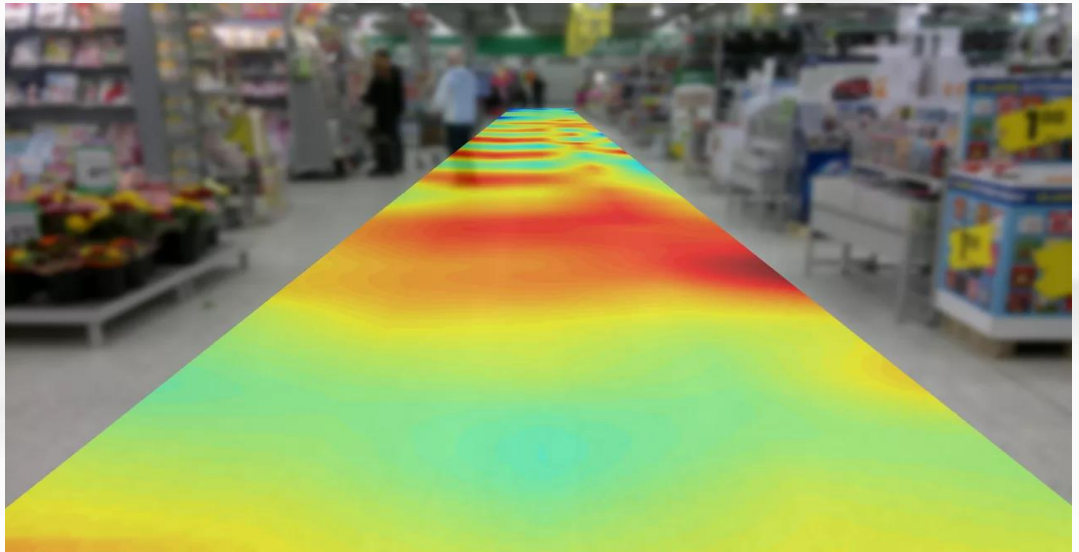
Baidu: Magnetic Fingerprinting

IndoorAtlas





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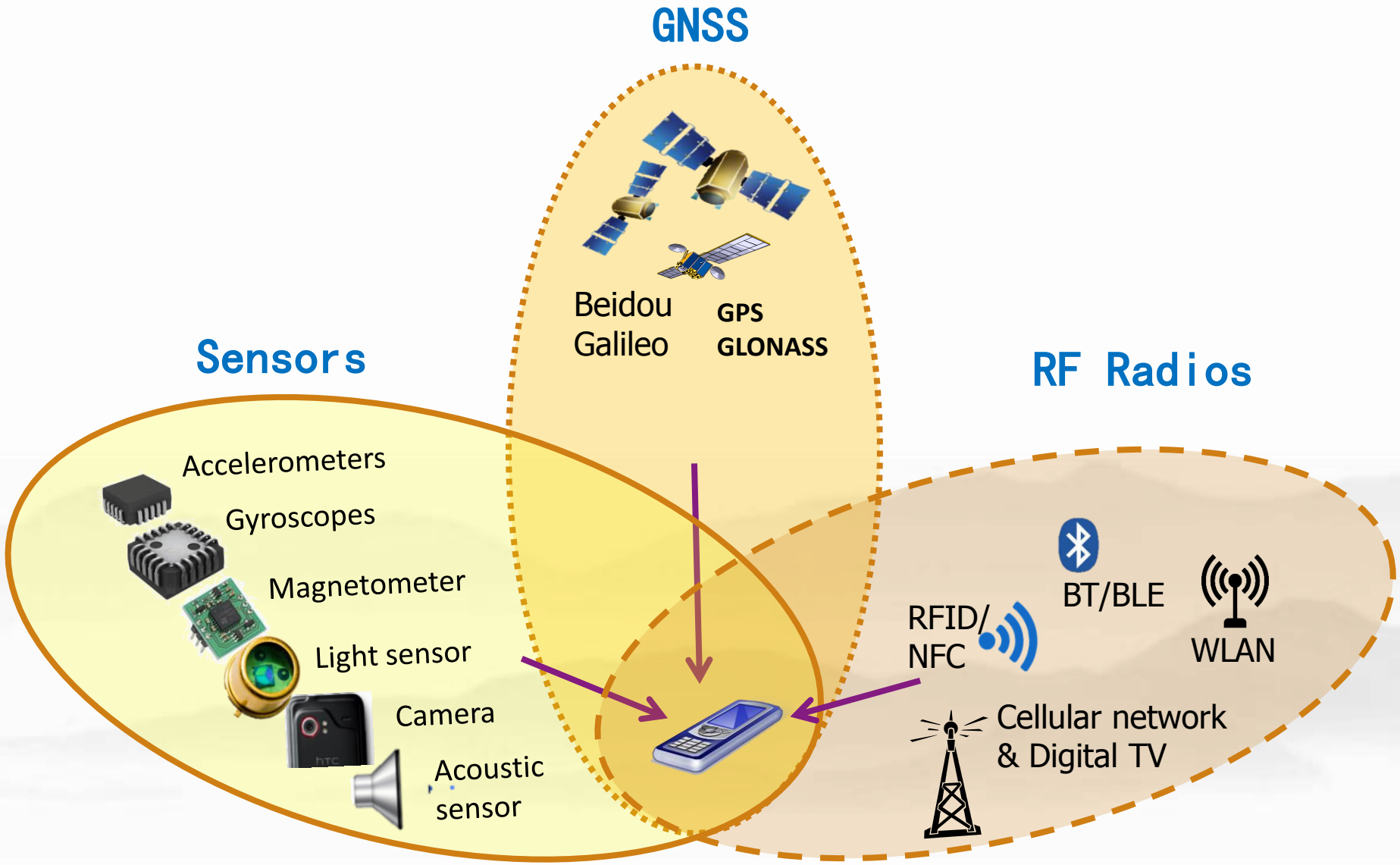
Contents

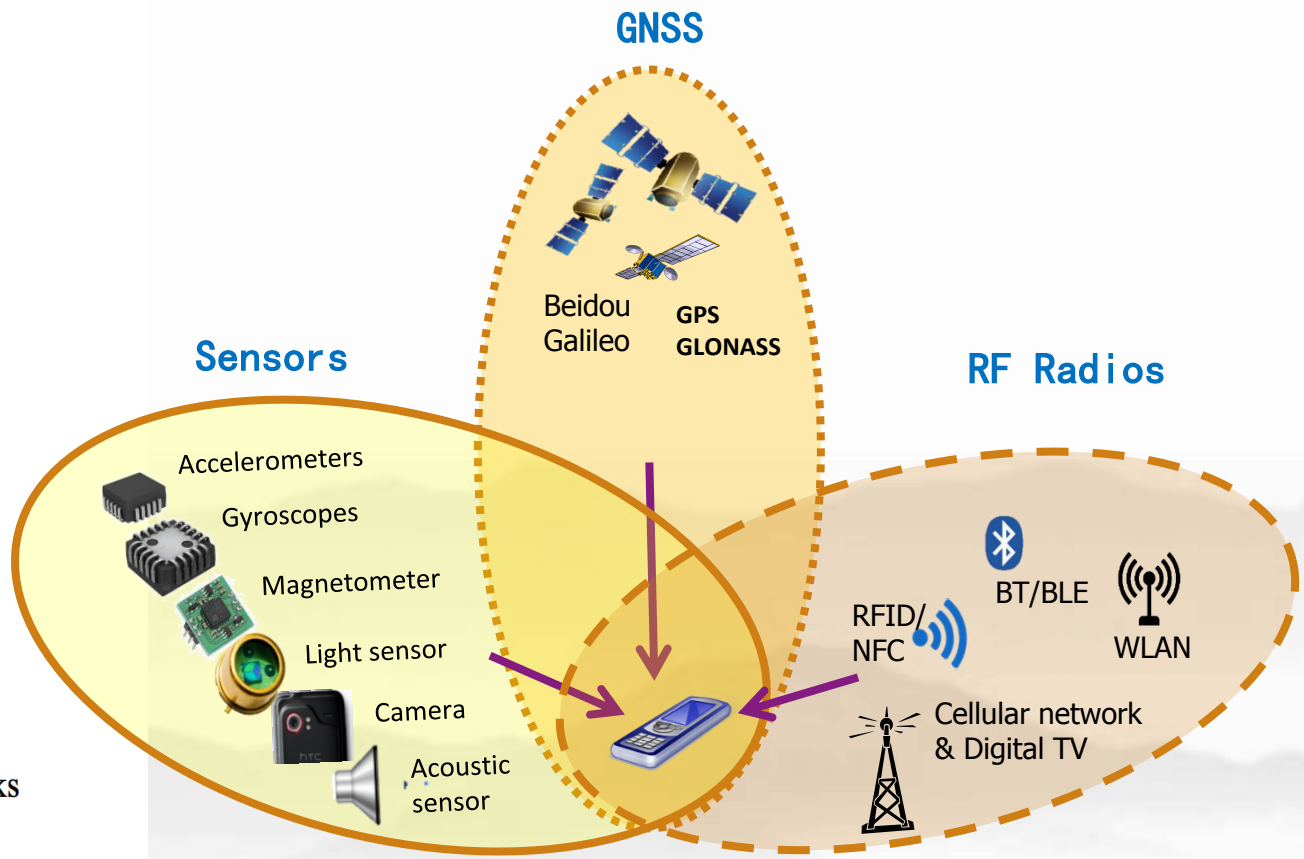
Positioning Sensors and RF Radios in Smartphones



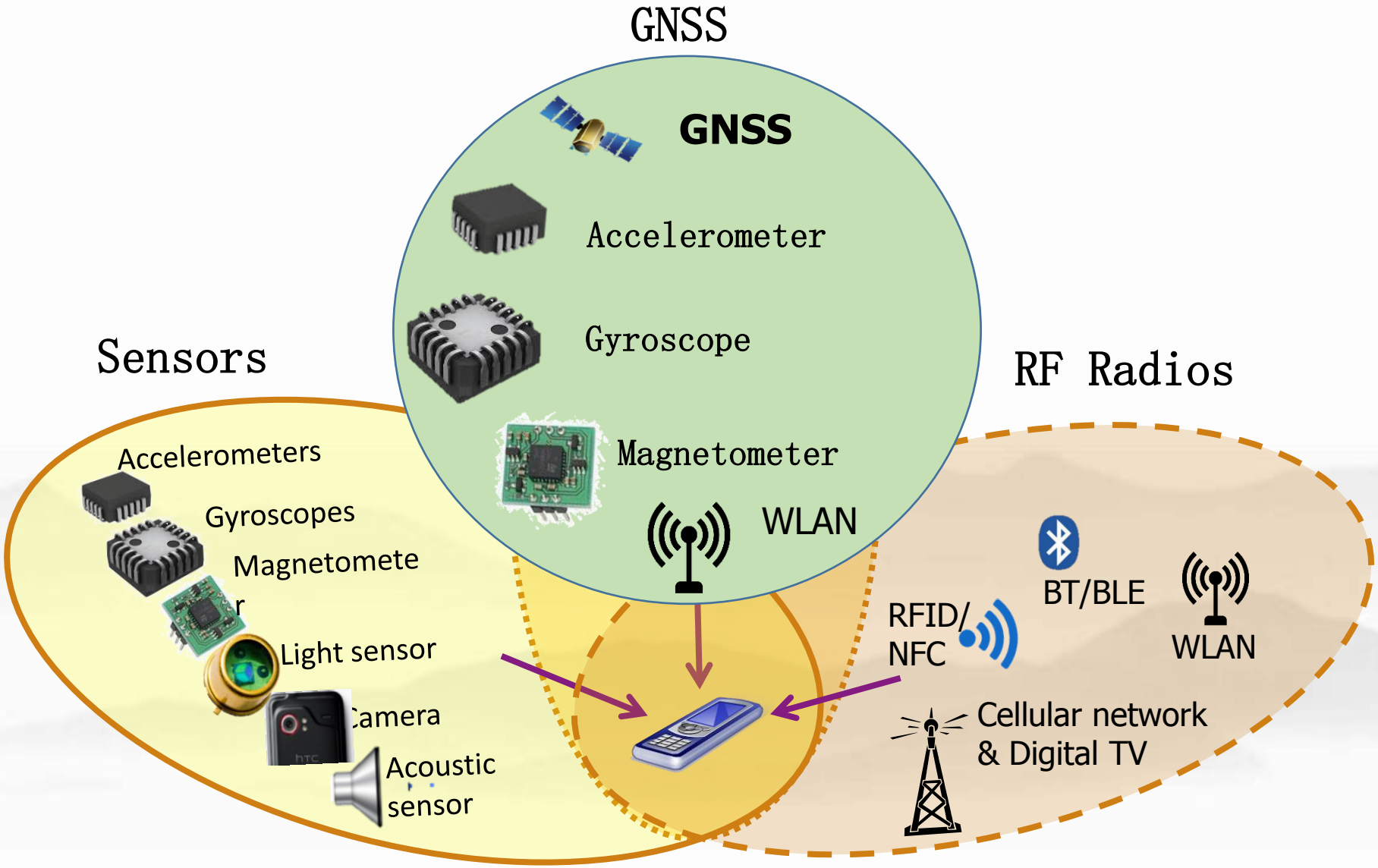
Typical Observables

List of Mobile Positioning Observables

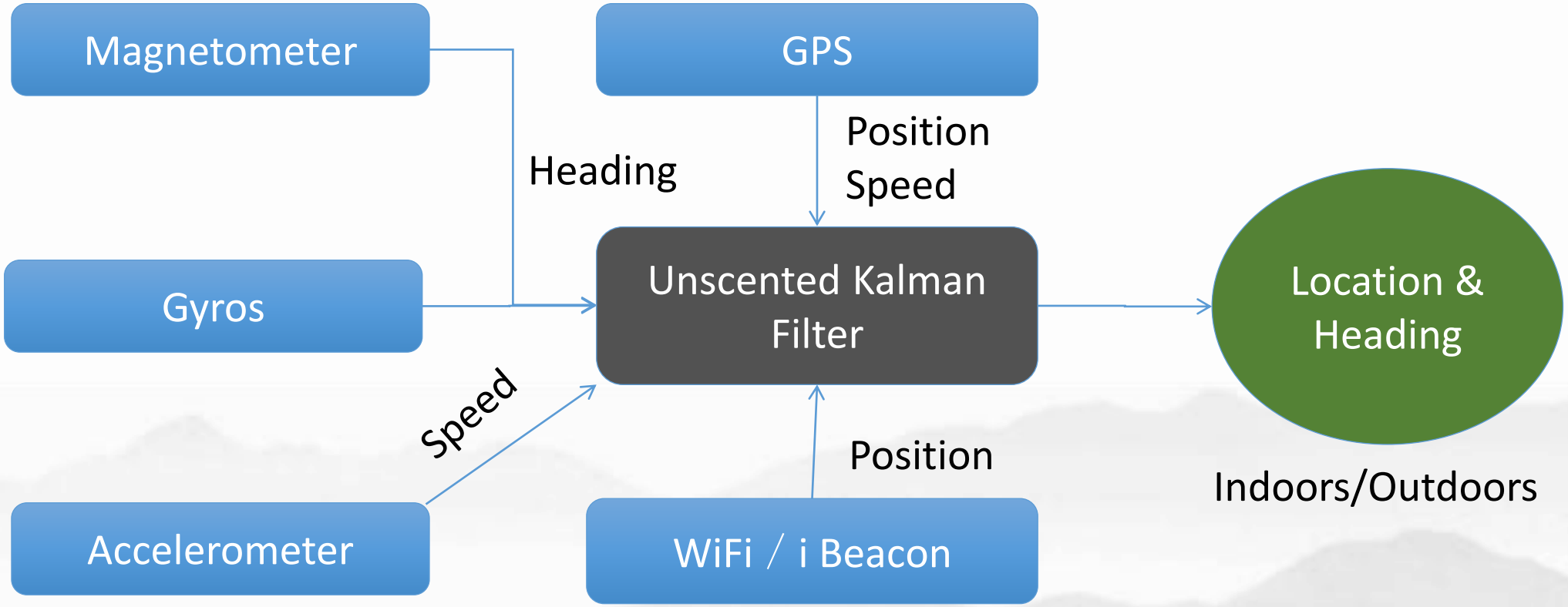
Observables	*Sensors or Networks*
Range	GNSS receiver, cellular networks
Ranging difference	GNSS receiver, cellular networks
Traveled distance	Accelerometer, camera
Speed	GNSS receiver, accelerometer, camera
Acceleration	Accelerometer
Angles/azimuth	Digital compass, cellular network
Angle rates	Gyroscope
Signal strength	WLAN, Bluetooth, RFID, cellular network
Cell-ID	MAC address, base stations in cellular networks
Image/image features	Camera



Positioning With WiFi， Sensors and GNSS

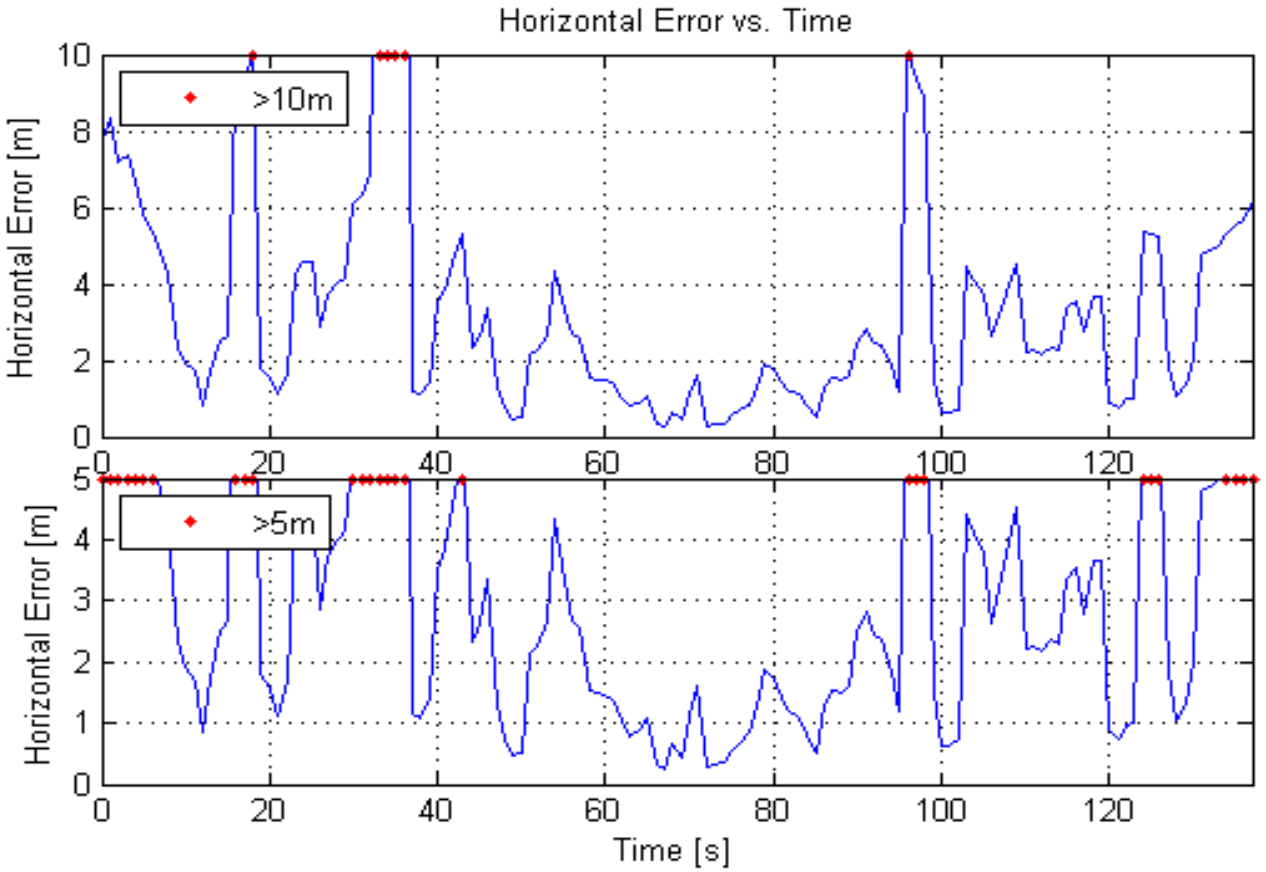


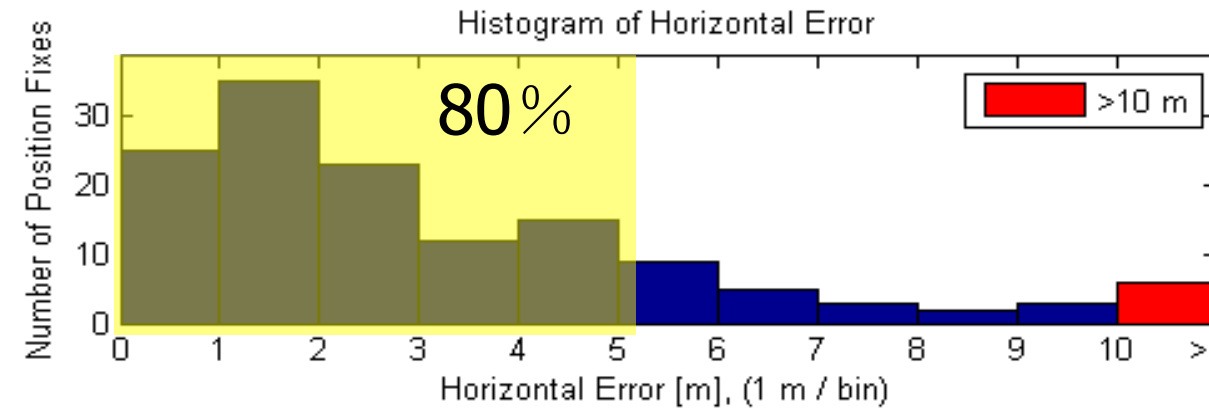
Fusing Sensor and RF Measurements

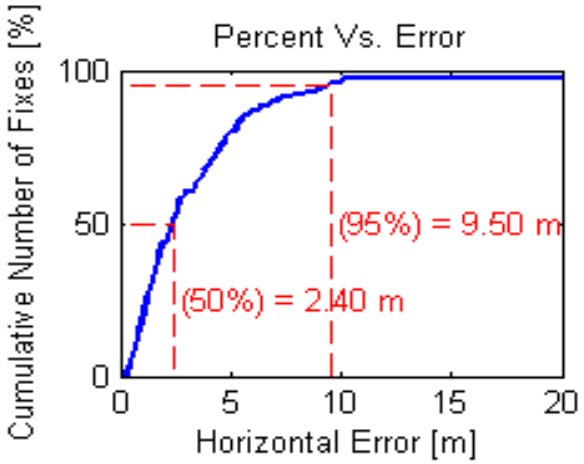


Chen, R., Chu, T., Liu, K., Liu, J., & Chen, Y. (2015). Inferring Human Activity in Mobile Devices by Computing Multiple Contexts. Sensors， 15(9), 21219–21238. http://doi.org/10.3390/s150921219

Positioning Accuracy

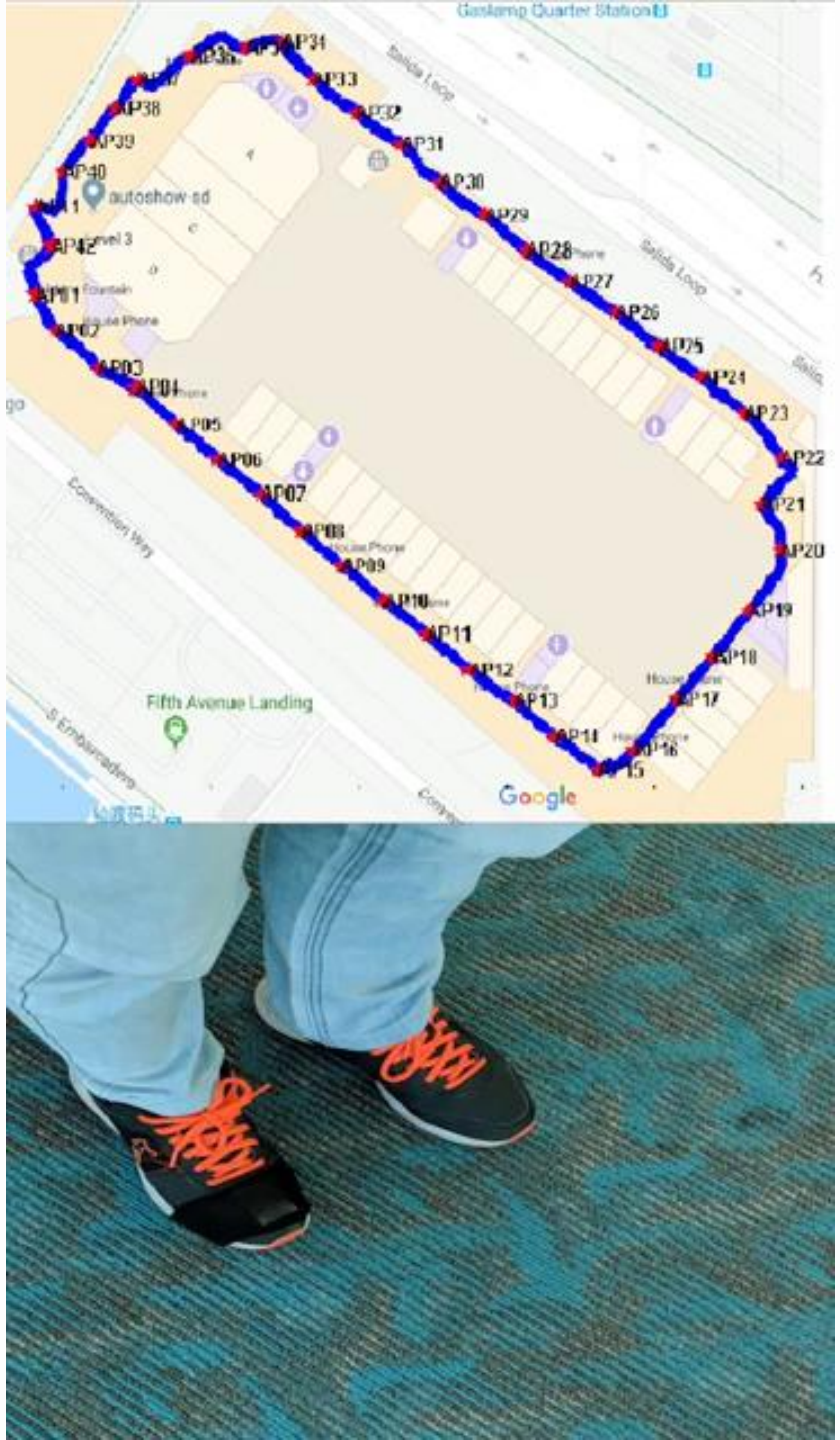






Testing Date: June 21, 2015
First Fix: 01:57:32 (UTC)
Last Fix: 01:59:49 (UTC)
Availability: 100 %
Error < 5 m: 79.71 %
Error < 10 m: 95.65 %
Maximum Error: 21.95 m
Mean Error: 3.52 m
Standard Deviation: 3.83 m

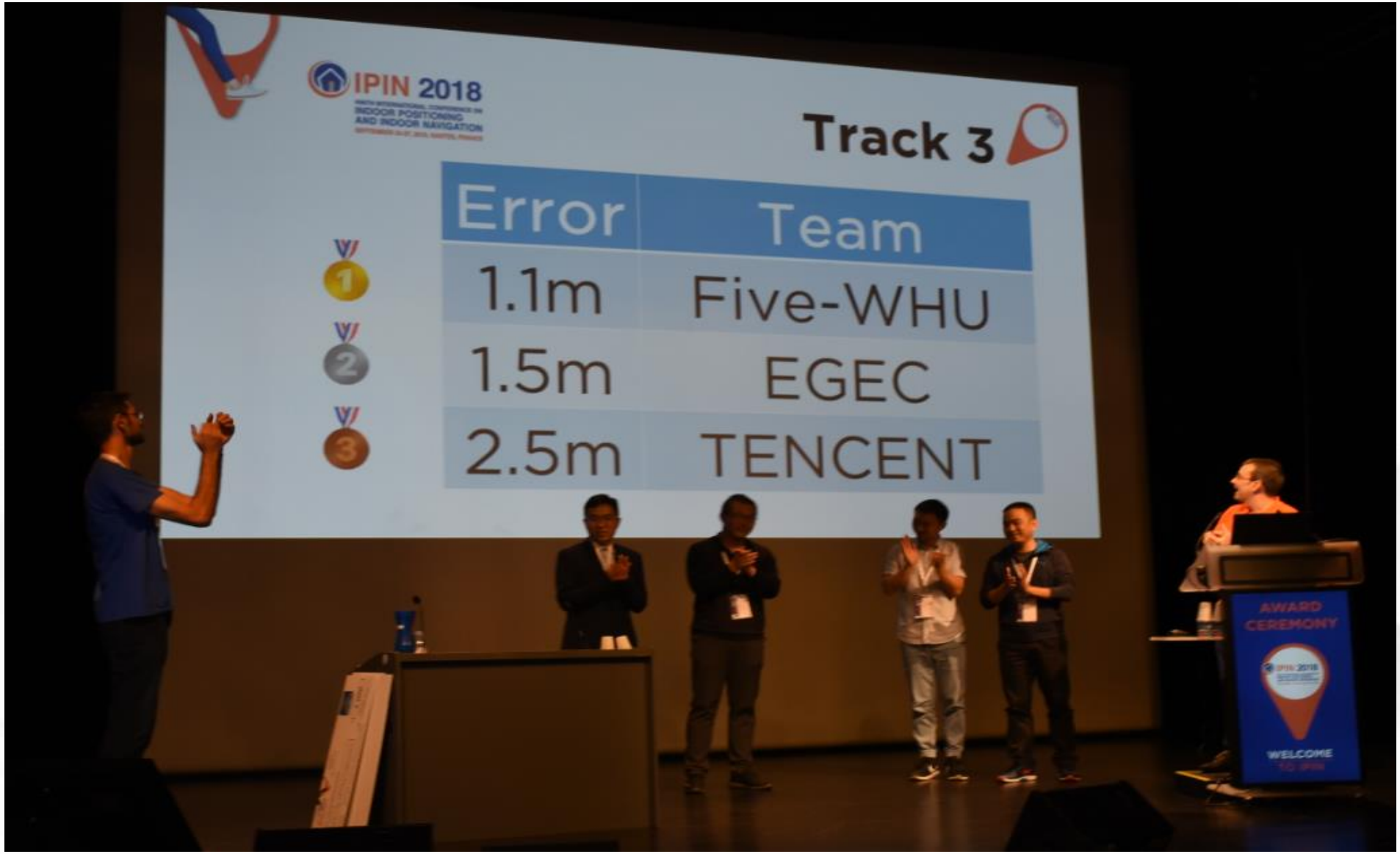
Ground Truth: GPS/INS



Real-Time： 2-5 meters under typical indoor environment

PerfLoc: NIST indoor Positioning Competition

Post-Processing Accuracy



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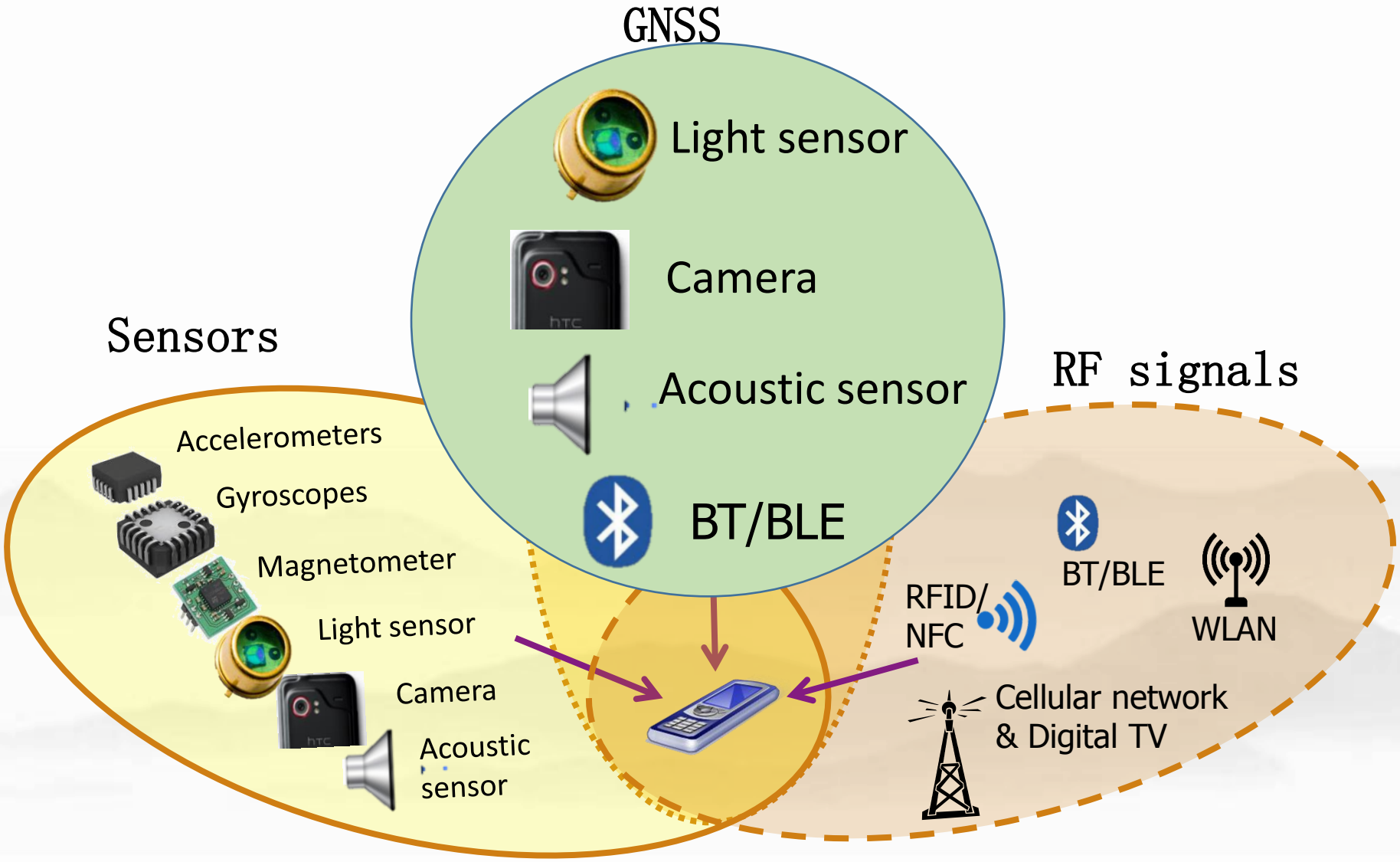
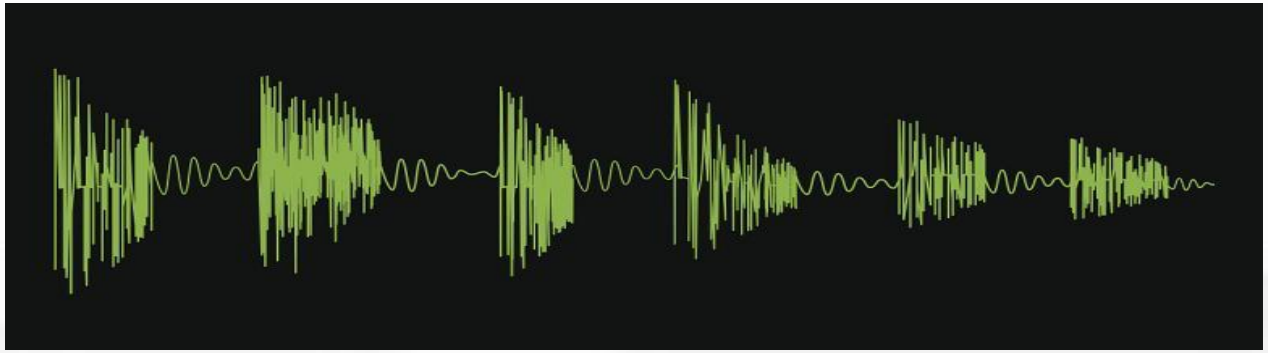
Contents

Positioning with New Sensors

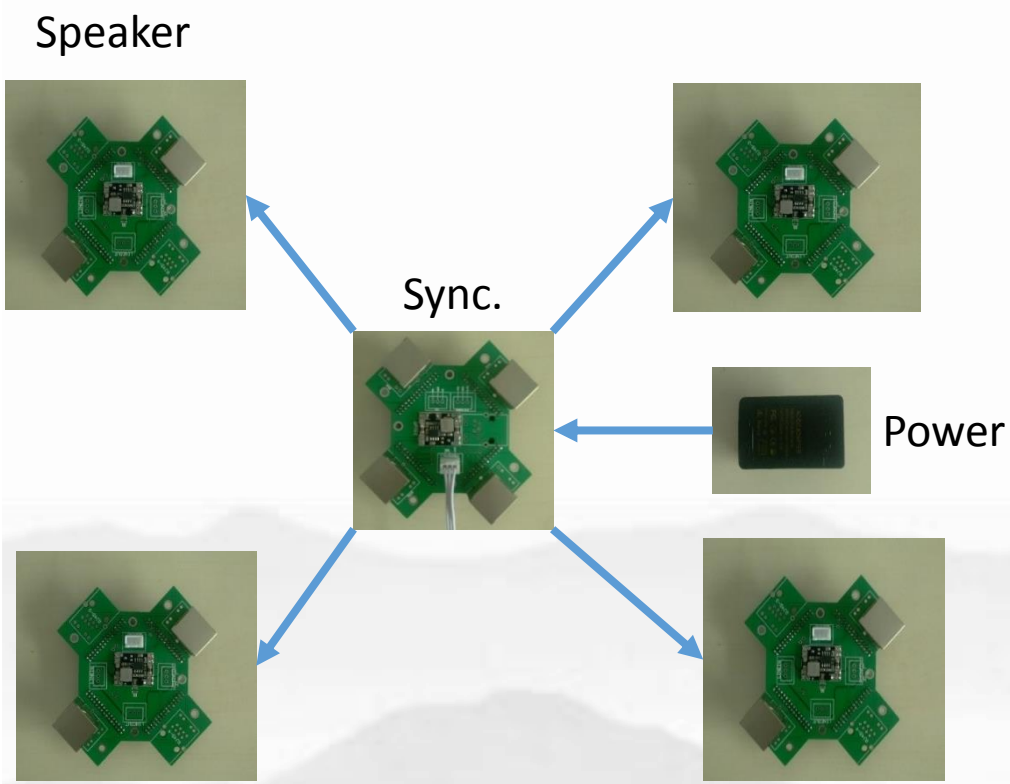


Positioning Based on Acoustic Signal

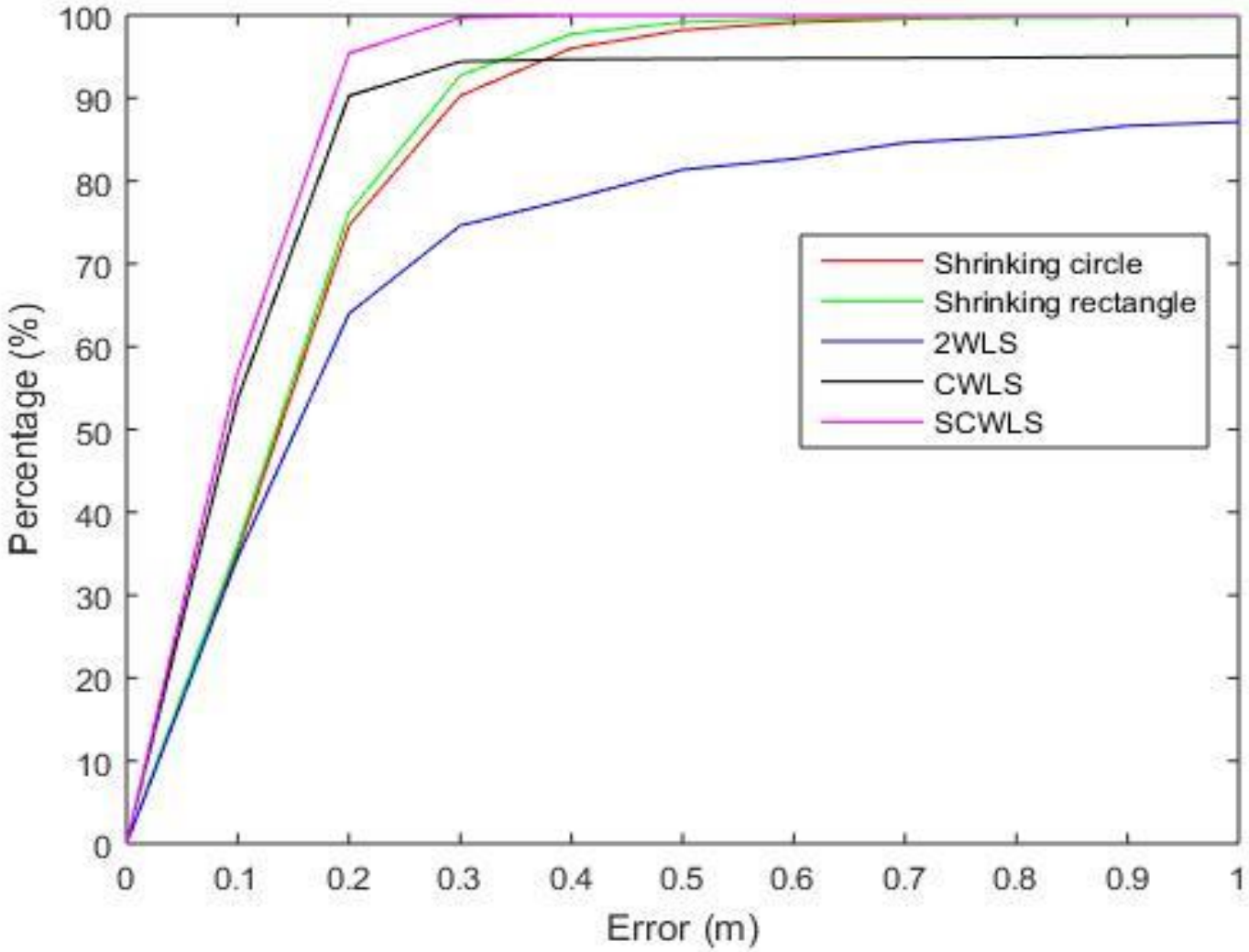


Acoustic Ranging Positioning

- **Using the Mic and Speakers of the Smartphone**
- **Working spectrum ranges from 16-21KHz Not hearable by human, not interfered by human voices**
- **The speed of sound is slow compared to RF signals, therefore, the clock synchronization requirement is not high.**
- **Measure TOA**
- **Positioning accuracy：decimeters**
- **Effective Range：5-20m**



Positioning Accuracy



0.2 m at 95%

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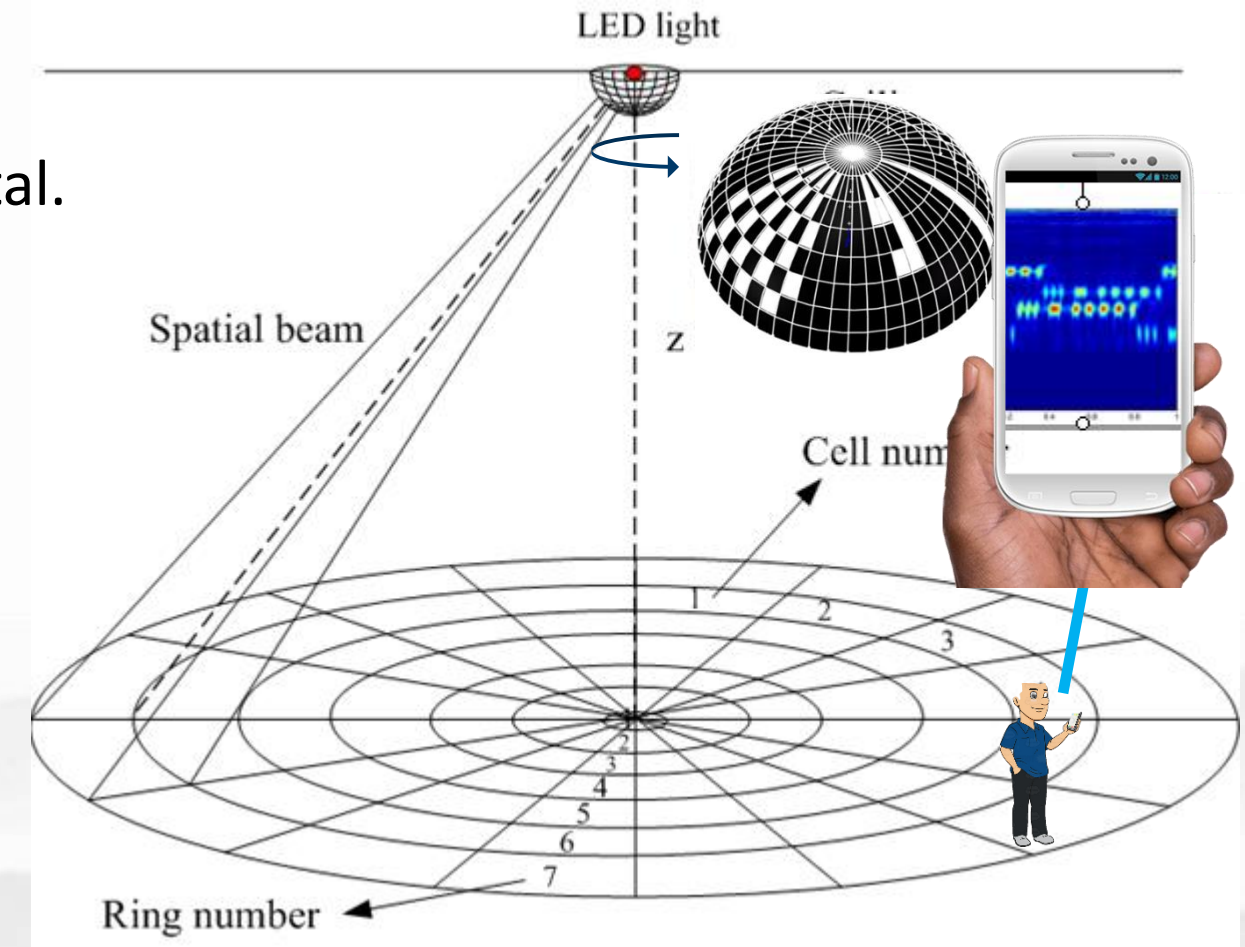
Positioning Based on Light Signal

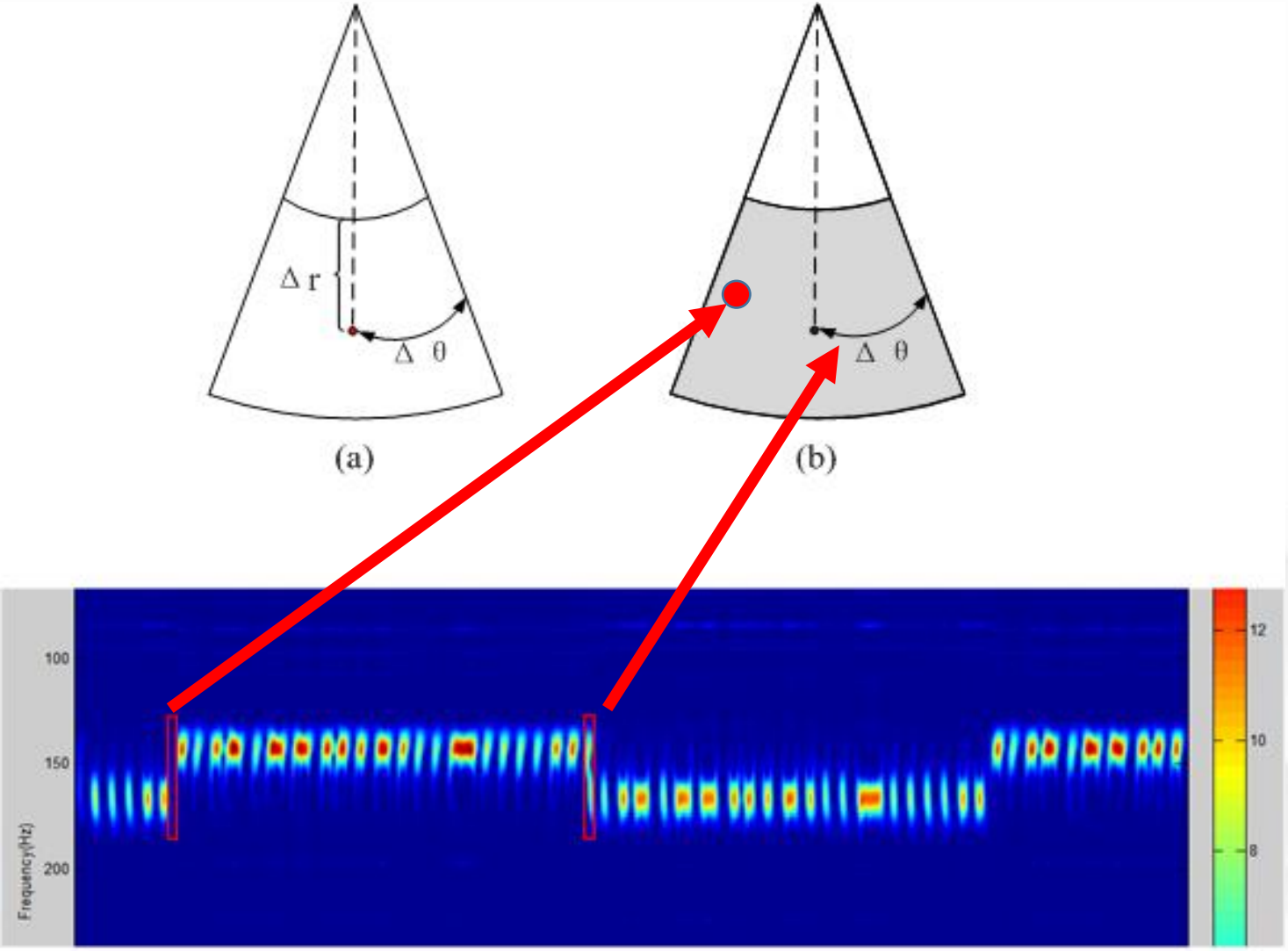
Positioning Using Light

- An light shade is divided into 8 rings， each ring has 48grids, there are 384 sectors in total.
- Each sectorial grid can be opened (0) or closed (1), by rotating the shade, the light sensor of the smartphone can receive different light patterns in different sectors.
- A sector is identified by the light patterns.
- No hardware change is needed from smartphones
- Positioning accuracy is 5-10cm.
- Single Station Positioning for Small Indoor Space



Light source： 850 nm Infrared

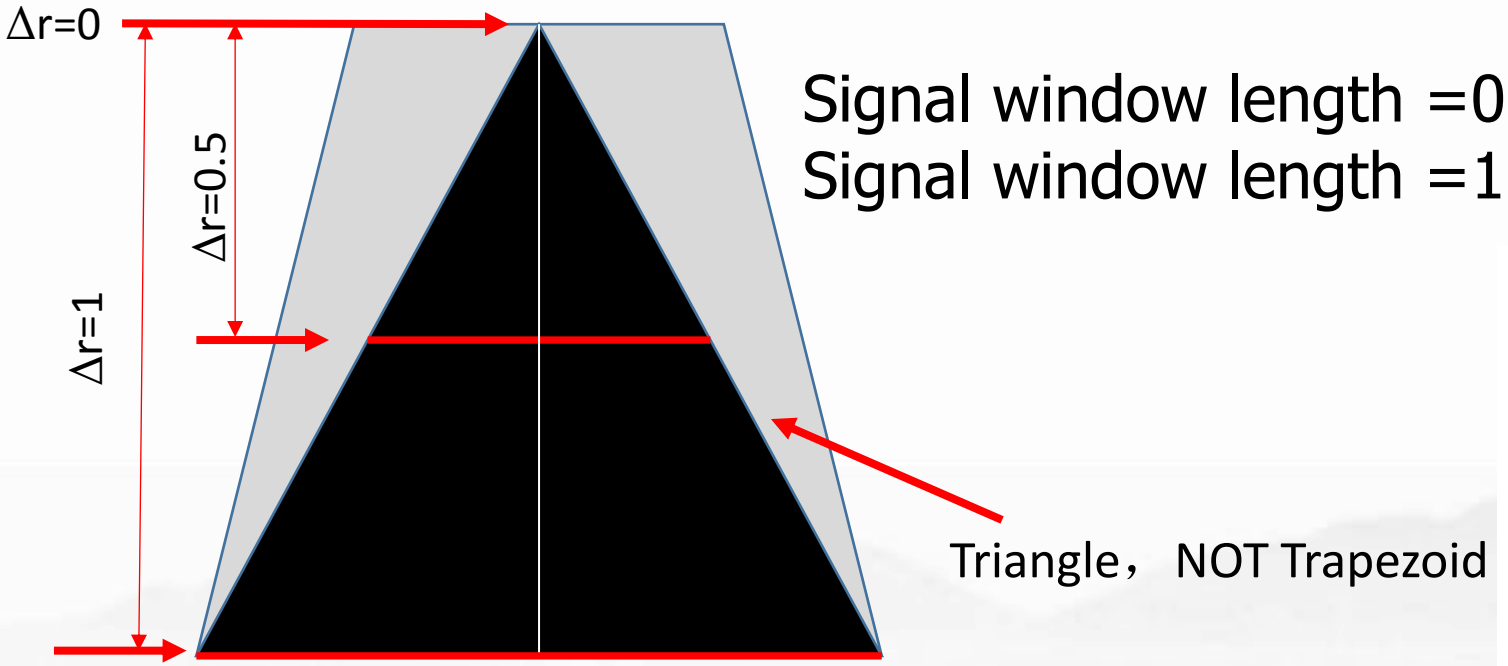
Correction in Longitude Direction



- (ring number, cell number) is too coarse grained (e.g., 0.5 m)
- Need to obtain two offsets: ΔΘ and Δr
- A fraction of cell period (signal window length) is used to estimate ΔΘ

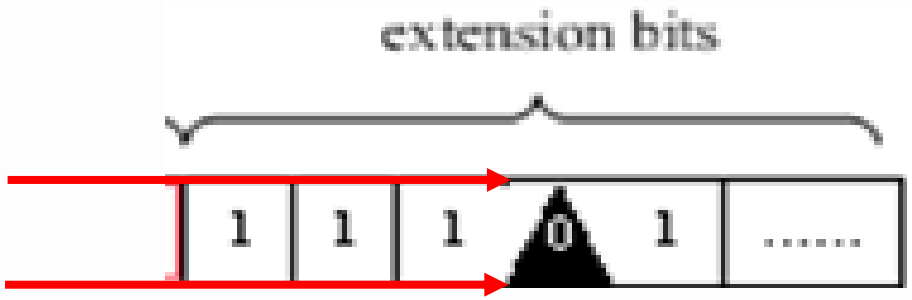
Correction in Radial Direction

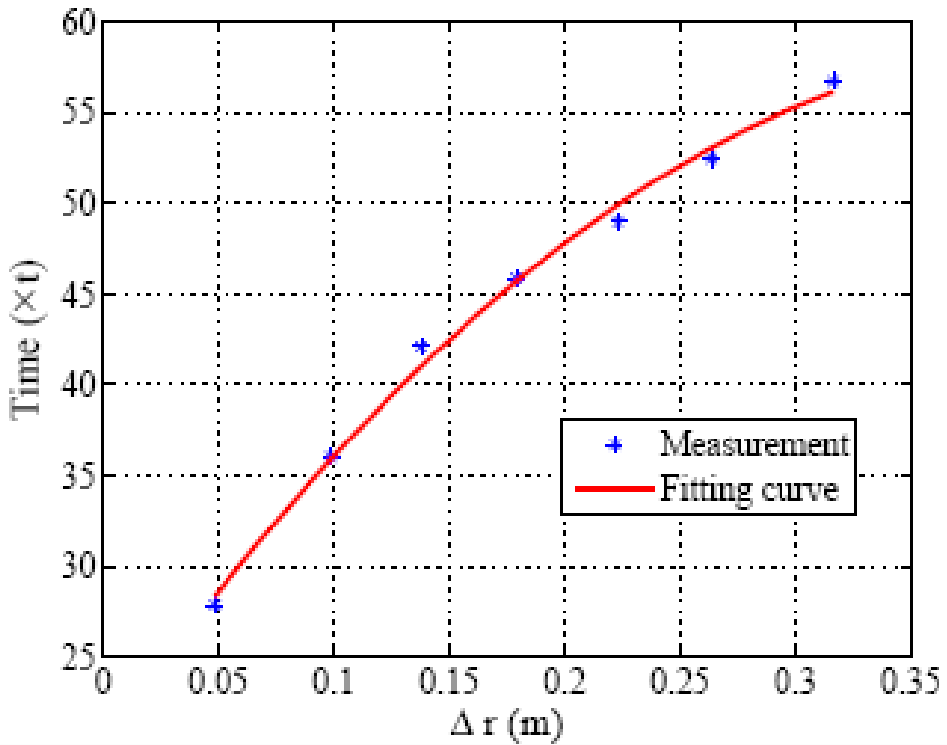
Inner ring, signal window length 0



Outer ring, signal window length 1

Signal window length =0
Signal window length =1





Signal window length varies between 0 and 1 for different Δr

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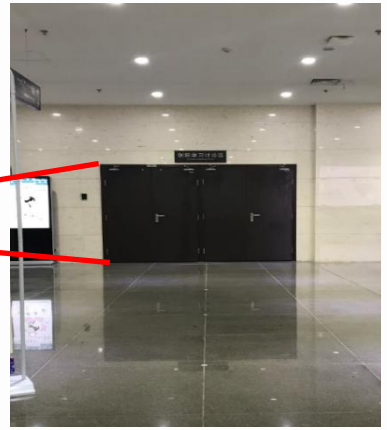
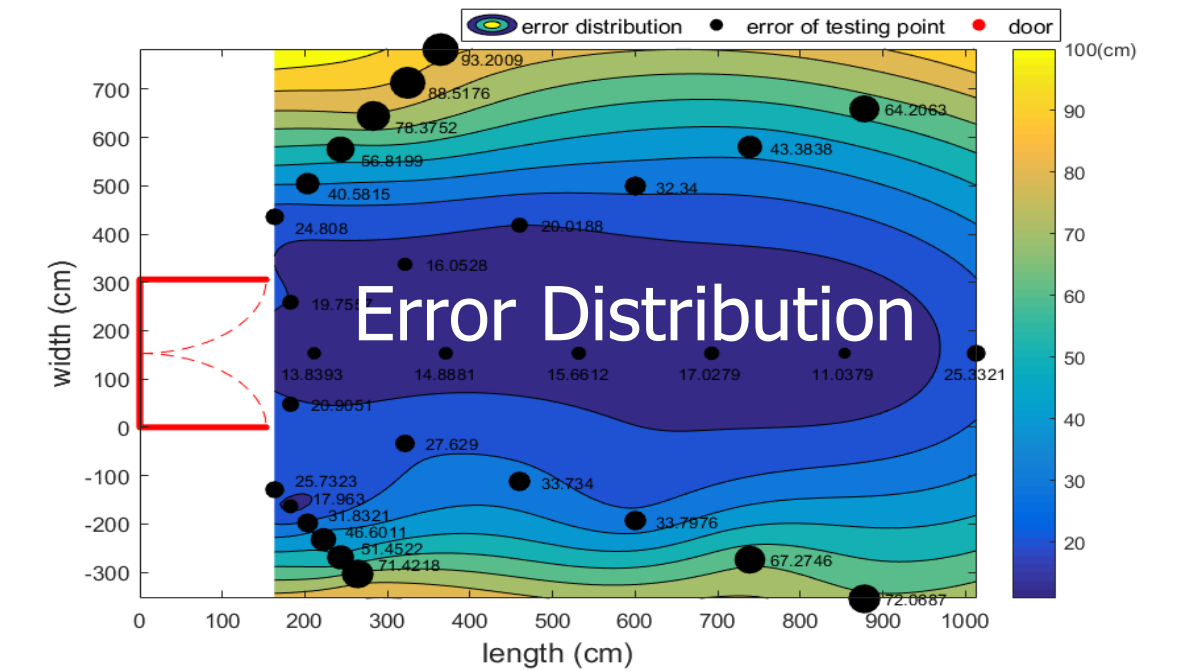
Visual Positioning with Point-Line-2D-3D Objects

Human Eyes vs Smartphone Camera

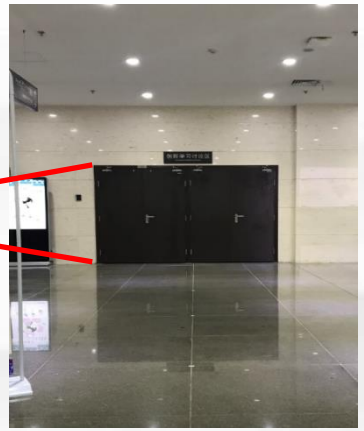
5 Types of smartphones



3 Test Fields



10 Students

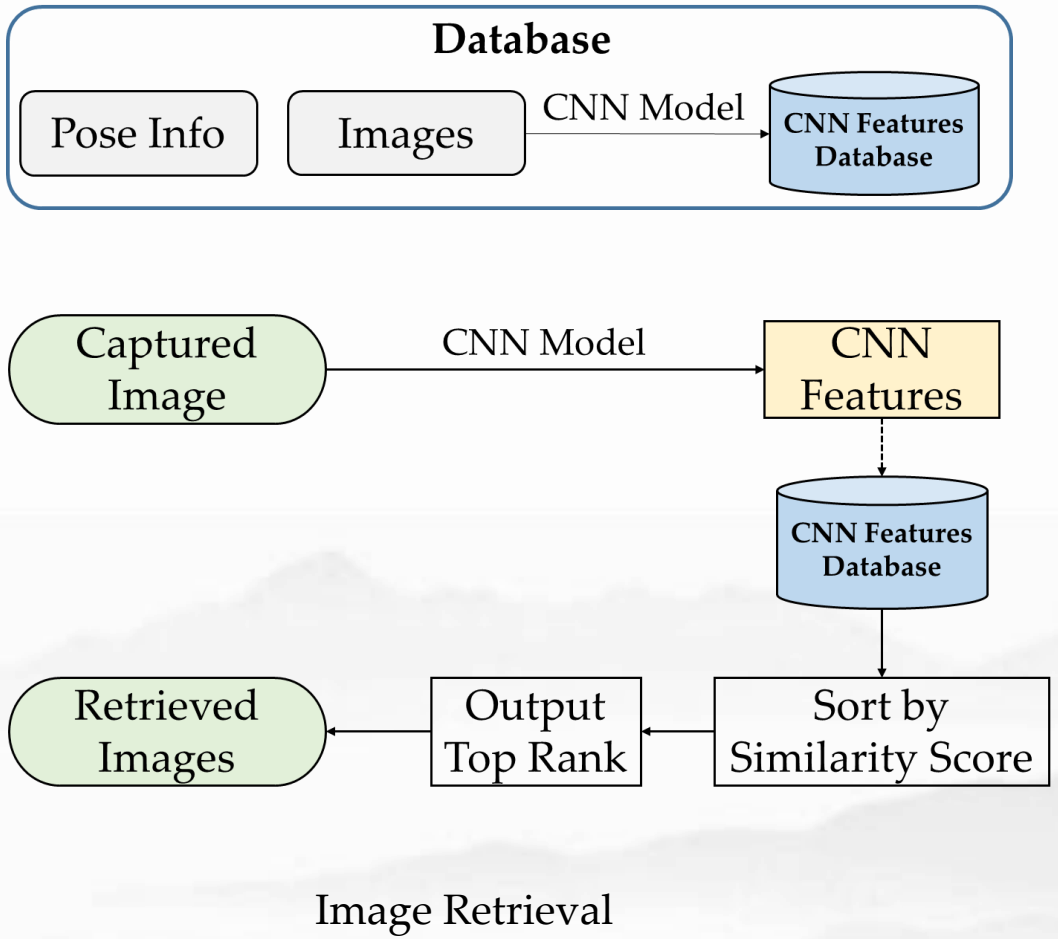


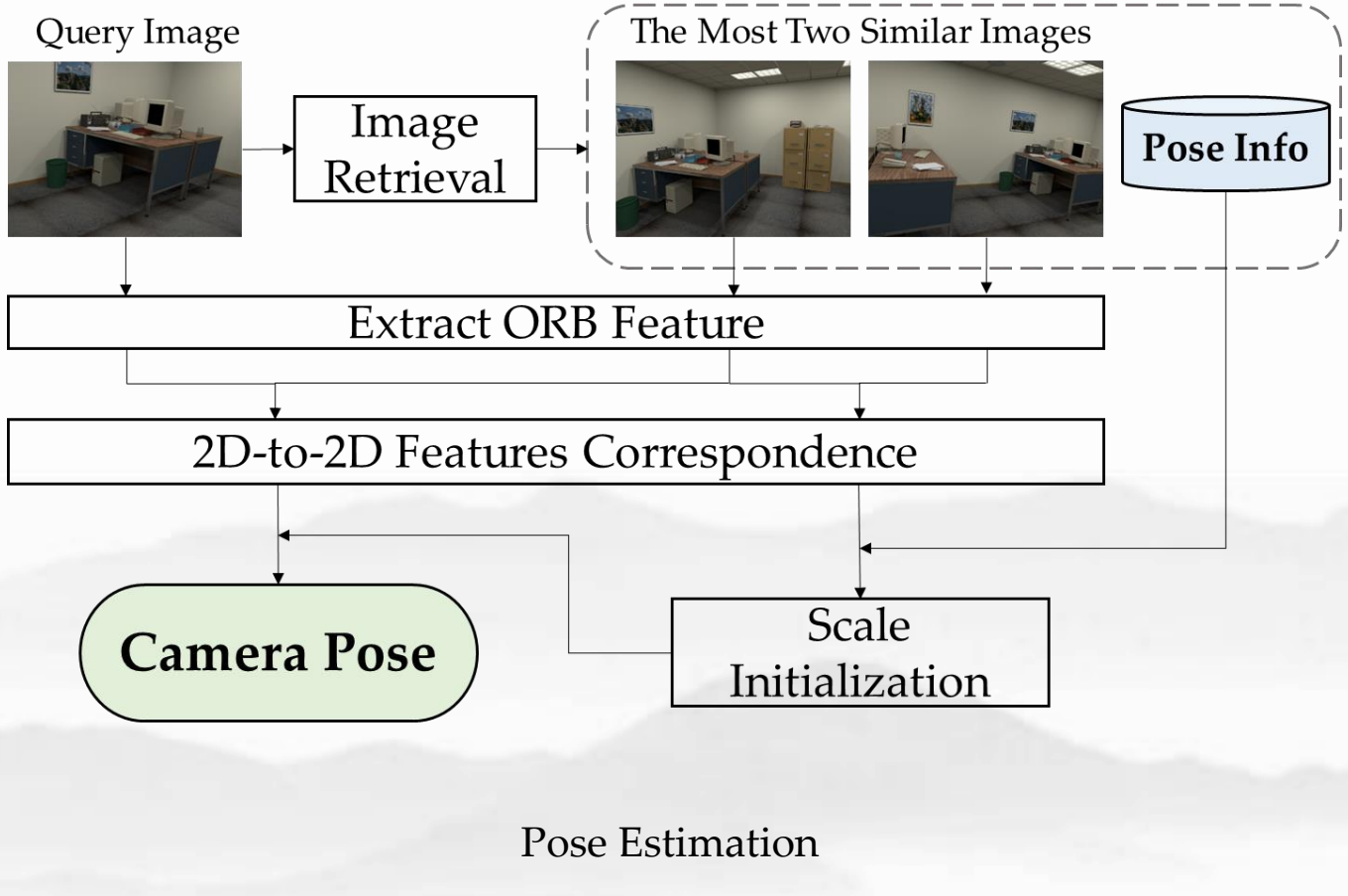
Positioning Error

Human Brain	Phone Camera
0.73m	0.31m

*Dewen Wu, Ruizhi Chen *, Liang Chen (2017).* Visual Positioning Indoors: Human Eyes vs Smartphone Cameras. *Sensors 2017, 17, 2645; doi:10.3390/s17112645*

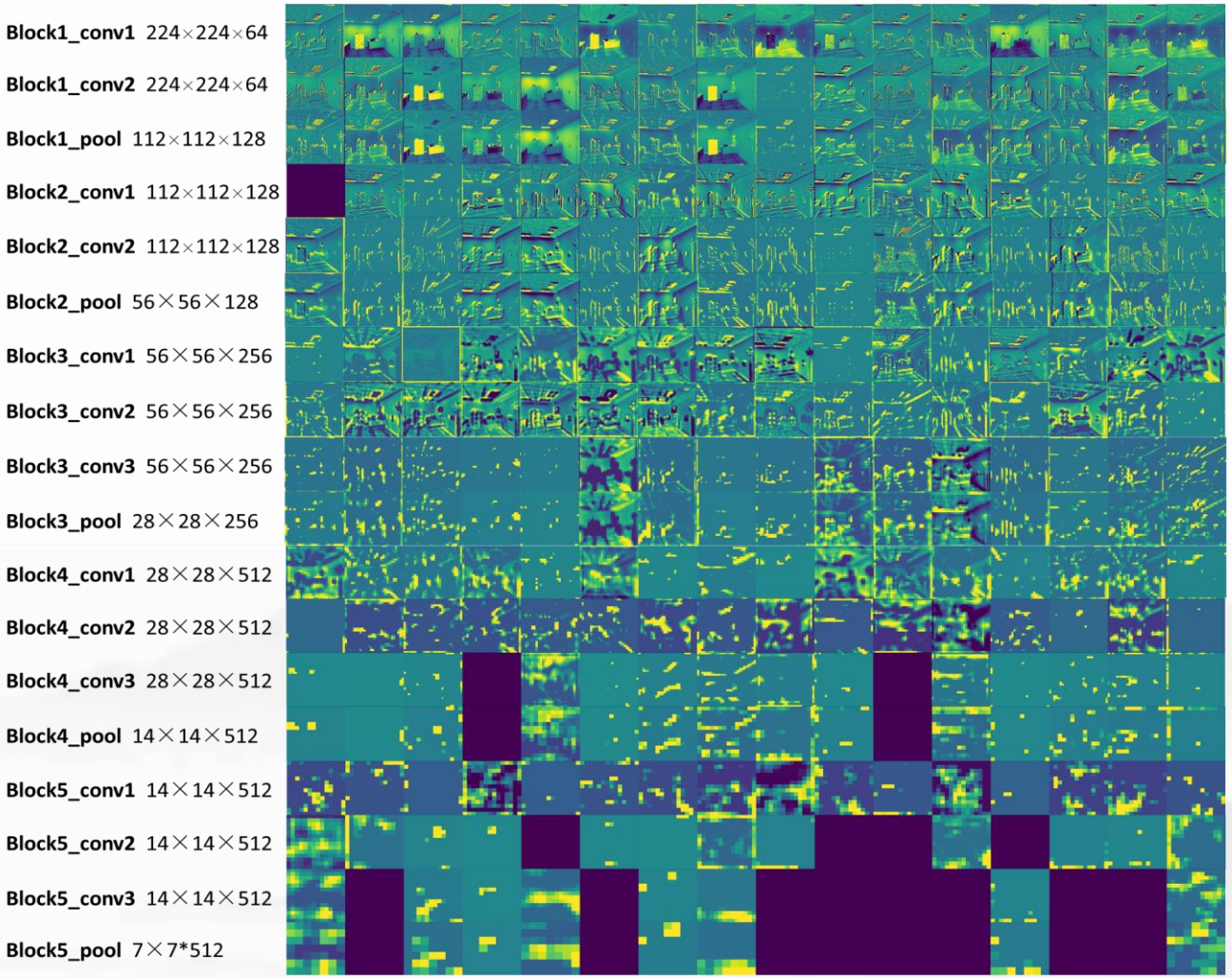
Indoor Visual Positioning aided by CNN-based Image Retrieval





Chen, Y.; Chen, R.; Liu, M.; Xiao, A.; Wu, D.; Zhao, S. Indoor Visual Positioning Aided by CNN-Based Image Retrieval: Training-Free, 3D Modeling-Free. *Sensors* 2018, *18*, 2692.

CNN-Features



Convolution layers visualization

- **Employ CNN model to extract features**
- **Rank images from database by feature similarity**

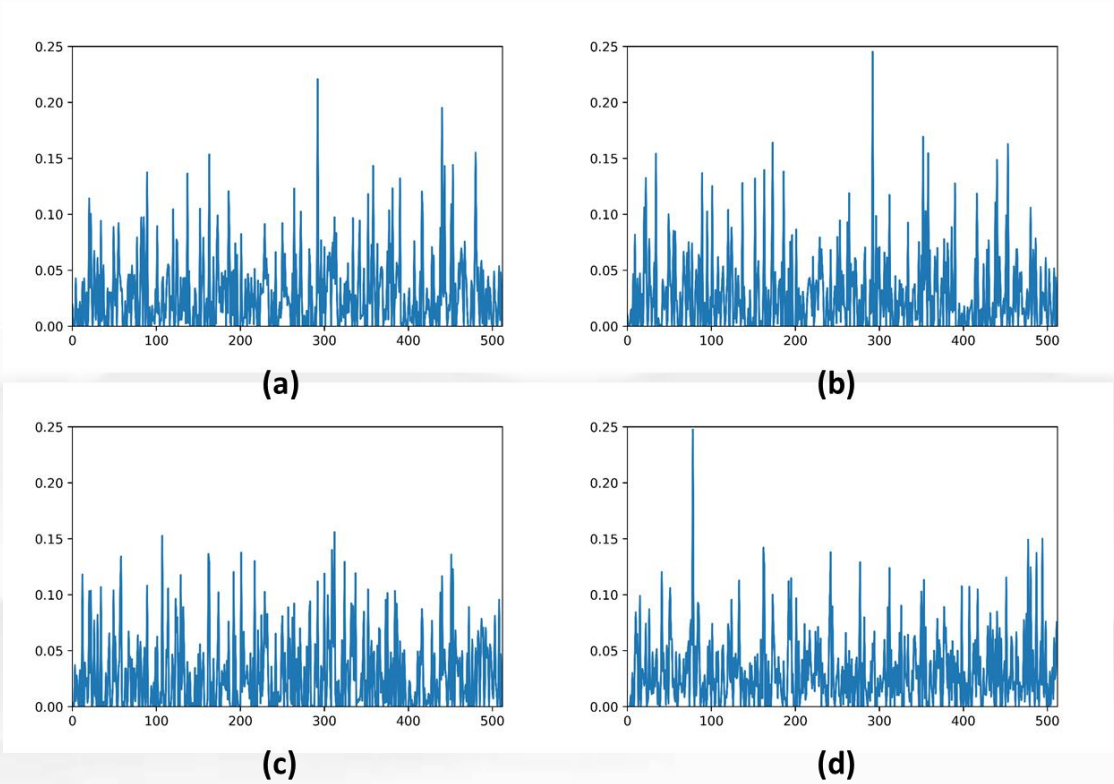


Image feature vectors visualization

Positioning Errors

Comparison based on the ICL-NUIM dataset

Method	Living Room 1495 Samples	Office Room 1533 Samples
PoseNet	0.60m, 3.64°	0.46m, 2.97°
4D PoseNet	0.58m, 3.40°	0.44m, 2.81°
CNN+LSTM	0.54m, 3.21°	0.41m, 2.66°
ours	**0.36m**, 4.36°	**0.31m, 2.47°**

- Better position accuracy, Comparable orientation accuracy;
- Much fewer images in database construction period (Training images vs. Reference images);
- 3D-Modeling Free;
- Training Free;
- A set of images with high-precision pose is the key.

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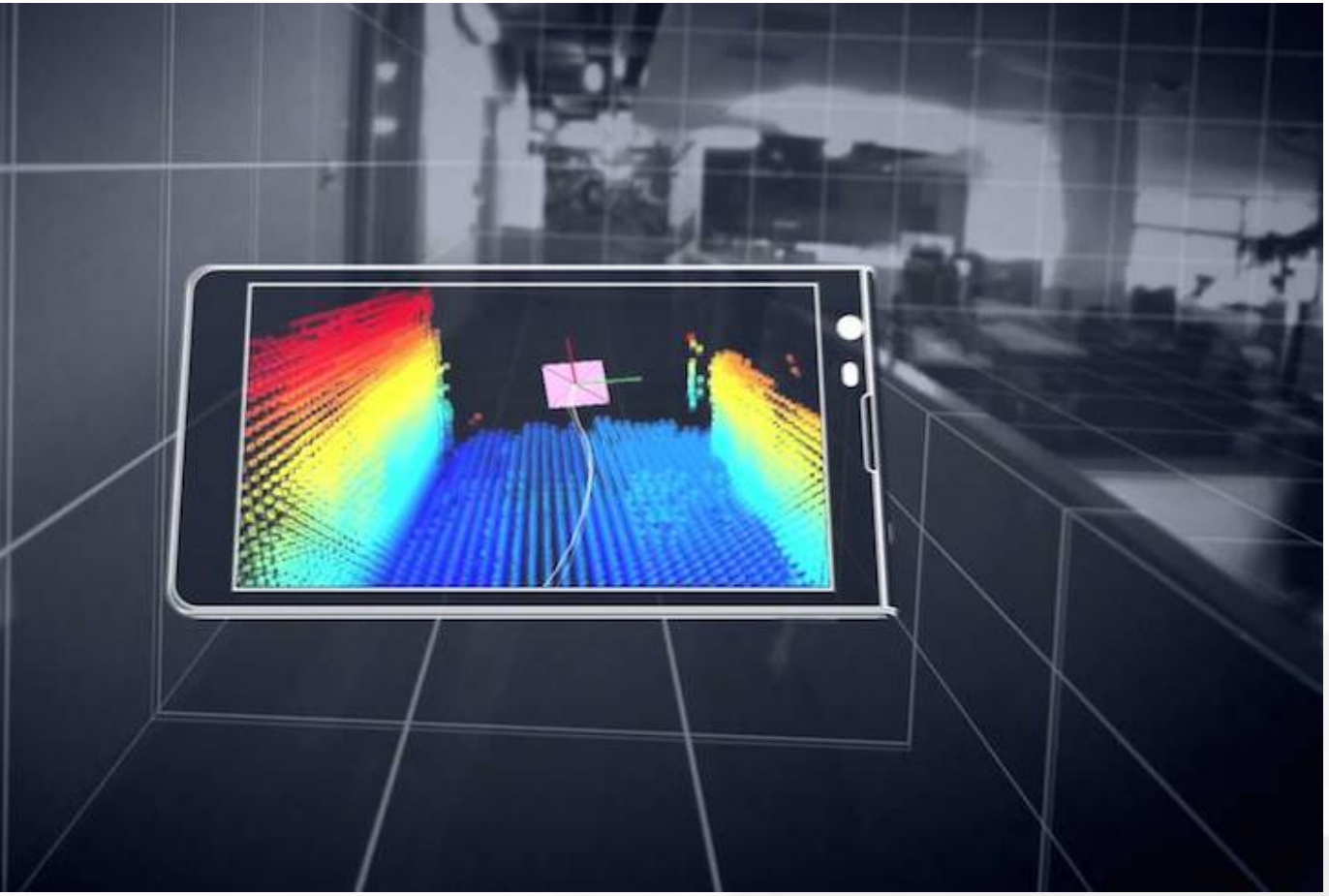
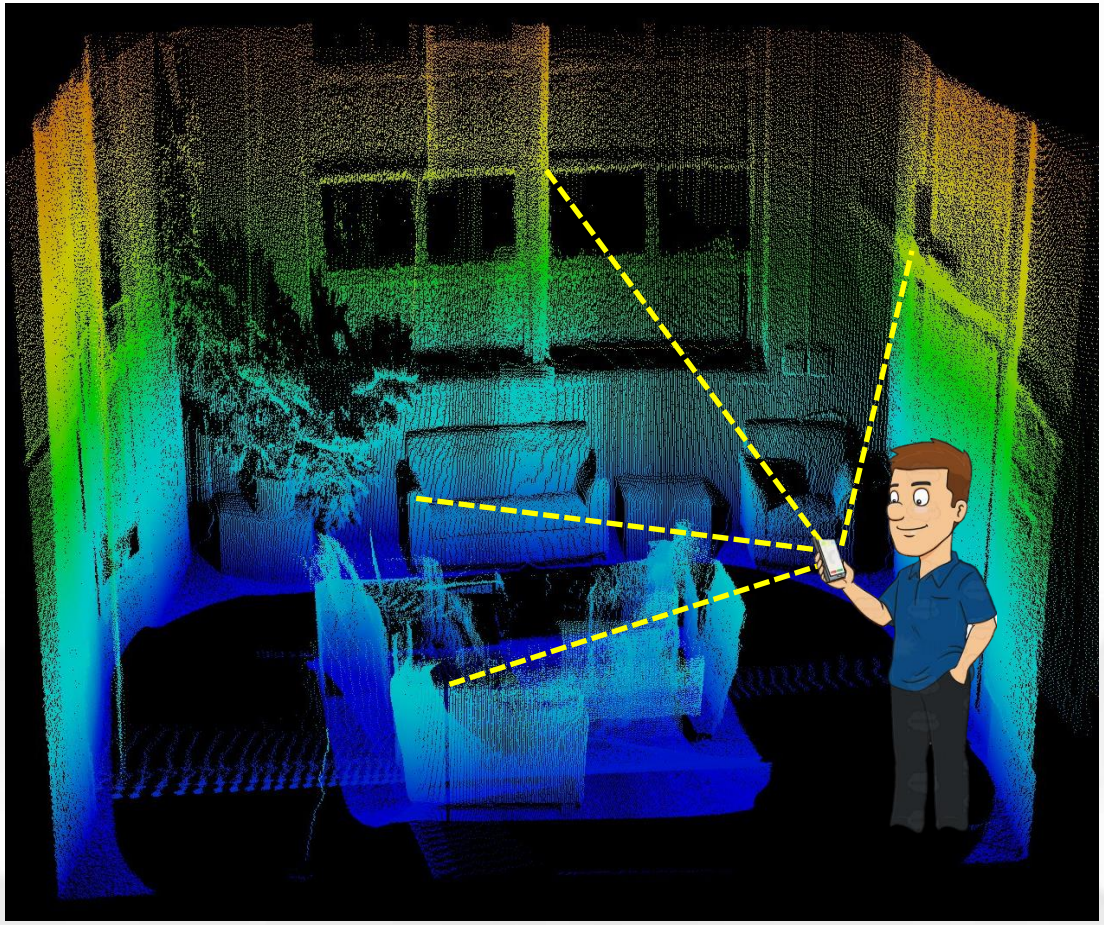
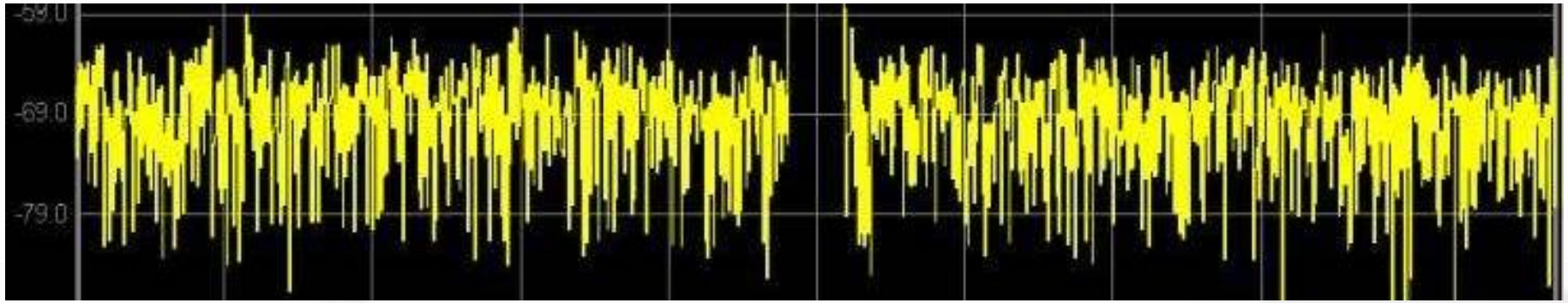
Visual Positioning With Depth Camera



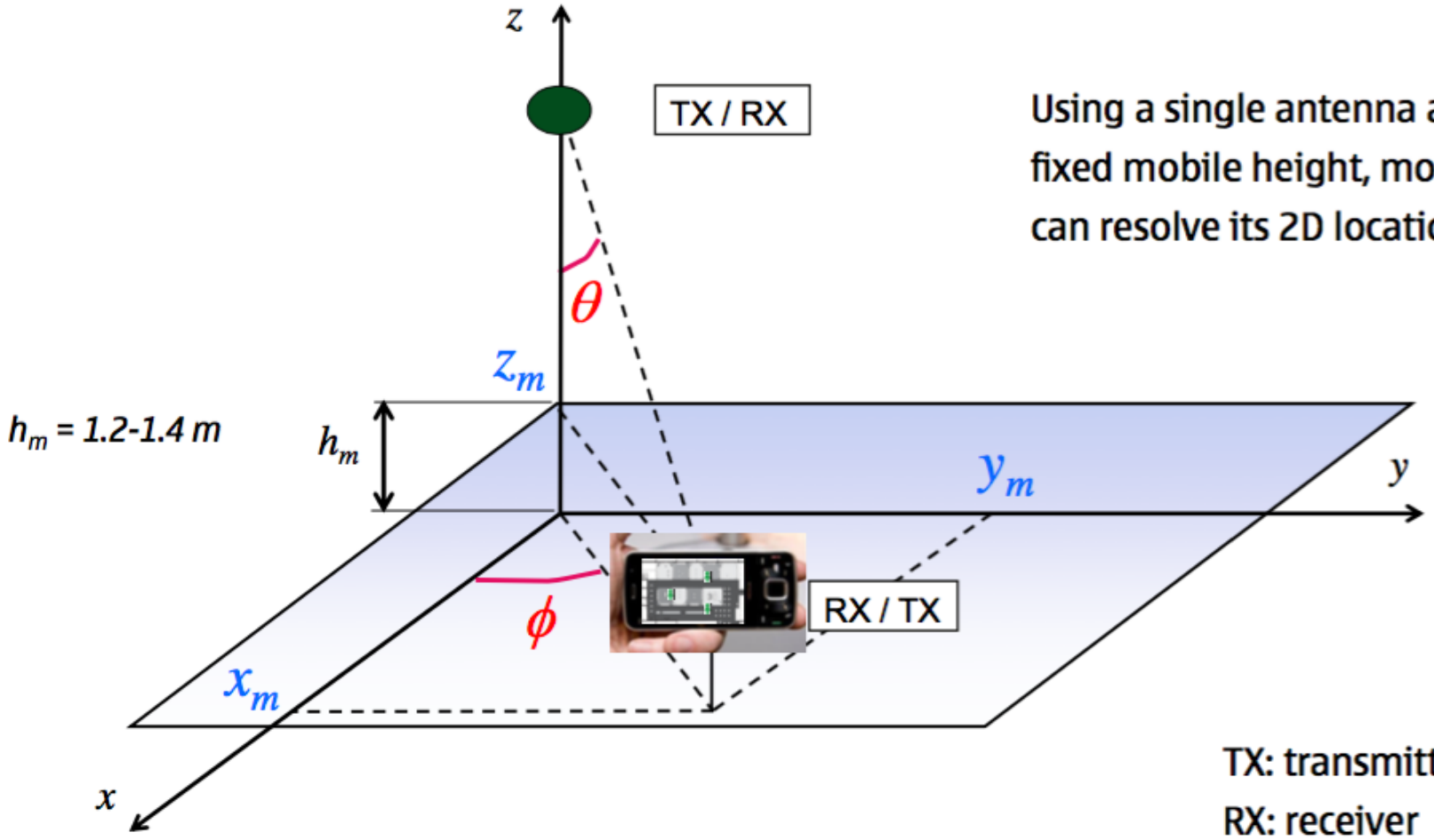


Positioning Based on RF Signal



Nokia BLE Antenna Array

Localization Principle with a Single Positioning Beacon



Using a single antenna and fixed mobile height, mobile can resolve its 2D location

TX: transmitter

RX: receiver

Positioning With an BT Antenna Array

+

- A pseudolite-based approach
- Broadcast BS positions in WGS-84
- TTFF (Time To First Fixed) 0.1 Sec.
- Low-cost, easy for installation
- Positioning update rate 1-10Hz
- Positioning accuracy: 1-2m

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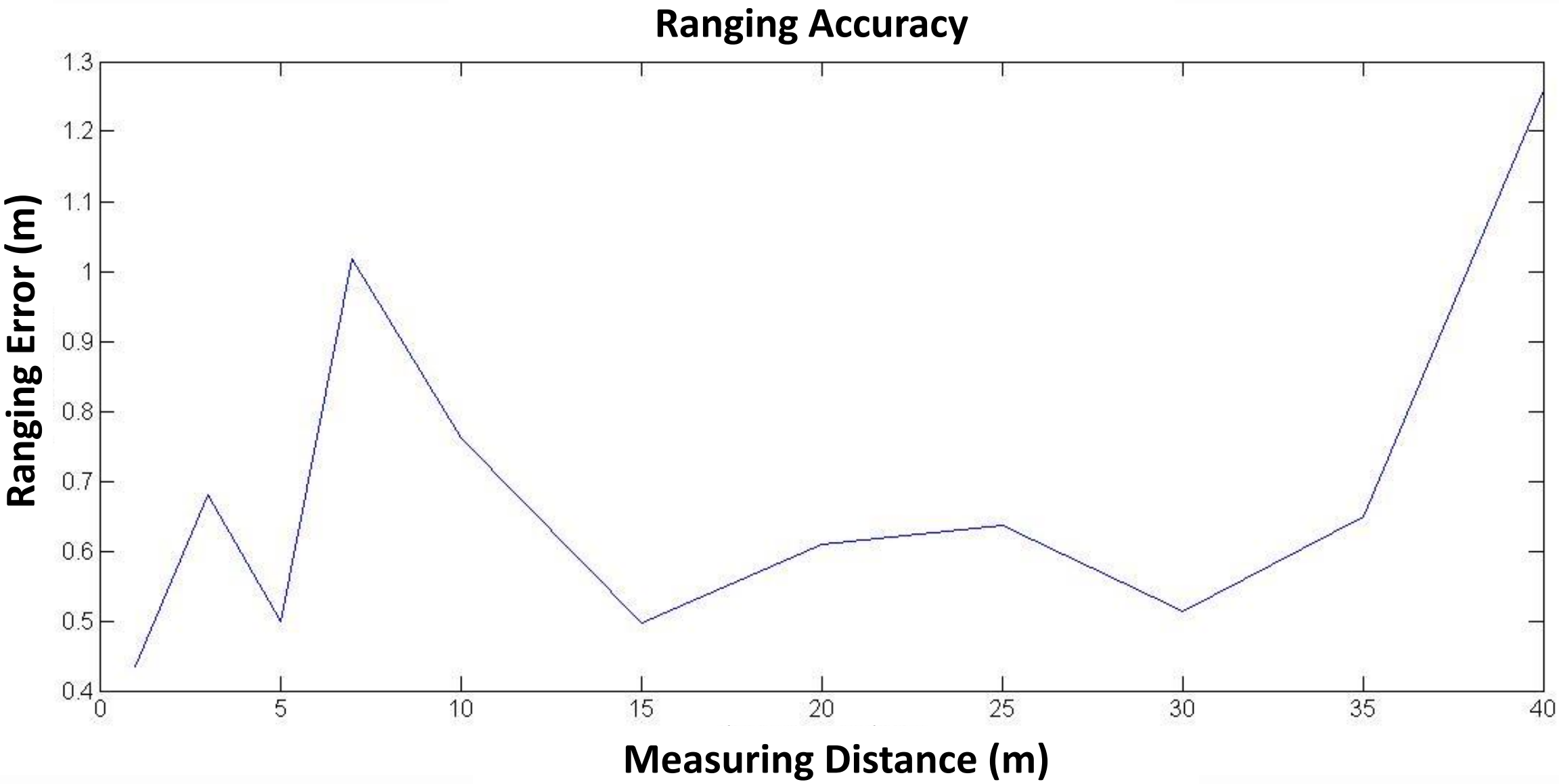
Wi-Fi Round Time Trip Ranging

Wi-Fi AP

Based on 802.11mc

Wi-Fi –RTT Ranging Accuracy



武汉大学 WUHAN UNIVERSITY

国家十三五重点研发计划项目

高精度室内定位演示系统

LIESMARS

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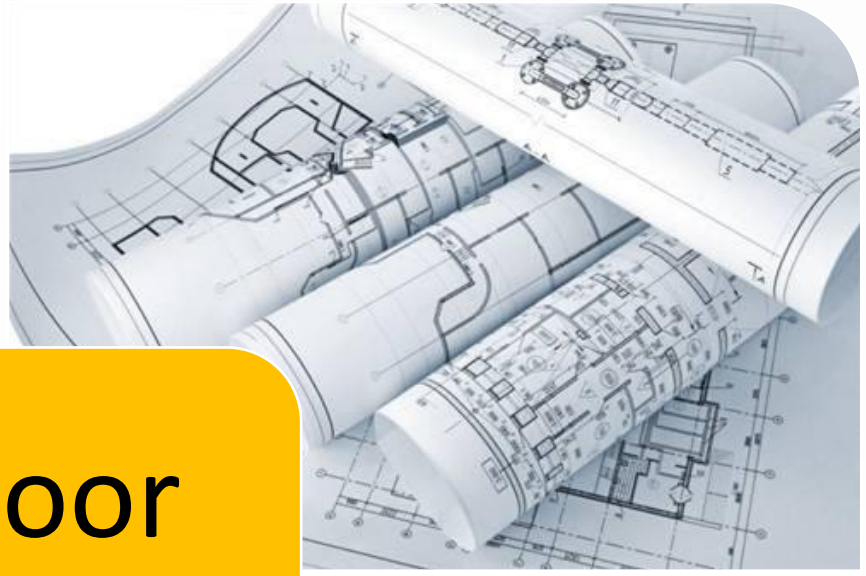
Contents

Indoor Mapping Approaches

Scanned FloorPlan



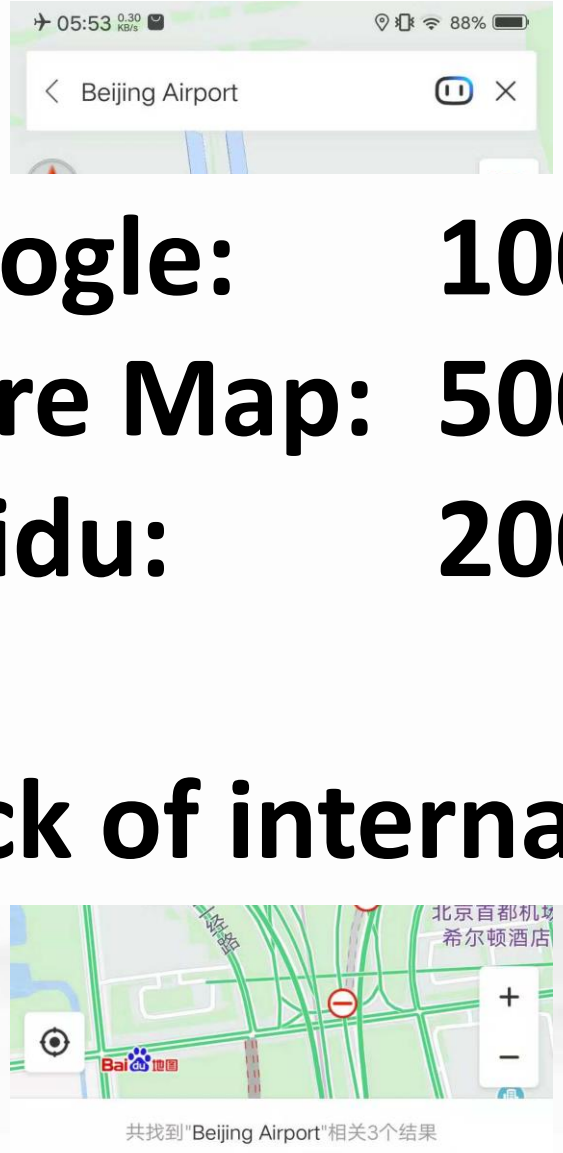
CAD/BIM

Indoor Maping

Crowded Sources

SLAM

An Example of Indoor Map



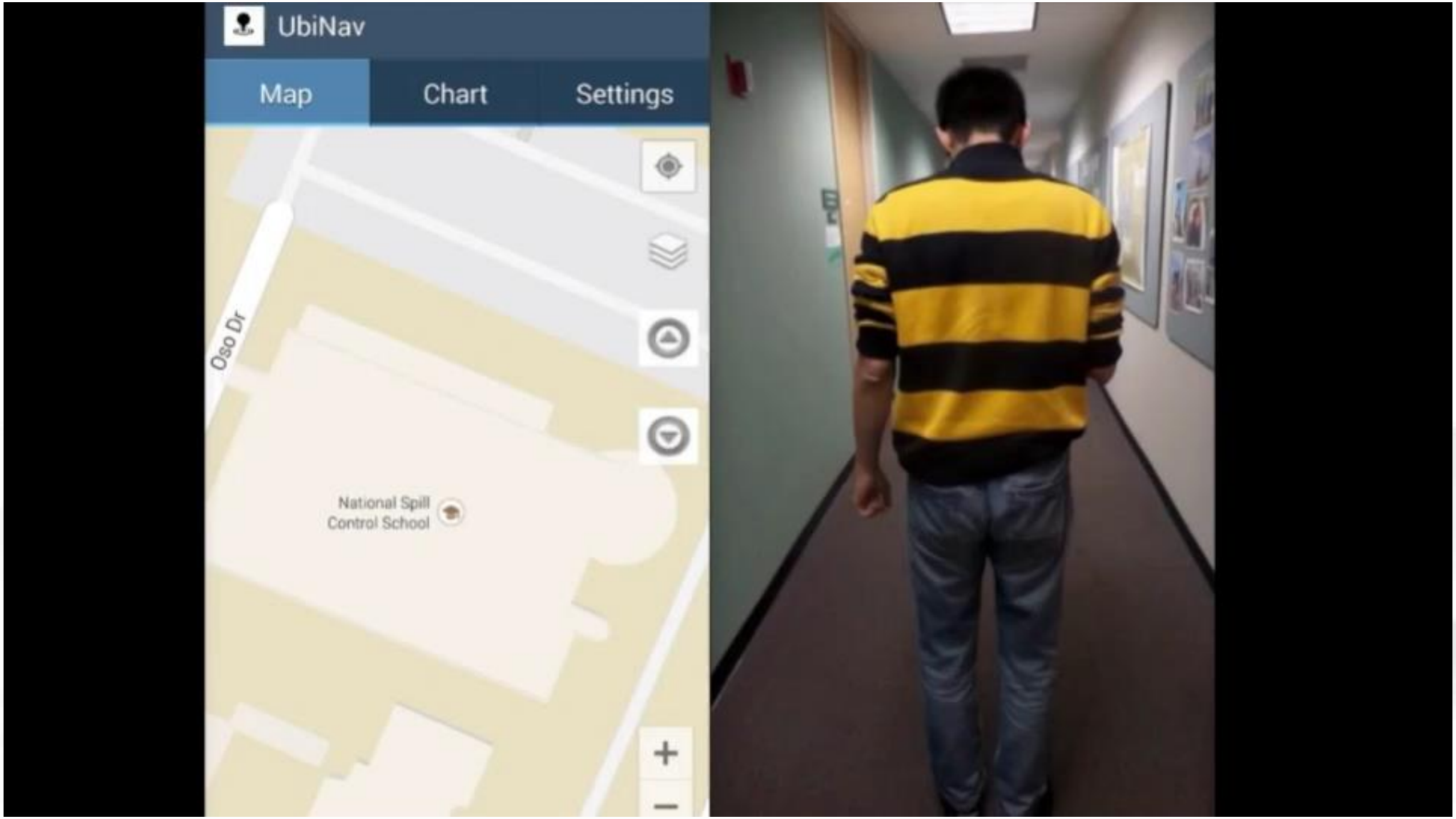
Google: 10000+

Here Map: 50000+

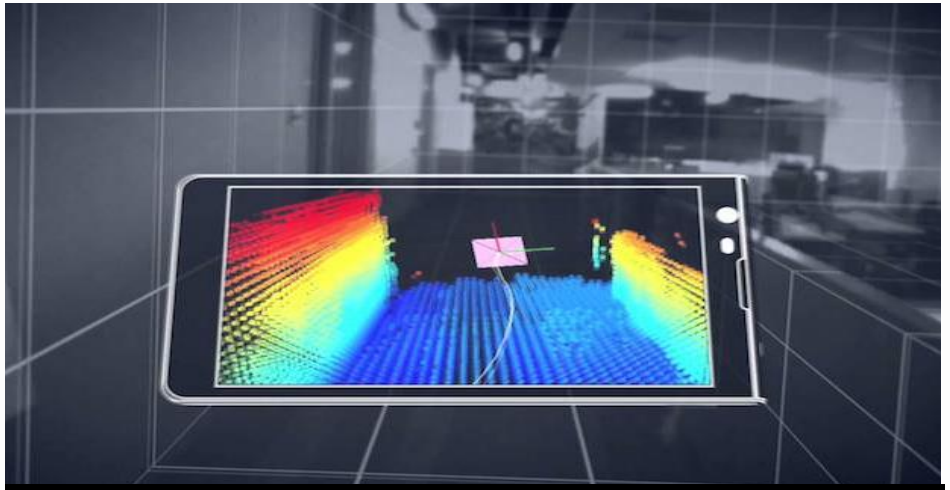
Baidu: 2000+ in China

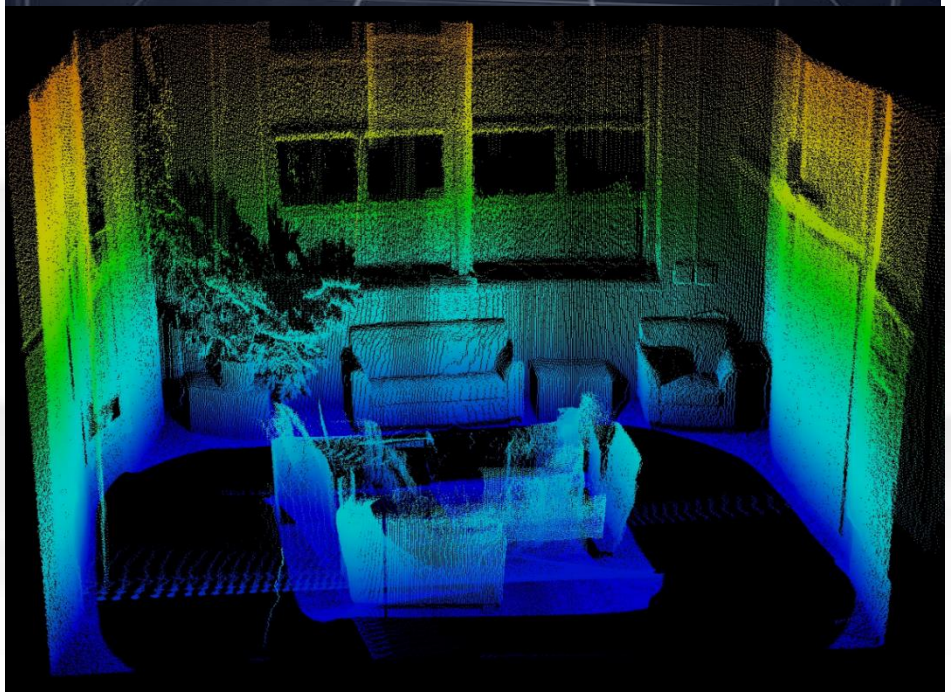
Lack of international standard

Indoor Mapping Demo

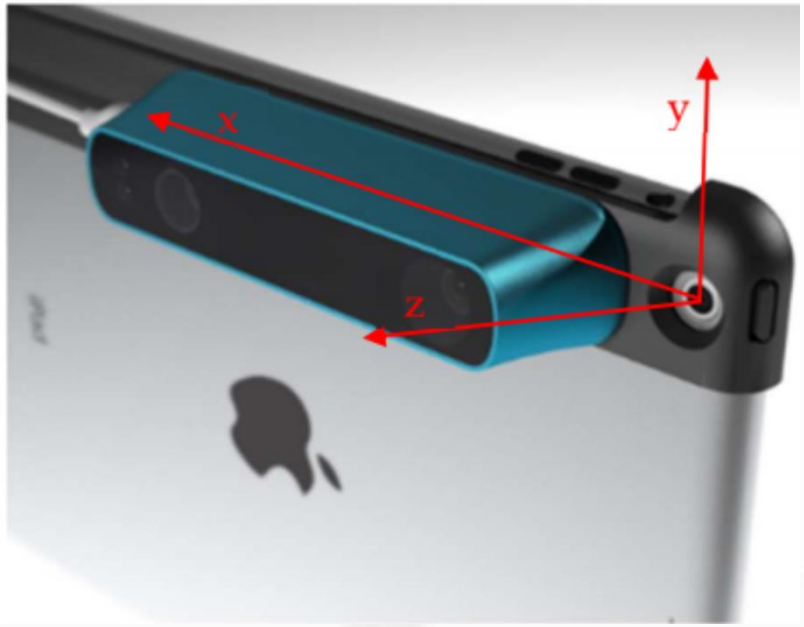


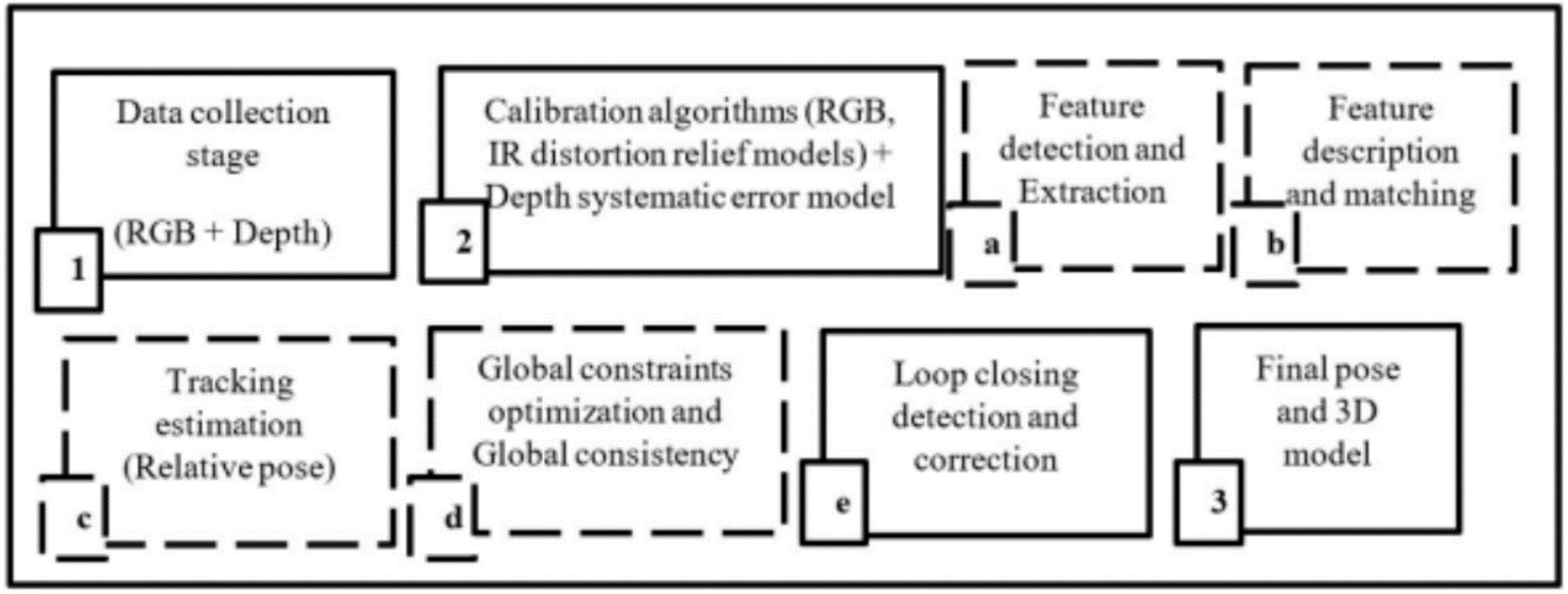
3D Modelling Based on Depth Camera





A Mobile SLAM Solution – FC RGB-D SLAM





PhD Thesis: **PRECISE RECONSTRUCTION OF INDOOR ENVIRONMENTS USING RGB-DEPTH SENSORS**

By

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Supervisor: Wu Chen

Department of Land Surveying and Geo-Informatics

Hong Kong Polytechnic University

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Hong Kong Central Metro Station

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Conclusions

- There are lots of positioning technologies for indoor, however, there is no such an indoor positioning technology that works like GNSS for outdoor.
- Using the built-in sensors and RF radios, smartphone positioning can achieve an accuracy of about 2-5meters in real time and about 1 meter by post processing.
- High precise indoor positioning technologies are capable to deliver centimeter level accuracy, but effective coverage of a single base station is limited. The new Wi-Fi ranging technology will resolve this problem partly.
- Integration of multiple positioning sources is probably the best option for complex indoor environments.
- Mobile devices with depth camera are capable of deliver 3D indoor models.

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Thank You！