Indoor Localization Technology and Algorithms Issues

Fan Ye

yefan@pku.edu.cn

Center for Energy-efficient Computing and Applications

EECS School, Peking University

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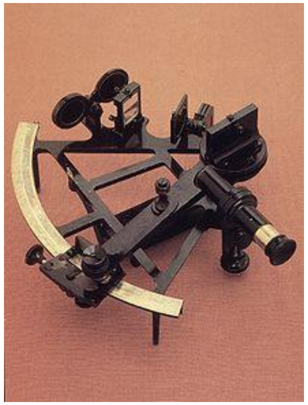
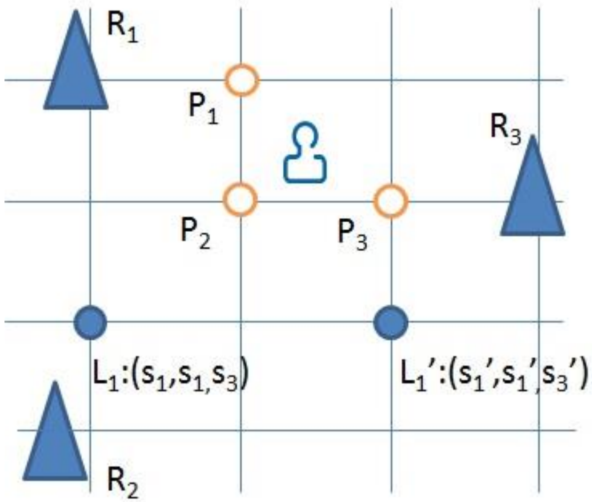
Outline

- Motivation
- Sextant: physical feature based indoor localization
- indoor floor plan reconstruction (ongoing work)
- Summary



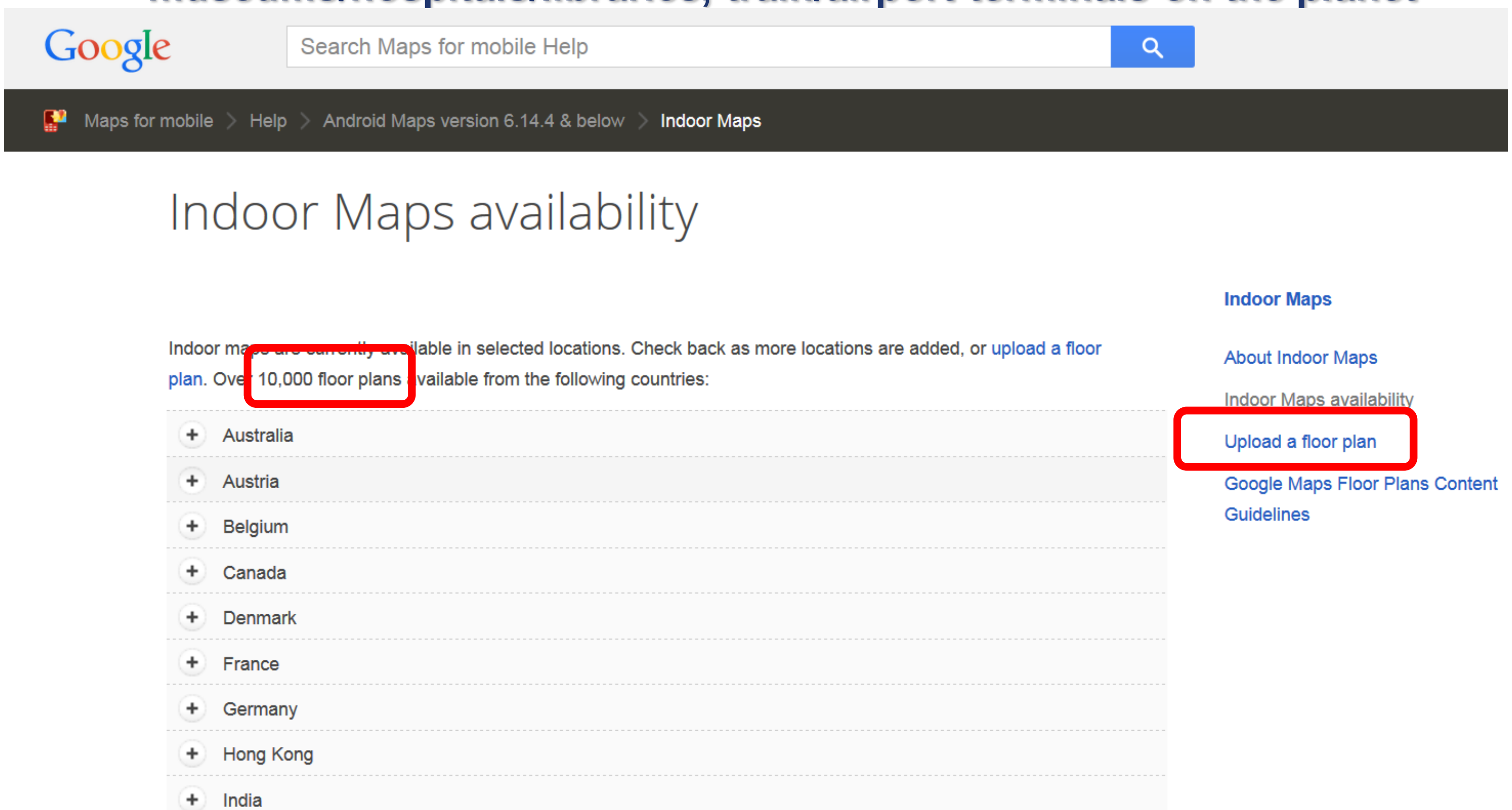
Motivation

- **Indoor Localization**
  - **Provides the location of users in a complex building**
    - **Shopping malls, train stations, airports**
  - **Essential for navigating the building, finding nearby products/stores/services**
- **More than a decade of research**
  - **Main stream technology: RF signature based**
    - **Each location has its unique signal pattern: Wifi (Radar 00'), cellular tower (Otsason et. al 05')**
    - **Other signatures possible: FM radio (Chen et. al. 12'), magnetism (Chung et. al. 11')**
  - **Special hardware to measure distance**
    - **Ultrasound (Cricket 00'), infrared (ActiveBadge 92'), bluetooth (Bruno et. al 03')**
- **Where are we now?**



The Service Availability is far from Ubiquitous

- **Indoor location service still sporadic**
  - **Only a small fraction of shopping/convention/sport centers, museums/hospitals/libraries, train/airport terminals on the planet**



The Service Availability is far from Ubiquitous

- **Indoor location service still sporadic**
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- **Two major obstacles of ubiquitous availability**
  - **Human efforts in building and periodic calibration of signature maps**
    - **Measure signal at fine grained grid points (e.g., 2m apart)**
    - **Some work (EZ, Zee, LiFS) starts to leverage crowdsourcing; but incentive/installation lacking**
  - **Difficulty in obtaining a floorplan**
    - **Business negotiation or uploading by the building owners**
- **Two pieces of work tackling the obstacles**
  - **Sextant: Environment physical feature based localization**
  - **Jigsaw: Indoor floor plan reconstruction via mobile crowdsensing**

Physical features as localization references

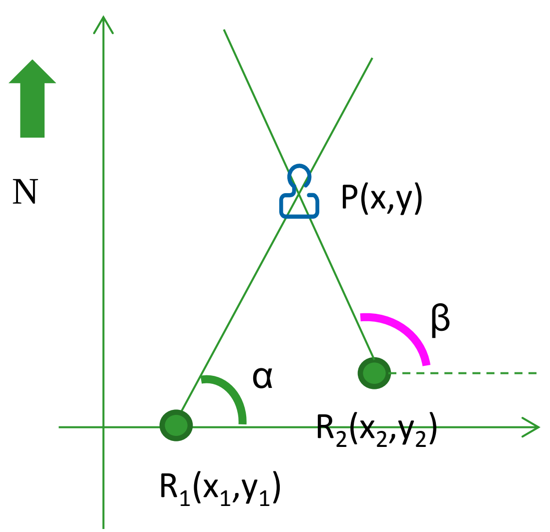
- **Use the relative position to environmental physical features for localization**
  - **Logos of stores, paintings on the wall, ATM machines**
  - **Use them as reference points**
  - **Measure distances/orientation to physical features**
  - **Triangulate for the user location**
- **Advantages:**
  - **Physical features are abundant in the environment**
    - **unlike AP/cellular tower etc that may not have sufficient number or coverage**
  - **Physical features seldom move**
    - **No need for periodic calibration**
  - **Physical features are not affected by ambient RF signals**
    - **E.g., microwaves, human movements affect WiFi signals**

Challenges for physical feature based localization

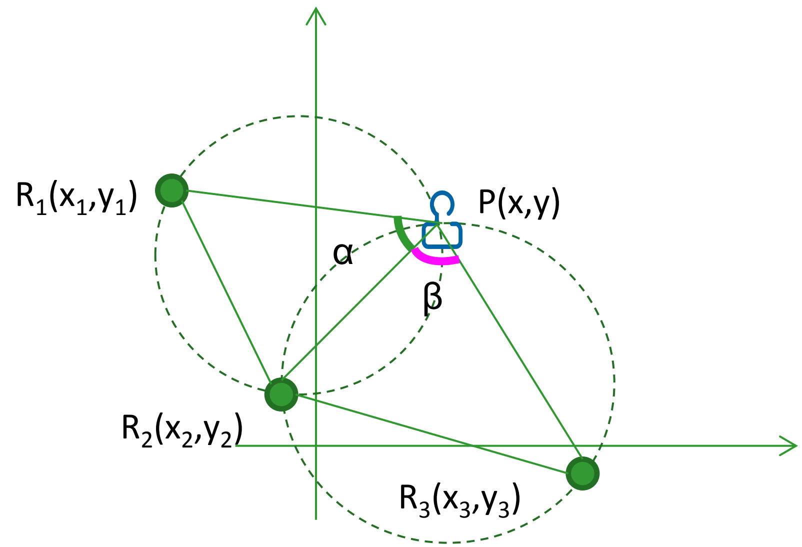
- What triangulation method is feasible on modern mobile devices?
  - Different methods require different kinds of distance/orientation inputs
- Rules to choose reference points to minimize localization errors?
  - Multiple reference points may exist nearby
- How to quickly establish the coordinates of reference points?
  - User location is calculated based on the coordinates of reference points

Orientation and Distance measurements

- What orientation/distance measurements are available on smartphones?
  - Absolute angle by the compass
  - Relative angle by the gyroscope
  - No sensor can measure distance directly
    - Some work measures pair-wise distances by sound (e.g., Beepbeep), but not to a physical feature
- Triangulation based on absolute and relative angles



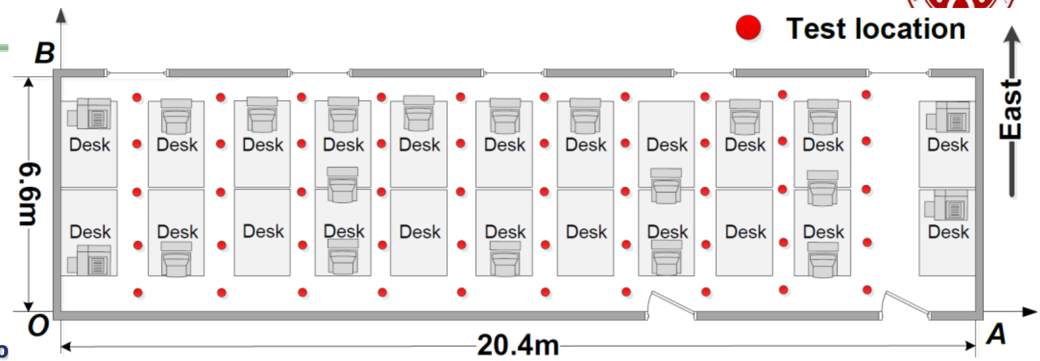
a) Absolute angle based

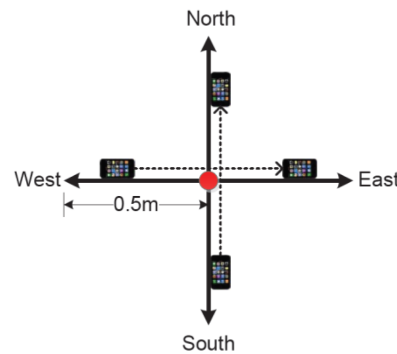


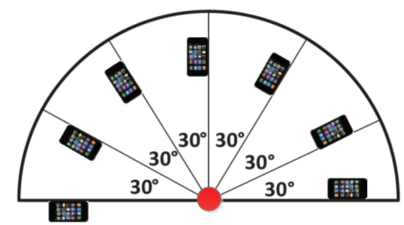
b) Relative angle based

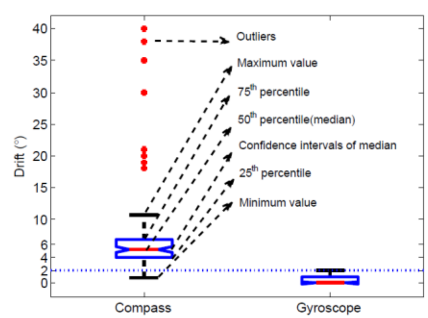
Study on accuracy of angle measurements

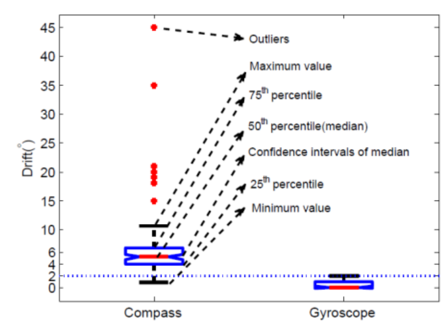
- **At each of the 50 test locations, repeat two experiments**
  - Move the phone along two 1m straight lines without rotation at 25cm steps
  - Rotate the phone along radial lines at 30º steps
  - Observation: gyro has much smaller errors (1~2º) in both cases, while compass has large outliers (up to 40º)
    - Larger outliers than observed by Zee 12’
- **Repeat the 2nd experiment**
  - 3 buildings: classroom, lab, stadium
  - 3 times of the day: 10AM, 2PM, 10AM
  - Rotate at different speeds: 10º in 2/5 seconds
  - Observation: same consistently small error, follow normal distribution (stdev ~2º, 95% ~6º)
- **Discovery: the gyro is much more accurate**





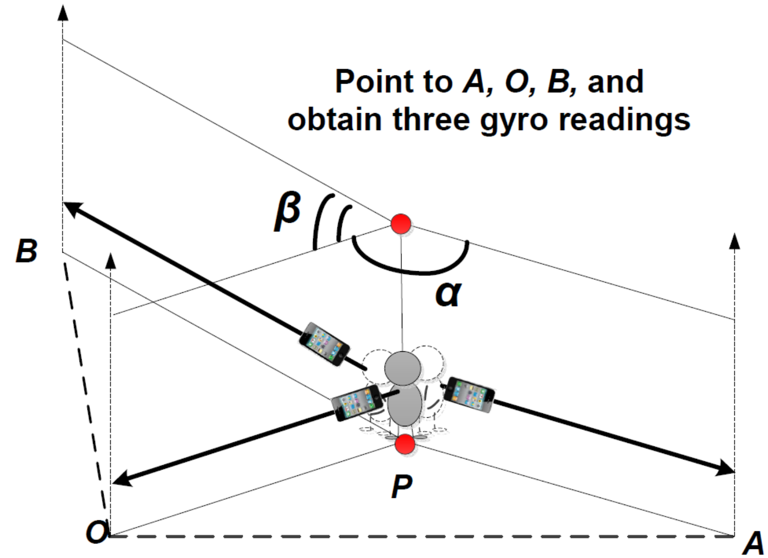


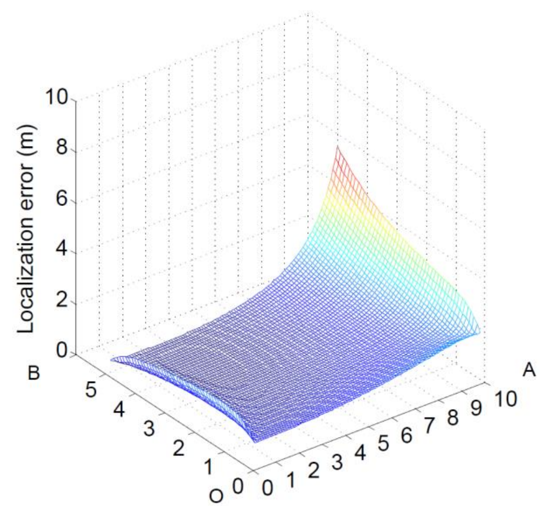




User operations in localization

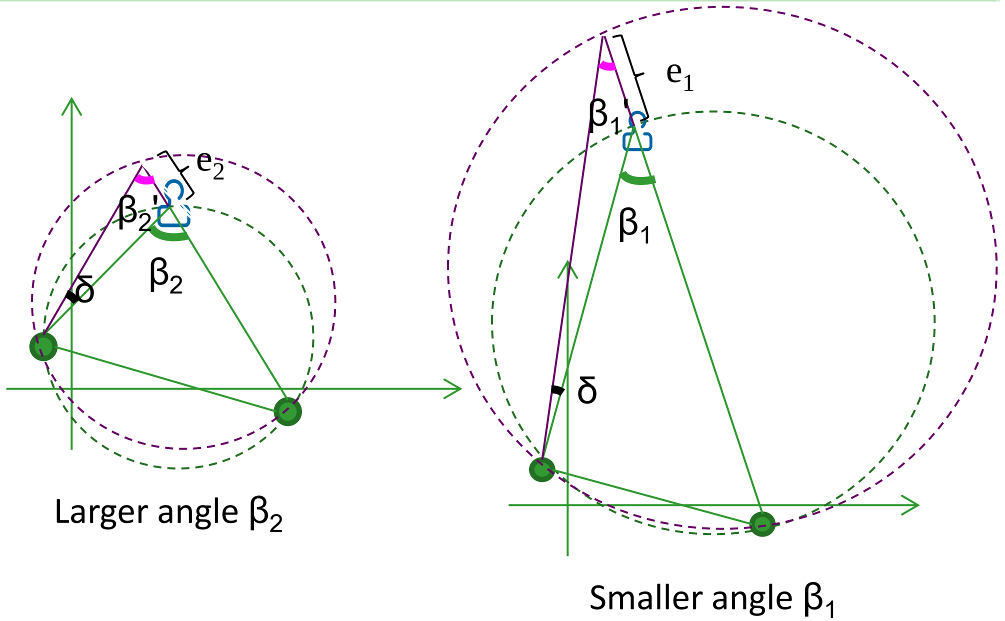
- **The user points to 3 reference objects one by one**
  - **The gyro measures the two angles α,β**
  - **With the coordinates of the 3 reference points A, O, B, the user location can be calculated**
- **Which reference points to choose when they are all around?**
  - **Numeric simulation: always pick A,O,B in a rectangle area, assuming a constant angle error of 6º**
  - **Observation: the error is small (<1m) when the user is close to the center reference point O, but much larger when far away (~6m)**



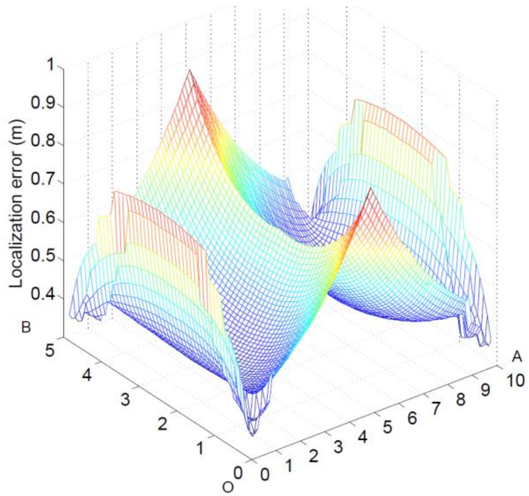


Rule of thumb for reference point selection

- **Intuition behind large errors caused by small acute angles**
  - The same angle error δ, but β2>β1, thus e1>e2
  - Smaller angle indicates longer distance, thus the same angle error causes more displacement

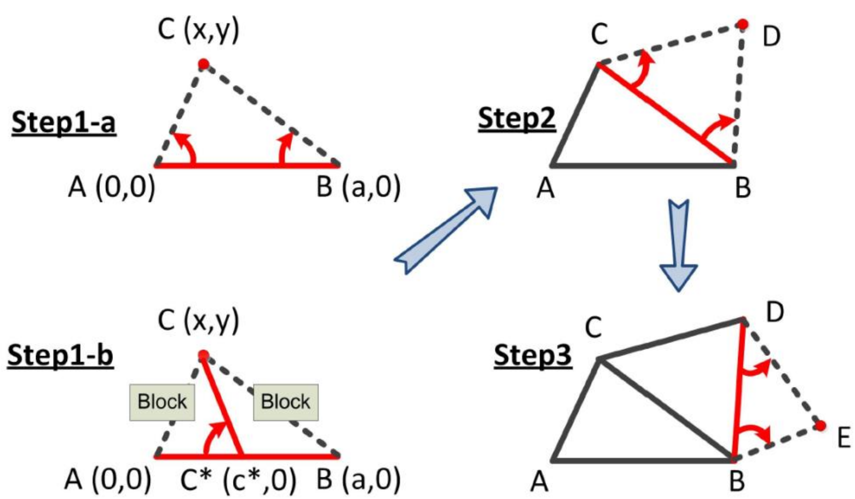


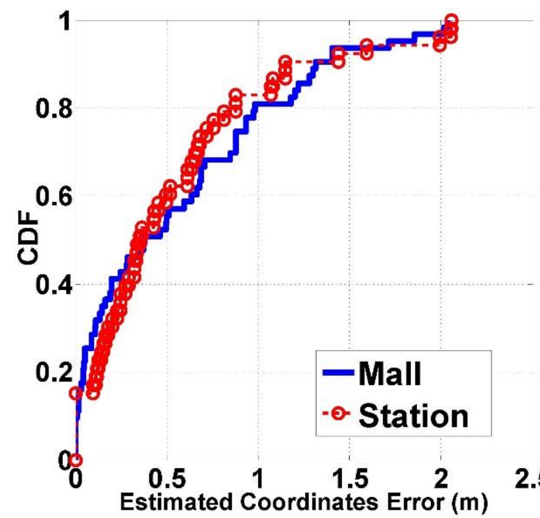
- Simple rule of thumb: closest point
  - Choose the closest reference point as the middle one, and one left/right as two additional points
  - Repeat the previous numeric simulation
    - Maximum error 1m



Establish a coordinate system in a new environment

- **How to establish the coordinates of reference points?**
  - **The coordinates are needed to calculate user location**
  - **Using a tape measure?**
- **Leverage the same idea for user localization**
  - **Measure the distances and establish coordinates for a few initial reference points**
  - **Incrementally localize the coordinates of new reference points one by one**
- **Experiments in both a mall (150x70m) and a train station (300x200m)**
  - **WiFi grid 2m apart needs signatures at 2600/15000 locations, repeated each month**
  - **Ours a one time cost of 2~2.6 man-hours**



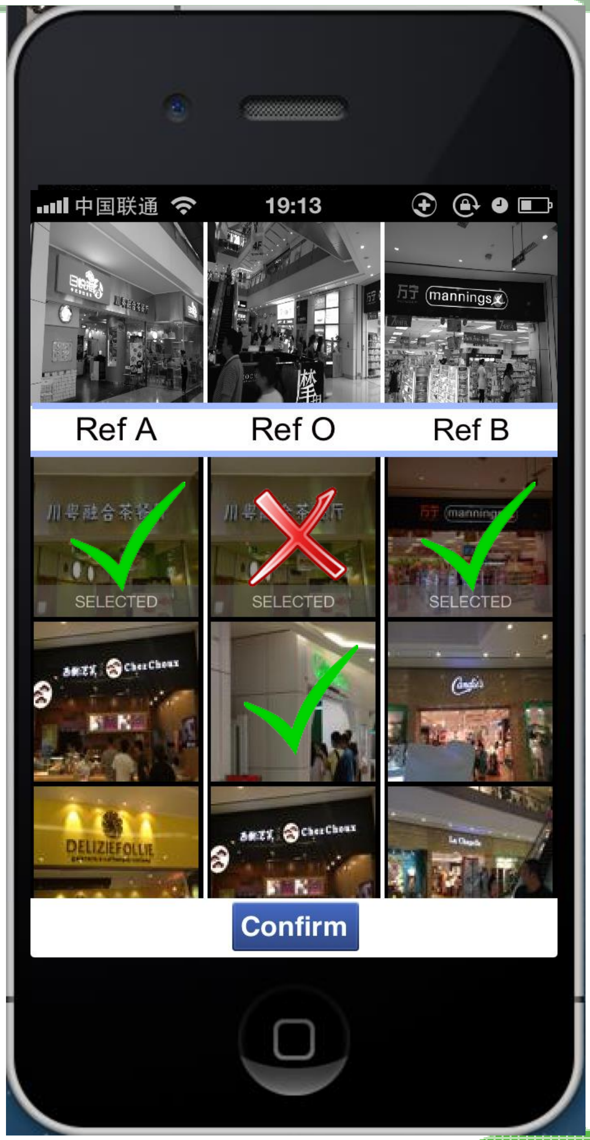


How does the system know which reference points were used?

- A naïve idea: have the user input the ID/names of used reference point
  - Difficult to design a naming convention for reference points
  - Hard for users to remember/recognize which is which
- Solution: use camera to take photos and automatically identify the reference point
  - The provider takes a few photos for each reference points as benchmark
  - Each test image is matched against benchmark photos
    - A ranking is produced among reference points
- We leverage existing vision algorithms and library
  - SURF vs SIFT for feature extraction
    - Extract features from the image, each features is a 64 vs. 128 dimension vector
    - Two vectors from two images “match” if their Euclidean distance is less than a threshold
  - OpenCV library
  - SURF chosen due to better accuracy/cost ratio

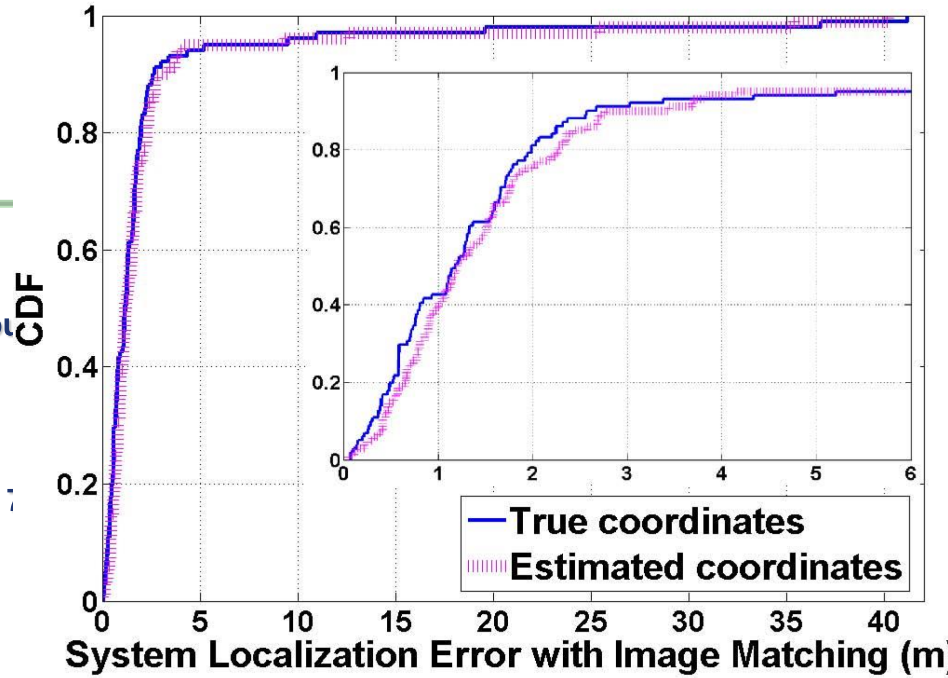
Reference object identification

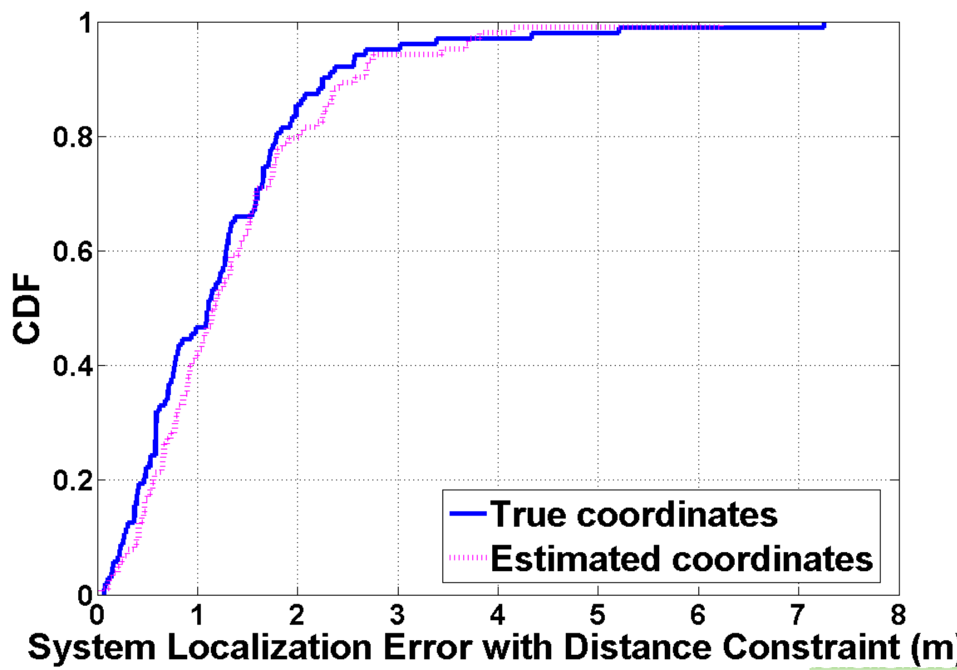
- **User correction**
  - 4x3 matrix
  - Top row user photos, below are top 3 matched benchmark photos
  - Users click on correct matched photos, then ‘OK’ for final localization
  - Top 4 has marginal improvement in accuracy

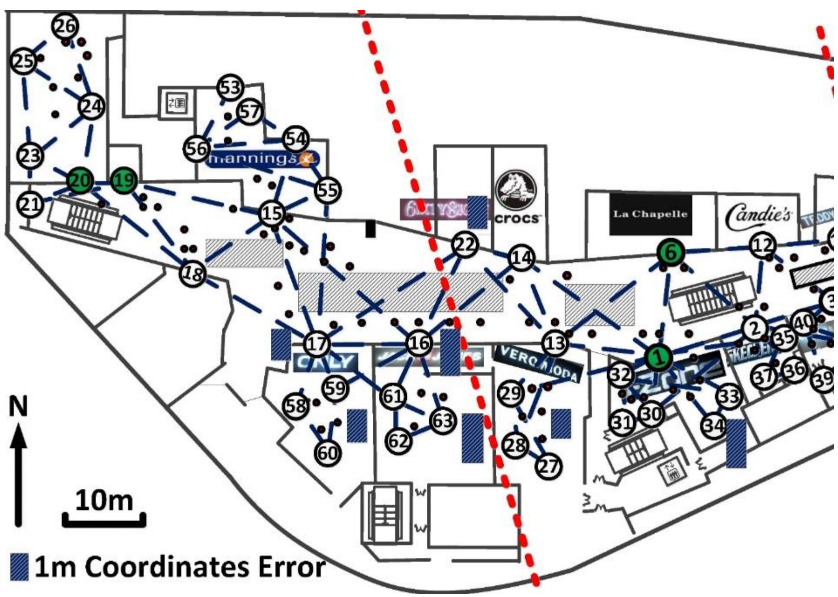


ECMall

- Relatively smaller open space
  - 150x75m2,22+41 out/inside ref points, 51+57 ou
    side test locations
- Localization error
  - 80% 2m w/o user correction, max from 42m to 7
    with heuristic constraints

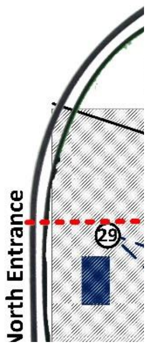


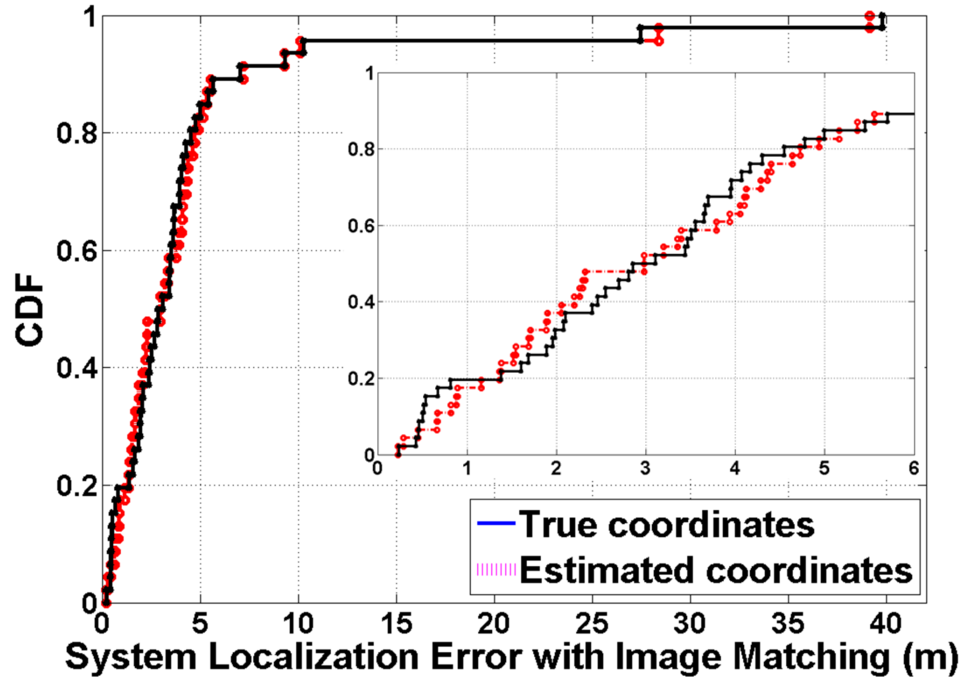


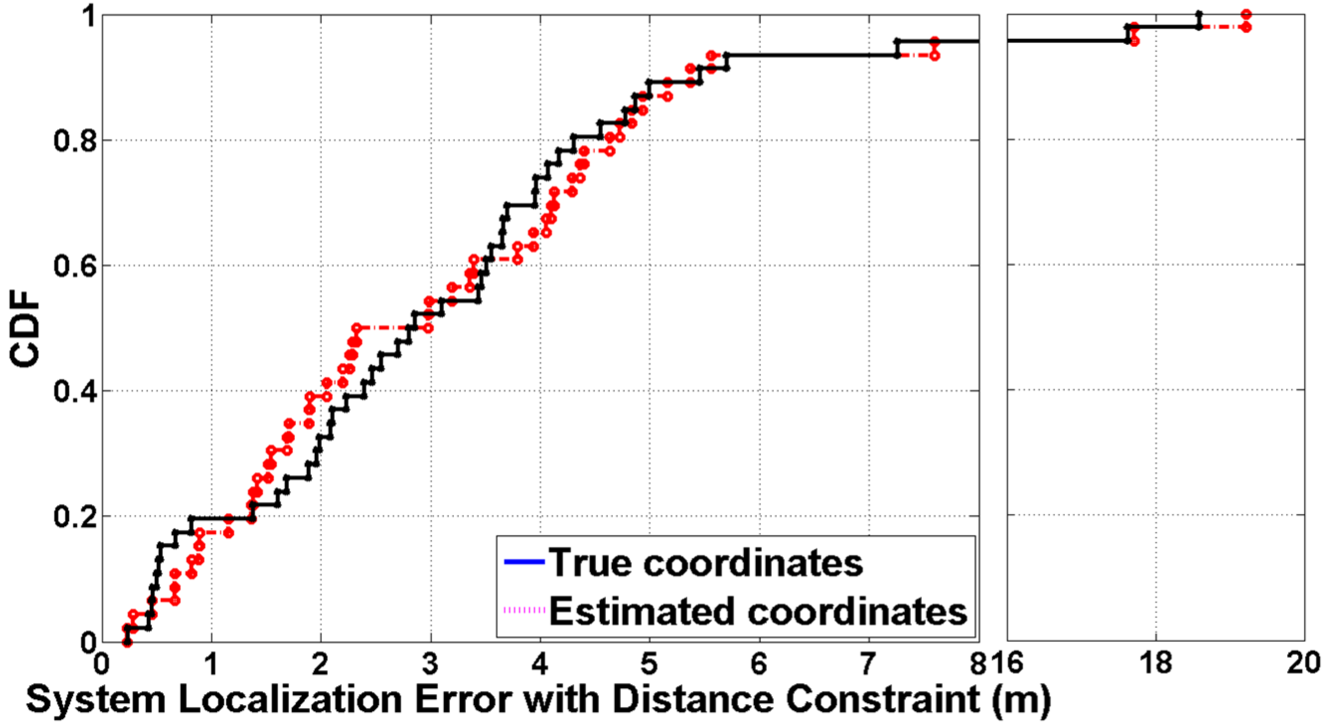


Beijing Railway Sc

- **Large open space**
  - 300x200m^2, 53 reference points, 62 test locations
- **Localization error**
  - 80% ~5m after user correction
  - Max from 42m to 19m with heuristic constraints
  - Latest Google Indoor Maps ~6m accuracy







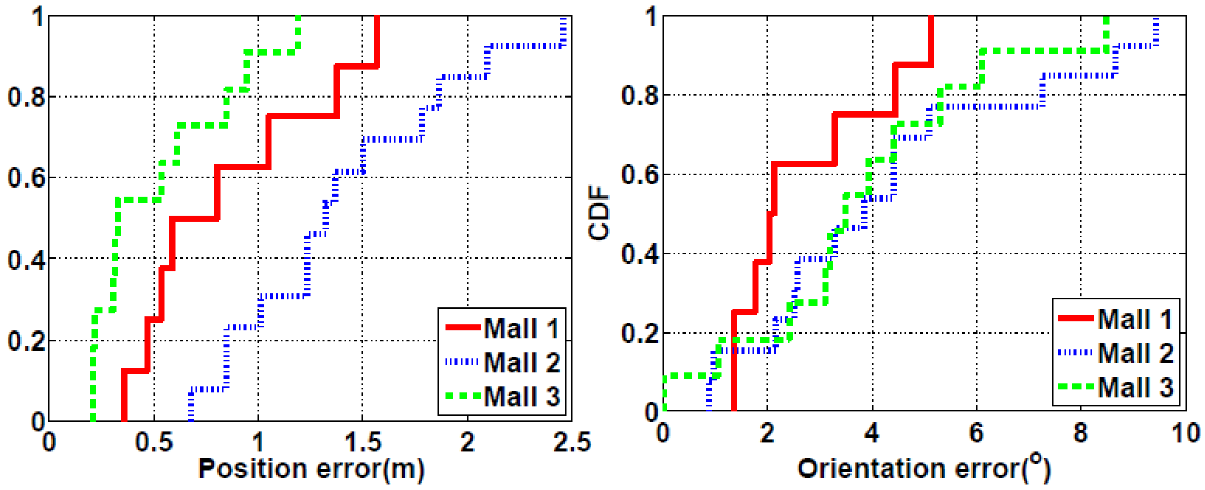
Indoor Floor plan reconstruction

- **Crowdsensing based construction**
  - Gather piecewise data (e.g., images, inertial sensor data) from individual mobile users
  - Extract floor plan information
  - Put pieces together into a complete floor plan
- **Benefits**
  - Service providers (e.g., Google) don't need to negotiate with building owners one by one
  - No need to hire dedicated personnel for inch-by-inch measurements either

Preliminary landmark placement results

◆ Landmark placement performance

- Experiments in 3 malls of 150x70 and 60x40m sizes
- Store position error 1-2m
- Store orientation error 4-10 degrees



Summary

- **Sextant**
  - **Environmental physical features provide a new approach for localization**
- **Reconstruction**
  - **Leverage crowdsensed image and inertial data to reconstruct the floor plans**
- **Together they may enable indoor localization service for the whole planet**

Thank you!

Questions?