Ubiquitous and Mobile Computing
CS 528: *LOCALIZE YOURSELF IN MALLS: An Anatomy of a Commercial Localization System with One-million Users*

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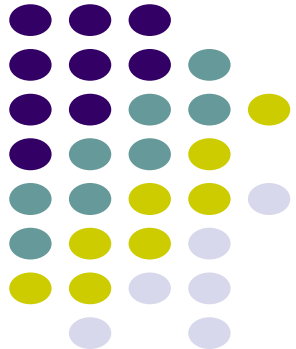
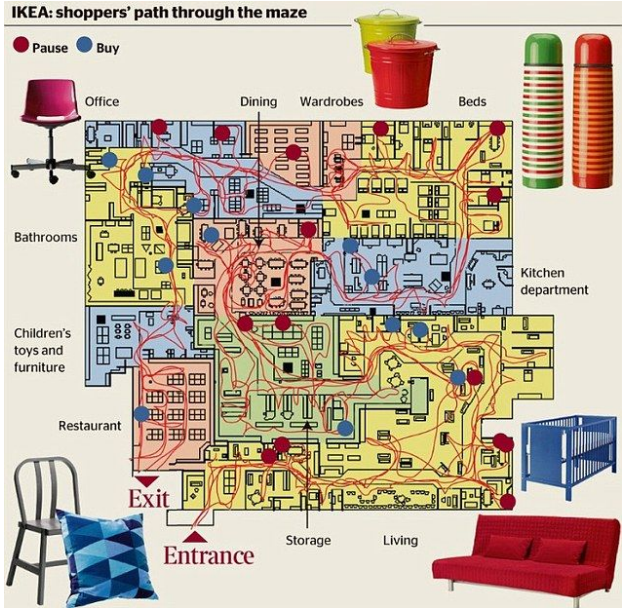


Problem

- In **modern shopping malls**, the **complex layouts** and dynamic configurations highlight the urgent need for efficient indoor localization systems to assist visitors in **quickly finding** specific stores and **points of interest.**



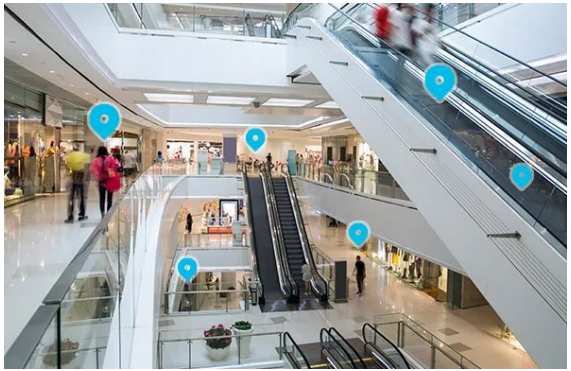
Challenges To Implement Indoor Localization

Many solutions are impractical in shopping malls:

- **GPS signals are weak** inside buildings
- Do not work on **off-the-shelf smartphones.**
- **WiFi scanning frequency is limited** on smartphones.
- Require **excessive infrastructure** deployment.

Idea

The solution provided by the authors is an application call MLoc. a smartphone-based localization system for indoor malls (commercial complex buildings) typically with tens or hundreds of retail stores. MLoc helps customers find paths to stores (e.g., the nearest Starbucks) by providing accurate, easy-to-use localization and storelevel navigation. **Using BLE, GMF and IMU sensors.**



Related Work

There has been extensive research on indoor localization, with over 596,000 results on Google Scholar for "indoor localization". State-of-the-art solutions **can achieve sub-meter accuracy in lab settings.**

Very **limited reports on large-scale commercial deployments** of indoor localization systems.

1. Airport Benchmarking. 2016. Airlines and Airports are Beaconizing.
2. Locatify. 2020. BLE Beacon Museum Guide with real-time user location.

Related Work

The authors found there are only a **few generic challenging areas** like atriums, dead-end corridors etc.

This allows them to use classical algorithms like kNN and particle filtering, with some customizations, rather than building new algorithms from scratch.

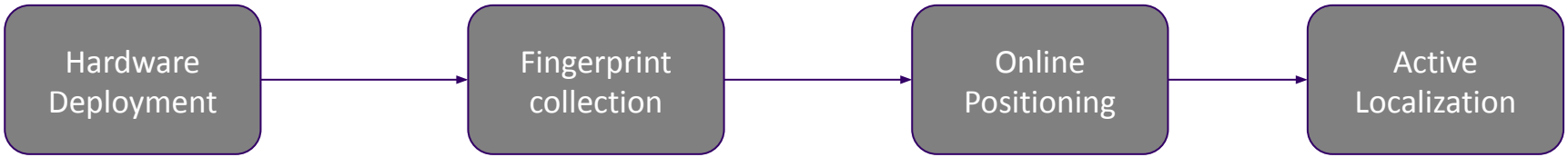
Lack of large-scale real-world deployment reports, and Focus on complex algorithms without consideration for practical deployment factors.

MLoc Method

MLoc System

Goal : Localize a user in a mall.

- Create a Map of the mall in the system and find where the user is within the map, and actively position the user within the map.

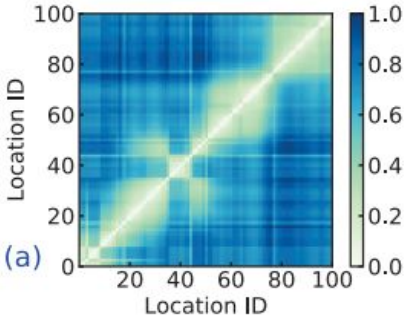


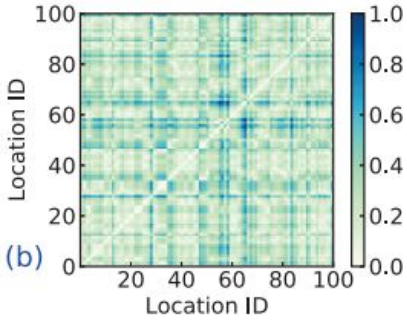
What is a Fingerprint ?

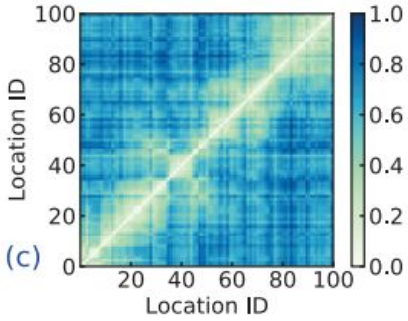
<u>Fingerprint:</u> Amount of signal strength interrupted due to the device.

BLE signal strength (RSSI)
Geomagnetic field strength (X, Y, Z axes)
Grid map of fingerprints indexed by location
Dead reckoning sensor data (accelerometer, gyroscope, etc.)

Fingerprint







BLE Fingerprint:
Low resolution
Slow to collect

GMF Fingerprint:
High resolution But noisy

Combine BLE & GMF:
Both are complementary

MLoc System - Hardware

Small-size and low-cost hardware

- Battery-powered BLE beacon
- Density: 5-15m

No additional power or networking cables.

MLoc System - Fingerprint Collection

Large-scale Fingerprint Collection

- Problem 1: A lack of ground truth location.
- Problem 2: Inefficient walking path of surveyors.

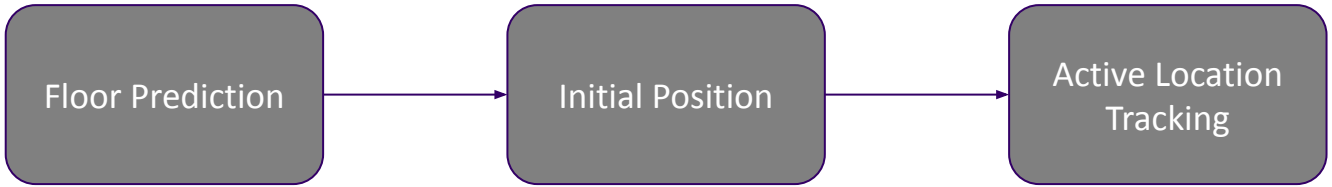
Solutions
- Use landmarks to locate themselves.
- Generate suggested paths for the surveyors.

<u>Landmark is needed for Localization</u>
(Machines Need Reference Points To Find Where They are In A Map Even For Immediate Next Step)

FIGURE 2. Data collection app.

MLoc System - Online Position

- Floor estimation: BLE
  - Floor change detection: IMU
- Initial positioning: BLE
- Location tracking: BLE & GMF & IMU



MLoc System - Online Position

Traditional algorithms

- KNN - Floor Identification and Initial Positioning in the Grid Map.
- Particle Filtering (PF) - Based on live data from IMU, find relative movement between actual mall and the grid map.

To Reduce Error While Localizing

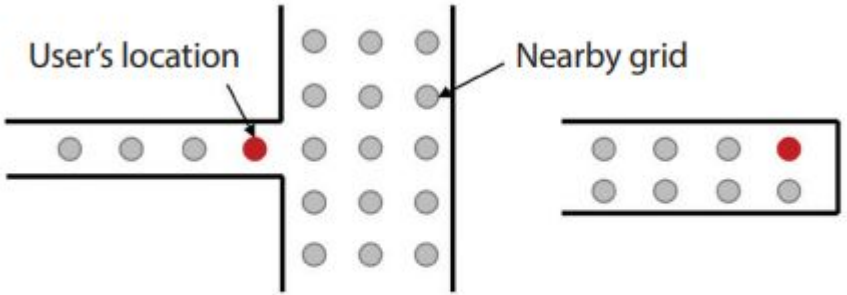
- Fine tuning on a per-site/floor basis.
- Normalized fingerprints for device heterogeneity.

MLoc System - Corner Case

Large Positioning Error:

• Connector and dead ends. (Classifier Fails Due To The Amount Of Neighbouring Points In The Edge Cases)

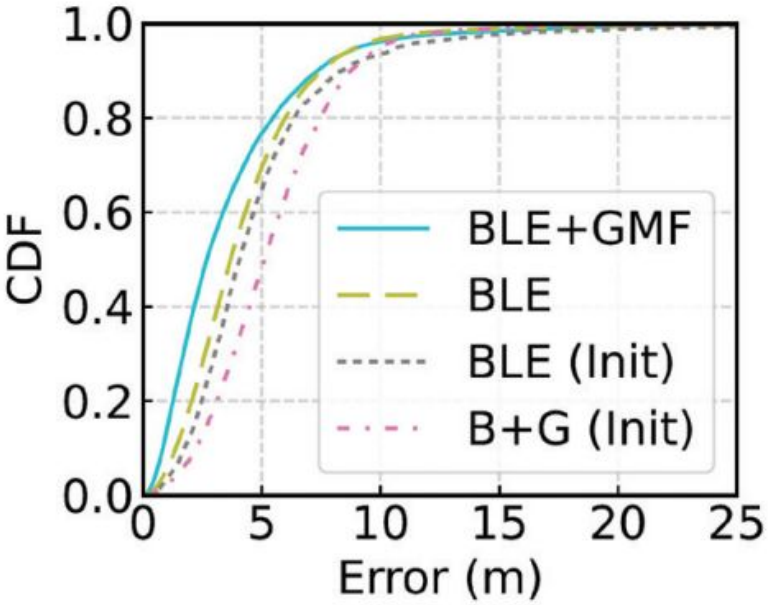
• Weighted Fingerprints Based On Layout



Results

Localization and Tracking Accuracy

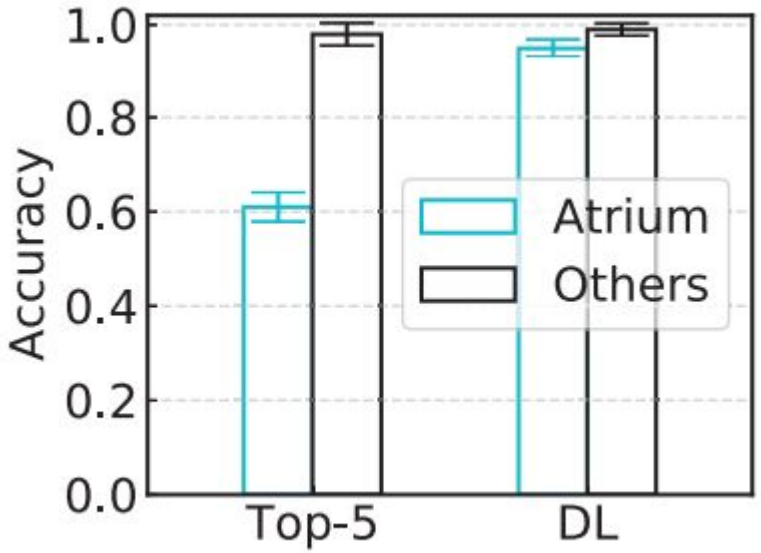
- An initial localization accuracy of 4.1m with per-site tuning.
- MLoc achieves a tracking accuracy of 2.4m.



Floor Errors In Wider Areas

- KNN has a large error (~40%).
- Lightweight DNN yields 96% accuracy.

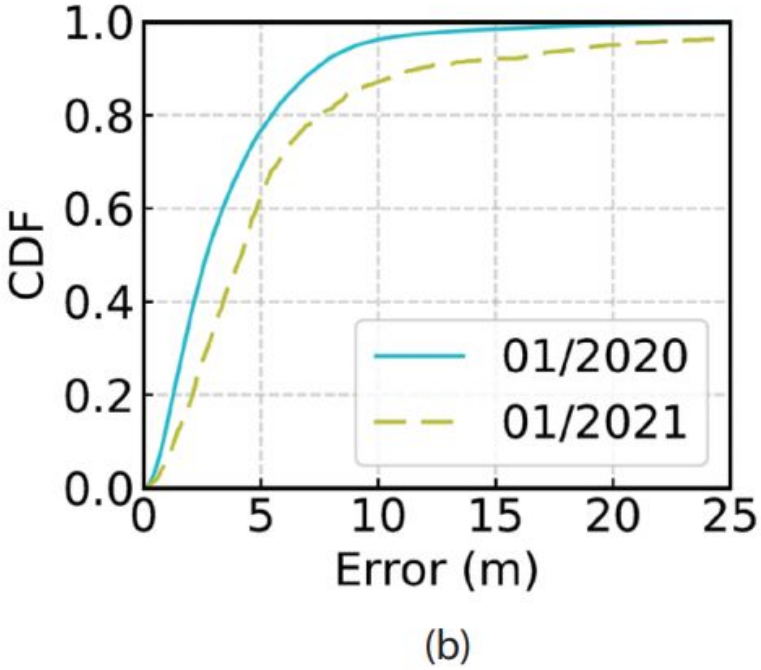
Justifies The Use Of DNN In Edge Cases



After One Year Usage

- Localization error remains at an acceptable level (4.6m).
- Without replacing failed beacons or updating training data.

Justifies Long Term Adoption



(b)

Marketing Benefits

- Coupons are marketed in the MLoc app.

- A sales event showed 22% coupon conversion rate, significantly higher than online ads. This demonstrates MLoc's marketing potential.

Discussion And Interesting Perspective

Discussions/Conclusions/Future Work

• MLoc uses BLE beacons and geomagnetic field fingerprints. It adopts a landmark-based outsourcing approach to collect training data. Customized mobile apps and path planning improve data collection.

• The paper shares insights on balancing tradeoffs for commercial viability. Low maintenance overhead and usability are as important as accuracy.

• The open-sourced dataset can facilitate further research and commercialization of indoor localization.

Interesting Perspective