SurroundSense: Mobile Phone Localization via Ambience Fingerprinting

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Context

Pervasive wireless connectivity  
+  
Localization technology  
=  

Location-based applications
Location-Based Applications (LBAs)

For Example:
- GeoLife shows grocery list when near Walmart
- MicroBlog queries users at a museum
- Location-based ad: Phone gets coupon at Starbucks

iPhone AppStore: 3000 LBAs, Android: 500 LBAs
Location-Based Applications (LBAs)

- For Example:
  - GeoLife shows grocery list when near Walmart
  - MicroBlog queries users at a museum
  - Location-based ad: Phone gets coupon at Starbucks

- iPhone AppStore: 3000 LBAs, Android: 500 LBAs

- Location expresses context of user
  - Facilitates content delivery
As if Location is an IP address for content delivery
Thinking about Localization from an application perspective...
Emerging location based apps need place of user, not physical location

Starbucks, RadioShack, Museum, Library

Latitude, Longitude
Emerging location based apps need place of user, not physical location

Starbucks, RadioShack, Museum, Library

Latitude, Longitude

We call this Logical Localization …
Can we convert from **Physical** to **Logical** Localization?
Can we convert from Physical to Logical Localization?

State of the Art in Physical Localization:

1. GPS  
   Accuracy: 10m
2. GSM  
   Accuracy: 100m
3. Skyhook (WiFi+GPS+GSM)  
   Accuracy: 10m-100m
Can we convert from **Physical** to **Logical** Localization?

State of the Art in **Physical** Localization:

- 1. GPS: Accuracy: 10m
- 2. GSM: Accuracy: 100m
- 3. Skyhook (WiFi+GPS+GSM): Accuracy: 10m-100m

Widely-deployable localization technologies have **errors** in the range of several meters.
Several meters of error is inadequate to logically localize a phone.
Several meters of error is inadequate to logically localize a phone.

The dividing-wall problem
Contents

- SurroundSense
- Evaluation
- Limitations and Future Work
- Conclusion
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It is possible to localize phones by sensing the ambience such as sound, light, color, movement, WiFi ...
Sensing over multiple dimensions extracts more information from the ambience

Each dimension may not be unique, but put together, they may provide a unique fingerprint
SurroundSense

- Multi-dimensional fingerprint
  - Based on ambient sound/light/color/movement/WiFi
Should Ambiences be Unique Worldwide?
GSM provides macro location (strip mall) **SurroundSense** refines to Starbucks
SurroundSense Architecture

Ambience Fingerprinting

- Sound
- Color/Light
- Acc.
- WiFi

Matching

Test Fingerprint

Logical Location

Candidate Fingerprints

GSM Macro Location
Fingerprints

- **Sound:**
  (via phone microphone)

- **Color:**
  (via phone camera)
Fingerprints

- **Movement:** *(via phone accelerometer)*

![Graphs showing movement in Cafeteria, Clothes Store, and Grocery Store](image)

- Cafeteria:
  - Moving
  - Static

- Clothes Store:
  - Moving
  - Static

- Grocery Store:
  - Moving
  - Static
Fingerprints

- **Movement:** (via phone accelerometer)

![Graphs of movement in Cafeteria, Clothes Store, and Grocery Store](image)

- **Cafeteria:**
  - Moving
  - Static
  - Queuing

- **Clothes Store:**
  - Moving
  - Static
  - Queuing

- **Grocery Store:**
  - Moving
  - Static
  - Queuing
Fingerprints

- **Movement:** (via phone accelerometer)

![Graphs showing movement patterns in different locations: Cafeteria, Clothes Store, Grocery Store.](image)

- **Cafeteria:**
  - Moving
  - Static

- **Clothes Store:**
  - Queuing
  - Seated

- **Grocery Store:**
  - Queuing
  - Seated
Fingerprints

- **Movement:** (via phone accelerometer)

![Graphs showing movement patterns in Cafeteria, Clothes Store, and Grocery Store. The graphs indicate periods of static and moving, with an arrow pointing to a specific time in the Clothes Store graph labeled "Pause for product browsing."
Fingerprints

- **Movement:** (via phone accelerometer)

  - **Cafeteria**
    - Moving
    - Static
    - Pause for product browsing

  - **Clothes Store**
    - Moving
    - Static
    - Short walks between product browsing

  - **Grocery Store**
    - Moving
    - Static

Fingerprints

- **Movement:** *(via phone accelerometer)*

![Graphs showing movement in different locations]

- **Cafeteria**
  - Moving
  - Static

- **Clothes Store**
  - Moving
  - Static

- **Grocery Store**
  - Moving
  - Static

*Walk more*
Fingerprints

**Movement:** (via phone accelerometer)

- Cafeteria
- Clothes Store
- Grocery Store

<table>
<thead>
<tr>
<th>Moving</th>
<th>Static</th>
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Fingerprints

- **Movement:** (via phone accelerometer)

- **WiFi:** (via phone wireless card)

\[ f(\text{overheard WiFi APs}) \]
Discussion

- Time varying ambience
  - Collect ambience fingerprints over different time windows

- What if phones are in pockets?
  - Use sound/WiFi/movement
  - Opportunistically take pictures

- Fingerprint Database
  - War-sensing
Contents

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Evaluation Methodology

- 51 business locations
  - 46 in Durham, NC
  - 5 in India

- Data collected by 4 people
  - 12 tests per location

- Mimicked customer behavior
Evaluation: Per-Cluster Accuracy

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<thead>
<tr>
<th>Cluster</th>
<th>1</th>
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Localization accuracy per cluster

![Localization accuracy per cluster graph](image)
Evaluation: Per-Cluster Accuracy

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Localization accuracy per cluster

Multidimensional sensing
Evaluation: Per-Cluster Accuracy

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Localization accuracy per cluster

Fault tolerance
### Evaluation: Per-Cluster Accuracy

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**Localization accuracy per cluster**

- **Sparse WiFi APs**

![Localization accuracy chart](image-url)

- *ChartData*
Evaluation: Per-Cluster Accuracy

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Localization accuracy per cluster

Accuracy (%)
Evaluation: Per-Scheme Accuracy

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<tr>
<th>Mode</th>
<th>WiFi</th>
<th>Snd-Acc-WiFi</th>
<th>Snd-Acc-Lt-Clr</th>
<th>SS</th>
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<tr>
<td>Accuracy</td>
<td>70%</td>
<td>74%</td>
<td>76%</td>
<td>87%</td>
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</table>
Evaluation: User Experience

Random Person Accuracy

CDF

Average Accuracy (%)
Why does it work?

The Intuition:

Economics forces nearby businesses to be different

Not profitable to have 3 coffee shops with same lighting, music, color, layout, etc.

SurroundSense exploits this ambience diversity
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Limitations and Future Work

- Energy-Efficiency

- Localization in Real Time

- Non-business locations
Limitations and Future Work

- **Energy-Efficiency**
  - Continuous sensing likely to have a large energy draw

- Localization in Real Time

- Non-business locations
Limitations and Future Work

- **Energy-Efficiency**
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- **Localization in Real Time**
  - User’s movement requires time to converge

- **Non-business locations**
Limitations and Future Work

- **Energy-Efficiency**
  - Continuous sensing likely to have a large energy draw

- **Localization in Real Time**
  - User’s movement requires time to converge

- **Non-business locations**
  - Ambiences may be less diverse
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SurroundSense

- Today’s technologies cannot provide logical localization
- Ambience contains information for logical localization
- Mobile Phones can harness the ambience through sensors

Evaluation results:
- 51 business locations,
- 87% accuracy

- SurroundSense can scale to any part of the world
Questions?

Thank You!

Visit the SyNRG research group @
http://synrg.ee.duke.edu/