Pazl: A Mobile Crowdsensing based Indoor WiFi Monitoring System

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Introduction

- 6 billion mobile subscriptions in the world [source: UN report, 2013].

- 1.4 billion smartphones will be in use by December 2013 [source: ABI, 2013] and expected to reach 2 billion by 2015 [source: Strategy Analytics, 2013].
Motivation

WLANs require permanent monitoring to capture all the dynamic aspects.

In the Informatics Forum:

Dynamic fluctuation of APs number at a single location
Motivation

In the Informatics Forum:

Manual site survey with Ekahau observing some coverage holes

Channel imbalance
Motivation

In the Informatics Forum:

Manual site survey with Ekahau observing some coverage holes

Channel imbalance

Need for continuous monitoring in space and time.
Motivation

- Traditional site surveys are expensive, intrusive and time consuming.
- People carry smartphones that can perform ubiquitous sensing.
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Pazl

Pazl - a mobile crowdsensing based indoor WiFi monitoring system.
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Continuous monitoring of the WiFi environment
Challenges

- To map any data we need to annotate it with its location.
- GPS is an established localization solution for outdoors, but not very reliable inside a building.
- Indoor localization:
  - WiFi fingerprinting or
  - Pedestrian Dead Reckoning (PDR).
Background – WiFi fingerprinting

Offline phase – data collection

Online phase – localization
Disadvantages of WiFi Fingerprinting

1. needs WiFi coverage.
2. Scanning the WiFi environment requires substantial amount of energy.
   - one order of magnitude more than the energy requirements for the accelerometer and compass.
   - not suitable for continuous tracking.
3. Many interferences (microwave ovens, people).
4. Disruptions in communication when done excessively.
Background - PDR

How it works?

- Compute consecutive positions starting from a known position
- Distance estimation
- Direction estimation

- Counting the number of steps.
- Step detection from acceleration:
  - Zero-crossing – count the number of acceleration crossing 0 value.
  - Peak detection
  - Auto-correlation – repetitiveness of human walking.
- Step length as a linear function of stepping frequency (R. Harle, 2012)
Background - PDR

How it works?
- Compute consecutive positions starting from a known position
- Distance estimation
- Direction estimation

Smartphones nowadays come equipped with magnetometers and gyros.
Background - PDR

How it works?
- Compute consecutive positions starting from a known position
- Distance estimation
- Direction estimation

Disadvantages:
- Noisy sensors
- Error accumulation
Pazl's localization solution

Application specific – PDR with periodic WiFi fingerprint and map knowledge assistance.
Activity recognition

- Activity recognition based on acceleration magnitude:
  \[ a = \sqrt{a_x^2 + a_y^2 + a_z^2 - g} \]

- Feature extraction: in time domain (mean, standard deviation, variant, correlation between axes) and in frequency domain (energy and entropy).

- Activity classifier trained for:
  - Walking
  - Static
  - Going up on stairs
  - Going down on stairs
  - Elevator moving up
  - Elevator moving down
  - Opening and closing doors (both in hand and in pocket)

- On the server Weka toolkit was used to classify the acceleration samples to activities.

<table>
<thead>
<tr>
<th>Window size</th>
<th>J48</th>
<th>Naive-Bayes</th>
<th>FT(tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>128 samples</td>
<td>70.5%</td>
<td>81.7%</td>
<td>80.5%</td>
</tr>
<tr>
<td>256 samples</td>
<td>74.2%</td>
<td>85.3%</td>
<td>81.9%</td>
</tr>
</tbody>
</table>
WiFi fingerprinting

- Euclidean distance approach.
- Vector of top 5 APs in signal strength
- Centroid of closest three matches
- Cells 1x1m

We have observed that some locations have consistently better accuracy.
WiFi fingerprinting

- Inaccuracy perimeter – the perimeter defined by the first three closest matching fingerprints in the database.
WiFi fingerprinting

- Inaccuracy perimeter – the perimeter defined by the first three closest matching fingerprints in the database.
Particle filter

- In the PDR, we observed that compass deviations and distance deviations between estimations and ground truth follow a close to normal distribution.

\[ f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]

- Weight on the distance choice

- Weight on the orientation choice

- Weight from activity confidence.

- Weight on distance to WiFi fix

\[ W = W_0 + W_d + W_c + W_a + W_f \]
Particle filter
Related work

- Building radio maps for WiFi fingerprinting using PDR.
  - WiFi-SLAM (B. Ferris et al., 2007)
  - ZEE (A. Rai et al., 2012).
Evaluation – Pazl localization system

- 5 participants on a track of 100 meters.
System Design

- Mobile application collecting sensor data on the phone
- Opportunistic data upload to the server for computations
- Server application running in the cloud
- Data is annotated with a location
- Create WiFi status reports
Evaluation – Pazl

- WiFi database was built by two participants.
- Activity classifier trained with the samples from two participants.
- In the experiment, 5 participants moved freely in the building for the period of a working day (10am-6pm).
- Monitoring at first floor in Informatics Forum.
Pazl site survey
Pazl compared to Ekahau
Future Work

- Remaining challenges
  - Energy-efficiency for long term running systems
  - Bootstrapping the application with indoor-outdoor transition detection
- Automate network management decisions using Pazl reports.
- Monitor other wireless environments.
Conclusions

- We move the monitoring perspective from the infrastructure to the client.
- Continuous monitoring through users mobility.
- Crowds map phenomena of common interest.
- Application specific indoor localization using a hybrid approach.
Thank you!

Questions?