A Context-enhanced Sector-based Indoor Positioning Library

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Jens Krösche is a professor in the Department of Mobility & Energy at the University of Applied Sciences Upper Austria. His research interests lie in the fields of context-aware computing, geographical information systems, navigation and positioning systems, and mobile information systems. The presented work is based on the results of a student’s master’s thesis.
Agenda

• Introduction
• Fundamentals
• Related Work
• Concept
• Implementation
• Evaluation
• Conclusion & Future Work
Introduction
INTRODUCTION

Motivation

• Location is one of the most important context features
  • Real-time navigation
  • Locating specific items in warehouses
  • Orientation in a large building complex (hospital, airport, ...)
  • ...

• Localization outdoors thanks to multiple existing GNSS no problem, but
  → requires non-obstructed line of sight
  → not usable for indoor localization
  → complex algorithms necessary to achieve the same indoors
Is the **same accuracy and precision** required **indoors** as it is **outdoors**?
INTRODUCTION

Goals

• Purely sector-based context-aware indoor positioning system

• Trade high accuracy for robust and cheap positioning

• No machine learning, artificial intelligence, or any form of data-based learning

• System is applicable to any building
Fundamentals & Related Work
Basic Positioning Methods

- Proximity Sensing
- Lateration
- Angulation
- Pattern Matching/Fingerprinting
- Dead Reckoning
FUNDAMENTALS & RELATED WORK

Basic Positioning Methods

- **Proximity Sensing**
  - Exploits the **limited range** of coverage of their pilot signals
  - Position of target **derived from base stations**

- **Fingerprinting**
  - Position of target **based on previously collected observations** of the site
  - Two phases:
    - **Off-line phase**: collect RSS values at pre-defined positions to create a database
    - **On-line phase**: match real-time RSS values to database
FUNDAMENTALS & RELATED WORK

Related Work

• RADAR
  one of the first approaches to exploit existing WiFi infrastructure

• Horus
  applying probabilistic methods to fingerprinting

• Sectjunction
  partitions the site according to RSS values to narrow the search space
Concept
CONCEPT

Overview

• **WLAN-based** indoor positioning system
  → follow the principles of proximity sensing
  → use existing network infrastructure

• Divide building into **sectors**
  → each access point inside a single sector
  → reduce complexity

• Utilize **filter pipeline** to derive position estimate
System Overview

- Components
  - Recording application
  - Simulation environment
  - Positioning library based on a filtering pipeline
Data Recording

- **Features**
  - Records various WiFi properties and sensor values
  - Predefined *routes* to establish calibration points
  - *Waypoint* scans at calibration points and *Intermediate* scans in regular intervals
  - *Record/Pause* and *export* features
CONCEPT

Recording Routes

- Background
  - Enable walkthrough simulation
  - Handle different scenarios
  - Based on building blueprints
CONCEPT

Route Simulation

• Features
  • Visualize level-based floor blueprints
  • Choose route to simulate
  • Visualize simulation data based on calibration points
  • Configure filtering pipeline
  • Visualize localisation sectors and positioning results
  • Manage simulation
Filter Pipeline

• Input
  • Scanned access points in near proximity
  • Sensor measurements of environment

• Output
  • Prioritized list of access points
Filter Pipeline

- AP
- Filter 1
- Filter 2
- ...  
- Filter N
- AP

raw scans

Process input to estimate sector

prioritized list
Implementation
IMPLEMENTATION

Iterations of Filter Pipeline

• Basic Pipeline
• Pressure Pipeline
• Graph (n = 1) Pipeline
• Blacklist Pipeline
• Graph (n = 2) Pipeline
IMPLEMENTATION

Basic Pipeline

Installed BSSIDs Filter

↓

Frequency Filter

↓

Sort-By Filter

↓

Distinct-By Filter

↓

Top-N Filter
IMPLEMENTATION

Pressure Filter

- Track four most recent barometer measurements
- Derive type of movement from ambient air pressure
  - air pressure going down  → target moving up
  - air pressure going up   → target moving down
IMPLEMENTATION

Graph (n = 1) Filter

- Limits involuntary sector jumps
- Limit estimates to be within 1 hops of previous estimation
IMPLEMENTATION

Blacklist Filter

- **maximumNumberOfSuggestions**: limit consecutive suggestions of a certain sector
- **numberOfScansBlocked**: limit number of times a certain sector is blocked

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of consecutive suggestions</th>
<th>Remaining blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4-2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4-3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3-19</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
IMPLEMENTATION

Graph (n = 2) Filter

- Limits involuntary sector jumps
- Limit estimates to be within 2 hops of previous estimation
Scenarios

- **Scenario #1: Change of Direction**
  At a certain point on the route, the target turns around and follows the route back

- **Scenario #2: Change of Floors**
  Two different flight of steps are used on this route to change from a higher to a lower floor and back

- **Scenario #3: Standing Still**
  The target standing still for an arbitrary amount of time at a certain point on the recording route

- **Scenario #4: Round Trip**
  The target follows a regular round trip, starting from a distinct location and arriving at the same location again
EVALUATION

Metrics

• Number of Correctly Estimated Sectors (NCES)
  • Parameterized → tolerated distance
    \[ d_{acc} = \frac{n_{corr}}{n_{total}} \]

• Average Distance to Correct Sector (ADCS)
  • Non-parameterized
    \[ d_{avg} = \frac{\sum_{i}^{n} \text{distance}(pos_{est}, pos_{corr})}{n_{total}} \]
## Performance Matrix

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pressure</th>
<th>Blacklist</th>
<th>Graph (n = 2)</th>
</tr>
</thead>
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<tr>
<td><strong>Scenario 1: Change of Direction</strong></td>
<td></td>
<td></td>
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<tr>
<td>NCES (td = 0)</td>
<td>0.640</td>
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NCES ... Number of Correctly Estimated Sectors  
ADCS ... Average Distance to Correct Sector
Conclusion & Future Work
Conclusion

- Best results achieved with Graph (n = 2) Pipeline
- Almost perfect results according to NCES with tolerated distance of 1
  \[ \rightarrow \text{most results off by only 1 sector} \]
- Overall performance favorable
- **HOWEVER:** Cell approximation is not realistic enough
Future Work

- Alternative cell approximation algorithms
  → signal propagation model

- More sophisticated filters
  → use more contextual information
  → analyze existing contextual information in detail