Smartphone Positioning Indoors

Ruizhi Chen

Wuhan University
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1. Introduction

2. Current Smartphone Positioning Technologies

3. Precise Smartphone Positioning Based on Built-in Sensors and RF Radios

4. Conclusions
Your Phone Knows Where You Are

“Where am I?”
The Location-Based Services (LBS) and Real-Time Location Systems (RTLS) market size was valued at USD 17.38 billion in 2017 and is projected to reach USD 68.85 billion by 2023, at a Compound Annual Growth Rate (CAGR) of 25.4% during the forecast period. The base year considered for the study is 2017 and the forecast period is from 2018 to 2023.

MarketsandMarkets™
Challenges for Indoor Positioning

- Complex topology
- Complex radio environment
- Complex human motion patterns
Visual Positioning Service – A Google Core Technology
iBeacon – An Apple Technology

![iBeacon diagram]

- **iBeacon**
- **Immediate**
- **Near**
- **Far**

![Image of iBeacon technology in use]
Baidu: Magnetic Fingerprinting
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Positioning Sensors and RF Radios in Smartphones

**GNSS**
- GPS
- GLONASS
- Beidou
- Galileo

**Sensors**
- Accelerometers
- Gyroscopes
- Magnetometer
- Light sensor
- Camera
- Acoustic sensor

**RF Radios**
- Bluetooth (BT/BLE)
- RFID/NFC
- Cellular network & Digital TV
- WLAN
Positioning With WiFi, Sensors and GNSS

- **GNSS**
  - GLONASS
  - Beidou
  - Galileo
- **RF Radios**
  - RFID/NFC
  - BT/BLE
  - Cellular network
  - Digital TV
- **WLAN**
- **Accelerometers**
- **Gyroscope**
- **Magnetometer**
- **Sensors**
  - Accelerometers
  - Gyrosopes
  - Magnetometer
  - Light sensor
  - Camera
  - Acoustic sensor
Fusing Sensor and RF Measurements

Magnetometer → Heading

Gyros → Speed

Accelerometer

GPS → Position

Speed

WiFi / iBeacon → Position

Unscented Kalman Filter

Location & Heading

Indoors/Outdoors

Positioning Accuracy

Ground Truth: GPS/INS

Horizontal Error vs. Time

Histogram of Horizontal Error

Testing Date: June 21, 2015
First Fix: 01:57:32 (UTC)
Last Fix: 01:59:49 (UTC)
Availability: 100 %
Error < 5 m: 79.71 %
Error < 10 m: 95.65 %
Maximum Error: 21.95 m
Mean Error: 3.52 m
Standard Deviation: 3.83 m
Real-Time: 2-5 meters under typical indoor environment

PerfLoc: NIST indoor Positioning Competition
# Post-Processing Accuracy

## Track 3

<table>
<thead>
<tr>
<th>Error</th>
<th>Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1m</td>
<td>Five-WHU</td>
</tr>
<tr>
<td>1.5m</td>
<td>EGEC</td>
</tr>
<tr>
<td>2.5m</td>
<td>TENCENT</td>
</tr>
</tbody>
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Positioning with New Sensors

Sensors
- Accelerometers
- Gyroscopes
- Magnetometer
- Light sensor
- Camera
- Acoustic sensor

GNSS
- GPS
- GLONASS
- BDS
- Galileo

RF signals
- BT/BLE
- RFID/NFC
- Cellular network & Digital TV
- WLAN

Light sensor
Camera
Acoustic sensor

BT/BLE
Positioning Based on Acoustic Signal
Acoustic Ranging Positioning

- Using the Mic and Speakers of the Smartphone
- Working spectrum ranges from 16-21KHz Not hearable by human, not interfered by human voices
- The speed of sound is slow compared to RF signals, therefore, the clock synchronization requirement is not high.
- Measure TOA
- Positioning accuracy: decimeters
- Effective Range: 5-20m
Positioning Accuracy

0.2 m at 95%
Positioning Based on Light Signal
Positioning Using Light

- An light shade is divided into 8 rings, each ring has 48 grids, there are 384 sectors in total.
- Each sectorial grid can be opened (0) or closed (1), by rotating the shade, the light sensor of the smartphone can receive different light patterns in different sectors.
- A sector is identified by the light patterns.
- No hardware change is needed from smartphones.
- Positioning accuracy is 5-10 cm.
- Single Station Positioning for Small Indoor Space.

Light source: 850 nm Infrared
Visual Positioning with Point-Line-2D-3D Objects
Human Eyes vs Smartphone Camera

5 Types of smartphones

3 Test Fields

Error Distribution

Positioning Error

<table>
<thead>
<tr>
<th>Human Brain</th>
<th>Phone Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.73m</td>
<td>0.31m</td>
</tr>
</tbody>
</table>

Indoor Visual Positioning aided by CNN-based Image Retrieval

CNN-Features

- Employ CNN model to extract features
- Rank images from database by feature similarity

Convolution layers visualization

![Convolution layers visualization](image)

Image feature vectors visualization

![Image feature vectors visualization](image)
## Positioning Errors

Comparison based on the ICL-NUIM dataset

<table>
<thead>
<tr>
<th>Method</th>
<th>Living Room (1495 Samples)</th>
<th>Office Room (1533 Samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PoseNet</td>
<td>0.60m, 3.64°</td>
<td>0.46m, 2.97°</td>
</tr>
<tr>
<td>4D PoseNet</td>
<td>0.58m, 3.40°</td>
<td>0.44m, 2.81°</td>
</tr>
<tr>
<td>CNN+LSTM</td>
<td>0.54m, 3.21°</td>
<td>0.41m, 2.66°</td>
</tr>
<tr>
<td>Our method</td>
<td><strong>0.36m, 4.36°</strong></td>
<td><strong>0.31m, 2.47°</strong></td>
</tr>
</tbody>
</table>

- Better position accuracy, Comparable orientation accuracy;
- Much fewer images in database construction period (Training images vs. Reference images);
- 3D-Modeling Free;
- Training Free;
- A set of images with high-precision pose is the key.
Positioning Based on RF Signal
Nokia BLE Antenna Array

Localization Principle with a Single Positioning Beacon

Using a single antenna and fixed mobile height, mobile can resolve its 2D location

$h_m = 1.2-1.4 \, m$

TX: transmitter
RX: receiver

Nokia Research Center
Positioning With an BT Antenna Array

- A pseudolite-based approach
- Broadcast BS positions in WGS-84
- TTFF (Time To First Fixed) 0.1 Sec.
- Low-cost, easy for installation
- Positioning update rate 1-10Hz
- Positioning accuracy: 1-2m
Wi-Fi Round Time Trip Ranging

Based on 802.11mc
Wi-Fi –RTT Ranging Accuracy

Test results in different multipath scenarios

Office room
Corridor
Underground parking
Mall hall
Positioning Accuracy

Cumulative Distribution

Absolute Error (m)

- 95% error: 1.5308 m
- 50% error: 0.7596 m
Conclusions

- There are lots of positioning technologies for indoor, however, there is no such an indoor positioning technology that works like GNSS for outdoor.
- Using the built-in sensors and RF radios, smartphone positioning can achieve an accuracy of about 2-5meters in real time and about 1 meter by post processing.
- High precise indoor positioning technologies are capable to deliver centimeter level accuracy, but effective coverage of a single base station is limited. The new Wi-Fi ranging technology will resolve this problem partly.
- Integration of multiple positioning sources is probably the best option for complex indoor environments.
Thank You!