The Great Indoors: Challenges and Use Cases

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Location on Mobile Devices in 2015

- Seamless indoor tracking of friends/family and coupon alerts
- Check-in to stores and aisles within stores accurately
- Find your car or a spot even with large indoor parking structures
- Location-based “indoor ads” to your phone – “$10 in free chips to gamble here”!
- Indoor navigation with 1m accuracy, always on
- Watch video and surf the web with relevant location-specific content

Bridging the Barrier Between the Physical and Digital Worlds

YOUR PHONE WILL BE YOUR INTERMEDIARY BETWEEN THE PHYSICAL & DIGITAL WORLDS

2015
Agenda

• Landscape of indoor positioning

• Use cases for indoor positioning

• Why indoor positioning needs new technology

• Technology pieces in indoor positioning

• Deployment scenarios
Landscape: Overview

LBS
- Facebook
- Foursquare
- Latitude
- Scvngr
- Gowalla
- Yelp
- Loopt

Chips

Venues

OEMs+HLOS
- Smartphones
- Tablets

Maps
- Point Inside
- Micello

Users
- Consumer
- Public Safety
- Enterprise

Venue Infra Vendors
Landscape: Location Applications

- **Machine Industry, Industrial Automation**
  - Micron

- **Machine Guidance, Surveying**
  - Millimeter

- **Pedestrian Navigation, Hospital Logistics, Product Tracking**
  - Meter

- **Emergency Response, Location Based Services, Tourism, Spots**
  - 100 m

Reference: IPIN 2010 Keynote Hilmar Ingensand & Rainer Mautz
Landscape: Consumer use cases

**Where?**
Consumer service is aligned with venue business and scales

**Indoor Venues Accessed by Consumers**

- Transportation Hub (airport, train station...)
- Shopping Mall
- Convention Center
- Entertainment (casino, tourist attraction...)
- University Campus
- Hospital
- Office Building

**Venue Search by User**
- Orientation in a new environment (visitors, travelers, etc.)
- New events/offers/alerts in a familiar environment

**Indoor Navigation by User**
- Distance/ time to destination
- Map searched or discovered destinations
- Route to destinations

**Indoor Discovery Pushed to User**
- Show places on navigation path
- Personal recommendations (based on user schedule, loyalty program, etc.)

Where?

Indoor Venues

Accessed by

Consumers
Landscape: Non-consumer use cases

- First responders
- Asset tracking
- Hospital logistics
- Industrial automation
Landscape: Venues

- **Shopping**
  - Retail store
  - Grocery store
  - Mall
- **Entertainment**
  - Museum
  - Casino
  - Theme parks (indoor areas)
  - Sports arena
- **Transportation hub**
  - Airport
  - Central railway station
  - Central bus station
  - Subway
- **Hospitality**
  - Convention center
  - Hotel
- **Public buildings**
  - Hospital
  - University
  - Government offices

Factors affecting need for and type of indoor positioning:

- % of New Visitors
- Frequency of looking for new place/ prod/ event/ service/user
- Complexity of structure (multi level, obstacles, no implicit path)
- Urgency of user to get to destination
- Venue Motivation for Promoting PoI
- User's Receptiveness to Offers
Indoor Positioning Verticals
## Convention Center – Potential Use Cases

### Consumer Application

#### Search
- **Place:**
  - “Qualcomm booth”
  - “Where is the cafeteria?”
- **Event:**
  - “Indoor LBS workshop today?”
  - “Where is the keynote speaker from Qualcomm presenting?”
- **User:**
  - “Where is my account manager?”

#### Discovery
- **Landmarks:** Registration counter, exhibition hall
- **Recommend places/events:**
  - Other exhibitors similar to search
  - Other relevant exhibitors nearby
  - Convention sponsors
- **Show POI on path**
  - New users: company affiliation, selected track
  - Profiled users: from searches, mailing list topics
- **Colleague or contact finder:** if already registered to that service

### Venue Application

#### Customer Data Analytics
- To show producer: Estimating attendance and event/booth attractiveness

### Navigation

- **User** is motivated by time efficiency
- **Event producer** is motivated by sponsorship inventory
Airport Indoor LBS Example – Potential Use Cases

**Consumer Application**

**Search**
- Event
  - “Flight AA131”
- Place:
  - “Gate number 15”
  - “Charging station nearby?”
  - Out of airport destination after landing
- Service
  - “I need a drink!”
  - “Car rental counter”
- Product:
  - “Advil?”
  - “A book for the flight”

**Discovery**
- Alerts
  - “Your flight is boarding and you are 15 min. away from the gate”
  - “Your connection is leaving from another terminal – Get directions”
  - “Your flight has moved to gate 2 – Get directions”
- Retail offers:
  - When enough time to get to gate
  - When flight is delayed
  - Show on navigation path
- Landmarks: Security check point, gate numbers
- Friend finder: if already registered to that service

**Venue Application**

**Customer Data Analytics**
- Get preferred routes for planning store and booth distribution
- Promote less crowded areas
- Identify long lines
- Identify repeating visits for promotion (airport loyalty program)

**Navigation**
- User is motivated by time efficiency
- Airport is motivated by filling time gaps
**Consumer Application**

**Search**
- **Service**
  - “The kids need to eat!”
  - Where is the coffee place we agreed to meet at?
  - “Where can I hang out with the kids while she’s shopping?”
- **Product**
  - “Kids apparel?”
  - “Perfumes?”
- **Place**
  - “Ann Taylor store?”
  - “Strollers rental station?”
  - “Restrooms with changing table?”
  - “Where did I park my car?”
- **Event**
  - “Where is the fashion show taking place?”

**Discovery**
- **Show POI on path**
  - Other stores related to recent search, stores where you have membership
  - Click through POI for info, promotional deal, etc.
- **Filter POI**
  - New users: general interest, membership program associated with phone or email address
  - Profiled users: from past searches, visits

**Landmarks**: Food court, fountain, play area, parking

**Friend finder**: if already registered to that service

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**Venue Application**

**Customer Data Analytics**
- Get preferred routes for planning signage distribution
- Automatic visitor counter

**Mall is motivated by efficient directory delivery and ad platform**
### Consumer Application

**Search**
- **Event**
  - Project meeting with customer X
  - Appointment with accountant
- **Place**
  - QRC-224C
  - 1234 Main St, suite #535
- **Service**
  - Available meeting room
  - Something to eat
  - Printer room

**Discovery**
- **Alerts**
  - “You are 15 min. away from your next meeting”
- **Landmarks**
  - Elevator
  - Stairs

### Venue Application

**Customer Data Analytics**
- Safety – identify populated areas in case of emergency
- Corporate devices – track field personnel
- Rental offices - traffic as an indicator of revenue for rental decisions

**Venue is motivated by:**
- Safety
- Employee efficiency (corp. building)
- Service differentiation (office rentals)
Summary

- Location applications have varying accuracy needs

- The type of venue determines the type of location applications and hence the accuracy needs

- The type of user (consumer, enterprise, public) determines the type of location application and deployment model even in the same venue

- Systems need to be designed with these varied needs in mind

- Next, let's see what are the technology pieces in an indoor positioning system
Technology Choices for Indoor Positioning
### Why indoor position needs new technology

#### Attenuation of various building materials (L1 = 1500 MHz)

<table>
<thead>
<tr>
<th>Material</th>
<th>[dB]</th>
<th>Factor [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>1 - 4</td>
<td>0.8 – 0.4</td>
</tr>
<tr>
<td>Wood</td>
<td>2 - 9</td>
<td>0.6 – 0.1</td>
</tr>
<tr>
<td>Roofing Tiles / Bricks</td>
<td>5 - 31</td>
<td>0.3 – 0.001</td>
</tr>
<tr>
<td>Concrete</td>
<td>12 - 43</td>
<td>0.06 – 0.00005</td>
</tr>
<tr>
<td>Ferro-Concrete</td>
<td>29 - 43</td>
<td>0.001 – 0.00005</td>
</tr>
</tbody>
</table>

- **Indoors:**
  - 100 times weaker

- **underground:**
  - 10000 times weaker

#### Signal Strength in Decibel Watt of GNSS Satellites

<table>
<thead>
<tr>
<th>Environment</th>
<th>[dBW]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite</td>
<td>+14</td>
<td>signal strength delivered from satellite</td>
</tr>
<tr>
<td>Outdoors</td>
<td>-155</td>
<td>unaided fixes OK for standard receivers</td>
</tr>
<tr>
<td>Indoors</td>
<td>-176</td>
<td>decode limit for high sensitive receivers</td>
</tr>
<tr>
<td>Underground</td>
<td>-191</td>
<td>decode limit for aided, ultra-high sensitive receivers</td>
</tr>
</tbody>
</table>

Reference: Rainer Mautz, 3rd Baltic-Swiss Geodetic Science Week, 2008
Technology pieces in indoor positioning

- Wireless beacons

- Ranging with the beacons

- Computing positions

- Making position meaningful to the user

- Handling transitions

- Non wireless techniques: vision and sensors
Wireless Beacons: Technology Choices

- GPS-based
- RFID
- Cellular-based
- UWB – e.g. Qcom Peanut Technology
- WLAN / Femto
- Bluetooth
Wireless Beacons: Needs and Challenges

• **GPS-based**
  – Assisted-GPS for weak signals, terrestrial pseudolite transceivers
  – Accuracy is still low and needs new infrastructure

• **RFID**
  – Passive tags and active tags
  – Active tags have better range hence lower deployment size
  – Needs new infrastructure

• **Cellular-based**
  – Possible if building is covered by many base stations. Example is use of GSM channels too weak for communication but used as fingerprints for location
  – Not very high accuracy and adds fingerprinting overhead

• **UWB**
  – More robust than RFID, lower power and less prone to interference
  – Needs new infrastructure
Wireless Beacons: Needs and Challenges

- **WLAN**
  - Wi-Fi APs are already deployed in many indoor locations (unlike IMES, UWB)
  - Wi-Fi air interface has the necessary hooks to enable positioning based on many measurable parameters (RTT, RSSI, AoA for 11n) without any changes to the air interface. Increasing BW with subsequent generations
  - In developed markets (N.America and W.Europe) Wi-Fi attach rate in sold handsets is expected to reach 47% by 2014 (Source: Strategy Analytics)
  - Smartphone drives new LBS applications (e.g. iPhone, Android) and is projected to be mostly Wi-Fi enabled (92% of Smartphone shipments in 2014 according to ABI Research)
  - Operators support WiFi in the smartphone to offload the traffic created by their data plans

- **Femto**
  - Low penetration, mainly in enterprise buildings. Helpful to non-smartphone users

- **Bluetooth**
  - Bluetooth beacons aren’t available in most venues despite efforts of proximity marketers
  - Short range Bluetooth requires large number of beacons for ubiquitous positioning
  - The interference avoidance mechanism of many overlapping Bluetooth beacons (specially long range) as well as their coexistence with Wi-Fi is not well studied
  - Companies who tried using Bluetooth for location ceased operations but some companies still offer proximity advertising at shopping facilities (Source: IMS Research)
Ranging Methods

• Time of arrival
  – The one-way propagation time is measured, and the distance between measuring unit and signal transmitter is calculated

• Time difference of arrival
  – Determine the relative position of the mobile transmitter by examining the difference in time at which the signal arrives at multiple measuring units, rather than the absolute arrival time of TOA

• RSS-based
  – Signal attenuation-based methods attempt to calculate the signal path loss due to propagation. Theoretical and empirical models are used to translate the difference between the transmitted signal strength and the received signal strength into a range estimate
Ranging Methods

• **Time of Flight**
  - This method is to measure the time-of-flight of the signal traveling from the transmitter to the measuring unit and back

• **Angle of Arrival**
  - The location of the desired target can be found by the intersection of several pairs of angle direction lines, each formed by the circular radius from a base station or a beacon station to the mobile target.

• **Pattern Matching**
  - Algorithms that first collect features (fingerprints) of a scene and then estimate the location of an object by matching online measurements with the closest *a priori* location fingerprints.
  - Probabilistic, *k*-nearest-neighbor (*kNN*), Neural networks, smallest *M*-vertex polygon (SMP), …
Ranging Methods: Needs and Challenges

- **Time of arrival**
  - Needs sync between transmitter and receiver for accuracy and a timestamp on the sender side. Sync needs to be very strict.

- **Time difference of arrival**
  - Need infrastructure support.

- **RSS-based**
  - Always possible with every hardware. Can be energy inefficient and path loss models vary widely with venue.

- **Time of Flight**
  - Less strict sync requirements than time of arrival.

- **Angle of Arrival**
  - Requires 2 reference points instead of 3 for 2-D positioning and not time sync is needed. Hardware requirements are complex and degradation with distance and multipath.

- **Pattern Matching**
  - Needs prior fingerprinting.
Computing Positions

- Triangulation

- MultiLateralation

- Hybrid Positioning

- Filtering
  - Position estimates can be noisy in indoor environments and filtering techniques maybe useful for improving user experience
  - Kalman, Extended Kalman etc…

- **Critical question: what is the computational efficiency and accuracy of estimates of different choices?**
Making position meaningful to the users

- For most indoor LBS applications, position indoors is not very useful without the availability of indoor maps.

- Indoor maps help the user conceptualize the position.

- Indoor maps are different from the outdoor world.
  - Can’t be independently mapped using satellite imagery.
  - Ownership can be with venue operators or lease holders and venue operator. Need sourcing arrangement with a large variety of entities.
  - Maintaining maps is not an easy problem due to the variety of relationships needed to make it happen.
  - Indoor maps can have higher modification rate than outdoor streets.
Maps: Needs and Challenges

- Maps currently are being made available by some small players
  - Tracing maps from publicly available information
  - Obtaining venue buy in to get map information
  - These are not very scalable approaches although they can work for high value venues like airports

- For ubiquity, we need a scalable approach that creates a mechanism for venues and map vendors to continuously have current maps available

- Some venues need instantaneous maps (trade shows) and we need a mechanism to have these as well

- Finally, indoor maps are not standardized and each provider has their own API. For app developers to reach scale, some common formats will need to emerge
Handling Transitions

• Positioning systems used outdoor and indoors can vary
  – How to decide when to trigger the different positioning systems while not wasting energy is an important problem

• Positioning systems used in different buildings can vary
  – Venues may have different infrastructure and a seamless positioning solution needs to discover the particular deployment and marshal the positioning engine to compute positions possible in different ways

• Beacons used in different parts of the same building vary
  – May need to combine measurements from different signal sources even in the same location and/or detect a particular region of a building to trigger a particular positioning solution
Non-Wireless Techniques: Sensor Technology

- Accelerometer
- Compass
- Proximity
- Gyros
- Barometric Pressure sensor
- Inertial MEMs Sensors

- Sensors can be used to augment indoor positioning systems when the number or geometry of wireless beacons are flawed
- Potentially can reduce use of the radio as well (still TBD)
- Maybe possible to build systems for emergency response that rely on few strategically placed beacons and sensors
Non-Wireless Technology: Vision

• The camera can be also be used as a sensor for indoor positioning

• If an indoor venue is mapped with vision descriptors the image from the camera can be used to detect which part of the indoor venue the user is in

• Challenge is to do this in an energy efficient way since the techniques tend to be computationally more expensive than trilateration

• Hybrid positioning with wireless beacons and vision is also a potential topic

• Several methods developed in mobile robotics can also be applied to this problem
Comparing Technology Choices: Performance Metrics

• Accuracy
  – Usually, mean distance error is adopted as the performance metric, which is the average Euclidean distance between the estimated location and the true location

• Precision
  – Usually, the cumulative probability functions (CDF) of the distance error is used for measuring the precision of a system

• Complexity
  – Complexity of a positioning system can be attributed to hardware, software, and operation factors

• Robustness
  – A positioning technique with high robustness could function normally even when some signals are not available, or when some of the RSS value or angle character are never seen before. Sometimes, the signal from a transmitter unit is totally blocked

• Scalability
  – A location system may need to scale on two axes: geography and density

• Cost
  – The cost of a positioning system may depend on many factors. Important factors include money, time, space, weight, and energy
Summary

• A wide variety of technology choices are possible for developing indoor positioning with different tradeoffs

• Due to the fragmented nature of the ecosystem it is likely that simple and robust solutions that do not require large amounts of new infrastructure deployment will succeed

• Technologies that require new infrastructure deployments can succeed in few places but are unlikely to scale, at least initially

• Station centric approach to positioning is powerful as it can take into account device sensors as well
Deployment Options
Deployment scenarios

- Indoor positioning may be deployed in several scenarios and needs to work well in all of these
- Venue may or may not have maps available
- Venue may or may not have wireless beacons
  - The number and geometry of these beacons also affect performance
- Venue may have wireless beacons but they may or may not be known to the positioning device
- Venue may always need new beacons due to an emergency – On the fly deployment.
  - First responders
Conclusions
Conclusions

• Indoor positioning opens up a market for many players
  – App developers, chip and infra vendors, OEMs, venues, mapping providers

• This also means that an ecosystem has to be developed for indoor positioning to succeed
  – Different from outdoor positioning due to the dependence on infra vendors, disjoint mapping providers and disjoint venue participation

• Indoor positioning is the next frontier in LBS and enables new and interesting services for consumers, public safety and enterprise
References

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• Various industry whitepapers from
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  – PointInside,
  – Intel

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