Localization Technologies
Localization

- Primary context information
  - Time is easier
- Applications
  - Location-based services
  - Navigation
  - Planning
  - ...

A Taxonomy of Location Sensing Techniques

- Triangulation
- Scene Analysis
- Proximity
Triangulation

- Measure distance from multiple reference points
  - 2D requires three and 3D requires four reference points
  - Domain-specific knowledge may reduce the number of reference points
- Measure distance direct
  - E.g. robot measures physically
  - Difficult to obtain automatically
- Measure by time-of-flight
  - Ultrasound or radio
  - Different receiver or round-trip delay
  - Difficult: reflections, precise clocks
- Measure by attenuation
  - Function correlating attenuation and distance (e.g. $1/r^2$)
  - Problems: environments with many obstructions
- Network-based distances
  - Multi-hop
Triangulation

\[
\begin{align*}
(x - x_A)^2 + (y - y_A)^2 &= d_A^2 \\
(x - x_B)^2 + (y - y_B)^2 &= d_B^2 \\
(x - x_C)^2 + (y - y_C)^2 &= d_C^2
\end{align*}
\]
Scene Analysis

- Scene observed from particular point
- Simplified scene and features which are easy to represent and compare
- Static analysis: lookup observed features in predefined dataset
- Differential analysis: track difference of successive scenes to estimate location
- Measurable physical phenomena
  - Visual images
  - Electromagnetic characteristic:
Proximity

- Objects presence sensed using a physical phenomenon with limited range
- Sensing by physical contact
  - Pressure sensors, touch sensors, capacity field detectors
- Sensing by monitoring wireless cellular access points
  - Devices in range of one or more access points
  - Cell geometry depends on wireless technology
- Sensing by observing automatic ID systems
  - Electronic card logs, computer login histories, landline telephone records, ...
  - Location of object can be inferred if monitoring device has a known location
Physical and symbolic location

- Physical location (e.g. 49°43’37”N 6°38’20’E)
  - May be augmented to provide symbolic location
  - e.g. Database mapping GPS coordinates to service locations
- Symbolic Location (e.g. Room H519)

Absolute and relative location

- Absolute location
  - Share the same reference grid (e.g. latitude, longitude, altitude)
  - Two collocated devices report equivalent position readings
- Relative location
  - Each object has its own frame of reference
  - E.g. relative bearing and distance
- Transformation between absolute and relative always possible?
Localized location computation
- Object being located computes its own position (e.g. GPS)
- Non localized: Object emits beacon used by the infrastructure
- Pro and Cons
  - localized: ensures privacy, scalability regarding number of objects
  - non localized: decreased computational and power demands, lower costs, and smaller form factor

Accuracy and precision
- Locate position to within X meters for Y percent of measurements
- Distance denotes accuracy
- Percentage denotes precision
- Improving accuracy and precision? (e.g. sensor fusion, adaptive fidelity)
Localization System Properties 3/3

- **Scale**
  - Coverage area per unit in infrastructure
  - Number of objects the system can locate per unit of infrastructure per time interval

- **Recognition**
  - Capability to recognize individual things
  - E.g. provide GUID to the system + external database

- **Cost**
  - Time: installation, administration
  - Space: amount of installed infrastructure, hardware size and form factor
  - Capital: price per mobile device, infrastructure, and support personnel

- **Limitations**
  - Indoor/outdoor
  - Collocated Systems
  - Physical constraints
  - User acceptance
GPS (Global Positioning System)

- Provides instantaneous position, velocity and time information almost everywhere on the globe at any time.
- **ONLY OUTDOOR**

- Receiver Tasks to perform
  - Selecting satellites
  - Acquiring GPS signals
  - Measuring and tracking
  - Recovering navigational data

- Available services
  - Standard Positioning Service (SPS): civil users, less precise (100 cm)
  - Precise Positioning Service (PPS): authorized military users, more precise (1cm)
Active Badge (AT&T Cambridge)

- First indoor badge system
- Based on infrared technology
- Each locatable wears a badge
- Emits a unique ID periodically
- Server collects data from fixed sensors (base stations)
- System provides symbolic absolute location information
- Sunlight and fluorescent light interfere with infrared
- Infrared limits cell sizes to small- or medium-sized rooms
Active Bat (AT&T Cambridge)

- Based on ultrasound
- Locatable carry Active Bat tags
- Request/Response protocol
  - Controller sends request via short-range radio
  - Bat replies with ultrasonic pulse
  - Controller resets ceiling sensors via wired network
  - Ceiling sensor measures distance using time from reset to ultrasonic pulse arrival
  - Estimated distance
- Central Server collects distance values and removes errors due to reflection

- Each bat has a unique ID
- Relatively exact (9cm, 95%)
- Can be used to compute orientation information
- Less scalability, no ease of deployment, and cost are disadvantages of this approach
Complementing the Active Bat system
Ultrasound emitters create the infrastructure
Receivers in the objects being located
Radio communication used for location
  Contains a string that describes the semantics of the area
System allows uncoordinated beacons to coexist in the same place (stronger signal wins)
Grid of ceiling sensors not required
Much less precise than Active Bat (about 1.2 x 1.2 m²)
Implements both, triangulation and proximity
Pros: privacy, decentralized scalability
Cons: lack of centralized management, computational/power burden placed on mobile receivers
RADAR (Microsoft)

- Building-wide tracking system based on IEEE 802.11
- Base stations measure signal strength and noise of wireless devices. Information used for centralized computation of 2D position
  - Scene-analysis (3m, 50%)
  - Signal strength triangulation (4.3m, 50%)
- Scene analysis and significant environmental changes?
- Pro: few base stations (existing infrastructure)
- Con: locatable must support WLAN, 3D nontrivial
Motion Star (Ascension)

- Virtual reality and motion capture
- Fixed antenna generates axial DC magnetic-field pulses
- Receiving antennas measure field pulse in three orthogonal axes (combined with earth magnetic field)
- Pro: Accurate resolution of 1mm, 1ms, and 0.1°
- Cons: implementation costs, object tethered to control unit, sensors must remain within 1-3m of transmitter, sensitive to metallic objects
Easy Living (Microsoft)

- Triangulation with 3 cameras in a small room
- Real-time 3D camera to provide stereo-vision position capability
- Limitations
  - Increasing scene complexity
  - More occlusive motion
  - Acceptance of ubiquitous public cameras
- Scalability
  - Processing power
  - Installation of cameras
Smart Floor (Georgia Tech)

- Embedded Pressure Sensors
- Capture Footfalls
- Data used for position tracking and pedestrian recognition
- Unobtrusive system
  - Does not require people to carry any device or tag
- Poor scalability and high incremental cost
- Many users in one room?
## Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
<th>Cost</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>1-5 meters, 95% (improvable)</td>
<td>Expensive infrastructure</td>
<td>Not indoors</td>
</tr>
<tr>
<td>Active Badges</td>
<td>Room size</td>
<td>Administration costs</td>
<td>Sunlight and fluorescent light</td>
</tr>
<tr>
<td>Active Bat</td>
<td>9cm, 95%</td>
<td>Administration costs</td>
<td>Required Ceiling sensor grid</td>
</tr>
<tr>
<td>Cricket</td>
<td>1.2m² region, ~100%</td>
<td>$10 beacons and receivers</td>
<td>No central management</td>
</tr>
<tr>
<td>RADAR</td>
<td>3-4m, 50%</td>
<td>802.11 network installation</td>
<td>Wireless NICs required</td>
</tr>
<tr>
<td>MotionStar</td>
<td>1mm, 1ms, 0.1°, ~100%</td>
<td>Expensive hardware</td>
<td>Control unit tether</td>
</tr>
<tr>
<td>Easy Living</td>
<td>Variable</td>
<td>Processing power, cameras</td>
<td>Ubiquitous public cameras</td>
</tr>
<tr>
<td>Smart Floor</td>
<td>Spacing of sensors, 100%</td>
<td>Installation of sensor grid, creation of dataset</td>
<td>Large populations</td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>150-300m, 95%</td>
<td>Upgrading Phone hardware and cell infrastructure</td>
<td>Cell coverage</td>
</tr>
</tbody>
</table>