Algorithms for Radio Networks

Localization

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Coarse Localization Techniques

- **Hop-distance**
  - in dense ad hoc networks or wireless sensor networks
  - approximate position by the number of hops to anchor points

- **Overlapping connections**
  - position at the intersection of the received transmission circuits

- **Localization point in the triangle**
  - determination of triangles of anchor points
    - in which the node lies
  - overlap provides approximate position

- "Fingerprinting" of signal strength measures
Localization methods

- **Dead Reckoning**: Relative localization depending on course and traveled distance
- **Triangulation**: Calculate the intersection of angular bearings
- **Trilateration**: Calculate the intersection of three range measurements (circles)
- **Multilateration with absolute ranges**: Calculate the intersection of at least four range measurements
  - In the plane: circles, in space: spheres
  - May be over-determined equation system
- **Multilateration with relative ranges**: Hyperbolic multilateration
  - Multilateration with unknown send time
  - Calculate intersection of hyperbolas / hyperboloids
Dead Reckoning

- Relative vector navigation, vectors of orientation $\phi_i$ and distance $d_i$
- Animals: “path integration” by special regions in hippocampus of desert ants (Wehner, 2003)
- Dead reckoning scheme:

Recursive:

$$x_i = x_{i-1} + d_i \cdot \cos \phi_i$$
$$y_i = y_{i-1} + d_i \cdot \sin \phi_i$$

Direct:

$$x_i = x_0 + \sum_{i=1}^{n} d_i \cdot \cos \phi_i$$
$$y_i = y_0 + \sum_{i=1}^{n} d_i \cdot \sin \phi_i$$
Dead Reckoning

- Example: Navigation of ships / airplanes
  - if course is known (compass)
  - if traveled distance is known (ship log, pitot tube)
- Prone to drift (water current, wind, wheel slip)
- Errors add up over time
Inertial Navigation

› Consider orientation and traveled distance as direction vector $s_t$ at time $t$.
› What if only acceleration $a_t$ is measured?
  • Inertial navigation, double integration
    \[ \ddot{s}(t) = \int \int a(t) \, dt^2 + s_0 + \dot{v}_0 \cdot t \]
  • Often also rotation is measured (angular velocity)
› Combine accelerometer, gyroscope, and compass:
  • Inertial Measurement Unit (IMU)

[F. Höflinger, 2013]
Inertial Navigation

- Foot-mounted MEMS-IMU
  - Errors add up over time
- Compensation: Zero velocity update
  - Detect footstep
  - Translation velocity is zero at this moment!

[Zhang, 2013]
Triangulation

› Given a side of known length and two adjacent angles
› In the plane:
  • Calculate the intersection point of the other sides
  • Duality with trilateration: Triangle congruency
    (angle-side-angle) $\leftrightarrow$ (side-side-side)
› On earth surface:
  • More complicated (spherical trigonometry)
Trilateration

\( \frac{h}{a} = \cos \beta_2 \)

\[ \frac{h}{x} = \cos \beta_1 \]
Triangulation

- Example: Navigation of ships / airplanes (cross bearing triangulation)
  - 1) Bearings of two objects on a map
  - 2) Time-shifted bearings of the same object
Triangulation

- Given a side of known length and the opposite angle
  - Triangle congruency: Does not define a triangle!
  - What else is possible?
- Given a lighthouse of known height $h$
  - Measurement of angle $\phi$, use a sextant
  - Calculation of distance $d = \frac{h}{\tan(\phi)}$
  - Measurement of lighthouse bearing
    - position in polar coordinates
- Height of lighthouse not known
  - Sail towards lighthouse

\[ d = \frac{h}{\tan \alpha} \]
\[ d = \frac{h}{\tan \alpha_2} \]
Triangulation

› Given a side of known length and the opposite angle
  • Measure angle $\phi$ of two landmarks (by theodolite or by laser scanner)
  • If $\phi = 90^\circ$: Ship’s position resides on Thales’ circle
  • Other angles: generalization of Thales’ circle
  • Circle of equal angles (“Fasskreisbogen”)

![Diagram of triangulation process]
Triangulation

- Given a side of known length and the opposite angle
  - Calculate position by a third landmark
Triangulation

- Height of Mt. Everest
  - 8,840 m above NN (Sickdhar, 1856)
  - 8,848 m (Survey of India, 1955)
  - 8,850 m (GPS, 1999)
  - 8,849 m (Radar reflectors, 2004)
  - ...

[A. Waugh, Mt. Everst & Deodanga, 1862.]
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