Computational Principles of Mobile Robotics

Post maintenance and localization

"You are in a maze of twisty passages all alike"

Pose maintenance

- It may be useful or necessary to know where a robot is relative to some spatial representation (a map).
- Often expressed computing $P(q|s)$ (probability that the robot is in state q given measurements s) and then choosing a maximum value of this.

Pose maintenance and localization

- Can distinguish between maintaining pose (good prior estimate) versus localization (no prior estimate).
- Can distinguish between global localization (where is here) versus local localization (is here different from other locations).

9.1 Simple landmark measurement

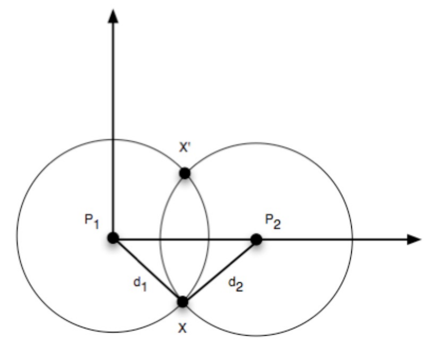
- Problem often involves determining if specific landmarks in the environment map to landmarks in the map and then using geometry to constrain the state of the vehicle.
  - Landmark properties influence the task (how easy are they to find, uniqueness, geometry properties).

9.1.1 Landmark classes

- Active versus passive
- Sensing modality, examples and properties
  - Vision -> generally implies bearing only relative information
  - Laser -> relative pose
  - GPS -> absolute position

9.1.2 Triangulation and trilateration

- Triangulation – use of bearings (angles) to determine geometry.
- Trilateration – use of distances to determine geometry.
  - Often incorrectly referred to as triangulation.



Robot senses P1 and P2 and estimates d1 and d2. Robot is either at x or x'.

Triangulation with uncertainty

- Perfect geometry is complicated in the real world as bearing and distance measures are corrupted with noise.
- Characterize the error in pose estimation as the **geometric dilution of precision (GDOP).** Given state estimate X and sensor readings S

$$\mathrm{GDOP} = \frac{\Delta \boldsymbol{X}}{\Delta \boldsymbol{S}}$$

In the limit, this becomes the Jacobian

9.2 Fingerprinting

- For a given sensor we can compute F(pose)=measurements.
- We can then seek to find the inverse of this that takes measurements and obtains the pose directly.
- The computational task involves modelling the inverse function.
  - DNN’s have found good successes here.
- Good performance for radio-based mechanisms (e.g., localization from base station signal properties).

9.3 Servo control

- Given a function I(q) that describes the sensor reading as a function of pose, then we can perform servo control (homing) by comparing I(q) to $I(q_{goal})$.
- If I(q) is smooth, then this can be very effective, especially for q near q_{goal}.

9.4 Recursive filtering

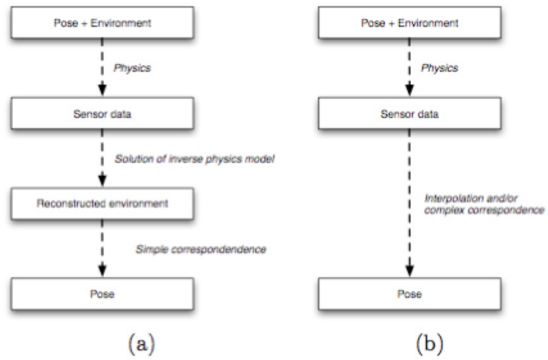
- Standard recursive filtering techniques (e.g., EKF, particulafilters) can be applied to the problem of ongoing state estimation.
  - Covered in some detail earlier.

9.5 Localization in ROS

- Navigation 2 stack provides implementation of standard tools for mapping and localization.
- Localization is provided via an adaptive Monte Carlo localization process.

9.6 Non-geometric methods: perceptual structure

- Assign to each location a **signature** that captures the sensor information.
- Construct a direct mapping between signature and location.



Pose estimation using geometry methods (a) and perceptual structure (b).

9.6.1 Eigenlandmarks

- Rather than having specific pre-defined landmarks, we can instead assume that our landmarks have some inherent structure that we can use.
  - E.g., pipe junctions, etc.
- Build an Eigenspace representation of the landmarks and use this lower dimensionality space to represent and recognize landmarks.

9.7 Correlation-based localization

- Occupancy-grid maps and local occupancy-grid measurements can be compared using correlation-based approaches.
- Let $P(z|s)$ be the probability that a location z is occupied given measurements s.
  - This can be correlated against the map to identify likely robot states.

9.8 Global localization

- If no good prior for the robot's pose exists then all potential states are equally likely (kidnapped robot problem).
- Global localization is very difficult, even in very simple 2D polygon worlds.
  - For general environments the problem is NP-hard.

9.9 Biological approaches to localization

- Biological systems exist that do localization very well.
  - Examples include songbirds, ants, others.
- Some evidence of multi-cue integration processes in some species.