Probabilistic Techniques for Robot Navigation

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Navigation for Hazardous Environments

- Highly unstructured environments.
- Tele-operation difficult as operators might lose orientation.
- Tele-operation might not be possible due to time delays.
- Can we go fully autonomous?

- Where are we with respect to autonomous navigation?
Both Approaches Might Fail

tele-operated

autonomous
Dimensions of Mobile Robot Navigation

mapping

localization

SLAM

integrated approaches

exploration

motion control

active localization
Fields of My Research

- Mobile robot development
- State estimation and models
- Adaptive techniques and learning
- Multi-robot systems
- Autonomous vehicles
- Embedded systems
- Mobile manipulation
- Exploration
- Applications
- ...
- Probabilistic robotics
Nature of Data

Odometry Data

Range Data
Probabilistic Robotics

Explicit representation and utilization of uncertainty

- Perception = state estimation
- Action = utility optimization
Probabilistic Robotics

Explicit representation and utilization of uncertainty

- **Perception** = state estimation

\[
Bel(x \mid z, u) = \alpha p(z \mid x) \int_{x'} p(x \mid u, x') Bel(x') dx'
\]

- **Action** = utility optimization

\[
\pi^*(x) = \arg\max_u \sum_{x'} p(x' \mid u, x)V^*(x')
\]
Probabilistic Techniques in Robotics

- Perception = state estimation
- Action = utility maximization

Key Questions
- Representation
- Maximization
e specially in the context of higher dimensions
Probabilistic Localization

\[ Bel(x \mid z, u) = \alpha p(z \mid x) \int_{x'} p(x \mid u, x') Bel(x') \, dx' \]
Vision-based Localization
Simultaneous Localization and Mapping (SLAM)

- To determine its position, the robot needs a map.
- During mapping, the robot needs to know its position to learn a consistent model.
- Simultaneous localization and mapping (SLAM) is a “chicken and egg problem”
Why SLAM is Hard: Raw Odometry
Application Example
Outdoor Campus Map

- 30 particles
- 250x250m²
- 1.75 km (odometry)
- 20cm resolution during scan matching
- 30cm resolution in final map
Maximum Likelihood Maps
3D Map of the Stanford Parking Garage

approx. 260MB
Application: Navigation with the Autonomous Car Junior

- Task: reach a parking spot on the upper level of the garage.
Autonomous Parking
Application: Autonomous Quadrotor Navigation

Custom-built system:
- laser range finder
- inertial measurement unit
- embedded CPU
- laser mirror
SLAM with the Quadrotor

Recall-Rate

Computed
Object Detection with the Quadrotor
Decision-Theoretic Formulation of Exploration

\[ \pi(\text{Bel}) = \arg\max_u \left[ E_z[I_{\text{Bel}}(z, u)] - \alpha \int_x r(x, u) \text{Bel}(x) \, dx \right] \]

reward (expected information gain)

cost (path length)
Real-world Application
Considering Pose Uncertainty during Exploration
Industrial Applications
Navigation in Urban Scenes
Summary

- Probabilistic Methods are a powerful tool for realizing systems that navigate autonomously.
- There has been substantial advance in the past
  - systems
  - technology
- Still, there substantial hurdles we need to take.