Robot Mapping

Introduction to Robot Mapping

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What is Robot Mapping?

- **Robot** – a device, that moves through the environment
- **Mapping** – modeling the environment

What is SLAM?

- Computing the robot’s pose and the map of the environment at the same time
  - **Localization**: estimating the robot’s location
  - **Mapping**: building a map
  - **SLAM**: building a map and locating the robot simultaneously

Related Terms

- State Estimation
- Localization
- Mapping
- SLAM
- Navigation
- Motion Planning
Localization Example
- Estimate the robot’s poses given landmarks

Mapping Example
- Estimate the landmarks given the robot’s poses

SLAM Example
- Estimate the robot’s poses and the landmarks at the same time

The SLAM Problem
- SLAM is a **chicken-or-egg** problem:
  → a map is needed for localization and
  → a pose estimate is needed for mapping
SLAM is Relevant

- It is considered a fundamental problem for truly autonomous robots
- SLAM is the basis for most navigation systems

SLAM Applications

- SLAM is central to a range of indoor, outdoor, in-air and underwater applications for both manned and autonomous vehicles.

Examples:

- At home: vacuum cleaner, lawn mower
- Air: surveillance with unmanned air vehicles
- Underwater: reef monitoring
- Underground: exploration of mines
- Space: terrain mapping for localization

SLAM Showcase – Mint

Courtesy of Evolution Robotics, H. Durrant-Whyte, NASA, S. Thrun

Courtesy of Evolution Robotics (now iRobot)
Probabilistic Approaches

- Uncertainty in the robot’s motions and observations
- Use the probability theory to explicitly represent the uncertainty

Definition of the SLAM Problem

**Given**
- The robot’s controls
  \[ u_1:T = \{u_1, u_2, u_3, \ldots, u_T\} \]
- Observations
  \[ z_{1:T} = \{z_1, z_2, z_3, \ldots, z_T\} \]

**Wanted**
- Map of the environment
  \[ m \]
- Path of the robot
  \[ x_{0:T} = \{x_0, x_1, x_2, \ldots, x_T\} \]
In Probabilistic Terms

Estimate the robot’s path and the map

\[
p(x_{0:T}, m \mid z_{1:T}, u_{1:T})
\]

distribution path map given observations controls

Full SLAM vs. Online SLAM

- Full SLAM estimates the entire path
  \[
p(x_{0:T}, m \mid z_{1:T}, u_{1:T})
\]
- Online SLAM seeks to recover only the most recent pose
  \[
p(x_t, m \mid z_{1:t}, u_{1:t})
\]

Graphical Model

\[
p(x_{0:T}, m \mid z_{1:T}, u_{1:T})
\]

Graphical Model of Online SLAM

\[
p(x_{t+1}, m \mid z_{1:t+1}, u_{1:t+1})
\]
Online SLAM

- Online SLAM means marginalizing out the previous poses

\[ p(x_t, m \mid z_{1:t}, u_{1:t}) = \int_{x_0} \ldots \int_{x_{t-1}} p(x_0:t, m \mid z_{1:t}, u_{1:t}) \, dx_{t-1} \ldots \, dx_0 \]

- Integrations are typically done recursively, one at a time

Graphical Model of Online SLAM

Why is SLAM a hard problem?

1. Robot path and map are both unknown

Why is SLAM a hard problem?

- The mapping between observations and the map is unknown
- Picking wrong data associations can have catastrophic consequences (divergence)
Taxonomy of the SLAM Problem
Volumetric vs. feature-based SLAM

Taxonomy of the SLAM Problem
Topologic vs. geometric maps

Taxonomy of the SLAM Problem
Known vs. unknown correspondence

Taxonomy of the SLAM Problem
Static vs. dynamic environments
**Taxonomy of the SLAM Problem**

Small vs. large uncertainty

![Diagram](image1.png)

**Taxonomy of the SLAM Problem**

Active vs. passive SLAM

![Diagram](image2.png)

Image courtesy by Petter Duvander

**Taxonomy of the SLAM Problem**

Any-time and any-space SLAM

![Robot](image3.png)

**Taxonomy of the SLAM Problem**

Single-robot vs. multi-robot SLAM

![Robots](image4.png)
Approaches to SLAM

- Large variety of different SLAM approaches have been proposed
- Most robotics conferences dedicate multiple tracks to SLAM
- The majority uses probabilistic concepts
- History of SLAM dates back to the mid-eighties

SLAM History by Durrant-Whyte

- 1985/86: Smith et al. and Durrant-Whyte describe geometric uncertainty and relationships between features or landmarks
- 1986: Discussions on how to do the SLAM problem at ICRA; key paper by Smith, Self and Cheeseman
- 1990-95: Kalman-filter based approaches
- 1995: SLAM acronym coined at ISRR’95
- 1995-1999: Convergence proofs & first demonstrations of systems
- 2000: Wide interest in SLAM started

Three Main Paradigms

Kalman filter  Particle filter  Graph-based

Motion and Observation Model

"Motion model"

"Observation model"
**Motion Model**

- The motion model describes the relative motion of the robot

$$ p(x_t \mid x_{t-1}, u_t) $$

**Motion Model Examples**

- Gaussian model

- Non-Gaussian model

**Standard Odometry Model**

- Robot moves from \((\bar{x}, \bar{y}, \bar{\theta})\) to \((\bar{x}', \bar{y}', \bar{\theta}')\)

- Odometry information \(u = (\delta_{rot1}, \delta_{trans}, \delta_{rot2})\)

\[
\begin{align*}
\delta_{trans} &= \sqrt{(\bar{x}' - \bar{x})^2 + (\bar{y}' - \bar{y})^2} \\
\delta_{rot1} &= \text{atan}2(\bar{y}' - \bar{y}, \bar{x}' - \bar{x}) - \bar{\theta} \\
\delta_{rot2} &= \bar{\theta}' - \bar{\theta} - \delta_{rot1}
\end{align*}
\]

**More on Motion Models**

- Course: Introduction to Mobile Robotics, Chapter 6

- Thrun et al. “Probabilistic Robotics”, Chapter 5
Observation Model

- The observation or sensor model relates measurements with the robot’s pose

\[ p(z_t \mid x_t) \]

distribution observation given pose

Observation Model Examples

- Gaussian model

- Non-Gaussian model

More on Observation Models

- Course: Introduction to Mobile Robotics, Chapter 7
- Thrun et al. “Probabilistic Robotics”, Chapter 6

Summary

- Mapping is the task of modeling the environment
- Localization means estimating the robot’s pose
- SLAM = simultaneous localization and mapping
- Full SLAM vs. Online SLAM
- Rich taxonomy of the SLAM problem
Literature

SLAM Overview

- Springer “Handbook on Robotics”, Chapter on Simultaneous Localization and Mapping (1st Ed: Chap. 37.1-37.2)

On motion and observation models

- Thrun et al. “Probabilistic Robotics”, Chapters 5 & 6
- Course: Introduction to Mobile Robotics, Chapters 6 & 7