Introduction to SLAM

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Topic of the Course
Simultaneous Localization and Mapping
- Graph-based SLAM using pose graphs
- Graph-based SLAM with landmarks
- Robust optimization in SLAM
- Relative pose estimation using vision

What is SLAM?
- Computing the robot’s poses 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 localizing the robot simultaneously

Localization Example
- Estimate the robot’s poses given landmarks

Courtesy: M. Montemerio
**Simultaneous Localization and Mapping or SLAM**

- **Build a map** of the environment from a mobile sensor platform
- At the same time, **localize** a mobile sensor platform in the map build so far
- **Online** variant of the bundle adjustment problem for **arbitrary sensors**

**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, 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 Applications**

- Indoors
- Undersea
- Space
- Underground

**SLAM Showcase – Mint**

Courtesy: Evolution Robotics (now iRobot)
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
  \[ x_{0:T} = \{x_0, x_1, x_2, \ldots, x_T\} \]

Probabilistic Approaches

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

\[ p(x) \]

“The robot is exactly here”

“The robot is somewhere here”
**In the Probabilistic World**

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

- Online SLAM means marginalizing out the previous poses

\[
p(x_t, m \mid z_{1:t}, u_{1:t}) = \\
\int \cdots \int p(x_{0:t}, m \mid z_{1:t}, u_{1:t}) \, dx_{t-1} \ldots dx_0
\]

- Integrals are typically solved recursively, one at a time

Why is SLAM a Hard Problem?

1. Robot path and map are both unknown

Why is SLAM a Hard Problem?

2. Map and pose estimates correlated
Why is SLAM a Hard Problem?

- The **mapping between observations and the map is unknown**
- Picking **wrong** data associations can have **catastrophic** consequences (divergence)

Three Traditional Paradigms

- Kalman filter
- Particle filter
- Graph-based

Volumetric vs. Feature-Based SLAM

Motion and Observation Model

"Motion model"

"Observation model"
### Motion Model
- The motion model describes the relative motion of the robot

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

- Gaussian model
- Non-Gaussian model

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

\[ p(z_t \mid x_t) \]

- Gaussian model
- Non-Gaussian model
Model for Virtual Observations

- Relate pairs of poses from which observations have been recorded

Reading Material

**Read SLAM overview**
Springer “Handbook on Robotics”, Chapter on Simultaneous Localization and Mapping, subsection 1 & 2 (see E-Campus)

**Revisit the math basics slide set**
See: sse2-00-background-math-basics.pdf

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