CSE-571
Robotics

Mapping

Some slides adapted from Dieter Fox, Cyrill Stachniss, and probabilistic-robotics.org
Fiducials: AR Tags
Occupyancy Grid Maps

- Introduced by Moravec and Elfes in 1985
- Represent environment by a grid.
- Estimate the probability that a location is occupied by an obstacle.

**Key assumptions**
- Occupancy of individual cells is independent

\[
Bel(m_t) = P(m_t | u_1, z_2, u_{t-1}, z_t) = \prod_{x,y} Bel(m_t^{[xy]})
\]

- Robot positions are known!
Using Bayes:

- Log odds representation:

\[
l_{t,i} = \log \left( \frac{p(m_i|z_{1:t}, x_{1:t})}{1 - p(m_i|z_{1:t}, x_{1:t})} \right)
\]

\[
l_{t,i} = l_{t-1,i} + \log \left( \frac{p(m_i|z_t, x_t)}{1 - p(m_i|z_t, x_t)} \right) - \log \left( \frac{p(m_i)}{1 - p(m_i)} \right)
\]
Incremental Updating of Occupancy Grids (Example)
Resulting Map Obtained with Ultrasound Sensors
Occupancy Grids: From scans to maps
Tech Museum, San Jose

CAD map

occupancy grid map
3D Map Requirements

- Full 3D Model
  - Volumetric representation
  - Free-space
  - Unknown areas (e.g. for exploration)

- Updatable
  - Probabilistic model
    (sensor noise, changes in the environment)
  - Update of previously recorded maps

- Flexible
  - Map is dynamically expanded
  - Multi-resolution map queries

- Compact
  - Memory efficient
  - Map files for storage and exchange
Map Representations

Pointclouds

▪ Pro:
  ▪ No discretization of data
  ▪ Mapped area not limited

▪ Contra:
  ▪ Unbounded memory usage
  ▪ No direct representation of free or unknown space
Map Representations

3D voxel grids

- **Pro:**
  - Probabilistic update
  - Constant access time

- **Contra:**
  - Memory requirement
    - Extent of map has to be known
    - Complete map is allocated in memory
Map Representations

2.5D Maps

- 2D grid
- Height value(s) in each cell

**Pro:**
- Memory efficient

**Contra:**
- Not completely probabilistic
- No distinction between free and unknown space
Map Representations

Octrees

- Tree-based data structure
- Recursive subdivision of space into octants
- Volumes allocated as needed
- Multi-resolution
Map Representations

Octrees

- **Pro:**
  - Full 3D model
  - Probabilistic
  - Flexible, multi-resolution
  - Memory efficient

- **Contra:**
  - Implementation can be tricky
OctoMap Framework

- Based on octrees
- Probabilistic representation of occupancy including unknown
- Supports multi-resolution map queries
- Lossless compression

- Open source implementation as C++ library available at http://octomap.sf.net
Examples

- Cluttered office environment

Map resolution: 2 cm
Examples: Office Building

- Freiburg, building 079
Examples: Large Outdoor Areas

- Freiburg computer science campus
  
  (292 x 167 x 28 m³, 20 cm resolution)
OctoMap Implementation

- Open source C++ library
- Fully documented
- Can be easily adapted to your projects
- ROS integration
- Includes OpenGL viewer
- Already used by several other researchers

http://octomap.sf.net