CSE-571
AI-based Mobile Robotics

Mapping

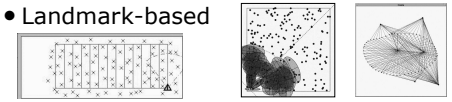
Several slides courtesy of Wolfram Burgard

Types of SLAM-Problems

- Grid maps or scans

[Lu & Milios, 97; Gutmann, 98: Thrun 98; Burgard, 99; Konolige & Gutmann, 00; Thrun, 00; Arras, 99; Haehnel, 01;…]

- Landmark-based



[Leonard et al., 98; Castelanos et al., 99: Dissanayake et al., 2001; Montemerlo et al., 2002;…

Problems in Mapping

- Sensor interpretation
  - How do we extract relevant information from raw sensor data?
  - How do we represent and integrate this information over time?
- Robot locations have to be known
  - How can we estimate them during mapping?

Occupancy 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

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

  - Robot positions are known!

Updating Occupancy Grid Maps

- Idea: Update each individual cell using a binary Bayes filter.

$$Bel(m_t^{[xy]}) = \eta\ p(z_t \mid m_t^{[xy]}) \int p(m_t^{[xy]} \mid m_{t-1}^{[xy]}, u_{t-1}) Bel(m_{t-1}^{[xy]})\, dm_{t-1}^{[xy]}$$

- Additional assumption: Map is static.

$$Bel(m_t^{[xy]}) = \eta\ p(z_t \mid m_t^{[xy]}) Bel(m_{t-1}^{[xy]})$$

Updating Occupancy Grid Maps

- Updated using inverse sensor model and odds ratio

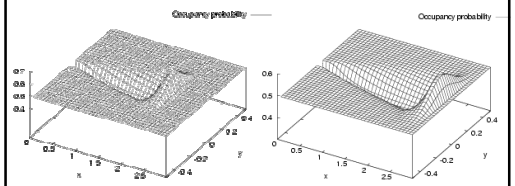
$$Bel(m_t^{[xy]}) = 1 - \left(1 + \frac{P(m_t^{[xy]} \mid z_t, x_t)}{1 - P(m_t^{[xy]} \mid z_t, x_t)} \cdot \frac{1 - P(m_t^{[xy]})}{P(m_t^{[xy]})} \cdot \frac{Bel(m_{t-1}^{[xy]})}{1 - Bel(m_{t-1}^{[xy]})}\right)$$

- or log-odds ratio

$$\overline{B}(m_t^{[xy]}) = \log odds(m_t^{[xy]} \mid z_t, x_t) - \log odds(m_t^{[xy]}) + \overline{B}(m_{t-1}^{[xy]})$$

Typical Sensor Model for Occupancy Grid Maps

Combination of a linear function and a Gaussian:



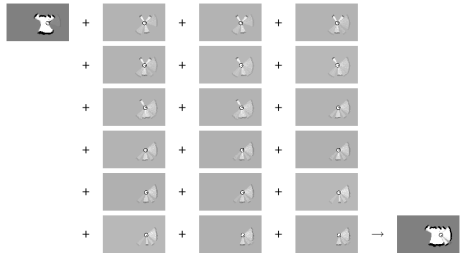
Alternative: Simple Counting

- For every cell count
  - hits(*x*,*y*): number of cases where a beam ended at <*x*,*y*>
  - misses(*x*,*y*): number of cases where a beam passed through <*x*,*y*>

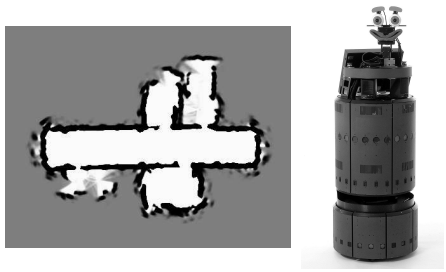
$$Bel(m^{[xy]}) = \frac{\text{hits}(x, y)}{\text{hits}(x, y) + \text{misses}(x, y)}$$

- Assumption: *P*(*occupied*(*x*,*y*)) = *P*(*reflects*(*x*,*y*))

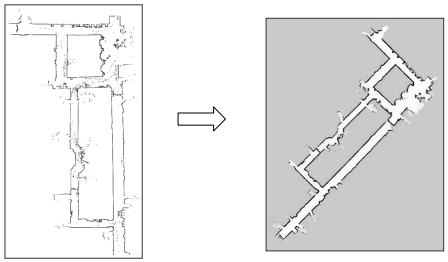
Incremental Updating of Occupancy Grids (Example)



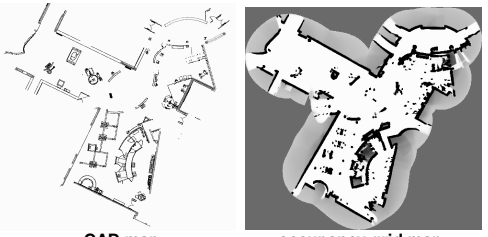
Resulting Map Obtained with Ultrasound Sensors



Occupancy Grids: From scans to maps



Tech Museum, San Jose



CAD map | occupancy grid map