A particle filter SLAM approach to online iceberg drift estimation from an AUV

Petter Norgren

Department of Marine Technology, NTNU

October 27th, 2016
Outline

- Motivation
- Simultaneous Localization and Mapping (SLAM)
- Preliminary results
- Summary and way forward
Iceberg mapping using AUVs

Motivation

- Detailed keel geometry needed to develop iceberg drift models.
- Accurate navigation may be a problem.
  - Deep waters make down-looking DVL useless for bottom-tracking.
- Mission planning in moving reference frame.
  - Unknown translational velocity (measurable using DVL when directly below).
  - Unknown rotational velocity (not possible to measure with DVL).
- Warping of measured data due to motion of ice.
The AUV ice mapping problem

Problem statement

- Estimate AUV position relative to ice.
  - Reference measurements to a ice-fixed coordinate system to avoid warping.
  - Use relative position for guidance of vehicle to generate optimal path for mapping.
- Estimate translational and rotational velocities of the ice.
- Obtain 3D geometries of the underside of the ice.
The AUV ice mapping problem

Chosen strategy

- Bathymetric distributed particle filter SLAM [1].
  - Rao-blackwellized particle filter.
  - One 1D EIF for each cell in map.
  - Ancestry tree to avoid costly copy operations.
- Grid-map of predefined size and resolution.
- Static iceberg in moving reference frame.
- Upward-looking multibeam sonar.

Outline

• Motivation
• Simultaneous Localization and Mapping (SLAM)
• Preliminary results
• Summary and way forward
Simultaneous Localization And Mapping

- The robot is exploring an unknown, static environment.

Given
- A set of inputs (i.e. robot controls, $U_{0:k}$).
- Observations of nearby features from some sensor ($Z_{0:k}$).

Estimate
- Map of features ($m$).
- Pose/path of the robot ($x_k$).
Ice mapping SLAM algorithm

Particle filter algorithm

0. **Initialize** particles with initial ice pose. Initialize empty map (and insert prior information, if any).

1. **for** k=1 to **end**
   2. **for** i = 1 to $N_{	ext{particles}}$
      3. **Propagate** each particle to next timestep.
      4. **Weight** particle based on agreement with map.
   5. **end for**
  6. **Resample** particle set based on weights.
  7. **Update** the maps of the surviving particles.

8. **end for**
Propagate

Iceberg model

\[ \dot{\eta}_{io}^n = R_i^n(\psi_{io})v_{io}^i \]

\[ \dot{v}_{io}^i = -T^{-1}v_{io}^i + \omega_{io} \]

Courtesy: NOAA
Weighting

Multibeam observation model

Multibeam measurements:

\[ z = [r \quad \alpha \quad \beta]^T \]

Measurement function:

\[ \hat{z} = h(p_{ra}^i, E_z) + \omega \]

\[ h = \begin{bmatrix} \sqrt{b^2 + a^2 + d^2} & \text{atan} \left( \frac{a}{d} \right) & \text{atan} \left( \frac{b}{d} \right) \end{bmatrix}^T \]

Weighting of each beam is performed using the likelihood function for the normal distribution.
## Resampling

**Sampling importance resampling (SIR)**

1. Calculate importance weights $w_i$ for each particle (joint likelihood of each beam weight).
2. Normalize weights $q_i = \frac{w_i}{\sum w}$.
3. Resample particles with probability $q_i$.

I.e. particles that have good correspondence with map have higher probability for surviving (getting resampled).
Update

Observation map

- All observations are keyed with particle id and put in a grid-map.
- Ancestry tree keeps track on particle ancestry to avoid using one grid map per particle.
- If an update exist in grid square from a particular particle, estimate is updated using the extended information filter (EIF).
- Why EIF instead of EKF?
  - EKF has efficient prediction, but slow correction.
  - EIF has slow prediction, but efficient correction.
- One square in the grid contains one EIF per particle that has updated that square.
Outline

- Motivation
- Simultaneous Localization and Mapping (SLAM)
- Preliminary results
- Summary and way forward
Preliminary results
Execution time (100 particles)
Execution time (200 particles)
Outline

• Motivation
• Simultaneous Localization and Mapping (SLAM)
• Preliminary results
• Summary and way forward
Summary and way forward

• Iceberg SLAM is implemented and working for stationary iceberg.
  - Implement guidance system for following trajectory in ice-frame.
  - Test on drifting and rotating iceberg.

• Optimize algorithm for real-time execution.
  - Parallelize algorithm.
  - Look into more efficient data structures for maintaining data.

• Implement a more memory efficient map structure.
Thank you for your attention!