Fast Monte Carlo Localization of AUV Using Acoustic Range Measurement

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Introduction

• A novel online nonlinear Monte Carlo algorithm for multi-sensor autonomous underwater vehicle (AUV) navigation is proposed.
• The approach integrates the global constraints of range to, and GPS position of, multiple surface vehicles and relative pose constraints arising from observations of multiple beacon boats.
• The proposed method can be used to more accurately navigate the AUV, to extend mission duration, and to avoid surfacing for GPS fixes.
Introduction

- **AUV navigation and localization techniques:**
  - Inertial/dead reckoning
  - Acoustic transponders and modems
  - Geophysical

- **Acoustic navigation techniques**
  - Ultra short baseline (USBL)
  - Short baseline (SBL)
  - Long baseline (LBL) and GPS intelligent buoys (GIBs)
  - Single fixed beacon
  - Acoustic modem
Objective

• AUV + Unmanned Surface Vehicle (ASV)
• Measurement: ASVs have GPS fixes. The AUV has magnetometers and acoustic sensors.
• Objective: the pose uncertainty of the AUV is reduced using acoustic ranging (beacon ASC) and onboard magnetometers and AUV motion.
Localization Using ASC Beacons

- ASVs
- AUV
- GPS

- PF: address the nonlinearity of the AUV motion
- EKF: used for the range estimation
Proposed Method

• The posterior over the pose of the AUV
  \[ \prod_{n=1}^{N} p(r_n|z_{1:t}, x_{1:t}, x_0) p(x_{1:t}|z_{1:t}, u_{1:t}) \]

• \( r_n \): Range of the Nth beacon

• \( x_{1:t} \): pose, \( u_{1:t} \): control

• \( p(x_{1:t}|z_{1:t}, u_{1:t}) \) is estimated by a PF

• \( p(r_n|z_{1:t}, x_{1:t}, x_0) \) is estimated by an EKF
Proposed Method

- Each particle:

\[
<x_{1:t}, \mu_1^{[i]}, \Sigma_1^{[i]}, \mu_2^{[i]}, \Sigma_2^{[i]}, \ldots, \mu_N^{[i]}, \Sigma_N^{[i]}>
\]

- The proposed algorithms is a particle filter of many EKFs
Proposed Method

- The particle filter is used to estimate the pose $x(t)$ of the AUV;
- The EKF is used to estimate the range measurement.
  - $\mu$ and $\Sigma$ are the mean and variance of the beacon boat.
    - $\mu_1^{[i]}, \Sigma_1^{[i]}, \mu_2^{[i]}, \Sigma_2^{[i]}, \ldots, \mu_N^{[i]}, \Sigma_N^{[i]}$
    - $[i]$: particle ID, $N$: number of beacons
  - $\mu$ and $\Sigma$ of each beacon are updated using the EKF;
Proposed Method

• The innovation is based on range measurement $y$ and predicted range: $r = \sqrt{dx^2 + dy^2}$;

• $Sp$ (updated variance) and $Q$ (acoustic ranging uncertainty) of all beacons are then used for importance sampling to select more favored particles that represent both the pose $x(t)$ and corresponding range measurement $y$. Then corresponding $\mu$ and $\Sigma$ of all beacons of each favored particle are also selected.
Proposed Method

• Complexity:
  N: number of beacons
  M: number of particles

• Proposed method:
  - EKF with a large multivariate state vector: $O(M \log(N))$
  - simple particle filter: $O(M^N)$
Result

• Simulation results
Result

Particle Filter and EKF Localization Measurements
Result

- The bounded localization error
Conclusion

• a Monte Carlo method for on-board AUV navigation using acoustic ranges transmitted from multiple autonomous surface vehicles.

• The approach reduces localization uncertainty while maintaining computational efficiency, which allows for operation in real-time for underwater missions.
Future work - In Water Trials
Thank you!