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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

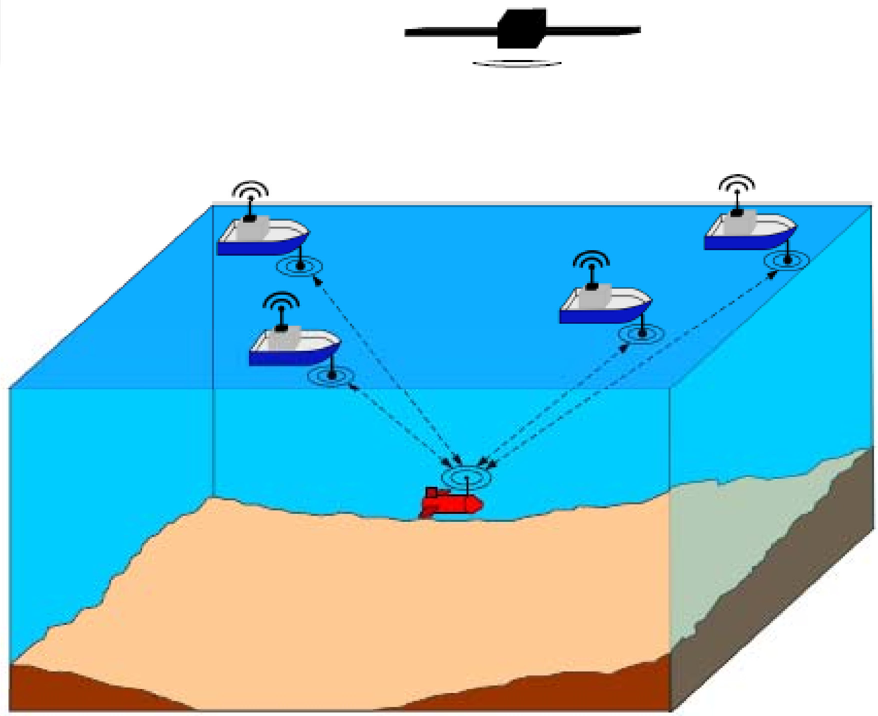
- **Acoustic navigation techniques**
  - Ultra short baseline (USBL)
  - Short baseline (SBL)
  - Long baseline (LBL) and GPS intelligent buoys (GIBs)
  - Single fixed beacon
  - Acoustic modem

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:

$$< x_{1:t}^{[i]}, \underbrace{\mu_1^{[i]}, \Sigma_1^{[i]}, \quad \mu_2^{[i]}, \Sigma_2^{[i]}, \quad \ldots \quad \mu_N^{[i]}, \Sigma_N^{[i]}}_{\text{beacons}} >$$

- 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.
  - μ and Σ are the mean and variance of the beacon boat.

$$\underbrace{\mu_1^{[i]}, \Sigma_1^{[i]}, \quad \mu_2^{[i]}, \Sigma_2^{[i]}, \quad \ldots \quad \mu_N^{[i]}, \Sigma_N^{[i]}}_{\text{beacons}}$$

[i]: particle ID, N: number of beacons

  - μ and Σ 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 μ and Σ of all beacons of each favored particle are also selected.

Proposed Method

- Complexity:

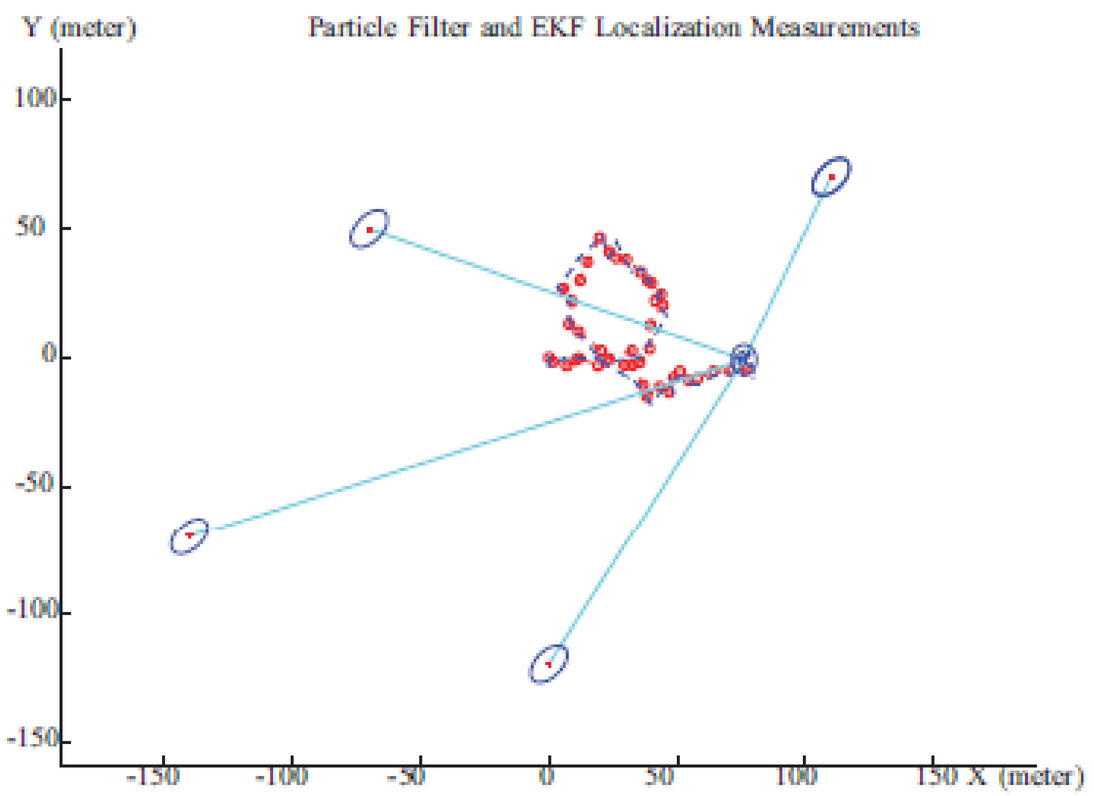
N: number of beacons

M: number of particles

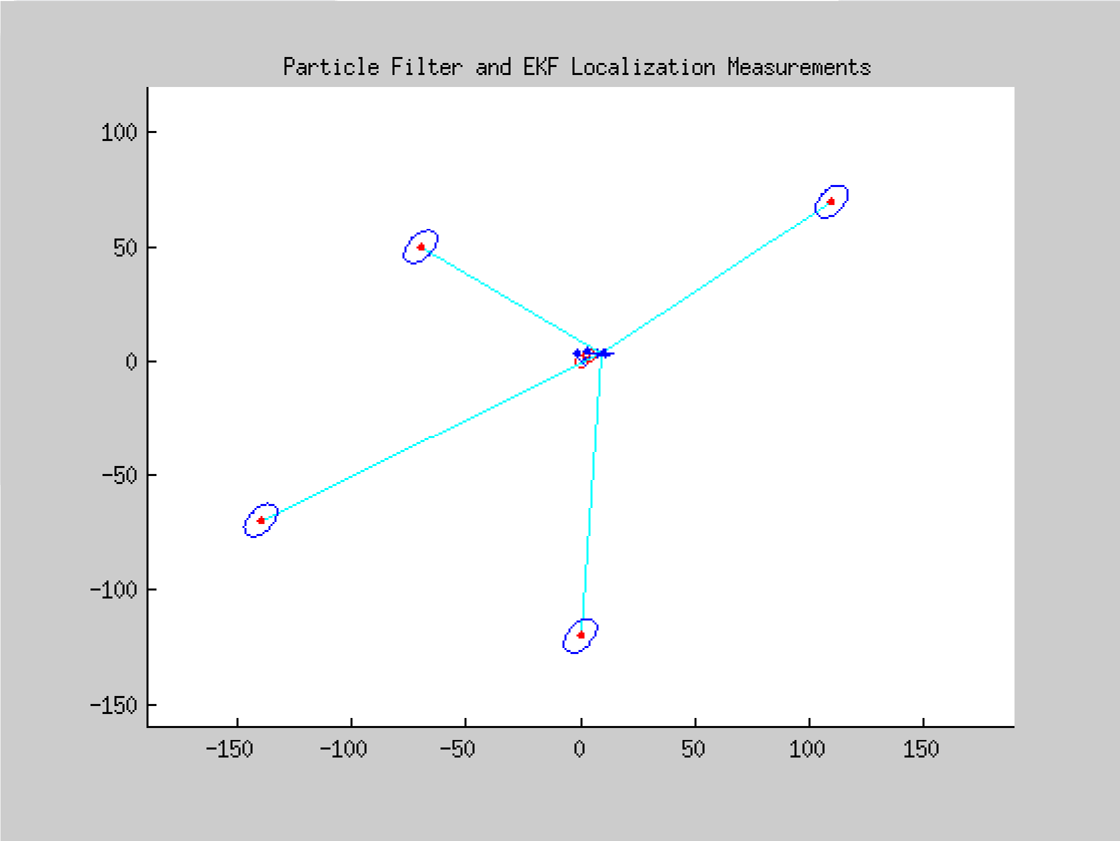
- Proposed method : $\mathcal{O}(M\,log(N))$
- EKF with a large multivariate state vector : $\mathcal{O}(N^2)$
- simple particle filter : $\mathcal{O}(M^N)$

Result

- Simulation results

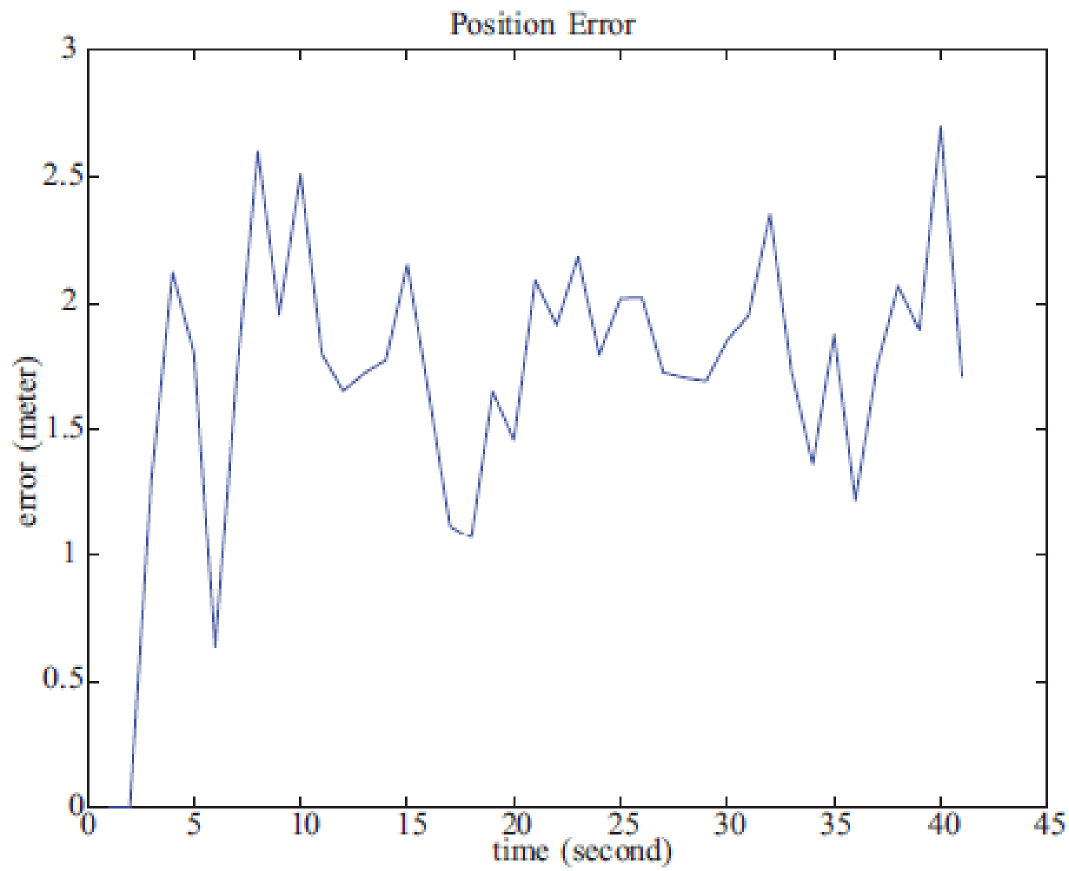


Result


Particle Filter and EKF Localization Measurements
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150

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!