Motion-Aware Self-Localization for Underwater Networks

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Mobile Underwater Networks

A collection of AUVs, drifters, robots, gliders with communication capability can:

- Obtain space-time correlations in 3D (Distributed Sensing)
- Track phenomenon of interest
- Perform adaptive sampling

- Research efforts [ASAP-Princeton], [AMOUR], [WISL], [SPAWAR-DSSN]

Our motivator:
- Drogues developed by Dr. Jules Jaffe (Scripps)
  - Vertical motion control through change in buoyancy
  - Drift with the currents
Distributed mobile networks: Applications

- Storm drain runoff
- Underwater Currents
- Phytoplankton: lifeline of the ocean
- Oil spill spreading
- Larval dispersion
- Monitoring marine eco-systems

Climate Change
What would my data mean?

Localization is a fundamental problem
Post-facto localization

Application scenario: Periodic Sampling

1. Estimate positions
2. Repeat periodically

Large amounts of data only analyzed centrally.

During mission: ranging  Post mission: Perform localization

Algorithms:
- Multi-dimensional Scaling
- Semi-definite programming
- ML-estimation
- Iterative multi-lateration
  ...
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The problem of non-concurrent ranging

- Collision avoidance: MAC-back off required
- Non-concurrent distance estimates
- Delay in obtaining distances combined with mobility → Change in positions during localization.
- With low data rates (80bps)(large delay) & current speeds up to 1.5 m/s: Significant displacement in nodes during localization
Impact of mobility on localization

Cumulative position error distribution

Effect of delayed distance estimates on existing localization algorithms
Mobility-aware localization

MAP estimate of positions at the localization instance:

$$\theta_{i,T_{loc}}^* = \arg\max p(\theta_{i,T_{loc}} \mid \{d_t\}_{t \in (0,T)})$$

Obtain marginal distributions from joint distribution of positions of all nodes in time epoch (0,T)

$$p(\theta_{i,T_{loc}} \mid \{d_t\}_{t=0}^T) = \int_\Theta p(\Theta, \theta_{i,T_{loc}} \mid \{d_t\}_{t=0}^T).d\Theta$$

Where, $$\Theta = \left\{ \{\theta_{k,t}\}_{t=0}^T \setminus \{\theta_{i,T_{loc}}\} \right\}$$

$$U$$: Set of all unknown nodes

Solution: Sum-product algorithm, message passing on a factor-graph

The general problem solved by the sum-product algorithm:

$$\sum_{x_1} g(x_1, x_2, x_3) = \sum_{x_2 \in A_2} \sum_{x_3 \in A_3} g(x_1, x_2, x_3)$$

Joint distribution represented via factor-graphs
Mobility-aware localization

Factor-graph representation of the localization problem

Operation of the algorithm:

\( \Theta_{1,t} \) State-variables

\( f_1 \) Statistical model for range measurements (from experiments)

\( f_2 \) Motion model

\( f_3 \) Initial distribution of node positions
Computationally efficient fine-grained localization

Adjust localization granularity to accuracy of position estimates

Position distributions
Mobility-Aware localization: Results

Motion during ranging epoch

Estimated position distributions

Cumulative error distribution of node positions

Even with a simple motion model,
Significant improvement in performance
Conclusion

• Instance of how communication delay affects network protocols underwater.

• Movement of nodes during ranging degrades localization performance significantly.

• Particularly a problem for short range networks

• Proposed a post-facto localization method to counter this effect.
Questions?

Underwater image: www.tylerjohnsonmusic.com