Target aided online sensor localisation in bearing only clusters

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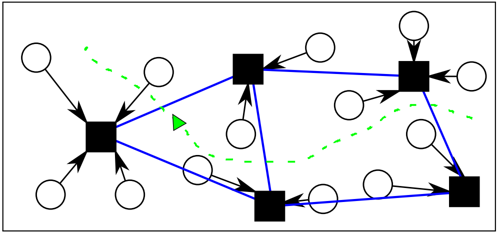
08/09/2014

Introduction

- Bearing-only sensors detect objects and record their line-of-sight (LOS) angles, in their sensor coordinate systems.
- Fusion clusters filter target detections.
- Sensor locations are needed for fusion and routing.
- GPS denying environments, jamming,...
- Target detections and Received Signal Strength (RSS) at the communication front-end are used.



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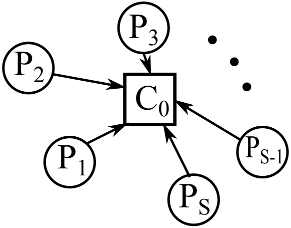
Problem Definition



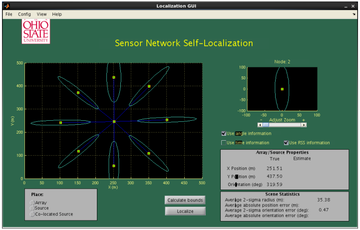
The cluster head C_0

1. collects target detections $Z^0_{1:T}$ in a time window of T with its on-board bearing only sensor,
2. receives $Z^i_{1:T}$ from peripheral P_i.
3. The i^{th} comm.s signal arrives at the receiver with power R^i (or Received Signal Strength-RSS).

- Find locations $\theta \triangleq [\theta_1, \theta_2, ..., \theta_S]$ given $Z^0_{1:T}, Z^1_{1:T}, ..., Z^S_{1:T}$ and $R_1, ..., R_S$.
- The uncertainties are captured within $l(Z^0_{1:T}, Z^1_{1:T}, ..., Z^S_{1:T}|\theta)$, and, $l(R^1, ..., R^S|\theta)$.

Conventional Approaches (1/3)

- Cramer-Rao Lower Bounds for $l(R^1, ..., R^S|\theta) = \prod l(R^i|\theta_i)$:



- High uncertainty because that $l(R^i|d^i = |\theta_i|)$ is log-normal resulting with a wide distribution.

Conventional Approaches (2/3)

- Target detections based likelihood is given by

$$
\begin{aligned}
l\left(Z^0_{1:T}, Z^1_{1:T}, \ldots, Z^S_{1:T} \middle| \theta\right) &= \prod_{t=0}^{T-1} p(Z^{0:S}_{t+1} | Z^{0:S}_{1:t-1}, \theta) \\
&= \prod_{t=0}^{T-1} \int p(Z^0_{t+1} | X_{t+1}) \prod_{i=1}^{S} p(Z^i_{t+1} | X_{t+1}, \theta_i) \\
&\times \quad \underbrace{p(X_{t+1} | Z^0_{1:T}, Z^1_{1:T}, \ldots, Z^S_{1:T}, \theta)}_{\text{Prediction distribution of a (centralised) filter.}} \, \mathrm{d}(X^{t+1})
\end{aligned}
$$

- Intractable, in general. Monte Carlo (MC) approx. needed.
- Increasing MC variance as the time window length T grows larger $\sim$ particle deficiency (Kantas, Doucet, et.al., 2010).

Conventional Approaches (3/3)

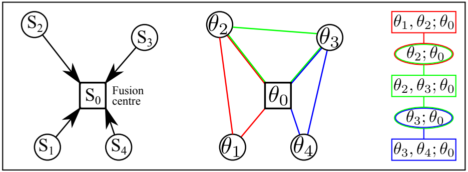
- Bayesian recursions for an online solution:

$$
\begin{aligned}
p_n(\theta_n) &\propto l(Z^{0:S}_{T(n-1)+1:Tn}|\theta_n)p_{n|n-1}(\theta_n) \\
p_{n|n-1}(\theta_n) &= \int f_n(\theta_n|\theta_{n-1})p_{n-1}(\theta_{n-1})\mathrm{d}\theta_{n-1}
\end{aligned}
$$

- Scalability of the update with the # of sensors S (equivalently, the dimensionality of θ):
  - Update is $\mathcal{O}((S^{\alpha+1}N)(ST)M)$.
  - N: The number of particles per sensor,
  - M: The number of progressive Importance Sampling (or, stochastic tempering) stages.
- With given N, M, and, the sophistication of the samplers, might fail to converge.

Proposed Solution (1/2)

- Divide the problem into simpler subproblems and merge their solutions.
- Use a Junction Tree (equivalently, a triangulated Markov Random Field) model for the localisation posterior:



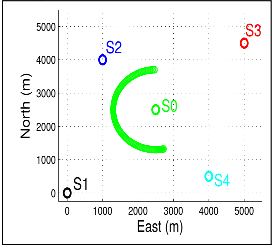
$$p(\theta) \propto \frac{\prod_{k=1}^{S-1} l(Z^0, Z^{i_k}, Z^{i_{k+1}} | \theta_{i_k}, \theta_{i_{k+1}})}{\prod_{k=2}^{S-1} l(Z^0, Z^{i_k} | \theta_{i_k})} \prod_{i=1}^{S} p_{0,i}(\theta_i).$$

Pairwise MRF models for self-localisation of range-bearing sensors(Uney, Mulgrew, Clark, “Cooperative sensor localisation for distributed fusion networks”).

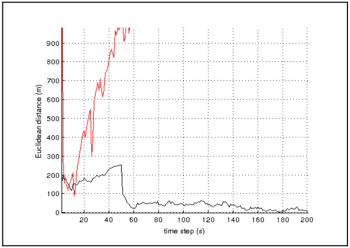
Proposed Solution (2/2)

- Update one marginal of $p_n(\theta_n)$ at a time using the Junction Tree message passing algorithm: The Importance Sampling scheme is detailed in the article.
- $\mathcal{O}(N(3T)S^{\beta+1})$ (as opposed to $\mathcal{O}((S^{\alpha+1}N)(ST)M))$ with typically much smaller N.
- Convergence properties are improved by the introduction of RSS likelihoods $l(R^i|\theta_i)$s to shape priors.

Example



- LOS angle standard deviation $\sigma_i = 0.5^\circ$.
- $T = 10$ step window-length , $N = 150$ particles per sensor.
- Final error (averaged over sensors) is 45.7m (%2.15 of the nearest peripheral distance (2121.3m of sensor 2).



- Tracking error (Euclidean distance) of the cluster (black) when location estimates are used (in comparison with cluster-head only (red) tracking).

Conclusions and Future Work

- We considered sensor localisation in bearing only sensor clusters for target filtering and routing.
- Our solution uses target detections and RSS measurements.
- Scales well with the number of sensors.
- Further empirical study of clutter effects using Bernoulli filters.
- Further empirical comparison of the accuracy and complexity of progressive Importance Sampling schemes and the proposed solution.

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) and Dstl.