Robust Distributed Network Localization with Noisy Range Measurements

IN4181 Wireless Sensor Networks - Localization
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Spatial Information

How:

• GPS
Spatial Information

How:

- GPS
- Measure Distance between Nodes (range)
Distance Measurements

[Propagation Loss]

- Path-loss
- Shadow fading
- Multipath fading

[G. Janssen, ET4358]
Distance Measurements

Ultrasonic
The Proposed Algorithm

- Distributed, Linear-Time
- Noise Aware
- Rather No Localization than Wrong Localization
- 2D Graph Realization Problem
Graphs

- The Graph Realization Problem = Finding Euclidean Position of Vertices. NP-Hard.
- Rigid Graphs: Finite Number of Realizations.
- However...
Graphs

(a) Ground truth

\[ \sigma_{err} = 0.37 \]

(b) Alternate realization

\[ \sigma_{err} = 0.34 \]

Better Error-metric can give Worse Results
Graphs

Flip Ambiguity
Graphs

Flex Ambiguity
Graphs

Flip Ambiguity Result
The Robust Quadrilateral (Quad)

Globally rigid: unique positions, up to rotation, translation and reflection
The Robust Quadrilateral (Quad)

\[ b \sin^2 \theta > d_{\text{min}}, \text{ where} \]

\[ b = |\text{shortest side}|, \quad \theta = \text{smallest} \ \angle, \quad d_{\text{min}} = \text{threshold based on noise}. \]
Phases of the Algorithm

Phase I - Cluster Localization

• For each node, find neighbours, find robust quads, trilaterate positions.
Phases of the Algorithm

Phase II - Cluster Optimization (Optional)

- Per cluster, refine positions using numerical optimization (spring relaxation, Newton-Raphson) because of error accum.
Phases of the Algorithm

Phase III - Cluster Transformation

- Connect clusters using *robust triangles*.
Results - Metrics

- $\sigma_p^2 = \text{Mean-square error in Euclidean 2D space}$
- $\sigma_d^2 = \text{Mean-square error in distance measurement}$
- $\bar{R} = \text{Cluster success rate, average percentage of localized nodes per cluster.}$
- $\tilde{R} = \text{Largest forest size / # nodes. forest = not localized with respect to other graph}$
Results - Hardware Deployment

![Plot of Hardware Deployment](image)

- Ground truth
- Localized positions
Results - Hardware Deployment

• Error in distance \((\sigma_d)\): 4.38cm
• Error in position \((\sigma_p)\): 6.82cm
• Cluster succes rate \((\bar{R})\): 0.97
• Largest forest \((\tilde{R})\): 0.95
Results - Simulation

robust quads
Results - Simulation

no robust quads
## Results - Simulation

<table>
<thead>
<tr>
<th>metric</th>
<th>Our algorithm</th>
<th>w/o robust quads</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_d$</td>
<td>1.0 cm  3.0 cm  5.0 cm</td>
<td>5.0 cm</td>
</tr>
<tr>
<td>$\sigma_p$</td>
<td>4.43 cm  14.39 cm  16.22 cm</td>
<td>54.87 cm</td>
</tr>
<tr>
<td>$\tilde{R}$</td>
<td>0.91  0.85  0.79</td>
<td>0.95</td>
</tr>
<tr>
<td>$\tilde{\tilde{R}}$</td>
<td>0.93  0.87  0.75</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Conclusion

• Works with noise;
• Errors can be bound;
• Robust quads reduce errors.
Questions?