Evaluating Lateration-Based Positioning Algorithms for Fine-Grained Tracking

Andrew Rice and Robert Harle
Computer Laboratory
University of Cambridge
UK
Introduction

- Fine-grained location information has many uses
  - new user interfaces
  - contextual inferences
  - location correlated sensing
  - routing
- We look at the performance of a number of lateration algorithms using real-world data in multipath environments
Algorithms

- Non-linear Regression (NLR) – minimize error across entire dataset
- Iterative NLR (INLR) – repeatedly remove outliers until fit is good enough
- Linear Least Squares (LLS) – linearise problem for direct solution
- RANSAC – Trilaterate a random triple and look for supporting data
- Trilaterate on Minima (ToM) – Trilaterate the shortest distances
Data Collection

- Ultrasonic sensor system (Bat system)
  - sensors in ceiling approx 2 per square metre
  - produces time-of-flight readings
- No reliable fine-grained simulation of an indoor environment and occupants exists
  - Cannot evaluate algorithms using simulated data
- Bat transmitters left in fixed position for 4 months
  - ground-truth position from laser survey equipment
Results

• Between 5% and 20% of sightings are multipath signals – this is not correlated with position.

• Location error is correlated with position.

<table>
<thead>
<tr>
<th></th>
<th>Error Middle</th>
<th>Error Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLR</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>RANSAC</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>NLR</td>
<td>0.24</td>
<td>0.41</td>
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<tr>
<td>LLS</td>
<td>9.57</td>
<td>24.69</td>
</tr>
<tr>
<td>ToM</td>
<td>0.63</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Iterative Non-Linear Regression Error

Middle of room

Against wall
RANSAC Error

Middle of room

Against wall
LLS Vertical Error

- Planar sensor array interacts badly with linearization for vertical information

**Top-down view**

**Side view**

![Graphs showing LLS and NLR positions in top-down and side views.](image-url)
Dependability

- Algorithm specific estimate of location error
- Dependability \((d) = \% \text{ of time that estimated error is less than actual error}\)
- Dependability strength \((d_s) = \text{actual error minus estimated error}\)

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>(d) (%)</th>
<th>(d_s) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLR</td>
<td>91.99</td>
<td>0.05</td>
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<tr>
<td>RANSAC</td>
<td>99.44</td>
<td>1.16</td>
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<tr>
<td>NLR</td>
<td>99.99</td>
<td>4.06</td>
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<tr>
<td>LLS</td>
<td>22.31</td>
<td>0.79</td>
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</table>
Conclusions

- INLR best accuracy but computationally expensive
- LLS is fast but suffers from outliers and is geometrically weak when using a planar sensor array
- INLR and RANSAC good at rejecting multipath signals
  - sensor geometry plays a more significant rôle
Finally

- NLMaP
  - implementation of all the investigated algorithms
  - open source, freely available
- http://www.cl.cam.ac.uk/Research/DTG