Real-time Scan Matching Using $L^0$-Norm Minimization Under Dynamic Crowded Environment

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Our Goal

- Realize autonomous mobile robots under crowded scene
ICP-based Scan Matching

Observation at time t-1

Observation at time t

Alignment gives us estimation of displacement
Issues

Static scene

Crowded scene
Related Works

– Use robust estimator (e.g. M-Estimator)

– Remove moving objects
  • Use landmarks [Wolf et. al, 2005]
  • Use tracking [Hahnel et. al, 2002] [Wang et. al, 2003]

– Solve moving object detection and localization simultaneously
  • EM-algorithm [Hahnel et. al, 2003]
  • Use integrated probabilistic model [Ven et. al, 2010]
Proposal

• Use L0-norm, a kind of robust estimator

• Accelerate by Locality Sensitive Hashing
  → Keep real-time (about 5 fps)
Flow of Algorithm

1. Observe environment by LIDAR

2. Generate candidates and select the best match from them
Review of ICP

• Minimize sum of squared distances of closest points

Observation at time t-1

Observation at time t
L0-Norm

• Minimize number of not-matched points

Assumption: static objects are dominant
Issue in L0-Norm Minimization

• Not use gradient information

Give up gradient-based optimization and use brute-force search
Locality Sensitive Hashing (LSH)

- For approximate closest point search
- Use multiple hash functions
  - Limit search range by hash values

Hash functions
Difference in L0-Norm Scan-Matching

• Search matched points, not closest points

• Not use location and index of the matched point

To know existence is only important
Scenario in LSH (1)

• All hash values are different
  → Closest point: continue to search points with similar hash values

→ L0-norm: no matched-point exists
Scenario in LSH (2)

• Multiple points have the same hash values
  → Closest point: select the best one by additional calculation

  → L0-norm: multiple matched-points exist
LSH for Scan-Matching

• Use a lookup table

Advantage

• Just access memory for calculation
• Binary is sufficient for each bin
EXPERIMENT
Purpose of Experiments

• Robustness to moving objects

• Accuracy in map generation
Setup of First Experiment (Robustness)

- About 25 persons move around the robot fixed
## Result

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE (x [cm], y[cm], θ [rad])</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2-norm</td>
<td>(3.37, 2.08, 0.016)</td>
</tr>
<tr>
<td>Threshold (30 percent)</td>
<td>(1.17, 0.033, 0)</td>
</tr>
<tr>
<td>Threshold (50 percent)</td>
<td></td>
</tr>
<tr>
<td>Cauchy</td>
<td>(1.33, 0.013, 0)</td>
</tr>
<tr>
<td>Biweight</td>
<td>(0.13, 0.002, 0)</td>
</tr>
<tr>
<td>L0-norm</td>
<td>(0.42, 0.015, 0)</td>
</tr>
</tbody>
</table>

**Verify plausibility of use of L0-norm**

![Graph showing comparison of different methods](image)
Estimated Maps

Threshold (30 percent)

Cauchy
Estimated Maps

Biweight

L0-Norm
# Calculation Speed

<table>
<thead>
<tr>
<th>Method</th>
<th># of localizations per second</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brute-force</td>
<td>190</td>
<td>-</td>
</tr>
<tr>
<td>kd-tree</td>
<td>1000</td>
<td>-</td>
</tr>
<tr>
<td>LSH</td>
<td>4430</td>
<td>14.42</td>
</tr>
</tbody>
</table>

More accelerated by parallel computing

ICP, Biweight

L0-norm
Setup in Second Experiments (Accuracy)

- About 25 persons move around the moving robot
Experimental Scene

Views from the robot  Range data obtained from LIDAR
Result

Point map obtained from 300 frames of range data
Occupancy Grid Map

Converted by Mobile Robot Programming Toolkit, MRPT  
http://www.mrpt.org
Accuracy
Indoor & Outdoor

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Result by RBPF-SLAM on MRPT
Result by Proposed Method

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Conclusion

- Use L0-norm, a kind of robust estimator

- Accelerate by Locality Sensitive Hashing
  → Keep real-time (about 5 fps)
Future work

• Balance accuracy vs. calculation time
  – Cauchy followed by L0-norm
  – L0-norm followed by Biweight
  – L0-norm + moving object detection
  etc....
Thank You For Your Attention