Improving 3D Scan Matching Time of the Coarse Binary Cubes Method with Fast Spatial Subsampling

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Outline

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2. THE COARSE BINARY CUBES (CBC) METHOD
3. SUBSAMPLING STRATEGY
4. EXPERIMENTAL RESULTS
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1. INTRODUCTION

- **3D Point Cloud Matching** is a basic operation in mobile robotics for localization and mapping.
- All scan directions and depths of a scan may contain relevant data. Farther regions have lower sampling densities.
- The search for scene matching is performed around an initial odometric estimation.
1. INTRODUCTION

• **Aim of this work**: to speed up 3D point cloud matching without losing accuracy with the Coarse Binary Cubes (CBC) method by applying an effective subsampling procedure.

• **Subsampling methods**: can be broadly classified as *range-independent* when a pre-computed mask is applied to the scan, and *range-dependent* when a representative set of points from the scan is selected (Mandow *et al.*, 2010).
2. THE CBC METHOD

- Which is the spatial transformation
  \[ T = [x_0, y_0, z_0, \alpha, \beta, \gamma] \]
  to project the second scan into the first scan that maximizes the number \( J \) of coincident occupied cubes of edge length \( E \)?
2. THE CBC METHOD

Example of a CBC match with $E = 0.3$ m
2. THE CBC METHOD

- **Objective function** $J(T)$ can be evaluated:
  - without using any 3D data structure,
  - in $O(n)$ time, where $n$ is the number of points.

- The search for $T$ is performed by evaluating different solutions with a variation of the Nelder-Mead method.

- CBC is a compelling alternative to Iterative Closest Points (ICP) and Normal Distribution Transform (NDT) for scene registration (Martínez *et al.*, 2012).
3. SUBSAMPLING STRATEGY

- **Data structures to evaluate** $J(T)$:
  - $I$ represents the integer index of the cube where a scan point is located.
  - $V$ is a binary vector indexed by $I$ whose ones correspond to occupied cubes and its zeroes to empty cubes.
  - $L$ is an unsorted integer list that contains the indices $I$ of the occupied cubes.

- **New subsampling stage:**
  - reduces the number of points to be projected and the computation of their corresponding indices $I$ for every prospective $T$. 

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3. SUBSAMPLING STRATEGY

- **Octree Cube Centers**: it divides recursively occupied cubes into 8 octants until a minimal octant size $E_s$ is achieved starting from the cube that contains the whole scan (Nüchter, 2009).

  - This is an effective strategy that is closely related with the uniform spatial representation implicitly used by CBC.
3. SUBSAMPLING STRATEGY

• Implementation with CBC data structures:
  - $V^s$ is created as a zero binary vector and the list of integers $L^s$ is empty.
  
  - The integer index $I$ of each point of the second scan is computed.
    
    - If $V^s(I) = 0$ then $V^s(I)$ is set to 1, and $I$ is inserted into $L^s$. Otherwise, no action is taken.
  
  - Finally, the coordinates of the centers of the occupied cubes is extracted from $L^s$. The subsampled set of points coincides with octree cube centers.
4. EXPERIMENTAL RESULTS

The mobile robot Quadriga:
- 4-wheel skid-steer vehicle (Morales et al., 2010),
- 0.82 m height,
- powered with batteries.

The Velodyne HDL-32 device:
- 32 laser beams,
- ranges from 1 m to 100 m,
- scanning time of 0.1 s,
- 360° x 41° field of view,
- 0.16° x 1.33° resolution.
4. EXPERIMENTAL RESULTS

The outdoor environment

robot position

Point cloud of a scan

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4. EXPERIMENTAL RESULTS

• Subsampling times:

<table>
<thead>
<tr>
<th>$E^s$ (m)</th>
<th>Octree (ms)</th>
<th>$V^s$ &amp; $L^s$ (ms)</th>
</tr>
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<tbody>
<tr>
<td>0.9</td>
<td>7</td>
<td>4</td>
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<tr>
<td>0.2</td>
<td>10</td>
<td>9</td>
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</table>

• Registration times:

- The gain with respect to the non-subsampled case increases linearly with $E^s$. 

![Graph showing the gain with respect to $E^s$](image)
4. EXPERIMENTAL RESULTS

• Registration accuracy:
  - A relation $E/E_s$ around 4 provides almost the same number of occupied cubes.
  - Accuracy only degrades when $E/E_s$ approaches 1.
  - A relation $E/E_s$ around 3 provides a compromise between accuracy and computation time.

Top view of a CBC alignment without subsampling
5. CONCLUSIONS

• CBC efficiency has been improved by selecting a subsampling method to obtain a reduced and representative set of points.

• Octree cube centers have been computed with efficient one-dimensional data structures and the relation with the size of the CBC cubes has been studied.

• Experimental results have been obtained with a multi-beam 3D laser scanner mounted on the Quadriga mobile robot.

• Work in progress: to combine subsampling with the parallel execution of CBC via multi-core and multi-threaded processors (Martínez et al., 2013).
Thank you!

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## 4. EXPERIMENTAL RESULTS

### Effect of $E^s$ on registration with $E= 0.9$ m

<table>
<thead>
<tr>
<th>$E^s$ (m)</th>
<th>$m$</th>
<th>$r$ (%)</th>
<th>$J(T_{gt})$</th>
<th>$J(T)$</th>
<th>$D_s$ (m)</th>
<th>$D_\alpha$ (°)</th>
<th>Time (s)</th>
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