Automatic Relative Orientation of Terrestrial Laser Scans using Planar Structures and Angle Constraints

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Introduction
Relative orientation of terrestrial laser scans

- Build overall point cloud from multiple scans
Relative orientation of terrestrial laser scans

- Build overall point cloud from multiple scans
- Object recognition (point cloud vs. model)
- Robotics (kidnapped robot)
In reality: \( \mathbf{x}_2' = \mathbf{R}\mathbf{x}_2 + \mathbf{t} \)

Find \( \mathbf{R} \) and \( \mathbf{t} \) which minimize \( \sum \| \mathbf{x}_1 - \mathbf{x}_2' \|^2 \)

- Nonlinear (due to \( \mathbf{R} \)), **but:**
- Closed form solutions by Sansò (1973), Horn (1987)
Main problem: finding correspondences

- Manual / semiautomatic: signalized points (LS software)
- Use heuristic based on proximity: “close points are corresponding points”
  - Iterative closest point (ICP) algorithm
    - Chen & Medioni (1991), Besl & McKay (1992)
    - Many variants, see e.g. Rusinkiewicz & Levoy (2001), Grün & Akca (2005)
  - Commercially available
  - Requires good initial alignment
Other than points: more meaningful primitives

- Planes, Cylinders, Torii, … (Rabbani et al., ISPRSJ 61(6))
- More complex primitives may fix more d.o.f.
- Very few, as compared to points in point cloud

Here: Planes

\[ \langle n_i, x \rangle - d_i = 0 \]
\[ \langle m_i, x \rangle - e_i = 0 \]
\[ \langle p_i, x \rangle - f_i = 0 \]
Other than points: more meaningful primitives

- 3 Plane correspondences required to determine Transformation
  - (actually: 2 for rotation, but 3 for translation)
Finding correct correspondences

$S_1$

Point Cloud 1

Segmentation

Collection of $p$ planar patches 1

Search for Correspondences

Compute “best” $R$, $t$

$R$, $t$

$S_2$

Point Cloud 2

Segmentation

Collection of $p$ planar patches 2
Problem 1: Rating of solution (score function)

- Typically, overlap between (aligned) scans would be used as score function.
- Standpoints far apart have only little overlap (though being aligned correctly).
- May have larger overlap when transformation is incorrect.
- “True” overlap is not known in advance.

- More elaborate score functions take more computation time.

- Not solved here…
Example: correct transformation yields little overlap (SP01-SP11)
Example: false transformation yields larger overlap (SP01-SP11)
Finding correct correspondences

\[
\binom{p}{3} \cdot \binom{p}{3} \cdot \frac{3!}{2}
\]
Problem 2: Reducing the number of possible combinations

- Testing all 1.15 billion solutions is not feasible
- Goal: Build a hierarchy of tests, or “filters”
  - the most inexpensive tests are applied first
  - expensive tests are only applied after a huge number of false solutions has been ruled out
  - the tests do not rule out the correct solution
- This is the topic of the paper
The test scene
Real test data

- **Riegl LMS-Z360i**
  - 360° x 90° f.o.v.
  - 12 mm single shot accuracy
- **Reference orientations by RiscanPro standard procedure**
  - Artificial targets, fine scan
  - Registration error in the range of a few millimetres
- **20 terrestrial scans**
  - 12 upright, 8 tilted
  - Spacing of approx. 5 m
  - Overlap 83% (SP01-SP02) down to 2.3% (SP01-SP12a)
All scans combined (removed points on ground)
Scan positions (drawn into map)
### Overlap of scan positions

- Count of overlapping points (within 0.5 m distance), given as percentage

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Angle constraint
Idea: angle constraint

- 3 normal vectors $\rightarrow$ 3 angles between normal vectors
- Angles between normal vectors must be the same in both scans
- Independent of scene content
Choice of angle tolerance

- Planes are estimated using many points
  - we expect quite accurate normal vectors
  - if so, we could set a small tolerance

- To find the tolerance from the real scene we
  - manually assigned planes between scans
  - computed angles between all pairs (total: 328 pairs)
  - computed differences
Choice of angle tolerance

Example for manual plane assignment

(SP01)

(SP09a)
Choice of angle tolerance

Result: more than 90% of the corresponding pairs show the same angles within 1°
Effect of filtering out angles outside tolerance

- Check which triples (out of 1.15 billion) lead to “correct” transformation (5° and 1m within reference)

<table>
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<td><strong>SP 01-10a</strong></td>
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<tr>
<td><strong>SP 01-11</strong></td>
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Determination of rotation component
Determination of rotation component

- Only two normal vector pairs required to determine rotation
- Number of possible combinations:
  \[
  \binom{50}{2} \cdot \binom{50}{2} \cdot 2 = 3 \times 10^6
  \]
- Number of compatible combinations →
  - 3-5% of total
  - approx. 140,000

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Determination of rotation component

- For each normal vector pair correspondence, compute rotation
- Compute angles $\omega$, $\varphi$ and $\kappa$
- Insert into histogram bins (bin size 2°)
- Sort bins in decreasing order of bin count
Closer look at SP01-02 (close) and SP01-09a (far)

- Bin counts in decreasing order
  - for close SP, a clear peak results
  - for SP far apart, no clear peak
  - indeed, for SP01-SP09a the correct rotation corresponds to the 8th largest bin
Close look at all bin counts

First 20 bins of SP01-02

Dot: correct solution

White: peak at first solution
Closer look at all bin counts

Peak is correct solution
Closer look at SP01-SP07

κ + 180°
Situation in map

Symmetry
(middle of crossing streets)
Closer look at failures / late solutions

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Determination of translation component
Determination of translation component

- For each of the 20 “best” rotations, search for translations
- Based on plane pair correspondences already established during rotation step
- Using RANSAC
- Rating of solutions: count identical planes (within 1m and 1°)

Ranking of correct (rotation + translation) solutions

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<th>03</th>
<th>04</th>
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Summary and Outlook
Summary I

1,15 billion triple correspondences

< 0.022% lead to correct transformations
Summary II

Rotation only

$S_1$  
3 million pair correspondences  
$S_2$

Filter: angle constraint

140,000 compatible correspondences

Filter: $\omega, \varphi, \kappa$ histogram

Keep 20 bins with largest count

Translation

Filter: Score based on plane equations

< 100 solutions

Filter: Score based on scan points

Final solution
Summary III + Outlook

- Relative orientation without initial values
- Based on extracted planes
- Uses simple filters to cut down search space
  - Angle constraint
  - Orientation bins
  - Score based on plane equations
  - Point cloud comparison comes last (not shown)

- Reduction factor: approx. 100 instead of 1.15 billion = $10^7$

- Work on final score function as well
  - Efficient
  - Selective
- Verify with other scenes