Point Cloud Registration
Using A Viewpoint Dictionary

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ICSEE 2016 – Eilat, Israel
Nov. 17, 2016
Goal

- Registration between a **global large-scale** point cloud and a **local** point cloud

**Local cloud** (stereo reconstruction) sporadic coverage, limited field-of-view

(terrestrial LiDAR) dense coverage, multiple viewpoints
Motivation

• Applications:
  – Accurate localization in large-scale environments (with better reliability than consumer-grade GPS)
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  – Multi-platform 3D environment modeling - registration between:
    ▪ airborne and terrestrial LiDAR clouds
    ▪ Structure from Motion (SfM) and LiDAR clouds
    ▪ etc.

Images: U.S. National Oceanic and Atmospheric Administration
Motivation

• Applications:
  – **Accurate** localization in large-scale environments (with better reliability than consumer-grade GPS)
  – **Multi-platform 3D environment modeling** - registration between:
    ▪ airborne and terrestrial LiDAR clouds
    ▪ Structure from Motion (SfM) and LiDAR clouds
    ▪ etc.
Outline

• Introduction

• Keypoint-based point cloud registration

• Point cloud registration using a viewpoint dictionary

• Conclusion
Keypoint-based point cloud registration

• Main steps:
  1. Keypoint detection
     ▪ Surface variation (Pauly et al., 2002)
     ▪ 3D SIFT (Rusu et al., 2011)

3D SIFT keypoint detection
(PCL, Rusu et al., 2011)

Image: Theiler et al., 2014
Keypoint-based point cloud registration

• Main steps:
  1. Keypoint detection
     ▪ Surface variation (Pauly et al., 2002)
     ▪ 3D SIFT (Rusu et al., 2011)
  2. 3D Descriptor computation
     ▪ Spin-Images (Johnson, 1997)
     ▪ Fast Point Feature Histogram - FPFH (Rusu et al., 2009)
Keypoint-based point cloud registration

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  5. Registration refinement - some variation of ICP - Iterative Closest Point (Besl and McKay, 1992)
Limitations of using keypoints

• Keypoint-based methods do not perform well when point clouds are significantly different

<table>
<thead>
<tr>
<th></th>
<th>Stereo (data)</th>
<th>LiDAR/SfM (model)</th>
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<td>Scene coverage</td>
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Stereo (local cloud)  LiDAR (global cloud)
Limitations of using keypoints

• Keypoint-based methods do not perform well when point clouds are significantly different.

Main difficulties:
  – Less repeatable keypoint detection
  – Fewer reliable correspondences
  – Unstable performance
    ▪ Ground truth
    ▪ Keypoint-based registration result

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Keypoint-based registration result
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- Conclusion
Proposed method: Point cloud registration using a viewpoint dictionary

• Main concepts:
  – Large-scale global cloud ➔ Dictionary of viewpoint-based smaller clouds
  – Local to global cloud registration ➔ Dictionary search

• Advantages:
  – Robust to point cloud noise
  – Can handle sporadic local clouds (e.g., stereo)

• Challenges:
  – Keep the dictionary compact
  – Perform dictionary search efficiently
Point cloud registration using a viewpoint dictionary - overview

Global cloud

Pre-processing

Viewpoint grid creation

Dictionary creation

Final candidate selection

ICP

Initial candidate selection

6DoF transformation estimation

Offline/Online

Local cloud
Main steps:

1. Create a grid of synthetic viewpoints
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Viewpoint dictionary based registration

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- Initial grid is regular in the $x, y$ plane
- Viewpoints are set at a constant height above ground
Viewpoint dictionary based registration

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- Initial grid is regular in the $x, y$ plane
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- Possible viewpoint restrictions:
  - Avoid viewpoints on rooftops
  - Filter out viewpoints in vegetation
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Viewpoint dictionary based registration
Main steps:

2. Create dictionary clouds for each viewpoint

- Divide area around each viewpoint into overlapping “slices”
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• Divide area around each viewpoint into overlapping “slices”
Viewpoint dictionary based registration

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Main steps:

2. Create dictionary clouds for each viewpoint

• Divide area around each viewpoint into overlapping “slices”
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Each “slice” (dictionary cloud) is aligned to a uniform pose such that:

- Viewpoint at origin
- Viewpoint normal $\parallel \hat{z}$
- Viewing direction $\parallel \hat{x}$
Main steps:

3. Given a local cloud, select candidate dictionary clouds

• Local cloud is transformed to the uniform pose

• Candidate selection criterion:
  – Minimal Root-Mean-Square Error (RMSE) between local and dictionary clouds

\[ RMSE = 1.97[m] \]
Viewpoint dictionary based registration

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• Local cloud is transformed to the uniform pose

• Candidate selection criterion:
  – Minimal Root-Mean-Square Error (RMSE) between local and dictionary clouds

\[ \text{RMSE} = 4.24 [m] \]
Viewpoint dictionary based registration

Main steps:

3. Given a local cloud, select candidate dictionary clouds

- Local cloud is transformed to the **uniform pose**

- Candidate selection criterion:
  - Minimal Root-Mean-Square Error (RMSE) between local and dictionary clouds

- A **GPS reading**, if available, can be used to restrict **search area**
4. Use ICP on candidates to refine registration

- Use of ICP allows sub-viewpoint-grid localization accuracy

- **Before ICP:**
  - $RMSE = 1.97[m]$
  - $Loc.\ error = 3.91[m]$
4. Use ICP on candidates to refine registration

- Use of ICP allows sub-viewpoint-grid localization accuracy

- **Before ICP:**
  - $RMSE = 1.97[m]$  
  - $Loc.\ error = 3.91[m]$  

- **After ICP:**
  - $RMSE = 1.22[m]$  
  - $Loc.\ error = 1.71[m]$
Main steps:

4. Use ICP on candidates to refine registration

- Use of ICP allows sub-viewpoint-grid localization accuracy
- Candidate with lowest RMSE after ICP

Final transformation (local to global)
Results – **stereo** local clouds

Keypoints Vs. viewpoint dictionary

- 7 stereo local clouds:
  - Noisy
  - Sparse
  - Sporadic scene coverage
Results — stereo local clouds

Keypoint-based registration

• Keypoint-based registration pipeline:
  – Keypoint detection: Surface variation (Pauly et al., 2002)
  – 3D descriptors: Spin-Images (Johnson, 1997)
  – Coarse registration: RANSAC
  – Registration refinement: ICP

• # local clouds where localization error < 3m: 0/7
  – Lowest loc. error was 25m
  – Difficulty to establish correct correspondences
Results – stereo local clouds

Viewpoint dictionary based registration

<table>
<thead>
<tr>
<th>Local cloud #</th>
<th>Localization error [m]</th>
<th>Yaw Error [deg]</th>
<th>Pitch Error [deg]</th>
<th>Roll Error [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.96</td>
<td>-6.35</td>
<td>-3.40</td>
<td>-6.00</td>
</tr>
<tr>
<td>2</td>
<td>74.94</td>
<td>135.83</td>
<td>-3.93</td>
<td>-2.75</td>
</tr>
<tr>
<td>3</td>
<td>2.41</td>
<td>4.18</td>
<td>-2.87</td>
<td>-2.85</td>
</tr>
<tr>
<td>4</td>
<td>0.48</td>
<td>0.94</td>
<td>1.90</td>
<td>-1.31</td>
</tr>
<tr>
<td>5</td>
<td>0.51</td>
<td>2.23</td>
<td>1.59</td>
<td>-3.29</td>
</tr>
<tr>
<td>6</td>
<td>1.16</td>
<td>3.13</td>
<td>0.45</td>
<td>-2.02</td>
</tr>
<tr>
<td>7</td>
<td>12.10</td>
<td>51.65</td>
<td>-0.19</td>
<td>3.87</td>
</tr>
</tbody>
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• # local clouds where localization error < 3m: 5/7

• Using keypoints: 0/7 (lowest loc. error was 25m)
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Conclusion

• Proposed novel point cloud registration framework:
  – Large-scale global cloud  →  Dictionary of viewpoint-based smaller clouds
  – Local to global cloud registration  →  Dictionary search

• Demonstrated advantages over using keypoints
  – Can handle substantially different characteristics of the global and local clouds (LiDAR vs. stereo)

• Future work:
  – Dedicated viewpoint descriptors
    ▪ Compact dictionary storage
    ▪ Efficient dictionary search
Acknowledgments

• Collaboration:
  – CEVA
  – Elbit Systems Land and C4I

• Point cloud data:
  – Elbit Systems Land and C4I

Thank You!