SIPL SIGNAL & IMAGE PROCESSING LAB
Department of Electrical Engineering, Technion

Omek Consortium

Technion - IIT

Point Cloud Registration Using A Viewpoint Dictionary

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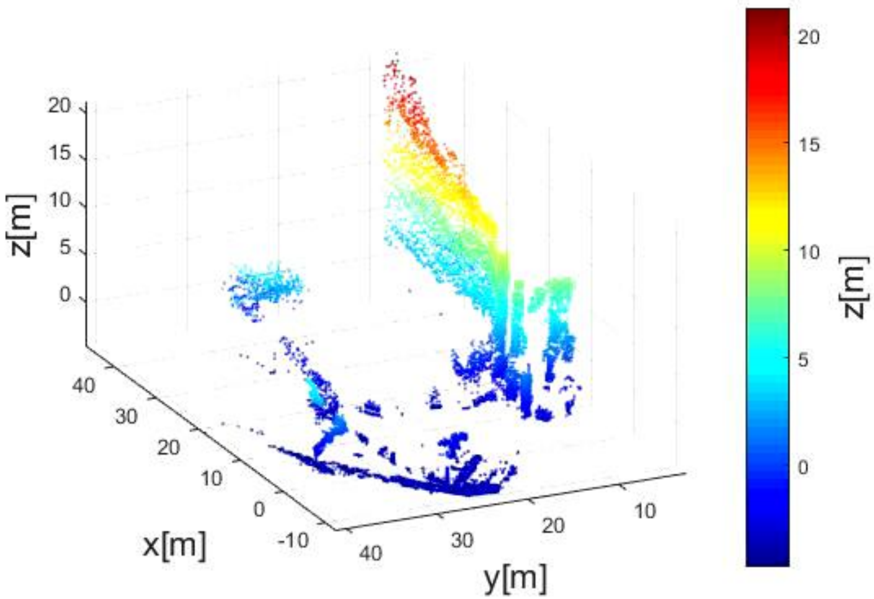
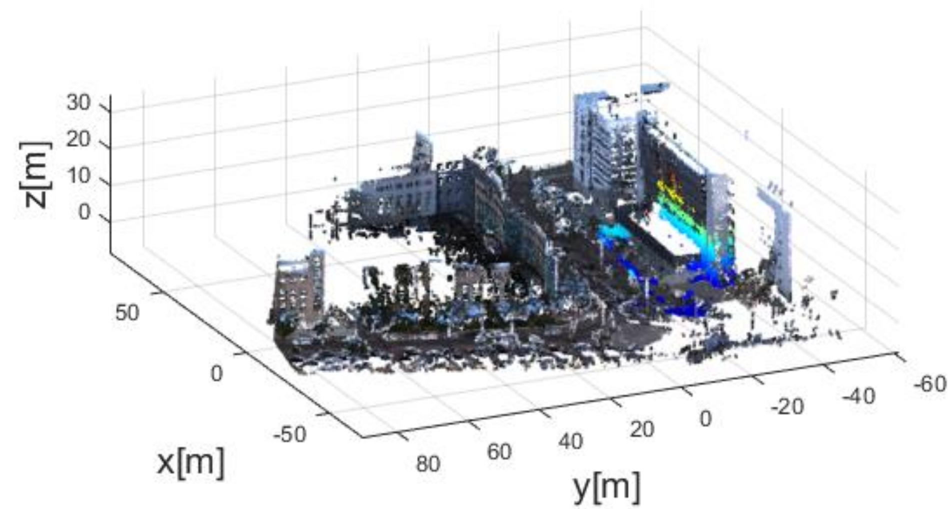
Goal

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



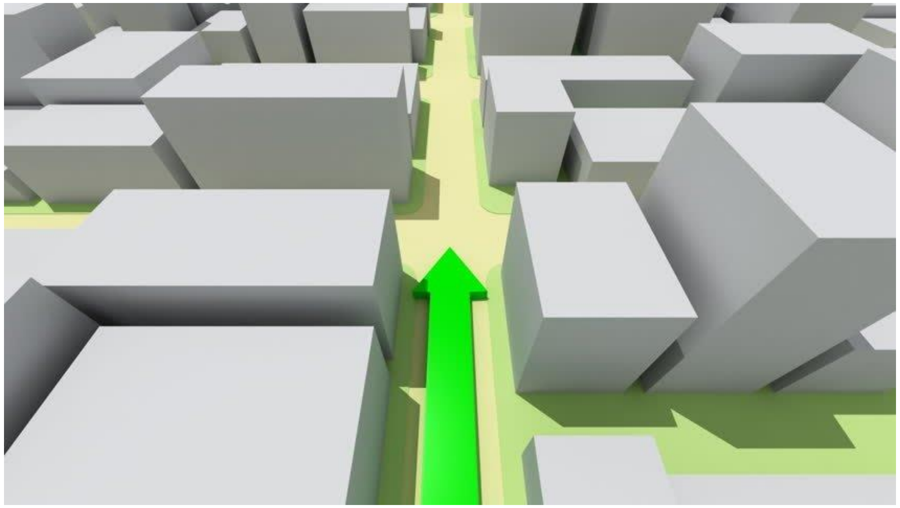


Local cloud
(stereo reconstruction)
sporadic coverage, limited field-of-view

(terrestrial LiDAR)
dense coverage, multiple viewpoints

Motivation

- Applications:
  - Accurate localization in large-scale environments (with better reliability than consumer-grade GPS)

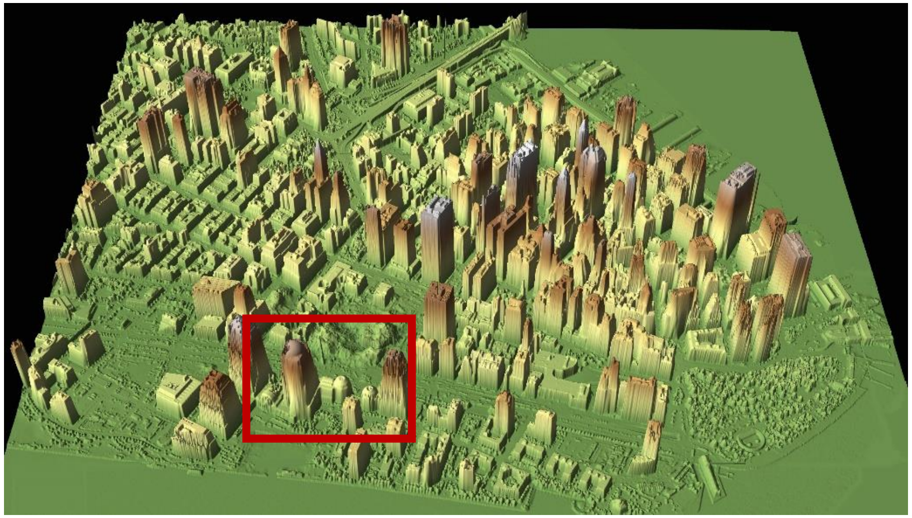


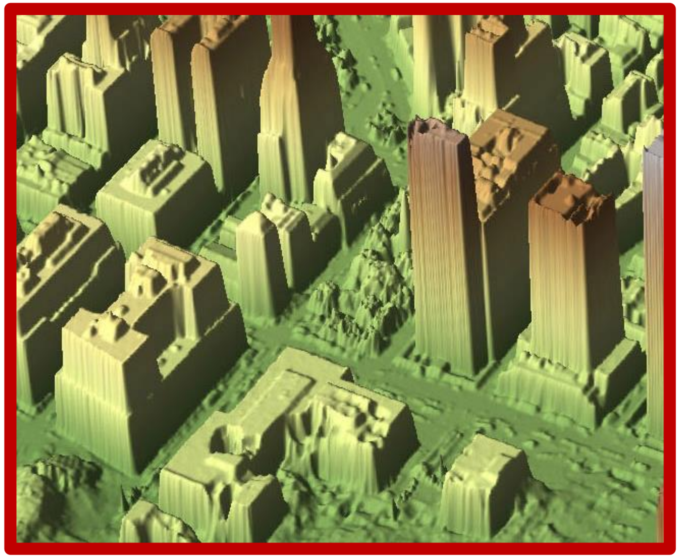
Images: navigation.com, shutterstock.com

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.

Airborne LiDAR





Images: U.S. National Oceanic and Atmospheric Administration

Motivation

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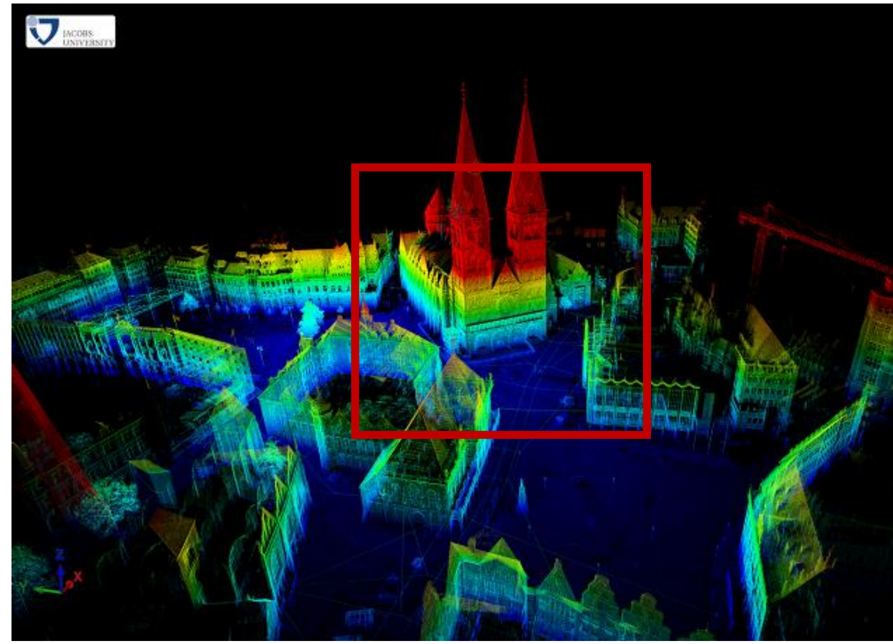
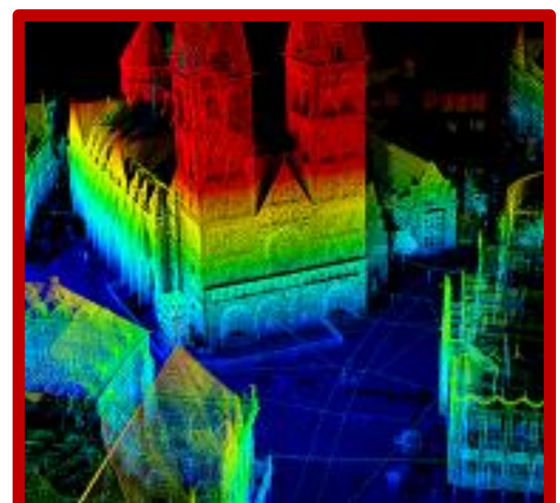
Terrestrial LiDAR





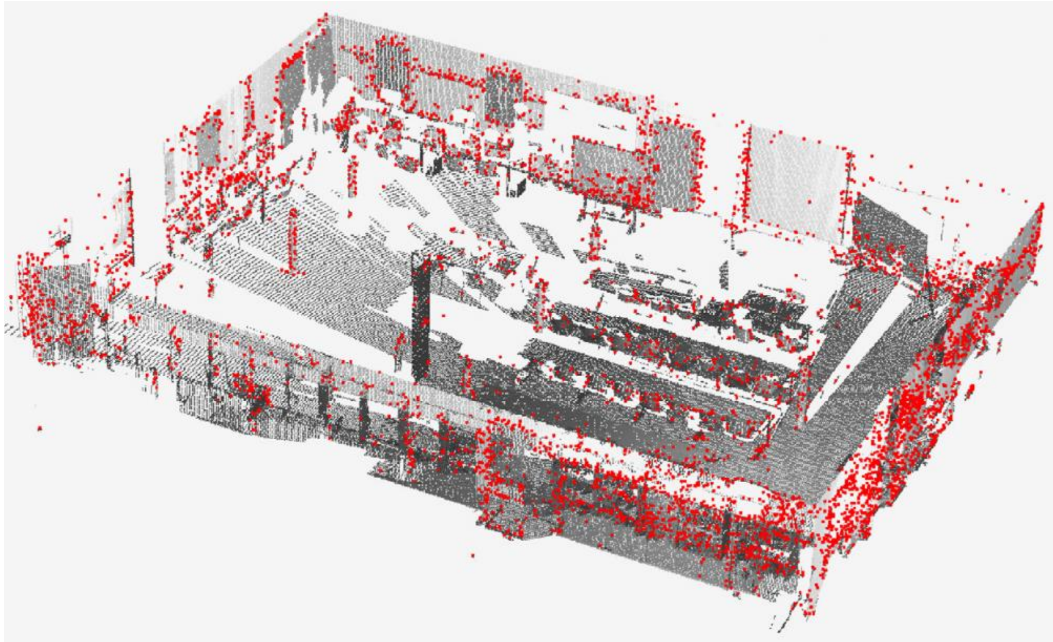
Images: Robotic 3D Scan Repository

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
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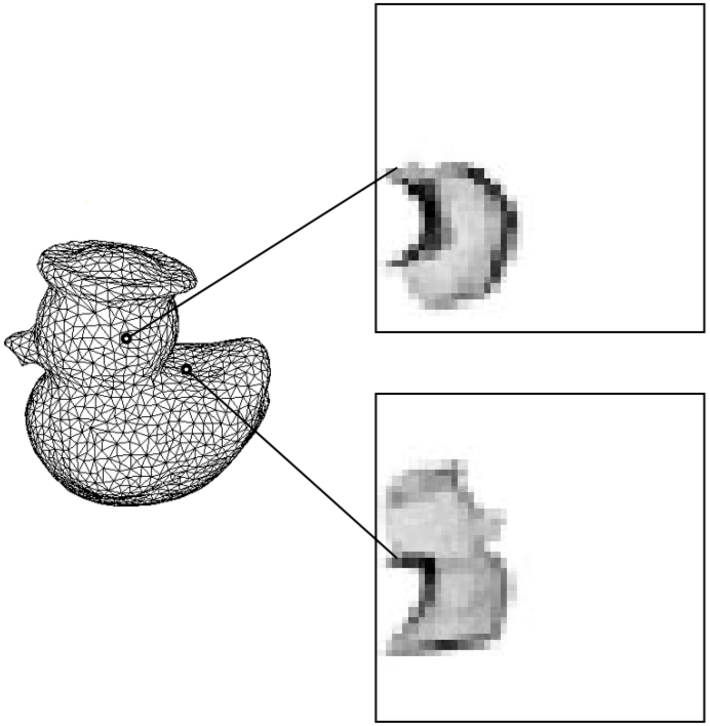
     - 3D SIFT (Rusu et al., 2011)
  2. 3D Descriptor computation
     - Spin-Images (Johnson, 1997)
     - Fast Point Feature Histogram - FPFH (Rusu et al., 2009)



Spin-Images (Johnson, 1997)

Keypoint-based point cloud registration

- Main steps:
  1. Keypoint detection
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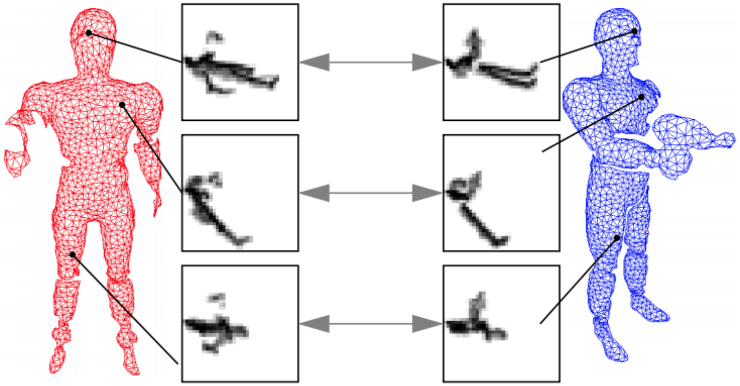
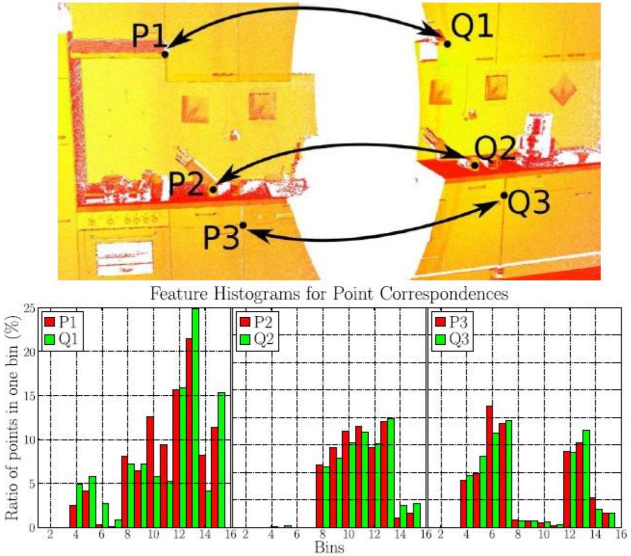
  3. Finding keypoint correspondences



Johnson, 1997



Rusu et al., 2009

Keypoint-based point cloud registration

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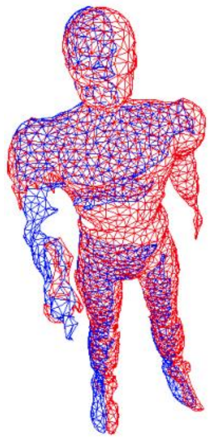
  4. Coarse registration (e.g., using some variation of RANdom SAmple Consensus - RANSAC)



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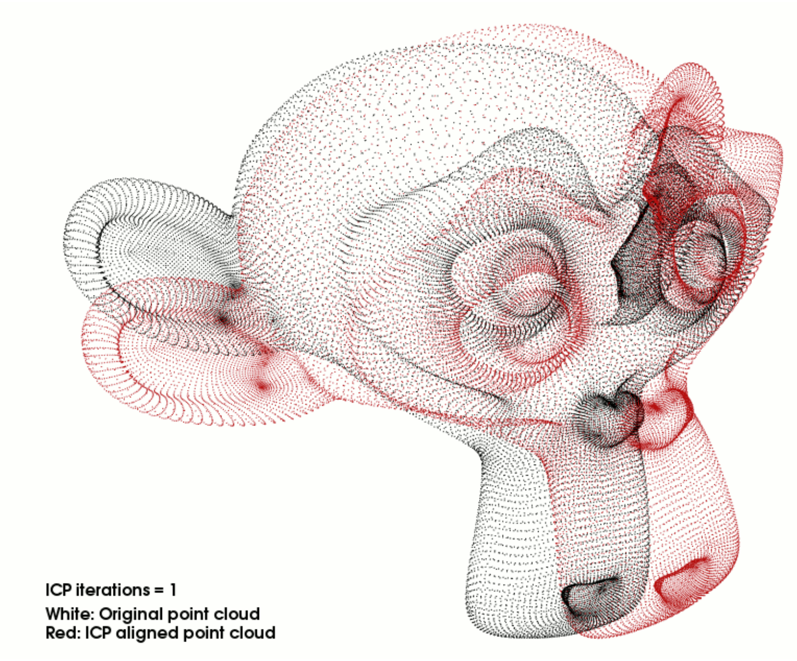
  5. Registration refinement - some variation of ICP - Iterative Closest Point (Besl and McKay, 1992)

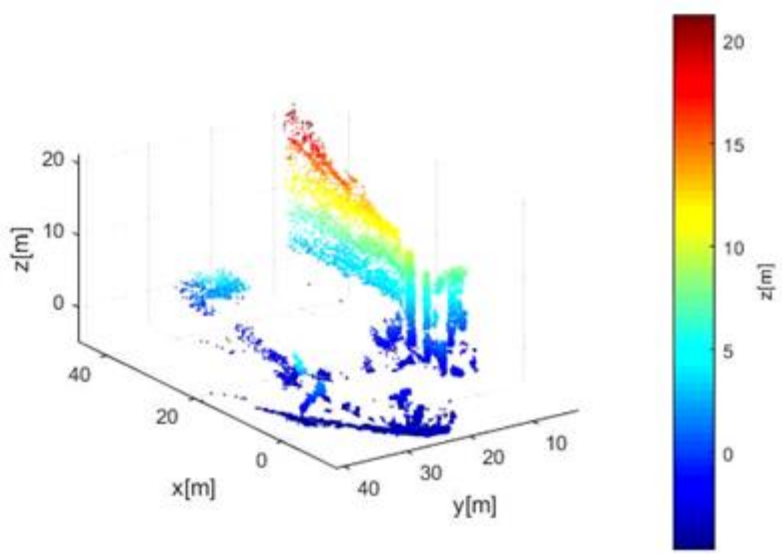


Source: pointclouds.org

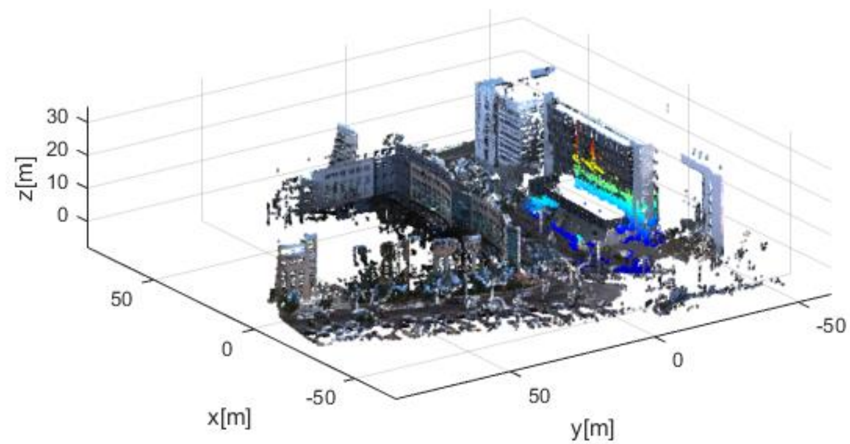
Limitations of using keypoints

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

	Stereo (data)	LiDAR/SfM (model)
Scene coverage	sporadic	full
Noise level	high	low
Density	low	high



Stereo (local cloud)



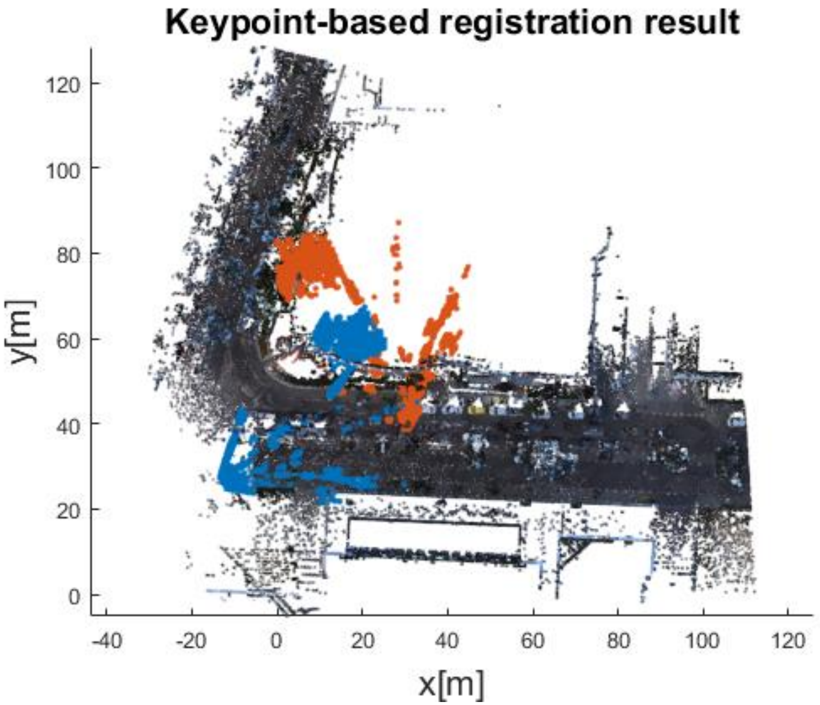
LiDAR (global cloud)

Limitations of using keypoints

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

	Stereo (data)	LiDAR/SfM (model)
Scene coverage	sporadic	full
Noise level	high	low
Density	low	high

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



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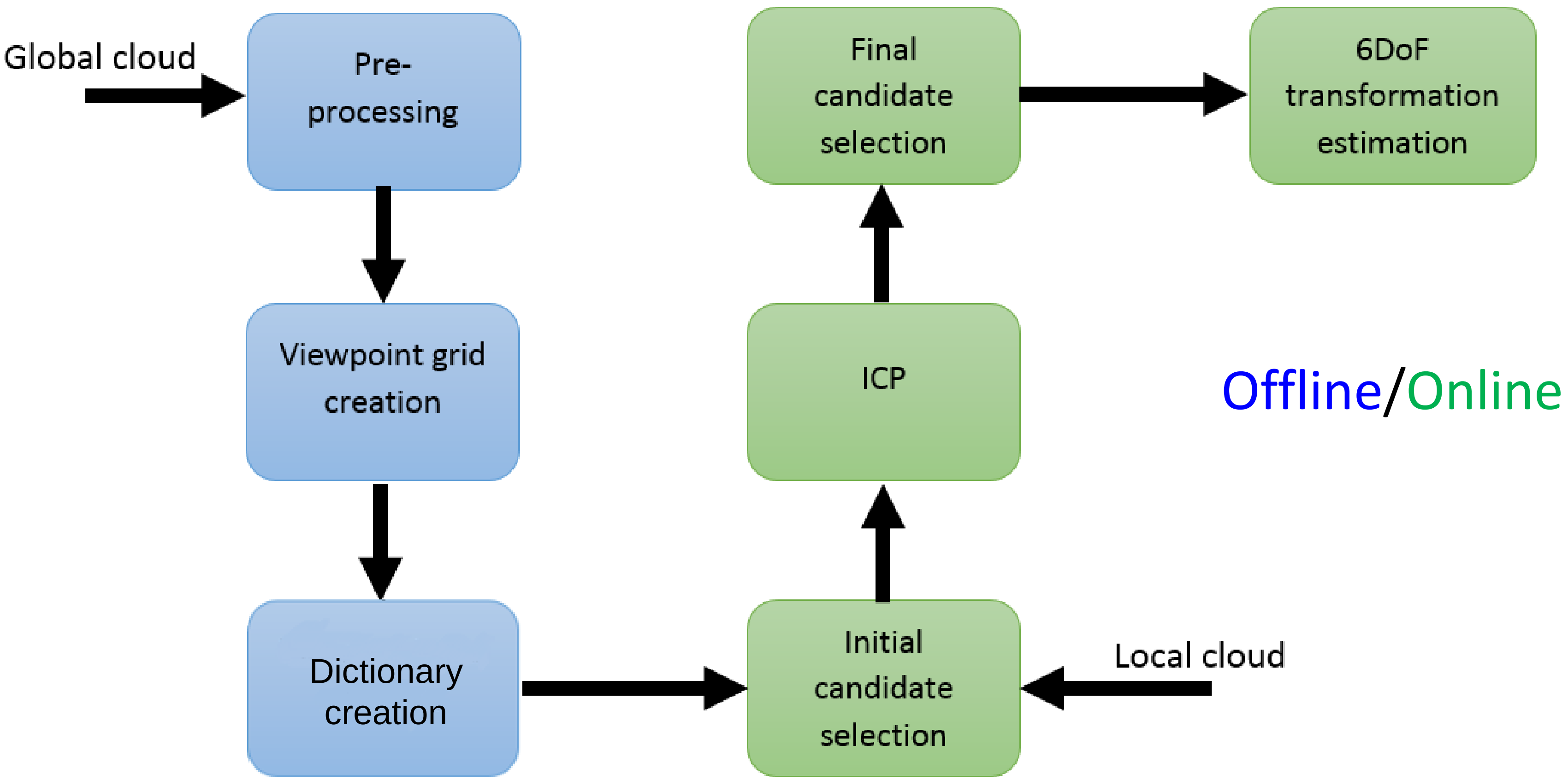
Proposed method: Point cloud registration using a viewpoint dictionary

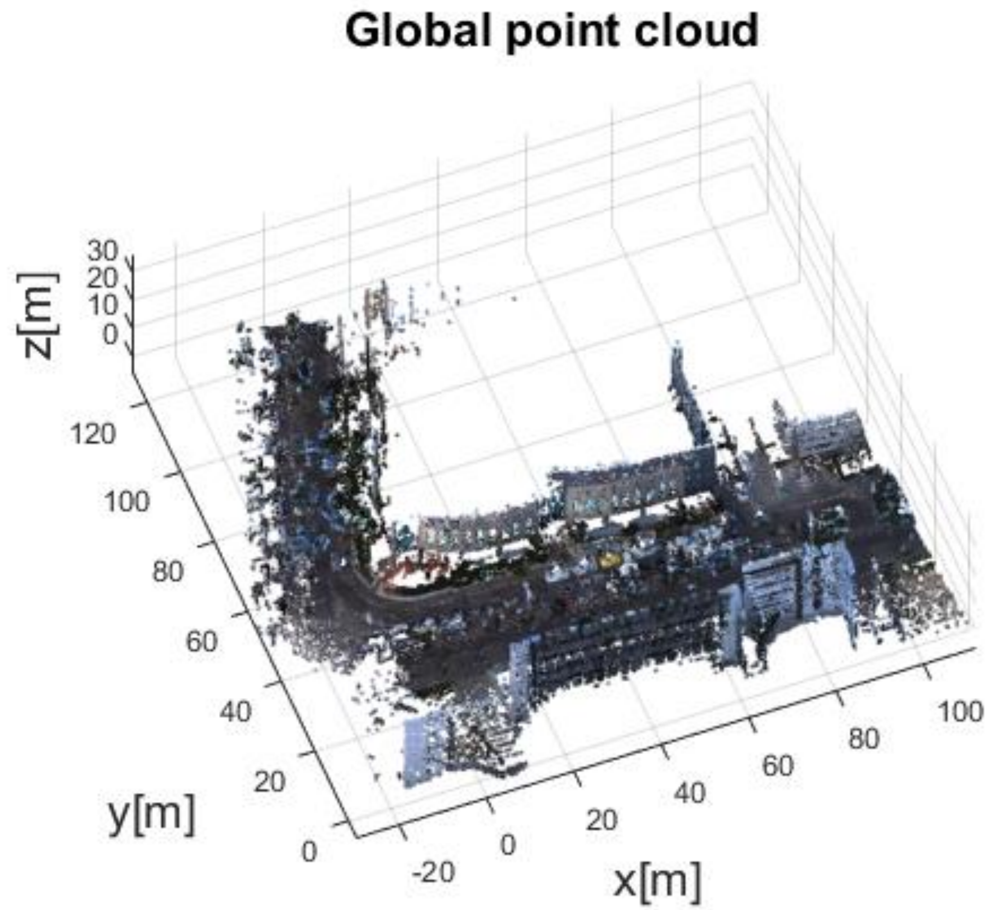
- Main concepts:
  - Large-scale global cloud → **Dictionary of viewpoint-based smaller clouds**
  - Local to global cloud registration → **Dictionary search**
- Advantages:
  - Robust to point cloud noise
  - Can handle sporadic local clouds (e.g., stereo)
- Challenges:
  - Keep the dictionary compact
  - Perform dictionary search efficiently

Point cloud registration using a viewpoint dictionary - overview



Main steps:

1. Create a grid of synthetic viewpoints



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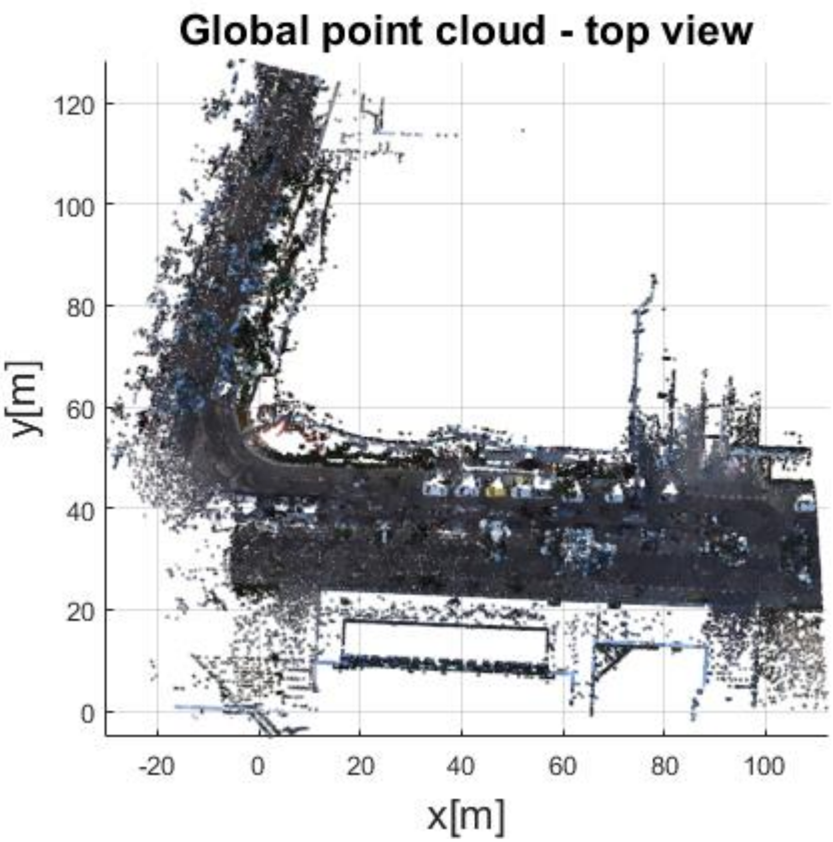
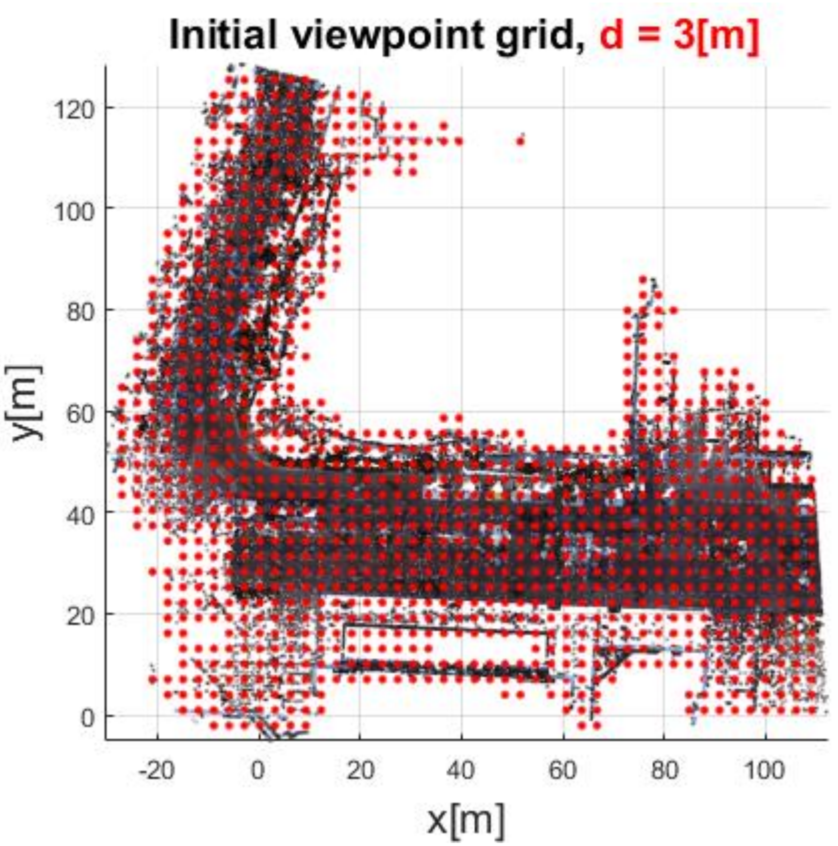


Main steps:

1. Create a grid of synthetic viewpoints

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



Main steps:

1. Create a grid of synthetic viewpoints

- Initial grid is regular in the x, y plane
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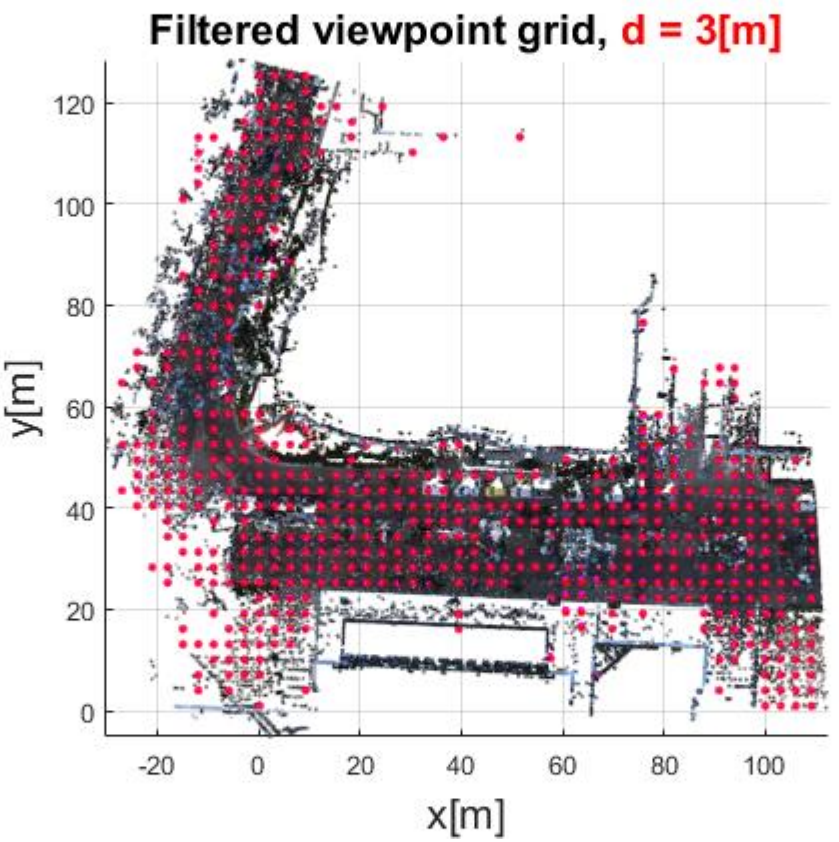
- Possible viewpoint restrictions:
  - Avoid viewpoints on rooftops
  - Filter out viewpoints in vegetation



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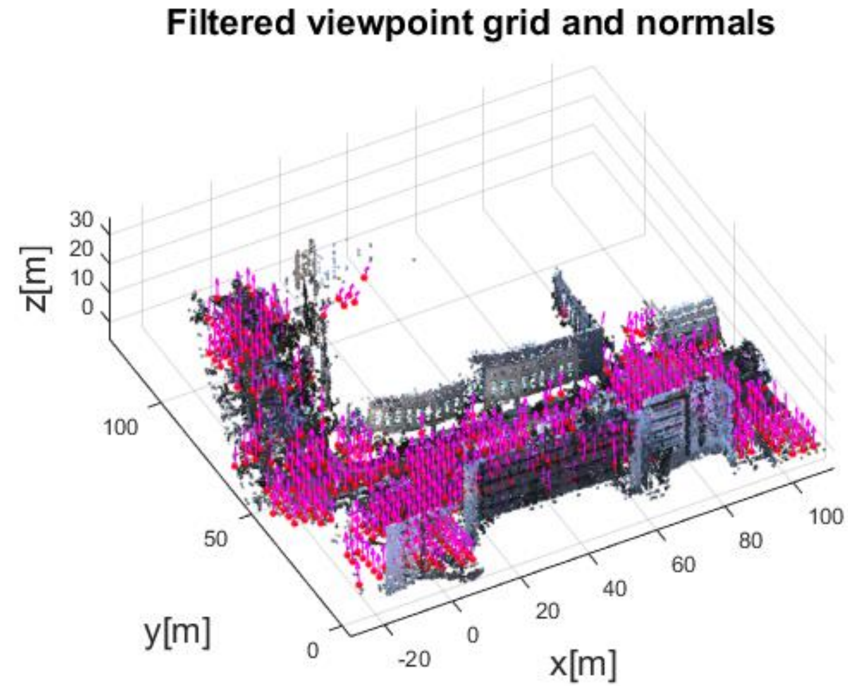
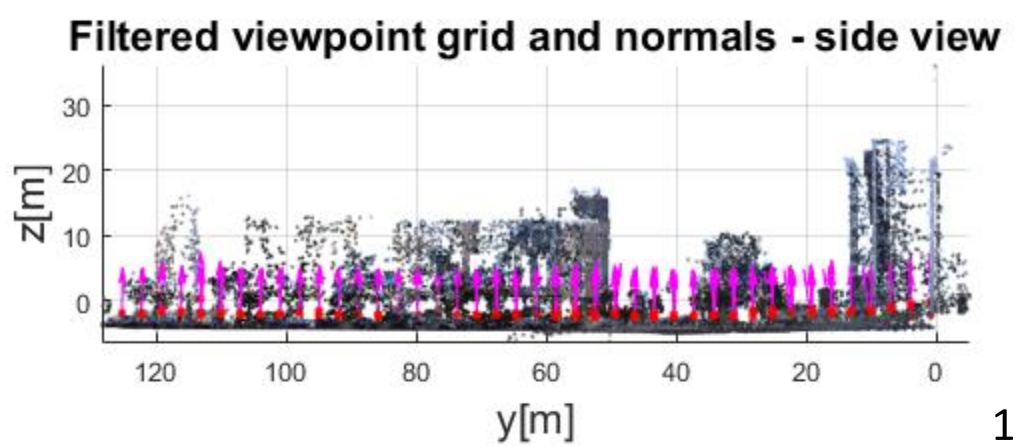
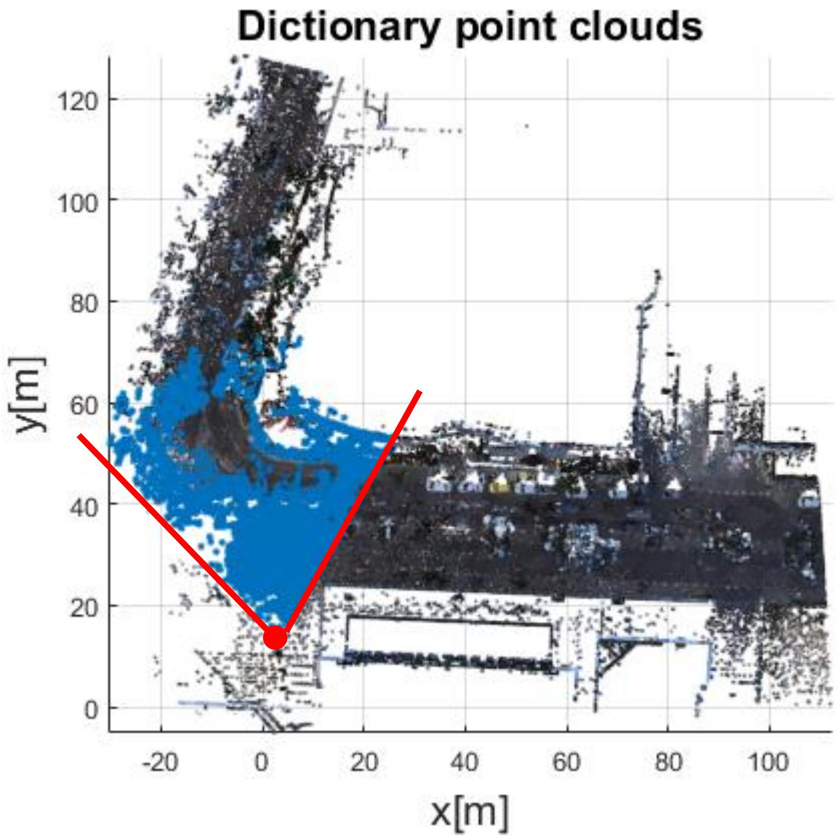




Main steps:

2. Create dictionary clouds for each viewpoint

- Divide area around each viewpoint into overlapping “slices”



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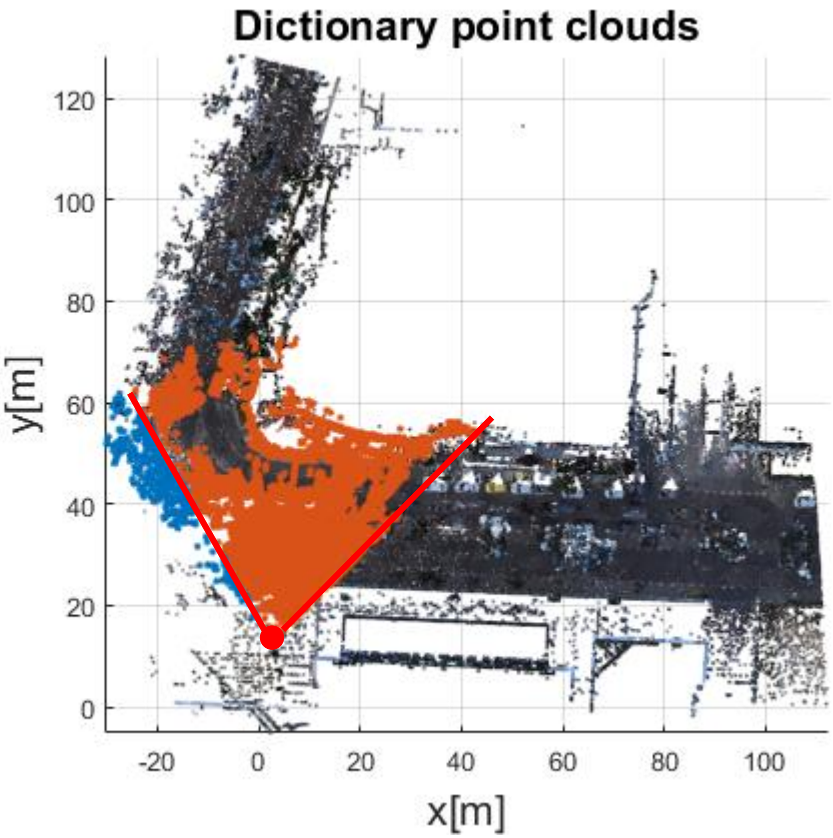

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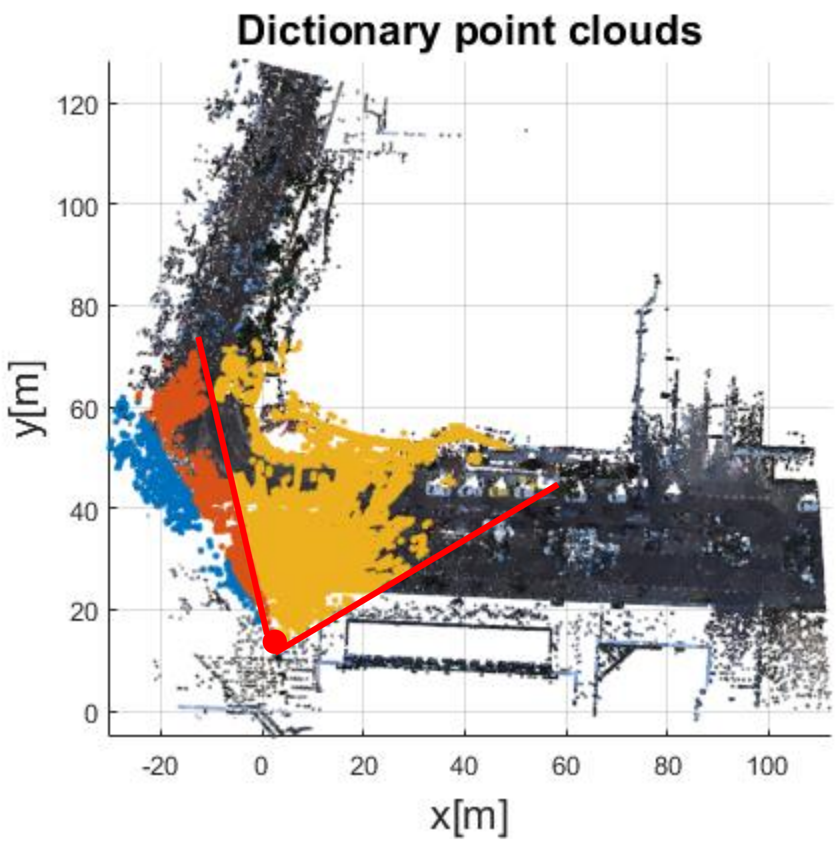

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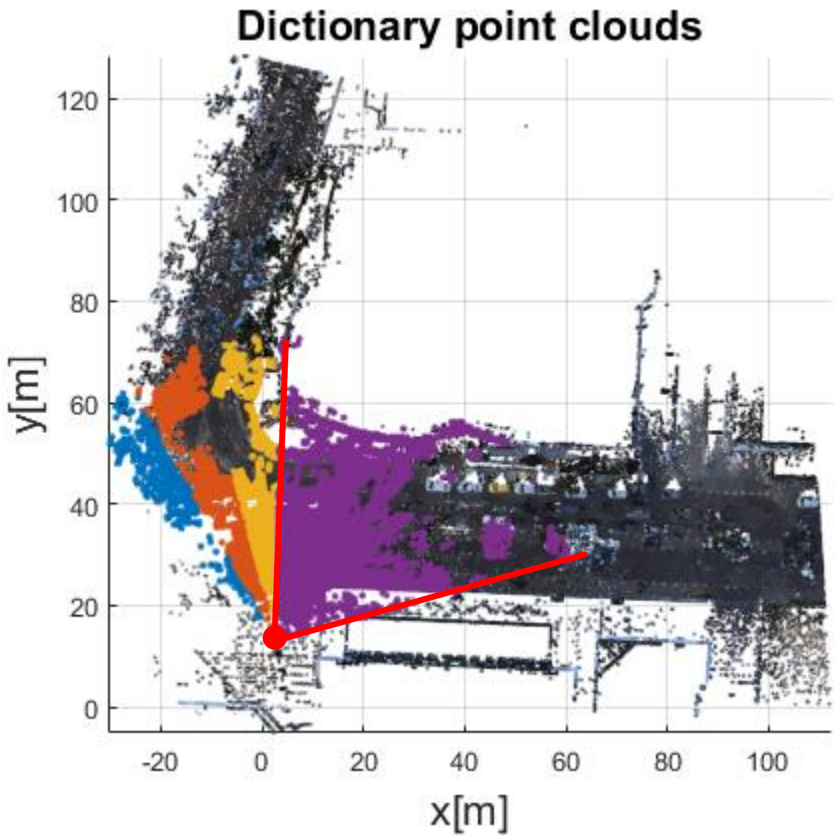
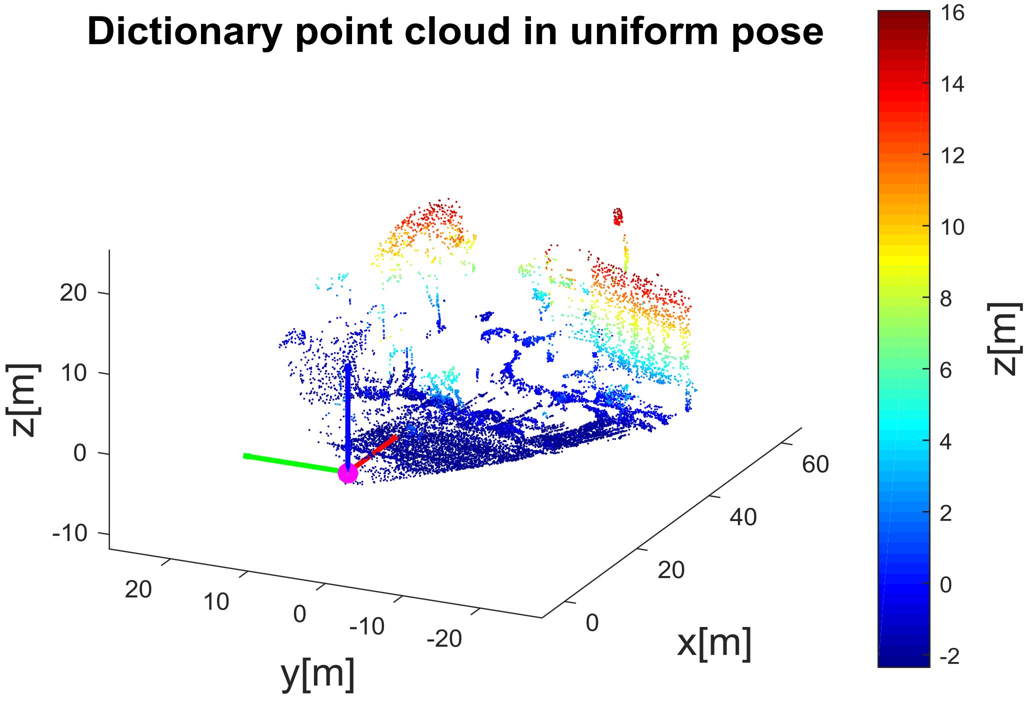


Main steps:

2. Create dictionary clouds for each viewpoint

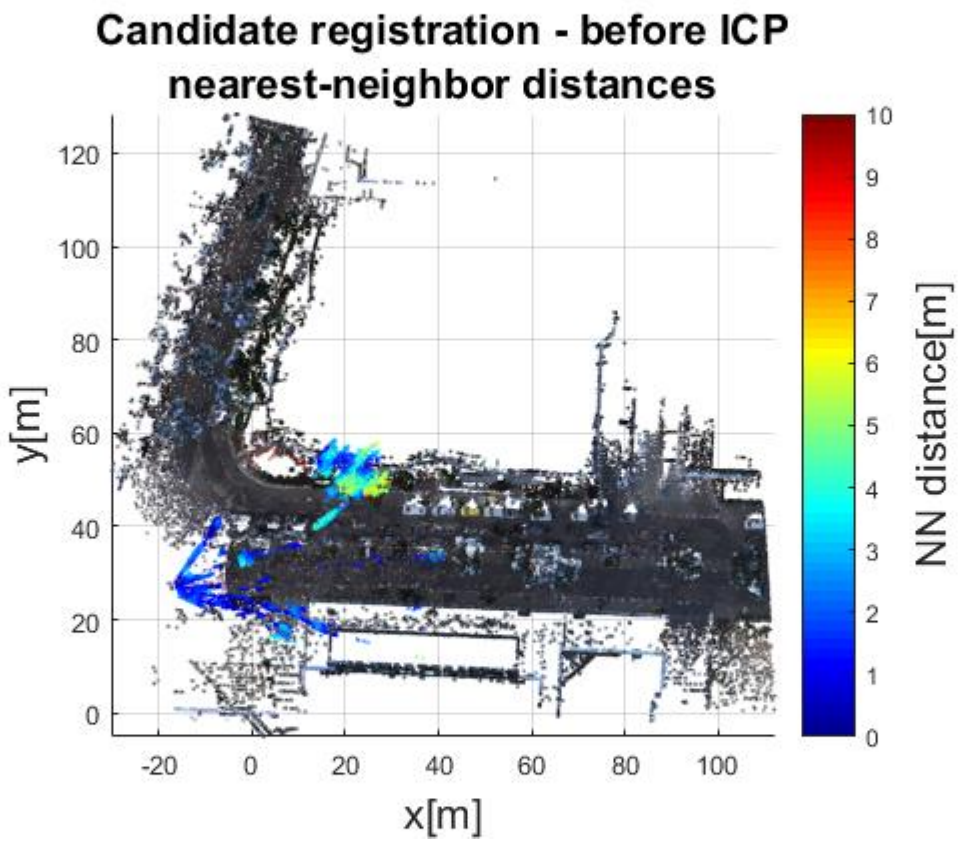
- Divide area around each viewpoint into overlapping "slices"
- Each "slice" (dictionary cloud) is aligned to a **uniform pose** such that:
  - Viewpoint at origin
  - Viewpoint normal || $\vec{z}$
  - Viewing direction || $\vec{x}$



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



$RMSE = 1.97[m]$

Main steps:

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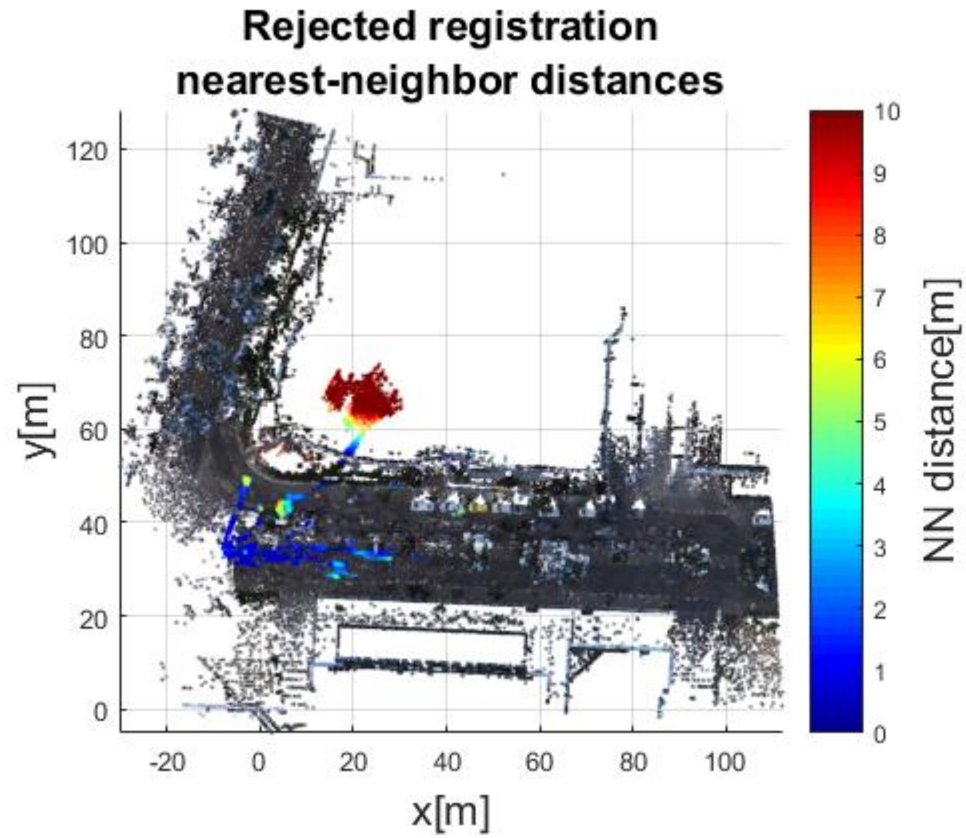

$$RMSE = 4.24[m]$$

Main steps:

3. Given a local cloud, select candidate dictionary clouds

- Local cloud is transformed to the **uniform pose**
- Candidate selection criterion:
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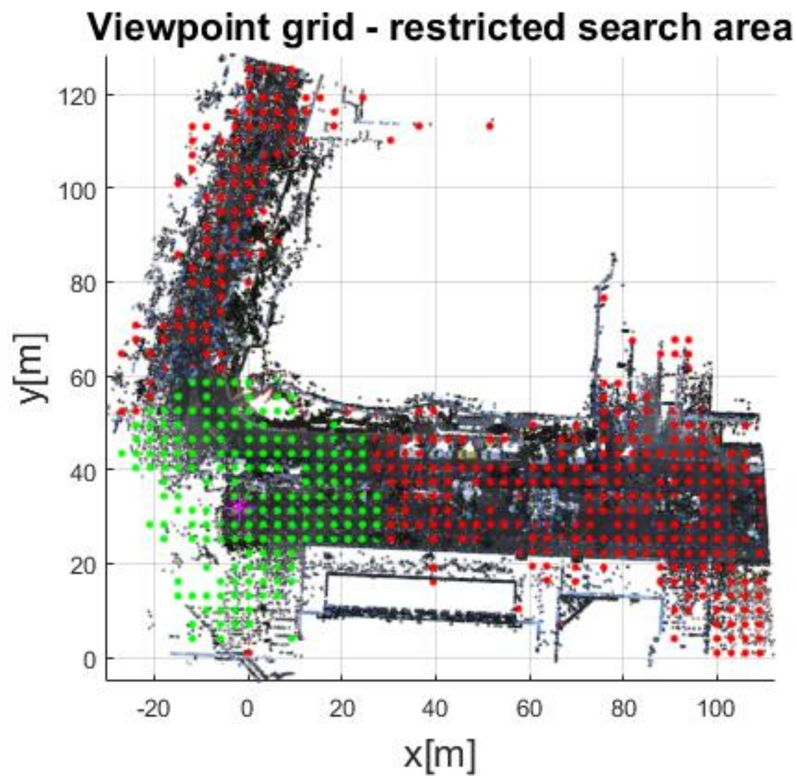
- A GPS reading, if available, can be used to restrict search area

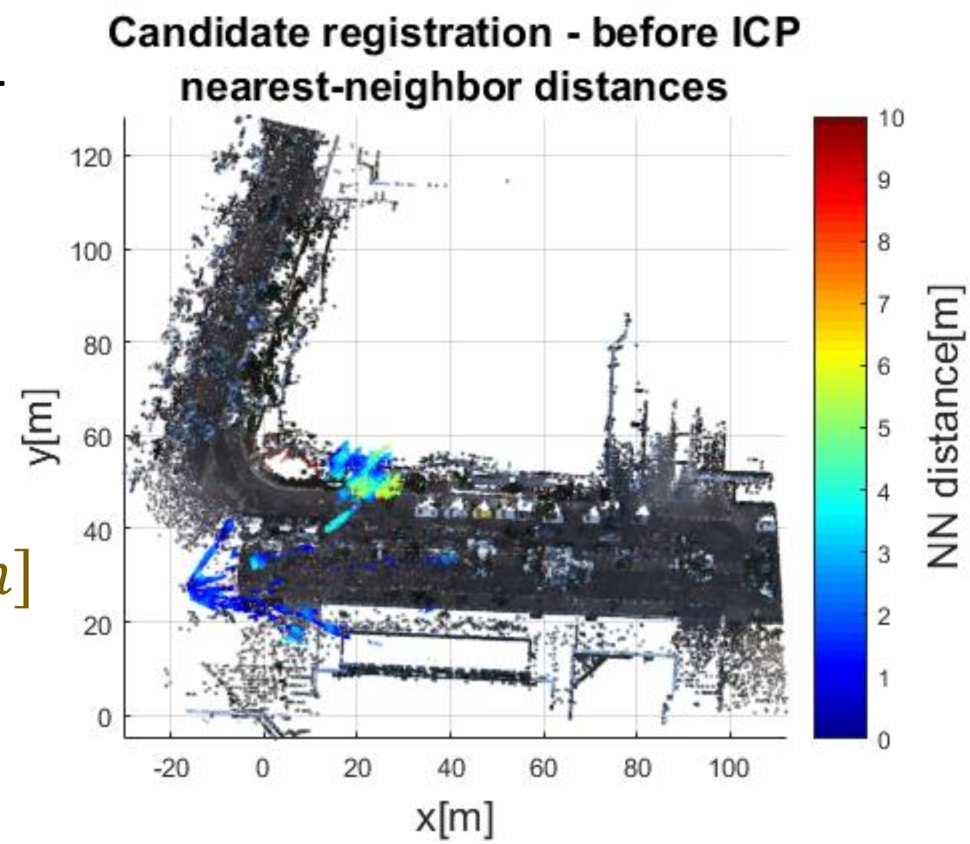


Main steps:

4. Use ICP on candidates to refine registration

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

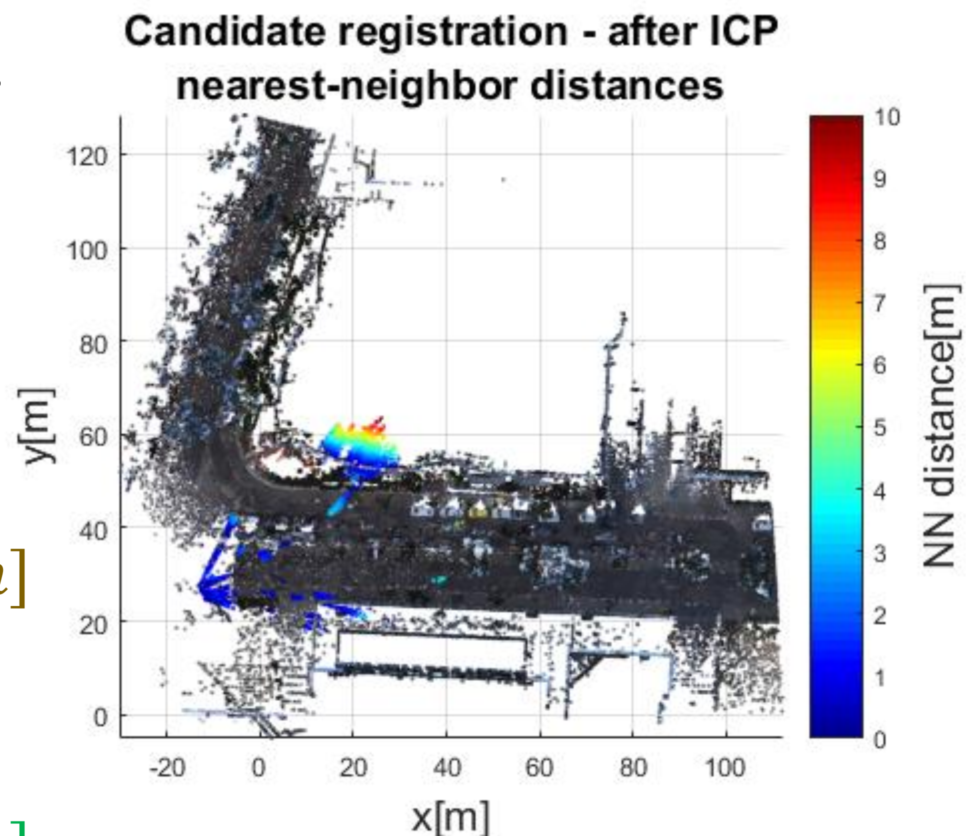
- Before ICP:
  - $RMSE = 1.97[m]$
  - $Loc. error = 3.91[m]$



Main steps:

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:

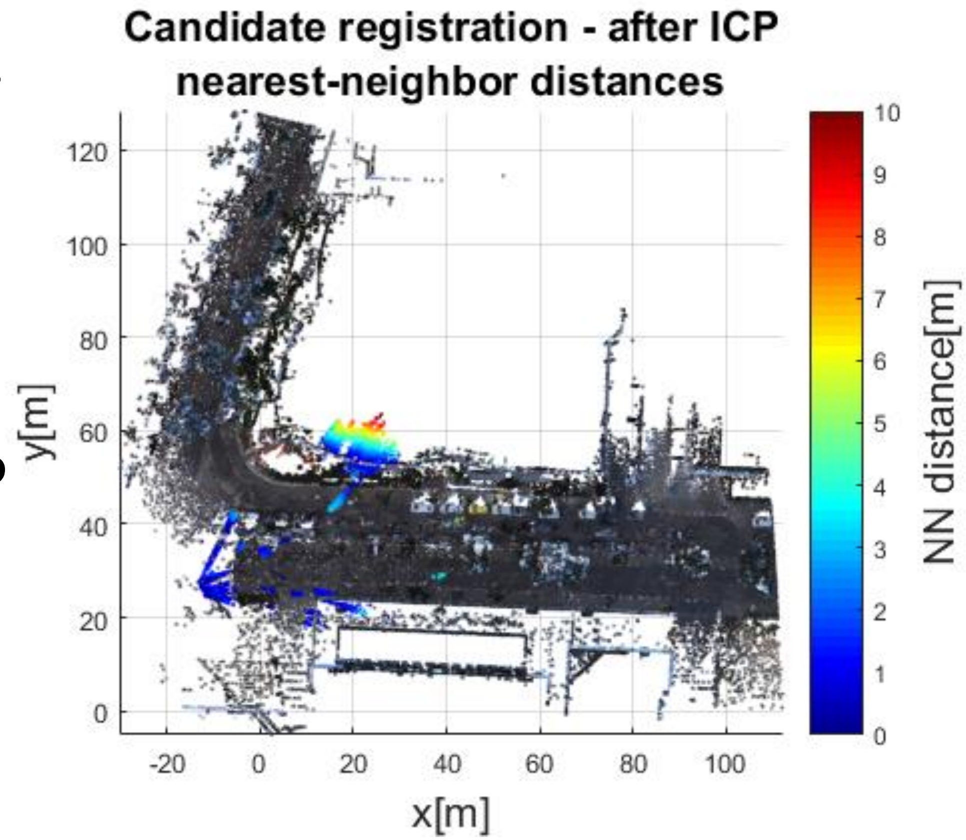
4. Use ICP on candidates to refine registration

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

- Candidate with lowest RMSE after ICP

↓

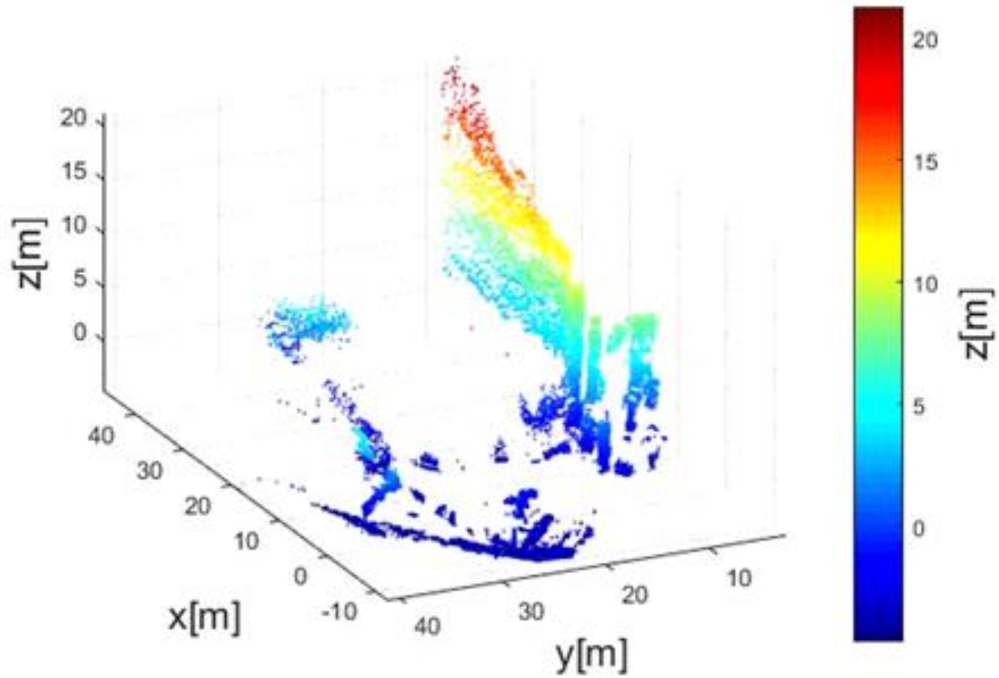
Final transformation (local to global)



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

Local cloud #	Localization error [m]	Yaw Error [deg]	Pitch Error [deg]	Roll Error [deg]
1	**2.96**	-6.35	-3.40	-6.00
2	74.94	135.83	-3.93	-2.75
3	**2.41**	4.18	-2.87	-2.85
4	**0.48**	0.94	1.90	-1.31
5	**0.51**	2.23	1.59	-3.29
6	**1.16**	3.13	0.45	-2.02
7	12.10	51.65	-0.19	3.87

- # 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

Technion - IIT

Omek Consortium

- Collaboration:
  - CEVA
  - Elbit Systems Land and C4I
- Point cloud data:
  - Elbit Systems Land and C4I

Thank You!