Analysis of the ICP Algorithm

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3D Scanning and Motion Capture Project Group 3

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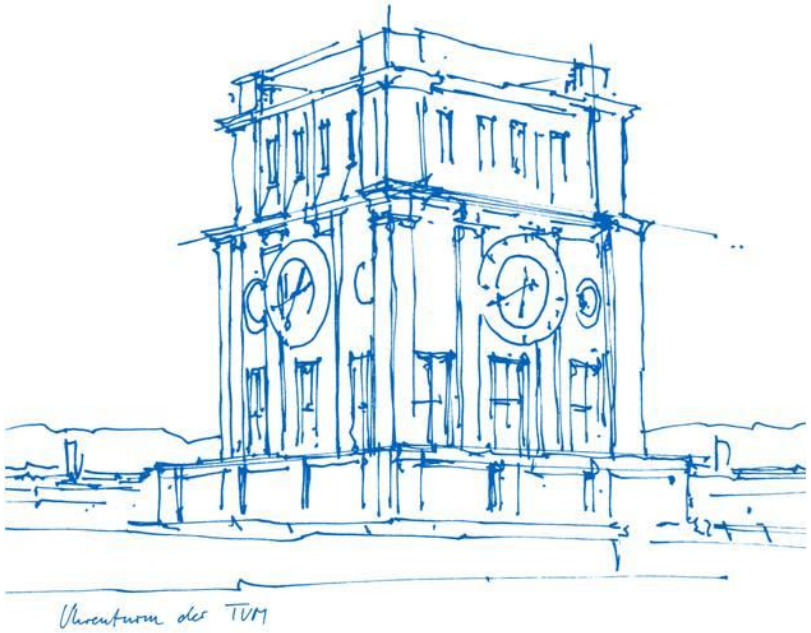
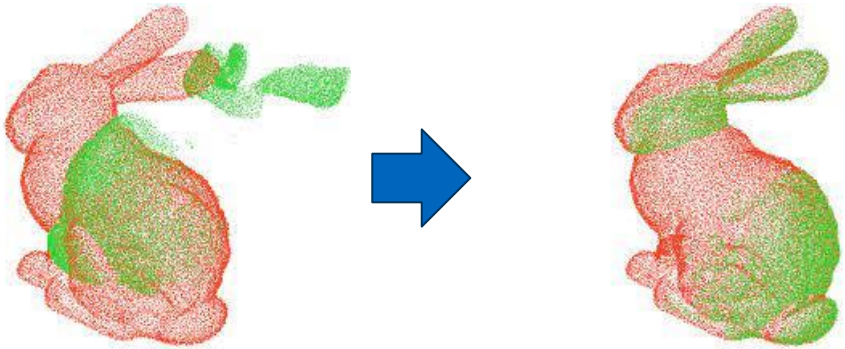


* The code is publicly available at:
https://github.com/PetropoulakisPanagiotis/ICP-Variants

* Additional experimental results can be found at:
https://drive.google.com/drive/folders/1zuWo1pvJ8PEGwiw_NTybL6bSAui2OWdO

Introduction & Motivation

- Many applications require 3D registration of point clouds
  - 3D reconstruction, autonomous driving, etc

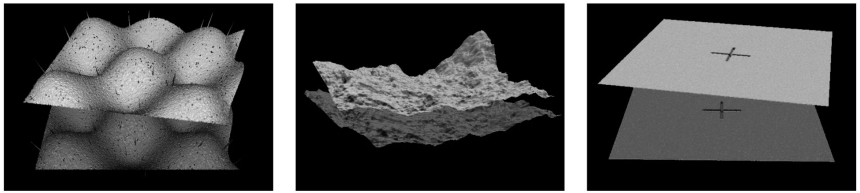


[Yang et.al]

- Many ICP variants have been developed to align 3D data
- People care about their **convergence** and **speed**
- We did a comprehensive analysis on various ICP variants

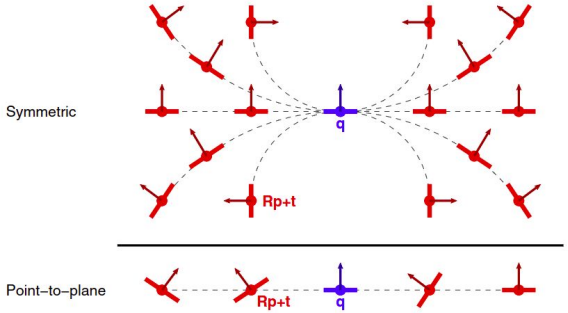
Related Works

- Rusinkiewicz & Levoy 2001
  - In-depth comparison of ICP Variants
  - Root Mean square alignment error on 3 scenes

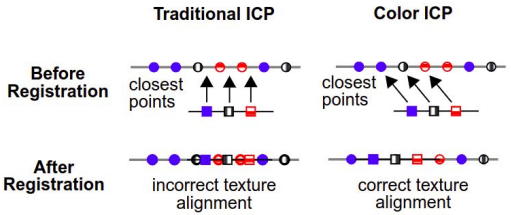


(a) Wave (b) Fractal landscape (c) Incised plane

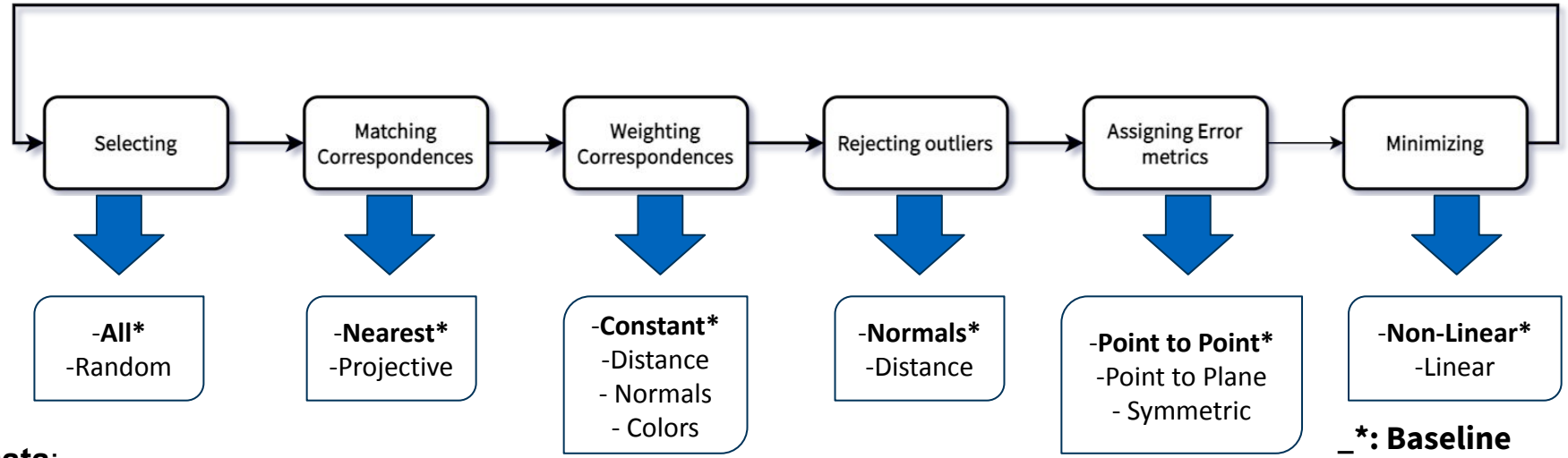
- Symmetric ICP [Rusinkiewicz 19]
  - Symmetric error metric



- Color ICP [Johnson 97]
  - Registration on 3D texture data



Methodology



Data:

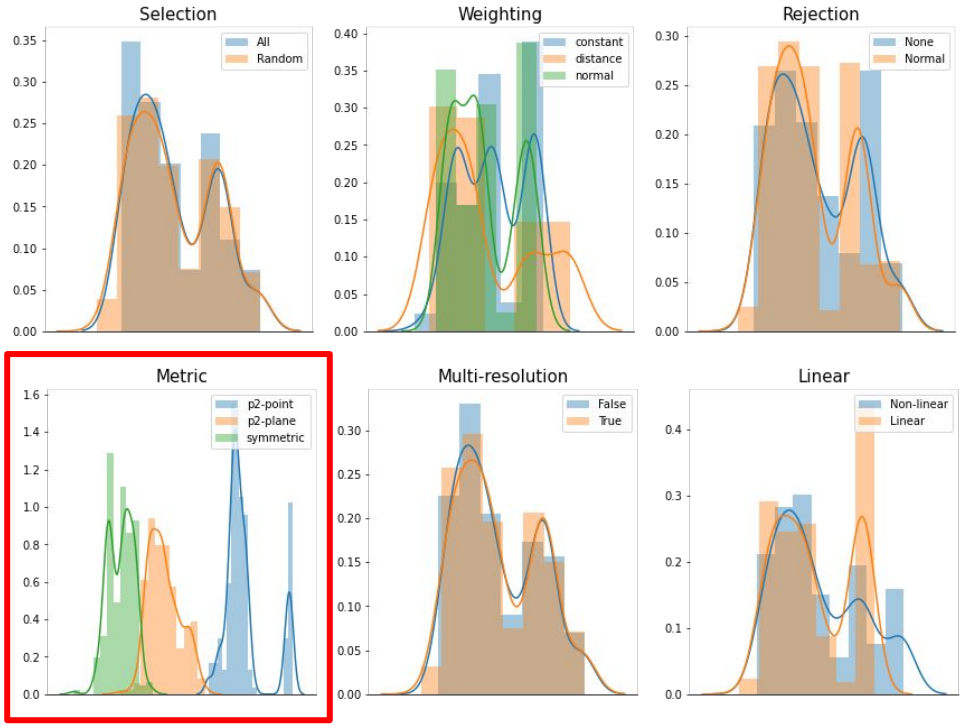
- Stanford Bunny
- RGB-D SLAM (freiburg1_xyz) [Sturm et.al. 2012]
- Benchmark point cloud registration [Fontana 2021]: various scenes

Convergence measure:

- RMSE
- Weighted average of Euclidean distances [Fontana 2021]

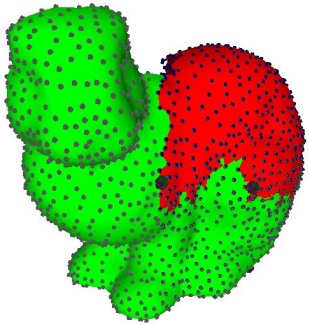
Analysis on bunny with multiple variants

RMSE for different variants

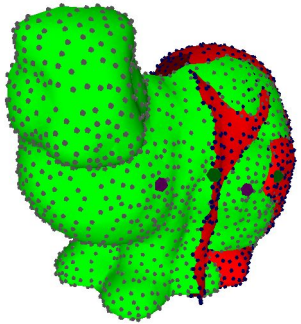


n = 5 trials
144 different variant configurations

Best result

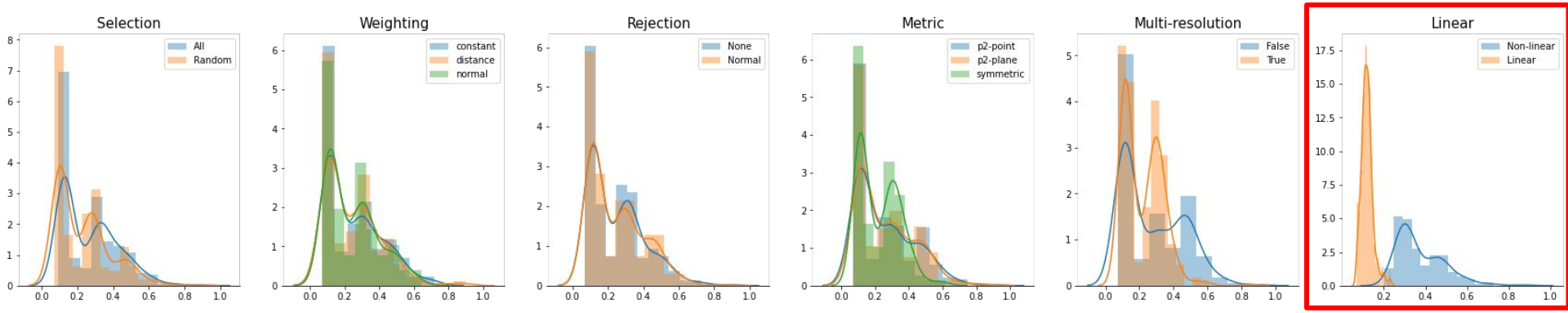


Worst result

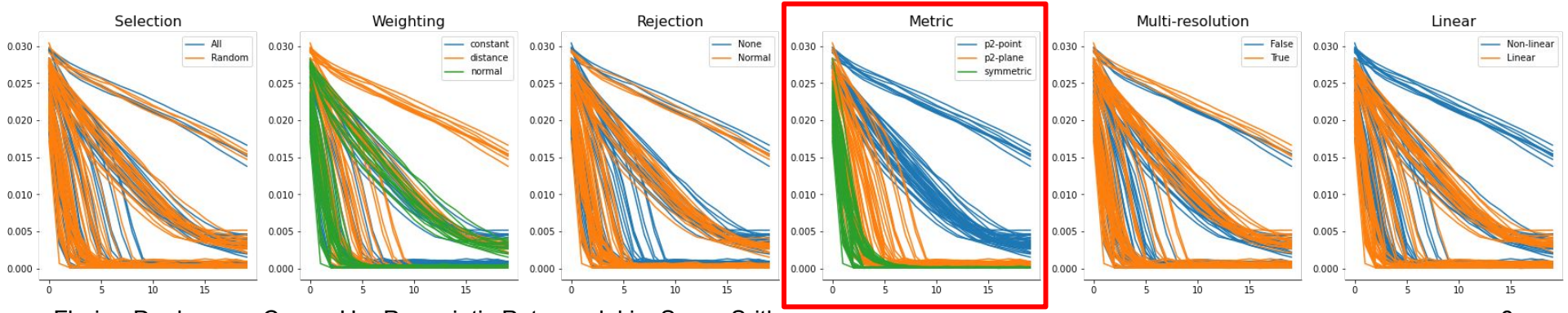


Analysis of convergence rate

Time for 20 iterations with different variants



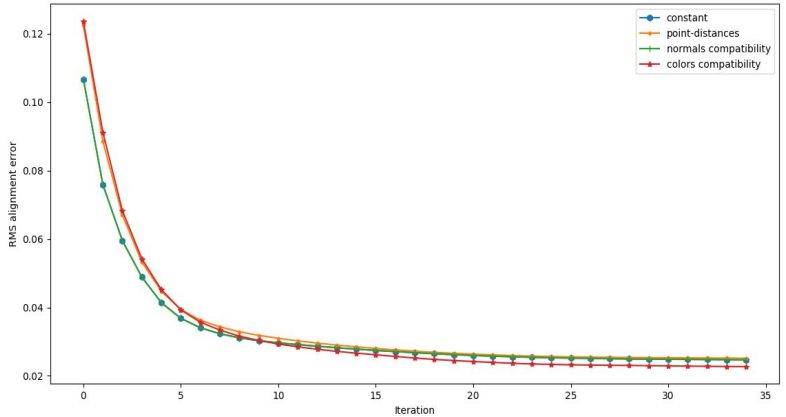
RMSE variation for 20 iterations

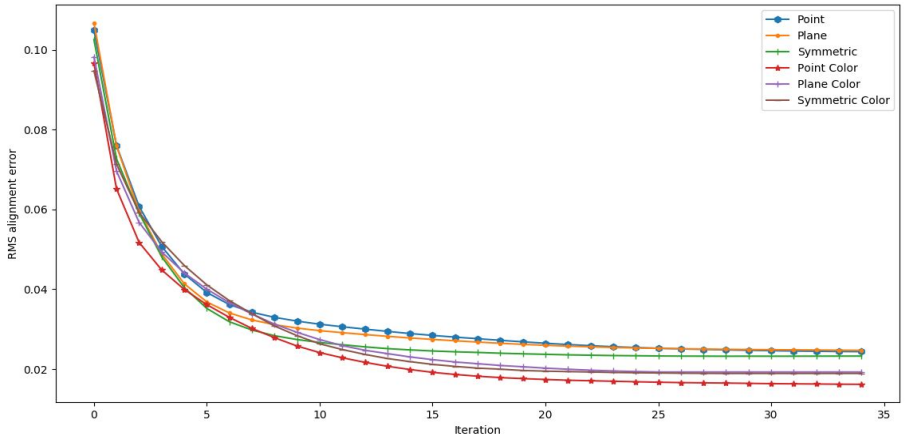


Color and Projective variants

Tested on freiburg1_xyz TUM RGB-D dataset

Color ICP Point-To-Point visualisation

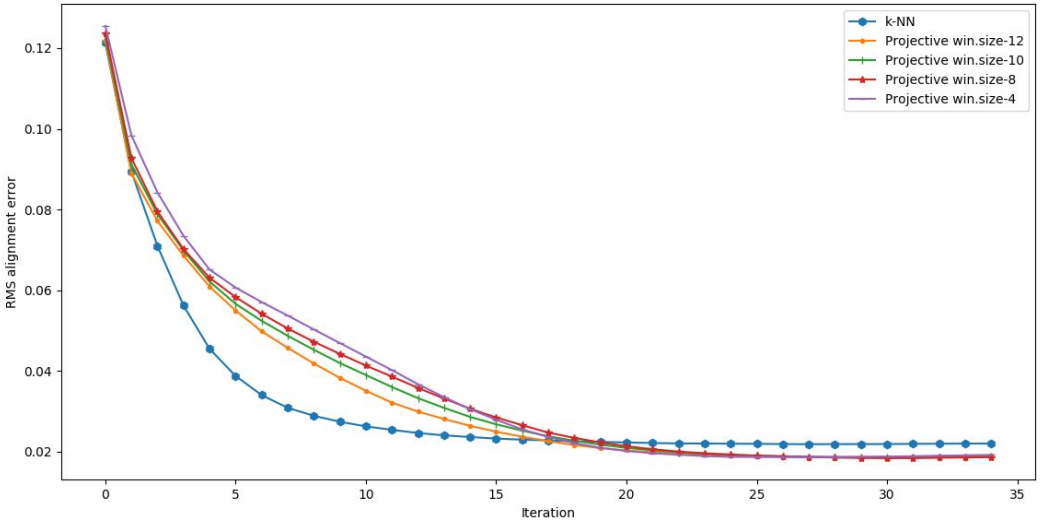




Color ICP (6-dim k-NN search) improves all metrics

- Colors compatibility (weighting step) achieves the lowest error
- Though, x1.76 slower than normals compatibility

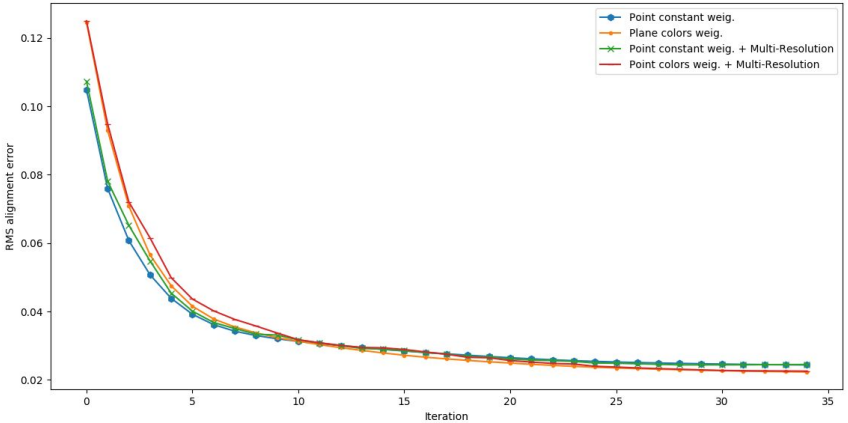
Color and Projective variants

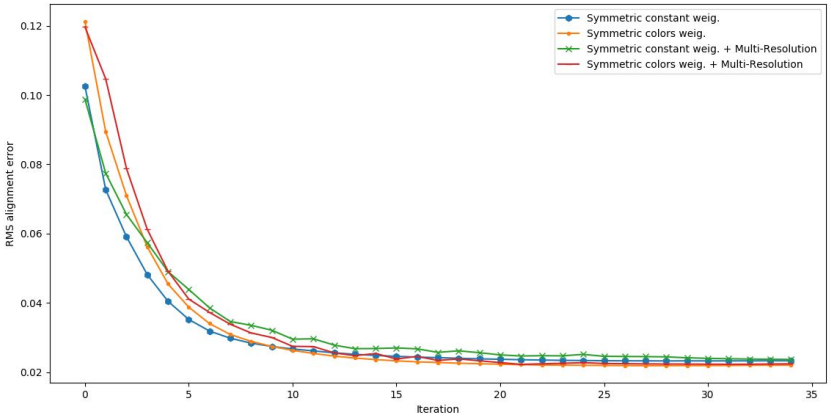


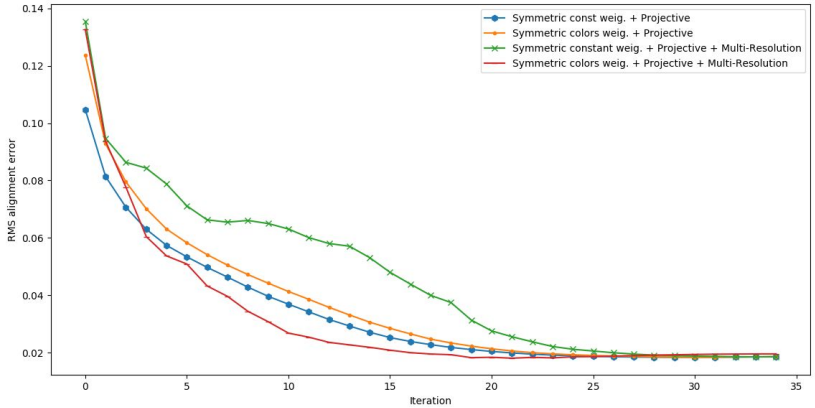
Projective (win.size 8) with Symmetric-ICP visualization

- Projective Search struggles at the beginning but outperforms k-NN in the end
- Projective (win.size 8) is x3.82 slower than k-NN

Multi-Resolution along with Color and Projective variants

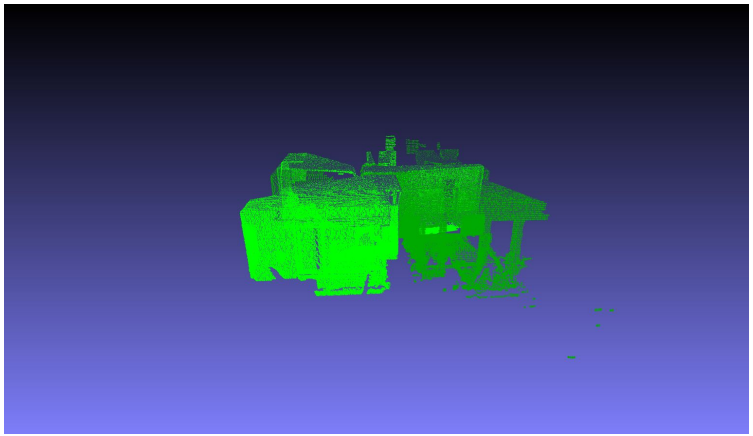






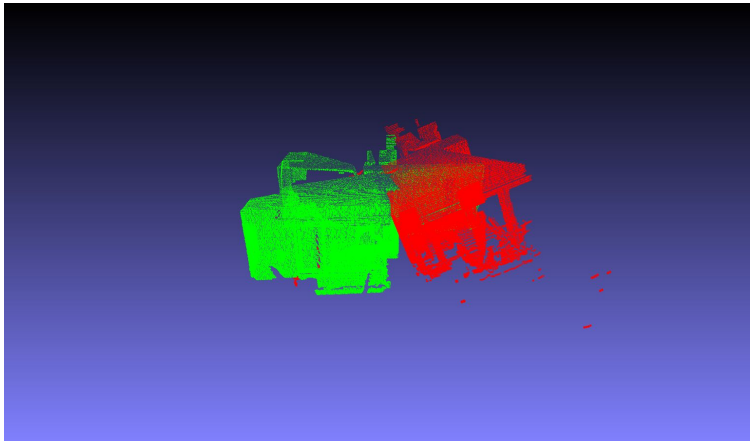
Multi-Resolution
blends well with Color
and Projective variants

Benchmark by Fontana et al.



Apply initial transform

Transformation can be scaled



$$\delta(P,G) = \frac{\sum_{i=0}^{n} \frac{\|p_i - g_i\|_2}{\|p_i - \overline{p}\|_2}}{n}$$

Same point cloud in poses P and G
Weighted Euclidean distance based on inverse distance to centroid

Compared variants

- Scaling factor θ = 0.1
- Point-to-plane up to 13.4% less error but also no difference for scene ”hauptgebaude”
- Symmetric ICP up to 22.1% less error but also 29.2% worse for scene ”plain”

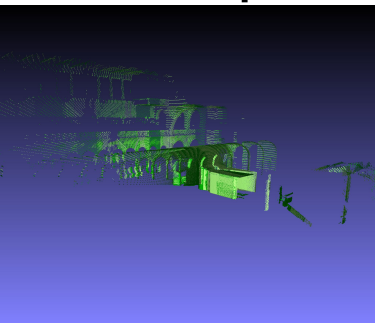
sequence	variant	θ	mean	median	std dev	min	max
plain	A	1	3.308733	2.965655	1.923608	0.196590	**9.371940**
	A	0.1	1.632221	1.26457	1.787482	0.0608	11.7137
	B	0.1	**1.41389**	**0.962364**	**1.616845**	**0.050266**	9.53577
	C	0.1	2.109305	1.33446	2.334786	0.079918	11.9195
hauptgebaude	A	0.1	0.384279	0.162546	**0.525487**	0.027522	3.61681
	B	0.1	0.387204	0.097541	0.616256	0.009919	**2.80592**
	C	0.1	**0.29951**	**0.071693**	0.639965	**0.005803**	4.39875
wood summer	A	0.1	0.840596	0.564219	**0.9287**	0.00579	4.22455
	B	0.1	0.813225	**0.294635**	0.944262	**0.004005**	**3.79686**
	C	0.1	**0.80033**	0.397184	0.930718	0.005369	3.82467

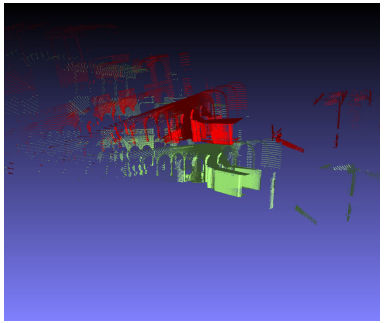
Table 1: Results for the benchmark by Fontana et al. [21]

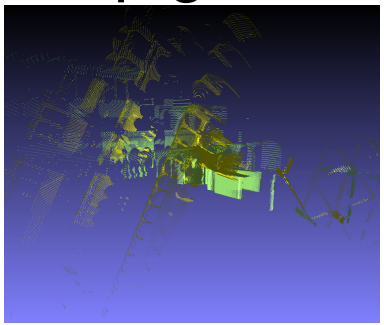
Table can also be found in report

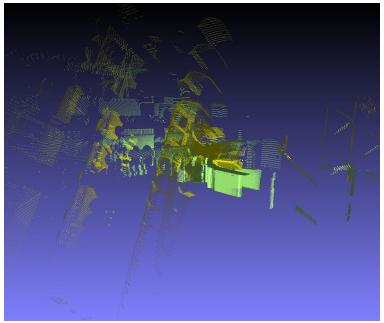
A = point-to-point
B = point-to-plane
C = symmetric ICP

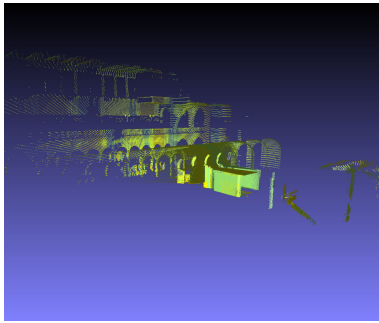
Example for scene “eth/hauptgebaude”

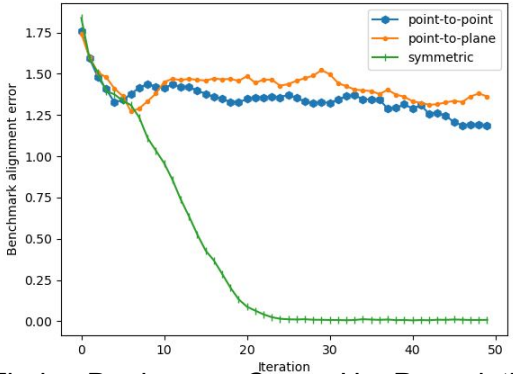

correct pose

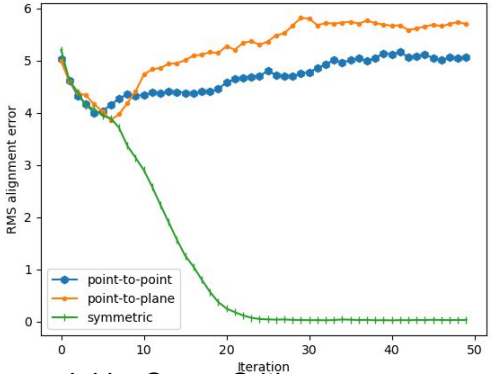

initial transform


point-to-point


point-to-plane


symmetric ICP





Conclusion

- Provided a comprehensive comparison
- Tested different data sets including real-world data
- Implemented classical and recent approaches
- Code publicly available at https://github.com/PetropoulakisPanagiotis/ICP-Variants