A 3D segments based algorithm for heterogeneous data registration

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A 3D SEGMENTS BASED ALGORITHM FOR HETEROGENEOUS DATA REGISTRATION

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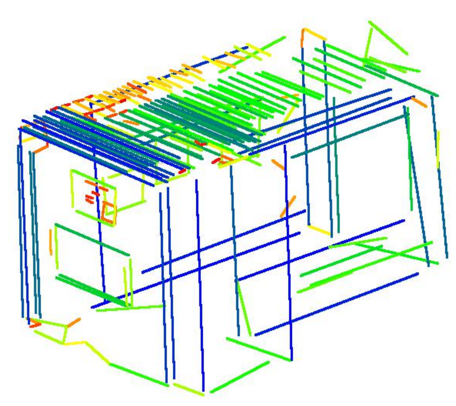
Context and Objectives of the Study

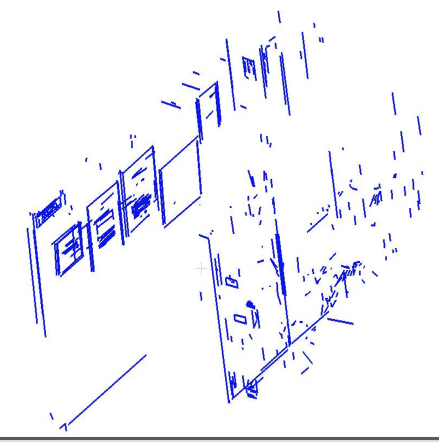
- Combining image and LiDAR draws increasing interest in surface reconstruction, city and building modeling for constructing 3D virtual reality models because of their complementary nature. However, to gain from this complementarity, these data sources must be precisely registered.
- The objective of this study is to propose a new primitive based registration algorithm that takes 3D segments as features in order to register heterogeneous data. The heterogeneity is both in data type (image and LiDAR) and acquisition platform (terrestrial and aerial).
- The basic idea of the proposed algorithm consists in defining a global robust distance between two segment sets and proposing a robust approach to minimize this distance based on RANSAC paradigm.

Feature Extraction



3D line segments detection from an indoor scan

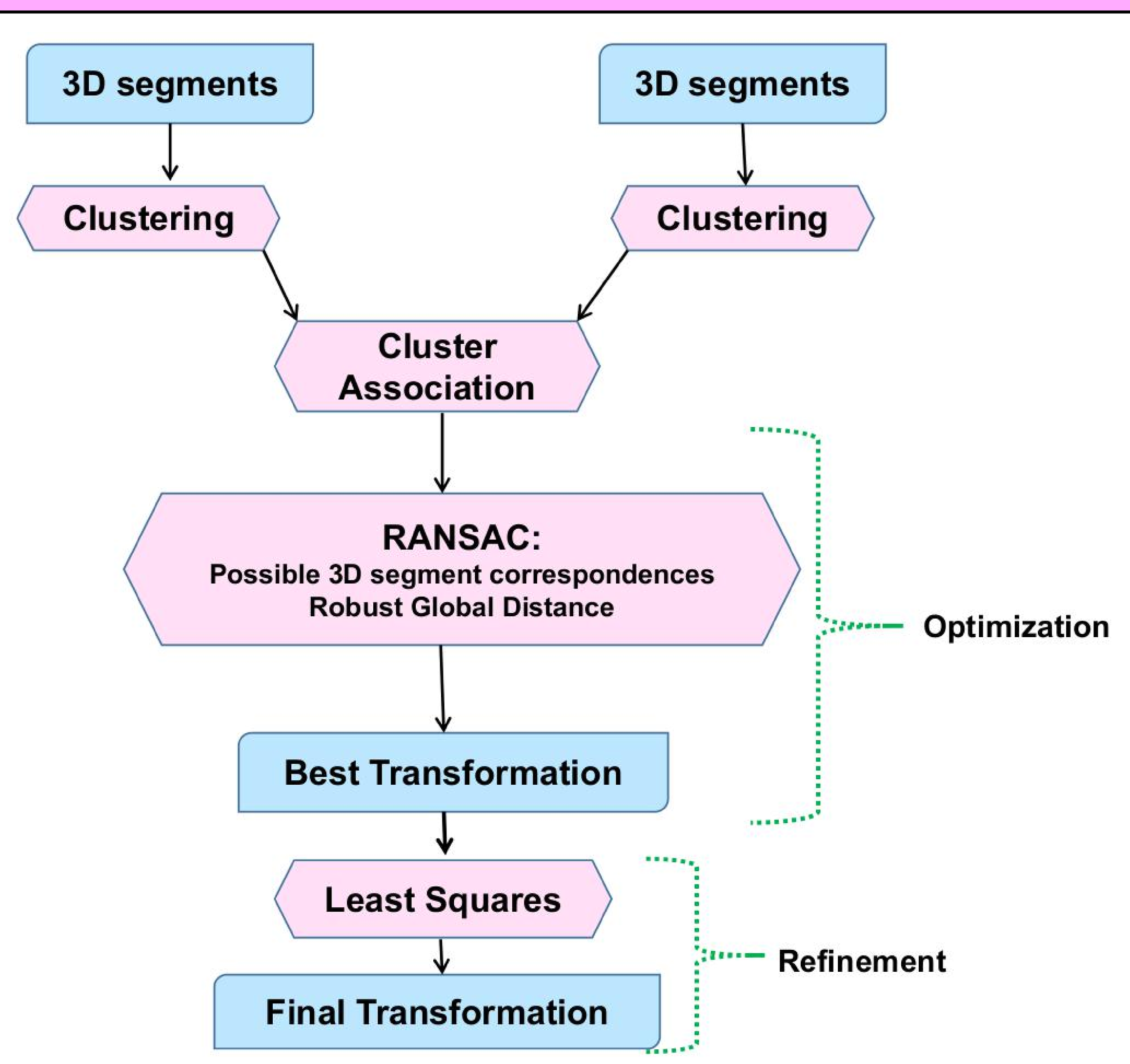
Lu, X., Liu, Y., & Li, K. (2019). Fast 3D line segment detection from unorganized point cloud. arXiv preprint arXiv:1901.02532.



3D line cloud reconstruction from image sequence

Manuel Hofer, Michael Maurer, and Horst Bischof. Efficient 3d scene abstraction using linesegments.Computer Vision and Image Understanding, 157:167–178, 2017.

Pipeline details



Global Robust distance between segment sets

We have two segments sets: L_1 and L_2

We define a distance between a segment l_1 and a segment set L_2 as:

$$E^{d_{thr}}(l_1, L_2) = |l_1| d_{thr}^2 - \sum_{l_2 \in L_2} |l_1^2 \cap l_2^1| max(0, d_{thr}^2 - dist(l_1, l_2)^2)$$

Finally we can write our final symmetrized robust distance between 3D segments sets as:

$$dist(L_1, L_2) = \sum_{l_1 \in L_1} E^{d_{thr}}(l_1, L_2) + \sum_{l_2 \in L_2} E^{d_{thr}}(l_2, L_1)$$

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3D segments directional clustering

Algorithm1: Greedy direction clustering

1. Input: set of segment L, each segment $L_i = [A_i B_i]$ has a director vector $v_i = \overrightarrow{A_i B_i}$, a length $len_i = \|v_i\|$ and a unit direction $d_i = \frac{v_i}{len_i}$

2. Initialize an empty set of 3D segment Clusters C. We will call direction of cluster c the weighted mean of the directions of 3D segments:

$$d(c) = \frac{\sum_{L_i \in C} sign(v_i . v_1) v_i}{\| \sum_{L_i \in C} v_i \|}$$

3. For each segment L_i:
- If $C = \emptyset$ or $max_{c \in C} d_i . d(c) < cos(\varepsilon)$, create a new cluster and add L_i to it.
- Else add L_i to the cluster $arg\ max\ d_i . d(c)$

Valid cluster associations

We have two segment sets S_1 and S_2

For each cluster associations

$$As = \{(c_1^1, c_2^1) \in S_1 \leftrightarrow (c_1^2, c_2^2) \in S_2\}$$

we have several possible forms.

As for each cluster c, we have two possible direction vectors:$\{d(c), -d(c)\}$: we can define the variables s_i^j: $i \in [1,2], j \in [1,2]$, $s_i^j = \pm 1$

- If one of the possible forms of As satisfies the condition:

$$| < s_1^1 d(c_1^1), s_2^1 d(c_2^1) > - < s_1^2 d(c_1^2), s_2^2 d(c_2^2) > | < \varepsilon$$

we consider that As is valid
- Else , we reject this association

Optimization

Simulted annealing simulation:

- A new solution is iteratively computed in the vicinity of the current solution.
- This new solution is accepted with certain probability depending of its energy(the robust distance in our case).

RANSAC optimization

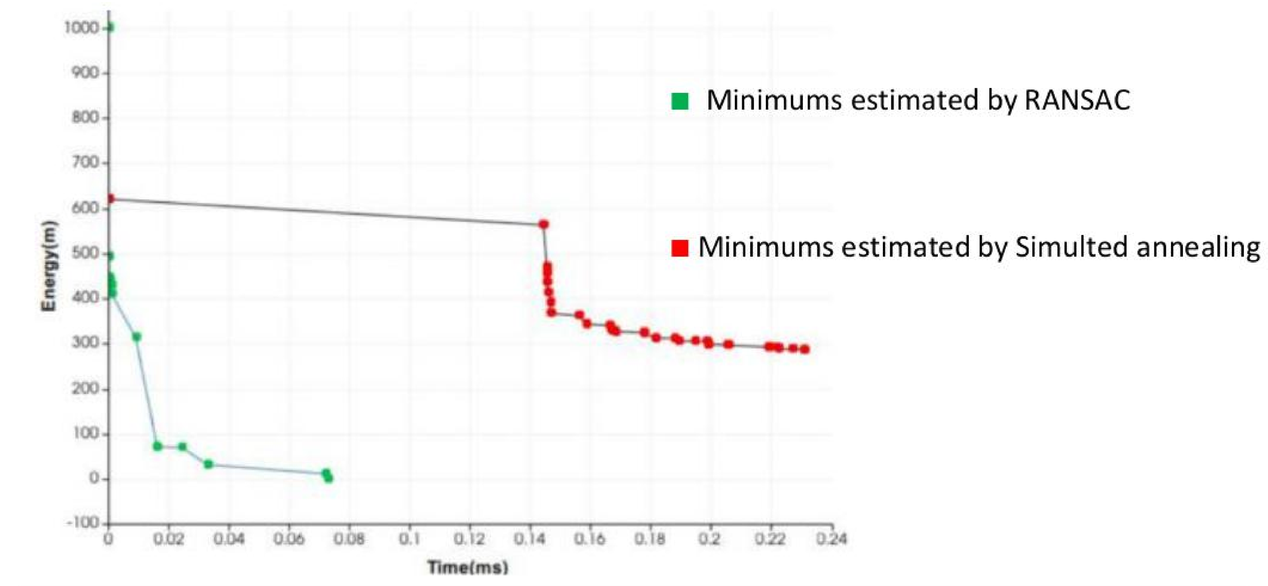
- At each RANSAC iteration, we randomly select a valid cluster association, then randomly select 3D segment in each of the associated clusters.
- We compute the rotation based on cluster association.
- we estimate the scale/translation that aligns the associated 3D segments.

We keep the sampled transformation that has the minimum robust distance.

Future Works

- Use planar polygons as primitives .
- Use combinations of more segments to have more characteristic features to match.
- Test the proposed algorithm for solving the aerial image/ Aerial LiDAR registration.

Evaluation on synthetic data

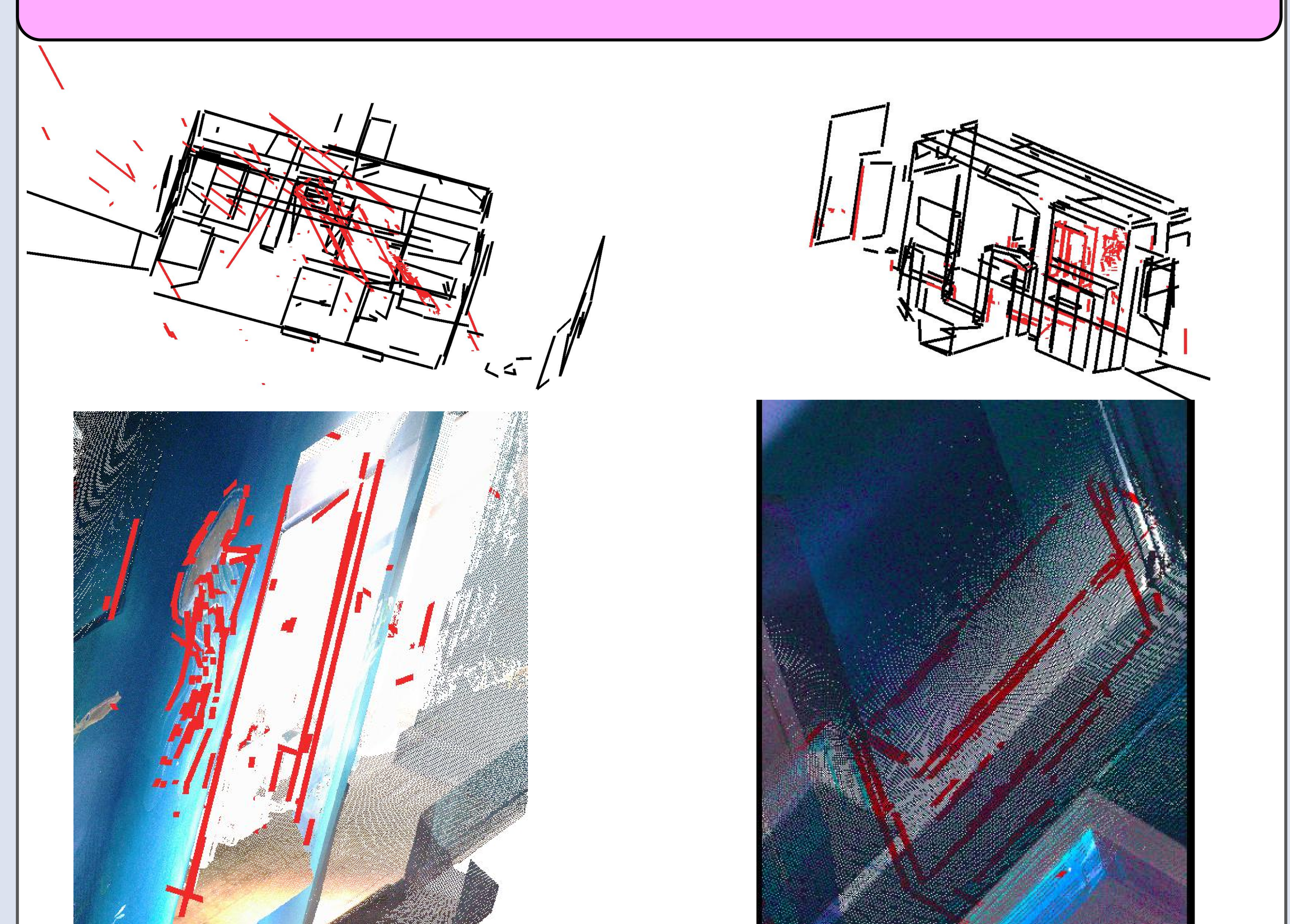


Comparison of the convergence speed and the robustness of RANSAC and simulated annealing

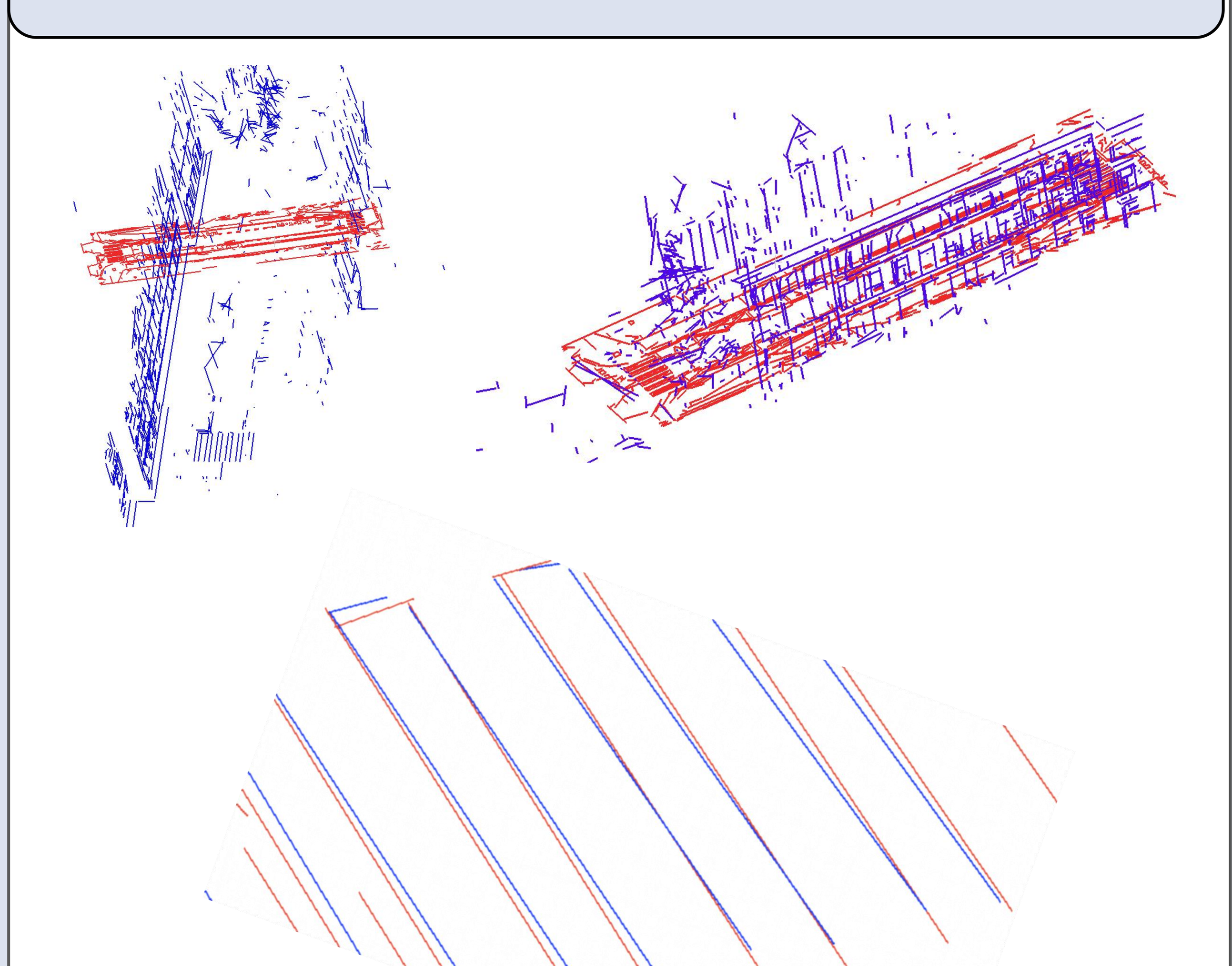
Transformation			Our result			ICL result		
Translation	Rotation	Scale (s_0)	Translation Error	Rotation Error	Scale (s)	Translation Error	Rotation Error	Scale (s)
0 m	0°	1	1.77e-15 m	1.06e-15°	$\frac{\lvert s-s_0\rvert}{s_0}$=0	3.6e-16 m	4.7e-15°	$\frac{\lvert s-s_0\rvert}{s_0}$=0
0.39 m	4.66°	0.85	0 m	0.04°	$\frac{\lvert s-s_0\rvert}{s_0}$=0	0.09 m	1.29°	$\frac{\lvert s-s_0\rvert}{s_0}$=0.005
1.31 m	15.66°	1.5	0 m	0.2°	$\frac{\lvert s-s_0\rvert}{s_0}$=0	0.20 m	15.39°	$\frac{\lvert s-s_0\rvert}{s_0}$=0.971
4.20 m	32.66°	2	0 m	0.2°	$\frac{\lvert s-s_0\rvert}{s_0}$=0	1.42 m	27.520	$\frac{\lvert s-s_0\rvert}{s_0}$=0.97

Performance tests of our algorithm on synthetic data using different initial errors.

Evaluation on Real data



Terrestrial image/Terrestrial LiDAR registration



Aerial image/Terrestrial image registration