A Plane-based Approach for Indoor Point Clouds Registration

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Aim: estimating the transformation $^1T_s$ that best registers two point clouds.

Approach: minimizing the global distance error between paired points [1].

Point cloud registration by ICP
Main drawbacks of ICP algorithm:

- sensitive to initialization;
- matching step can be time consuming (due to number of input points).
Contributions

- An algorithm performing fast and accurate registration in challenging datasets;
- A two-step minimization method performing successively plane-to-plane and point-to-plane distance minimization;
- A method robust to large motion or inaccurate initialization;
- An efficient score metric for finding best planes correspondences.
Proposed method framework

1. **Source planes extraction**
2. **Target planes extraction**
3. **Plane matching**
4. **Plane-to-plane distance minimization**
5. **Convergence is reached?**
   - Yes: **Point-to-plane distance minimization**
   - No: **Application of estimated transformation to source**
6. **Optimal transformation**
Plane Extraction

Based on region growing segmentation [2].

*Input point cloud.*

*Plane extraction result. Each extracted plane is in a different color. Red points are outliers.*
Plane matching

Correspondences characteristics:

- the distance between the projections of the origin on source and target plane:
  \[ d_o = \| \rho_s s^\top \rho_t t^\top \| \]

- the distance between the centroids of source and target plane:
  \[ d_c = \| \bar{p}_s - \bar{p}_t \| \]

- the area ratio between planes:
  \[ S_r = \frac{\min(s^\top S, t^\top S)}{\max(s^\top S, t^\top S)} \]

- the dot product of the normals of the planes:
  \[ \phi_n = s^\top n \cdot t^\top n \]

\[
\text{score} = \alpha \cdot \hat{d}_o + \beta \cdot \hat{d}_c + \gamma \cdot (1 - \hat{S}_r) + \delta \cdot (1 - \hat{\phi}_n)
\]

with \( \alpha + \beta + \gamma + \delta = 1 \)

Correspondences choice:

- All correspondences with a score smaller than a threshold are kept.
Distances minimization

Plane-to-plane distance definition:

\[ d_{\Pi}^i = \left( t^T R_s^s n_i - t_n_i \right) \]

- initialized with a closed-form method using a RANSAC to find inliers;
- solved using a Gauss-Newton approach.

Point-to-plane distance definition:

\[ d_{\Pi}^i = \| t^T n_i \cdot (t^T T_s^s p_i - t p_i) \|^2 \]

- solved using a Gauss-Newton approach using M-estimators.
Experiments

- The Autonomous Labs Systems dataset [3], including ground truth, is used to evaluate the accuracy of the method.
- Only the indoor environments are evaluated.

Apartment sequence

Stairs sequence

ETH sequence
Experiments: Comparison with state of the art algorithms

Successful registration [4]:
- translation error smaller than 10 cm;
- rotation error smaller than 2.5°.

\[ \Delta_t = \left\| t^{\hat{s}} - t^{s_k} \right\| \]
\[ \Delta_r = \arccos \left( \frac{\text{trace} \left( R_s^{\hat{s}} R_s^{-1} \right) - 1}{2} \right) \]
Experiments: Comparison with state of the art algorithms

Successful registration [4]:
- translation error smaller than 10cm;
- rotation error smaller than 2.5°.

\[ \Delta_t = \|t^T_s - t^*_s\| \quad \Delta_r = \arccos \left( \frac{\text{trace}(t^T R_s^{-1} t^T \hat{R}_s) - 1}{2} \right) \]

**Percentage of successful registration (translation and rotation combined) for the evaluated algorithms on each considered sequence [3].**

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Experiments: Comparison with state of the art algorithms

Processing time in milliseconds for each tested algorithm for all sequences.

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Conclusion

A plane-based registration algorithm:

- accurate in challenging datasets;
- robust to large motion between scans;
- fast to compute registration.


Thank you for your attention

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