Degeneracy Detection for RGB-D Odometry

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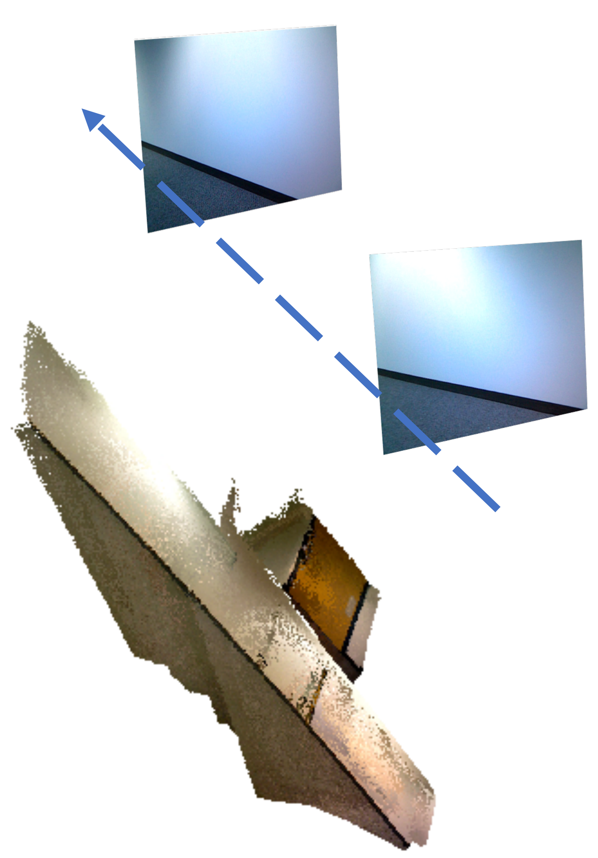
Introduction

Lack of geometric structures or texture features prevents accurate motion estimation. In such environment, the problem degenerates because of insufficient constraints.

This work provides an online algorithm to detect degeneracy based on fast dense RGB-D odometry [1].
The key ideas are:

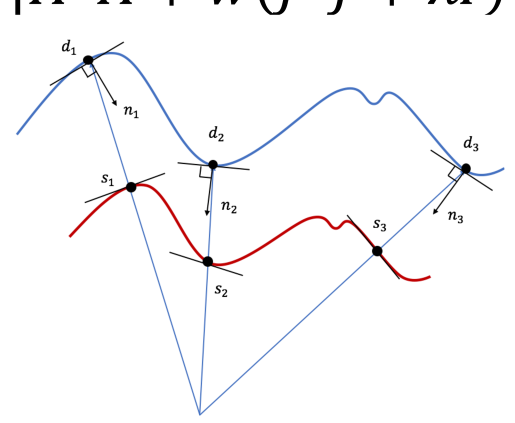
- Geometric and photometric degeneracy detection via planar-based and energy-based [2] methods respectively.
- Integrate two parts and find the common degenerate directions.
- Update the state of motion only in well-constrained directions.

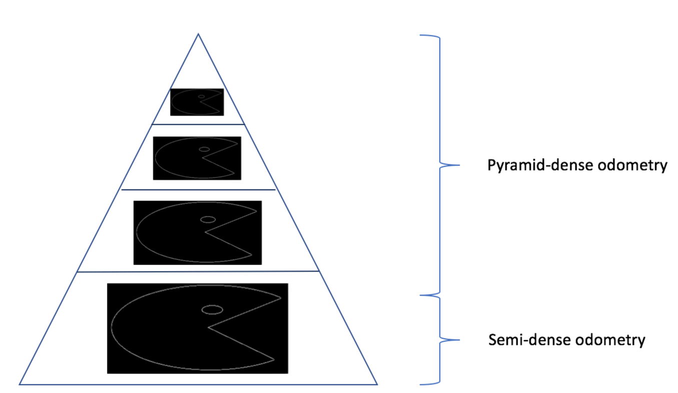


Preliminaries

Fast dense RGB-D odometry:

- Iterative Projected Plane (IPP) + Pyramid/Semi-dense RGB-D odometry
- $E = E_{geo} + wE_{pho}$
- $[A^TA + w(J^TJ + \lambda I)]x = A^Te + J^Tr$





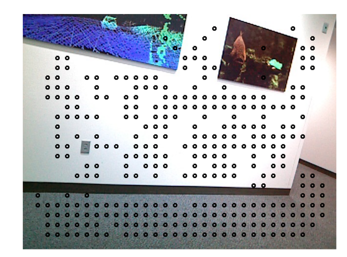
Conclusion and Future work

In this work, we actively detect degeneracy for geometric and photometric parts. Degenerate directions may be different for two parts. However, when we integrate them together, they may compensate in some directions.
Future work:

- Incorporate more sensors such as IMU. When degeneracy is detected, system mostly relies on IMU measurements.
- Create partial factors in factor graph and use loop closure to refine the motion.

Implementation

Degeneracy Detection on Geometric Part



Subplane's normal vectors: $n_1, \ldots, n_N$

$$M = \begin{bmatrix} n_{1x} & \cdots & n_{1z} \\ \vdots & \ddots & \vdots \\ n_{Nx} & \cdots & n_{Nz} \end{bmatrix}$$

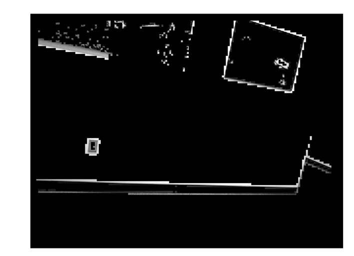
Do eigen decomposition to M^TM

$$\lambda_{thres} = \lambda_{max}/\lambda_{min}$$

Decide # degenerate directions: m

$[v_1^A \;\; \ldots \;\; v_m^A]$ **from** A^TA

Degeneracy Detection on Photometric Part



Jacobian matrix

$$J = \begin{bmatrix} j_{11} & \cdots & j_{16} \\ \vdots & \ddots & \vdots \\ j_{N1} & \cdots & j_{N1} \end{bmatrix}$$

Do eigen decomposition to J^TJ

$$\lambda_{thres} = \lambda_{max}/\lambda_{min}$$

Decide # degenerate directions: n

$[v_1^J \;\; \ldots \;\; v_n^J]$ **from** J^TJ

Combination

$$W = [v_1^A \;\; \ldots \;\; v_m^A \;\; v_1^J \;\; \ldots \;\; v_n^J]$$

Do eigen decomposition to W^TW

Rank of W: # zero λ_i = # degenerate directions in total

$$V = [v_1^W \;\; \ldots \;\; v_k^W \;\; v_{k+1}^W \;\; \ldots \;\; v_n^W]^T$$
$$V_f = [v_1^W \;\; \ldots \;\; v_k^W \;\; 0 \;\; \ldots \;\; 0]^T$$

Project x onto well-constrained directions $x = V^{-1}V_fx$

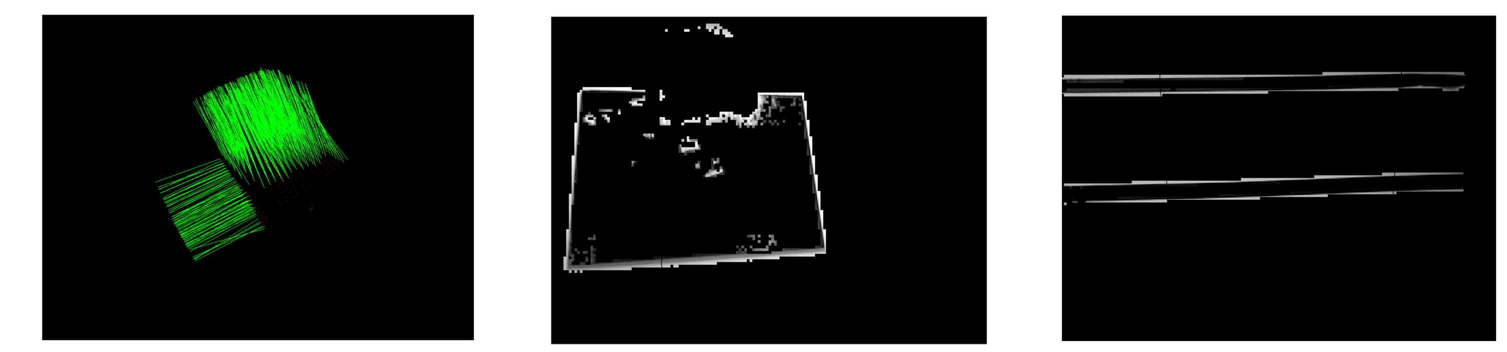
References

[1] M. Hsiao, E. Westman, G. Zhang, and M. Kaess. Keyframe-based dense planar slam. In *2017 IEEE International Conference on Robotics and Automation (ICRA),* pages 5110-5117, May 2017.
[2] J. Zhang, M. Kaess, and S. Singh. On degeneracy of optimization-based state estimation problems. In *2016 IEEE International Conference on Robotics and Automation (ICRA),* page 809-816, May 2016.

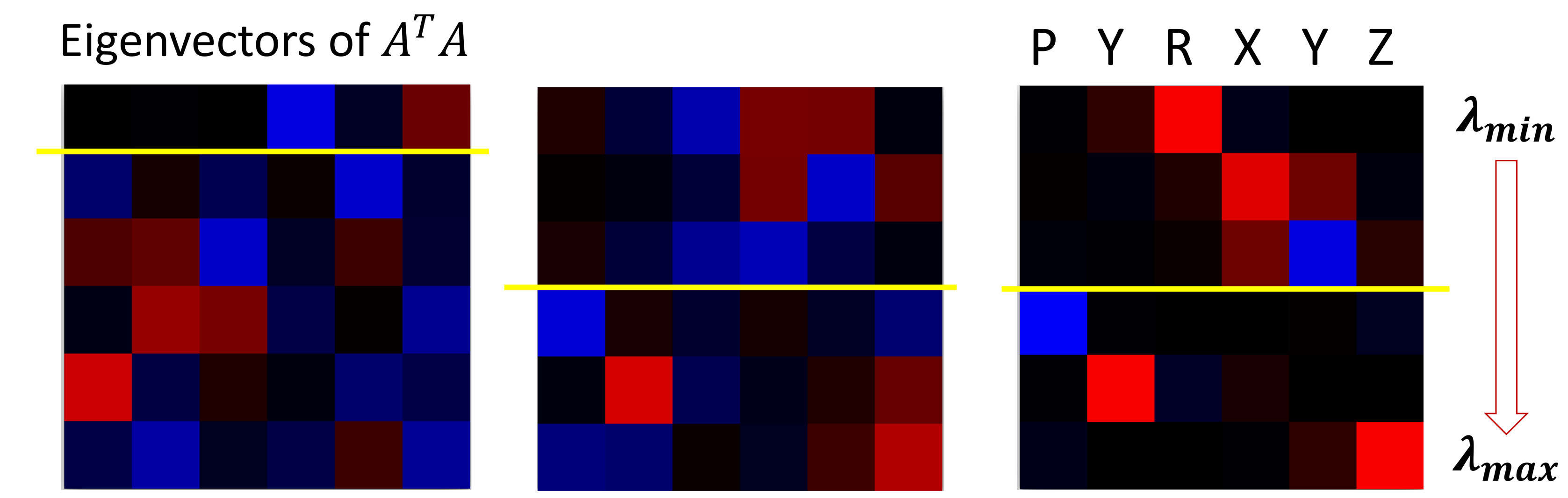
Results

Original Image

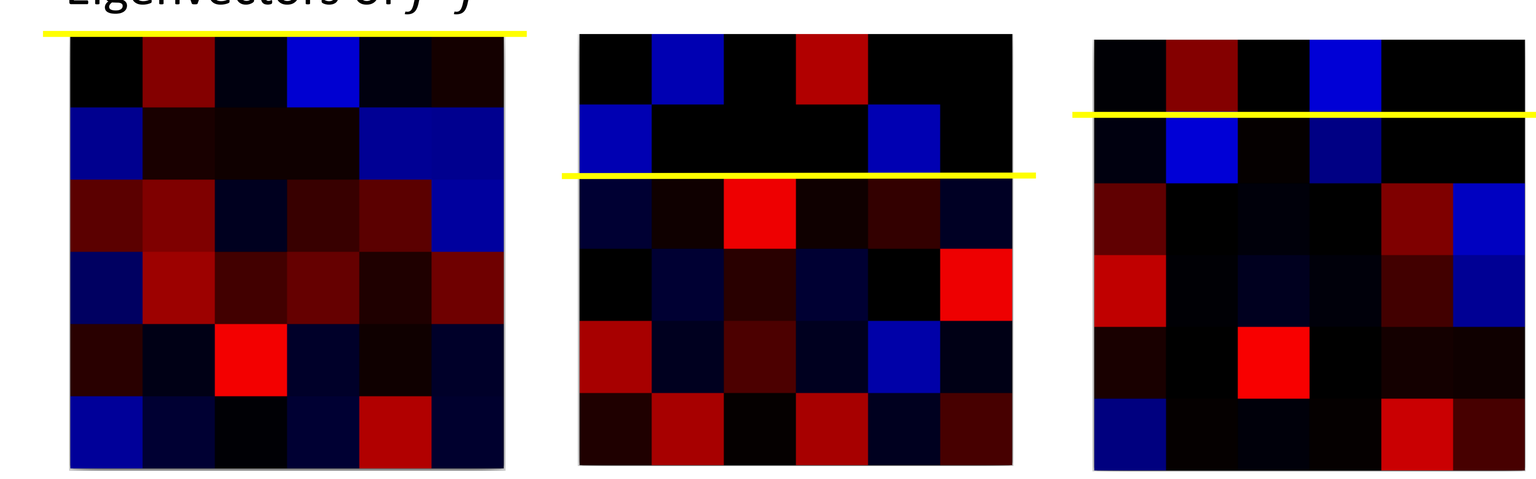
Normal vectors / Laplacian Image



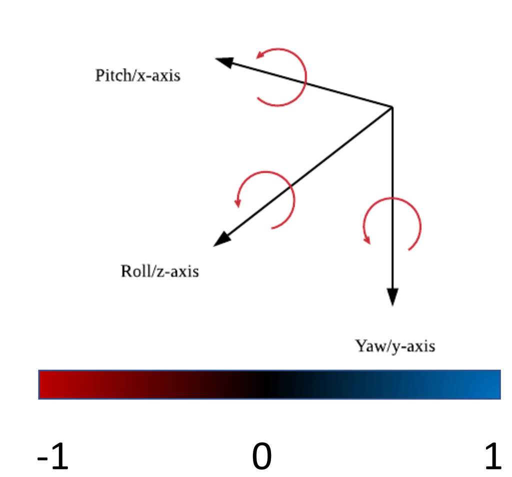
Eigenvectors of A^TA

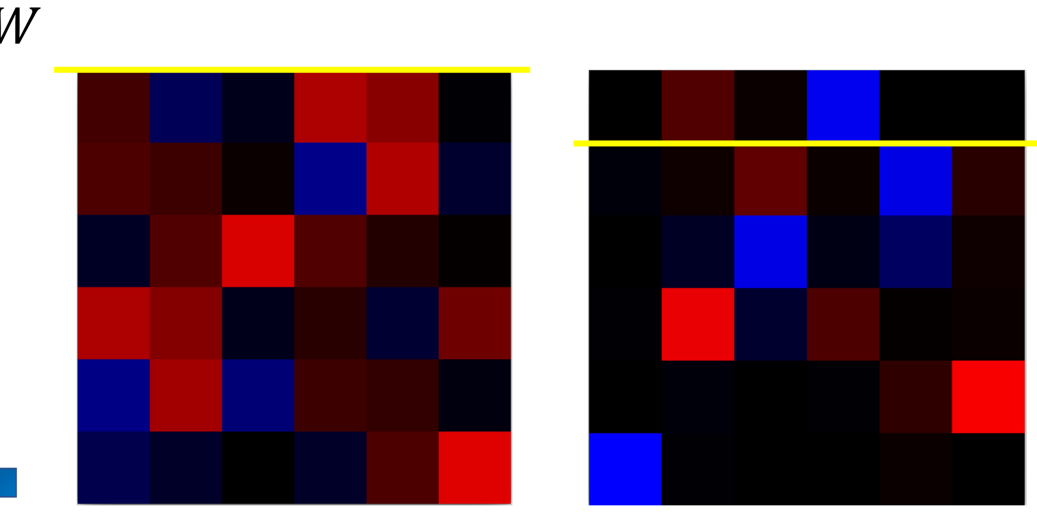


Eigenvectors of J^TJ



Eigenvectors of W^TW





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