Monocular Visual Odometry

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Monocular Visual Odometry

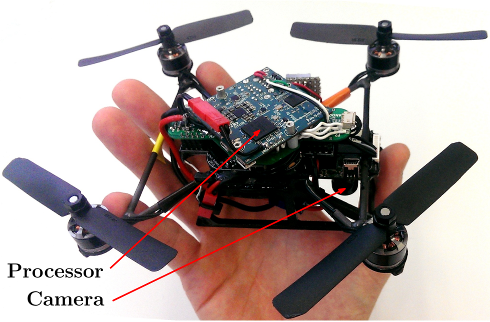
Goal

Estimate the egomotion of the Micro Aerial Vehicle (MAV) using only a single camera.

- Lightweight
- Low power consumption
- Moving platform: Stereo vision not necessary

"Visual Odometry"

Incrementally estimate the pose of the vehicle by examining the changes that motion induces on the images.



Visual Odometry

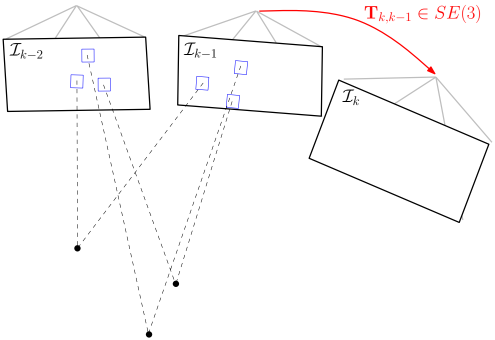
Problem Formulation

Two camera poses at adjacent time instants $k-1$ and k are related by the rigid body transformation

$$\mathbf{T}_{k,k-1} = \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ 0 & 0 \end{bmatrix} \in SE(3).$$

Concatenation of the relative transformations allows to recover the path:

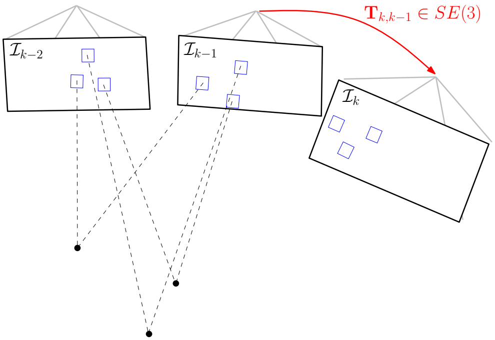
$$\mathbf{T}_{k,0} = \mathbf{T}_{k,k-1} \cdot \mathbf{T}_{k-1,k-2} \cdots \mathbf{T}_{1,0}$$



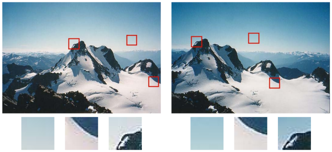
Feature-based Visual Odometry

Pipeline

1. Feature selection
2. Feature matching
3. Pose estimation
4. Pose refinement
5. Triangulation

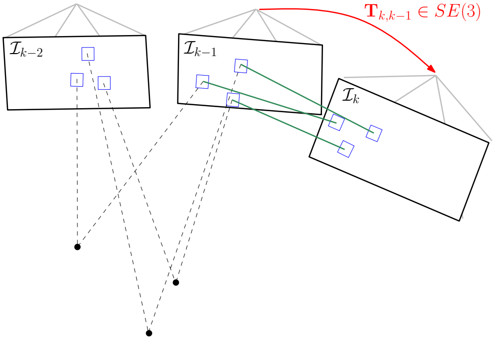


Which features?



Source: Szeliski, "Computer Vision: Algorithms and Applications", Springer 2010.

Feature-based Visual Odometry



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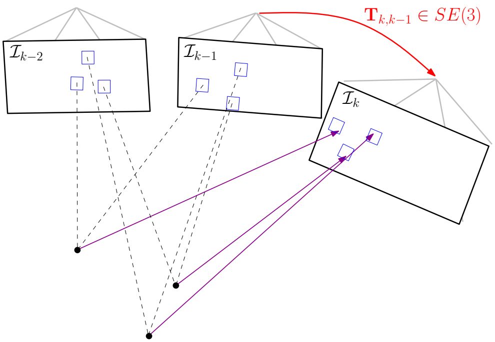
Matching Strategies

- Fast: SSD/NCC over small patch
- Robust: Match invariant feature descriptors, e.g., SIFT [Lowe, 2003]

Feature-based Visual Odometry



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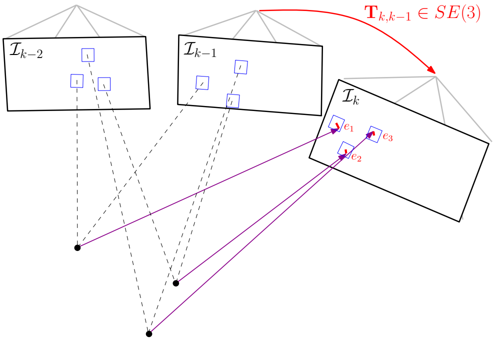
Epipolar Geometry

Three 3D point to 2D feature correspondences are necessary to estimate the 3D camera pose. [Kneip et al., 2011]

Feature-based Visual Odometry



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Minimize reprojection errors

$$\mathbf{T}_{k,k-1} = \arg\min_{\mathbf{T}} \sum_i \rho\left[e_i(\mathbf{T})\right], \qquad \text{typically} \quad \rho[.] \hat{=} \frac{1}{2\sigma^2} \parallel . \parallel^2$$

Can be solved with e.g. Gauss Newton.

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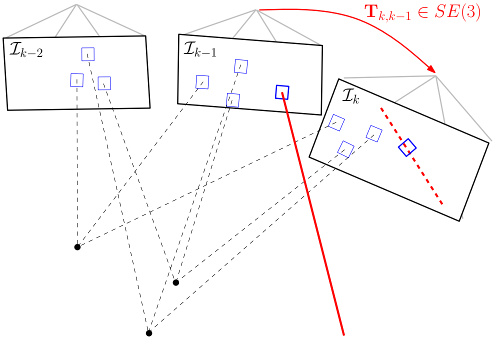

Triangulation

Search along Epipolar line for matching feature.

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Triangulation

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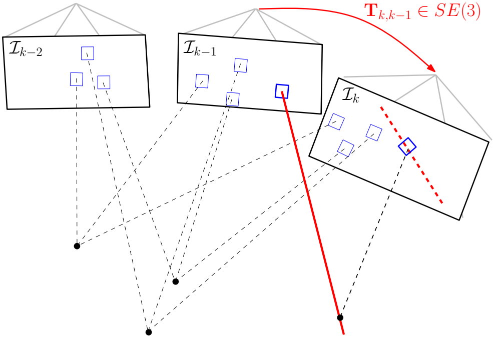


Implementation Details

- Make more robust by using many (hundreds) of features.
- Use motion model to speed-up feature matching.
- Use robust estimation techniques to handle wrong matches (e.g., RANSAC [Fischler and Bolles, 1981]).
- Minimize drift through incremental Bundle Adjustment: Joint optimization of frames and 3D points [Mouragnon et al., 2006] .
- Parallelize tracking and mapping [Klein and Murray, 2009] .

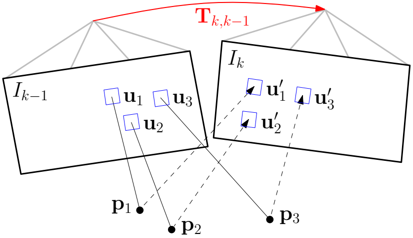
The direct approach

Minimize photometric error

$$\mathbf{T}_{k,k-1} = \arg\min_{\mathbf{T}} \iint_{\bar{\mathcal{R}}} \rho\left[\delta\mathcal{I}(\mathbf{T},\mathbf{u})\right] d\mathbf{u}.$$

where

$$\begin{aligned}\delta\mathcal{I}(\mathbf{T},\mathbf{u}) &= \mathcal{I}_k(\mathbf{u}') - \mathcal{I}_{k-1}(\mathbf{u}) \\ \mathbf{u}' &= \pi\left(\mathbf{T}\cdot\pi^{-1}(\mathbf{u}, z_{\mathbf{u}})\right)\end{aligned}$$



Advantages

- No costly feature extraction
- No costly robust feature matching

Bibliography

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Mouragnon, E., Lhuillier, M., Dhome, M., Dekeyser, F., and Sayd, P. (2006). 3D Reconstruction of Complex Structures with Bundle Adjustment: an Incremental Approach. *Proceedings of the 2006 IEEE International Conference on Robotics and Automation*, pages 3055–3061.