Monocular Visual Odometry

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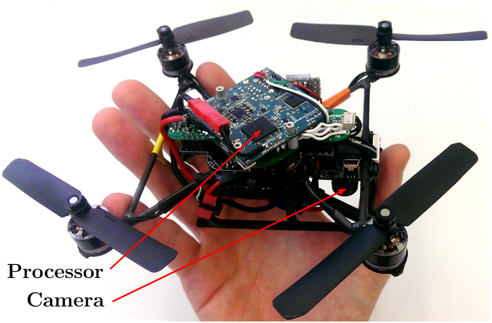
Goal

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

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



Visual Odometry

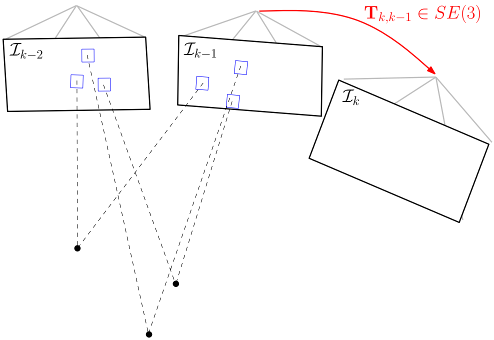
Problem Formulation

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:

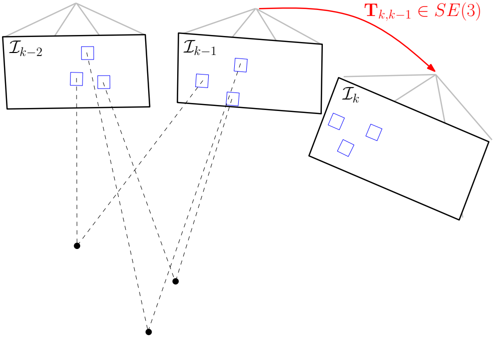
$$\mathbf{T}_{k,0} = \mathbf{T}_{k,k-1} \cdot \mathbf{T}_{k-1,k-2} \cdots \mathbf{T}_{1,0}$$



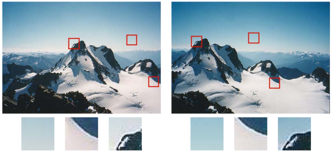
Feature-based Visual Odometry

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.

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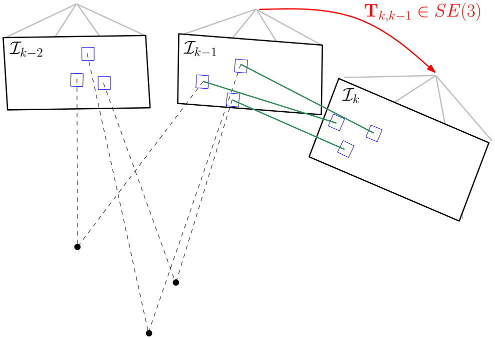

Matching Strategies

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

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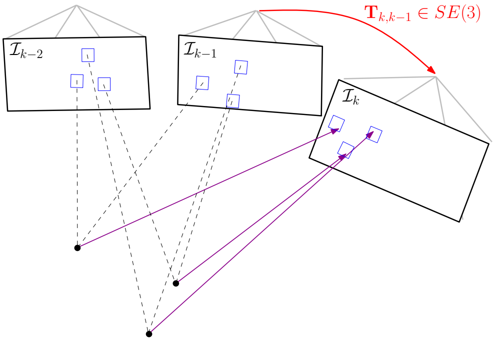

Epipolar Geometry

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

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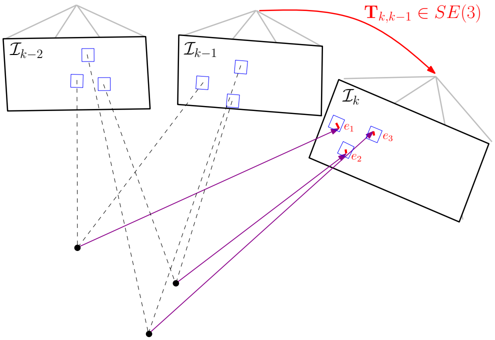

Minimize reprojection errors

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

Can be solved with e.g. Gauss Newton.

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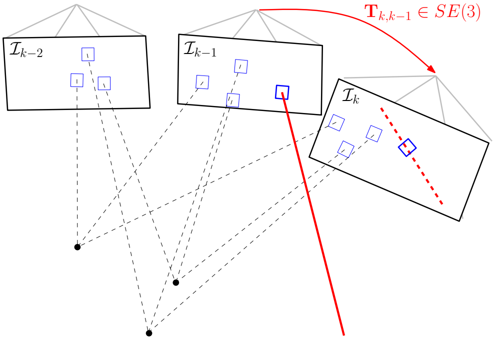
Triangulation

Search along Epipolar line for matching feature.



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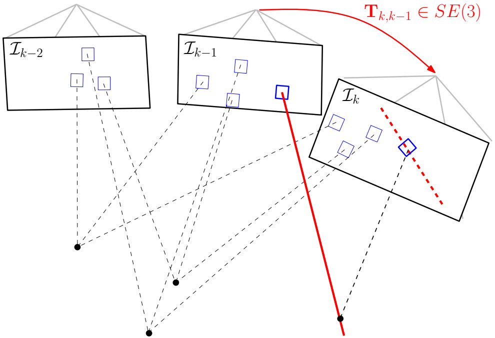


Triangulation

Search along Epipolar line for matching feature.

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] .

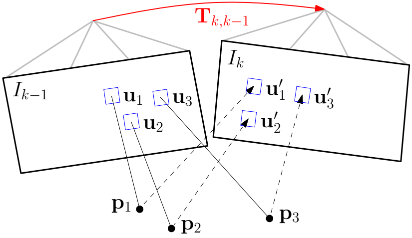
The direct approach

Minimize photometric error

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

where

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



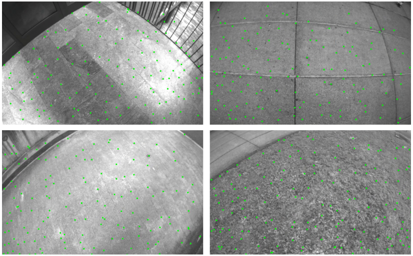
Advantages

- No costly feature extraction
- No costly robust feature matching

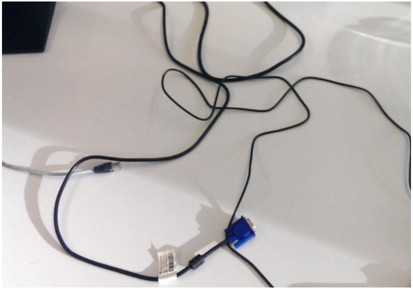
[Forster et al., 2014]

Future Challenges

- Robust performance in scenes of little, repetitive or high frequency texture.
- Robust tracking under disturbances: Moving objects, changing light conditions.
- Fast relocalization after tracking failure.



High frequency texture



No corners

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