- Introduction
- **Features and Feature Matching**
- Geometry of Image Formation
- Calibration
- Structure from Motion
- Dense Stereo
- Conclusion
Features and Feature Matching

- Original Image
- Mean Filter
- Gauss Filter
- Median Filter
- Sharpening
- Canny Edge Detector
Features and Feature Matching

Gaussian Filter – Smoothing the Image

The image shows a 3x3 Gaussian filter with weights 1, 2, 1 for the rows and columns. The filter is applied to an image to smooth it. The left side of the image shows the filter kernel, the center shows the kernel multiplied by 1/16, and the right side shows the smoothed image.
Features and Feature Matching

**Gradient Filter**

Sobel filter in x-direction

\[
\begin{bmatrix}
-1 & 0 & 1 \\
-2 & 0 & 2 \\
-1 & 0 & 1 \\
\end{bmatrix}
\]

Sobel filter in y-direction

\[
\begin{bmatrix}
-1 & -2 & -1 \\
0 & 0 & 0 \\
1 & 2 & 1 \\
\end{bmatrix}
\]

gradient x-direction

gradient y-direction
Feature Detection and Matching

Input: dense image sequences (video) or unordered, images (e.g. from the internet)
Question: is there overlap between the images?
Feature Detection – Harris Corners

Images are composed of 3 basic primitives:
- Planar Patches: regions with constant gray values (zero gradient)
- Edges: regions with constant gradient vector (normal)
- Points (corners): regions with variable gradient

\[ g(i, j) = \text{const}, \quad |\vec{g}| = 0 \]

\[
\vec{g} = \begin{pmatrix} g_x \\ g_y \end{pmatrix} = \begin{pmatrix} \text{const} \\ \text{const} \end{pmatrix}, \quad |\vec{g}| > 0
\]

\[
\vec{n} = \begin{pmatrix} \cos \theta \\ \sin \theta \end{pmatrix}
\]

\[
|\vec{g}| > 0
\]

\[
\vec{g} = \begin{pmatrix} g_x \\ g_y \end{pmatrix} = \begin{pmatrix} \text{var} \\ \text{var} \end{pmatrix}
\]

\[
|\vec{g}| > 0
\]
Feature Detection – Harris Corners

Corners, edges, and planes can locally be distinguished by computing the structure tensor \( J \). \( J(i, j) \) computes information on the local structure at position \((i, j)\) for a local image region \( S \) from the gradients:

1. Compute gradient images:
   \[
   I_x(i, j) = H_{gx} * I(i, j), \quad I_y(i, j) = H_{gy} * I(i, j)
   \]

2. Point-wise products for the components of the structure tensor
   \[
   I_{xx}(i, j) = I_x(i, j) \cdot I_x(i, j), \quad I_{yy}(i, j) = I_y(i, j) \cdot I_y(i, j), \quad I_{xy}(i, j) = I_x(i, j) \cdot I_y(i, j)
   \]

3. Local smoothing of the gradients
   \[
   J_{xx} = G_{LP} * I_{xx}(i, j), \quad J_{yy} = G_{LP} * I_{yy}(i, j), \quad J_{xy} = G_{LP} * I_{xy}(i, j)
   \]

4. Computation of trace and determinant
   \[
   J(i, j) = \begin{bmatrix}
   J_{xx} & J_{xy} \\
   J_{xy} & J_{yy}
   \end{bmatrix}, \quad \text{trace}(J) = (J_{xx} + J_{yy}), \quad \text{det}(J) = J_{xx} \cdot J_{yy} - J_{xy}^2
   \]

\textit{Harris and Stephens, 1988}
Feature Detection – Harris Corners

- Harris Corner Detector evaluates $J$:

  $$\lambda_0, \lambda_1 \text{Eigenwerte } J \Rightarrow \det(J) = \lambda_0 \lambda_1, \text{ trace}(J) = \lambda_0 + \lambda_1$$

  $$C_H = \det(J) - k \cdot (\text{trace}(J))^2, \quad 0 \leq k \leq 0.25, \quad k = 0.04$$

  $$C_H \begin{cases} > t \text{ for edges} \\ < t \text{ for corners and planes} \end{cases}$$

- $C_H$ measures the ‘cornerness’
- $C_H > t, \ t > 0$ potential corners
- select local maxima in a neighborhood (Non-Maxima-Suppression).

Harris and Stephens, 1988
Features and Feature Matching

Gradients – Harris Corner Detector

input image  →  gradient images  →  Harris corners

Harris and Stephens, 1988
Feature Point Matching

Pixel-wise patch comparison:

- **SSD** – Sum of Squared Differences
- **NCC** – Normalized Cross Correlation (invariant against brightness changes)
Feature Point Matching

Automatically detect hundreds or thousands of correspondences
Problem: outliers
Feature Detection and Matching

Transformations

Illumination changes:
- brightness
- exposure
- moving light sources/shadows

Affinity

Translation

Similarity

Euclidean

Projective

Original feature
## Feature Detectors & Descriptors

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From now on: SIFT-features (out of scope in this tutorial)

*Harris and Stephens, 1988, Lowe 2004, Szeliski 2011*
Problematic Cases
References


Wrap up

- automated detection of feature points in all images
- match feature points between images
- different methods depending on baseline between images, expected rotation, translation, and scale
- illumination brightness, exposure