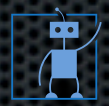


Robotics and
Embedded Systems

Applied Computer Vision for Robotics

5.11.2012

Philipp Heise

Brian Jensen

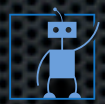
Sebastian Klose

Feature descriptors

Robotics and
Embedded Systems

- Features detected by Harris response
- How to compare detected features?
  - Solution: feature descriptor
  - Extract information around the interest-point from the image

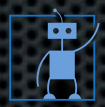
Feature descriptors



Robotics and
Embedded Systems

- Use raw pixel data for comparison/distance computation (e.g. SSD/SAD)
- Make the descriptor robust to appearance variation (e.g. rotation and scaling)
- Make the detected features in images well distributed and only select reasonable subset to reduce computational complexity

Brute force comparison



Robotics and
Embedded Systems

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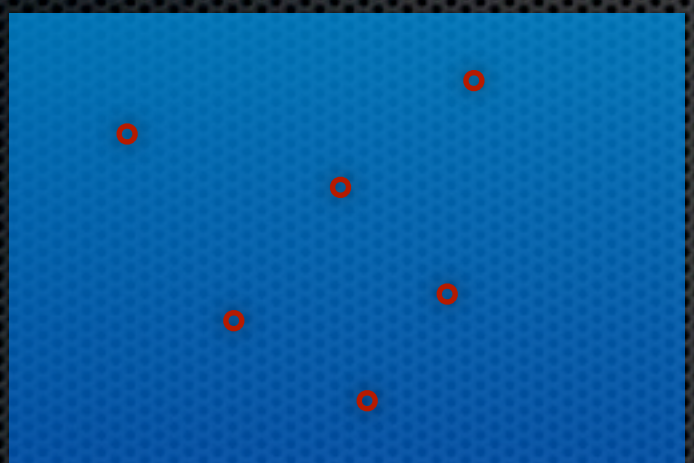

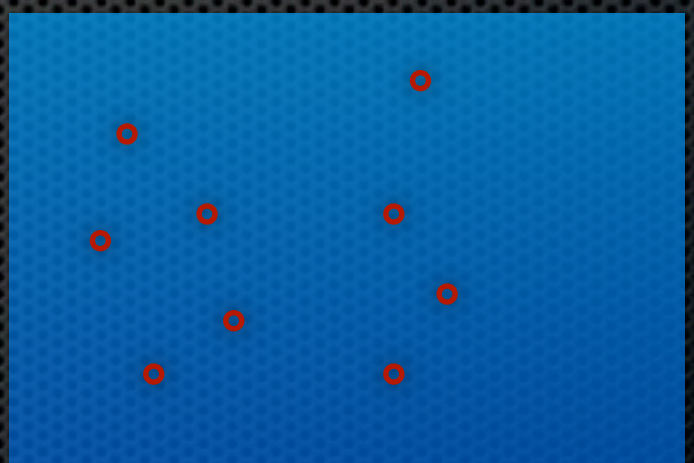

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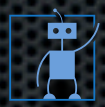

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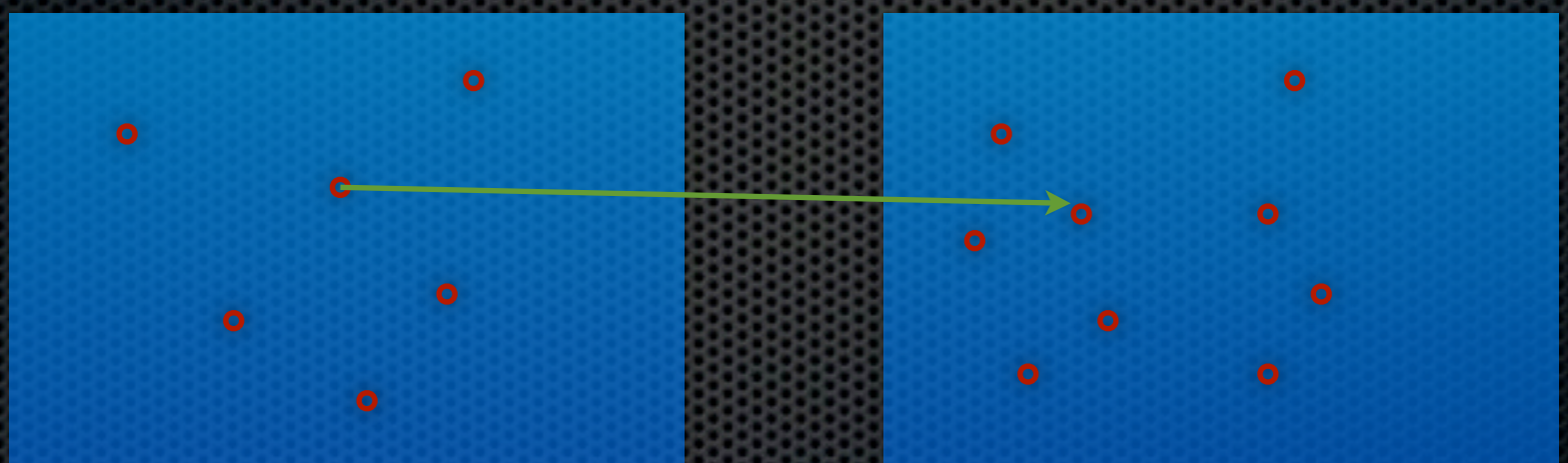

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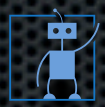

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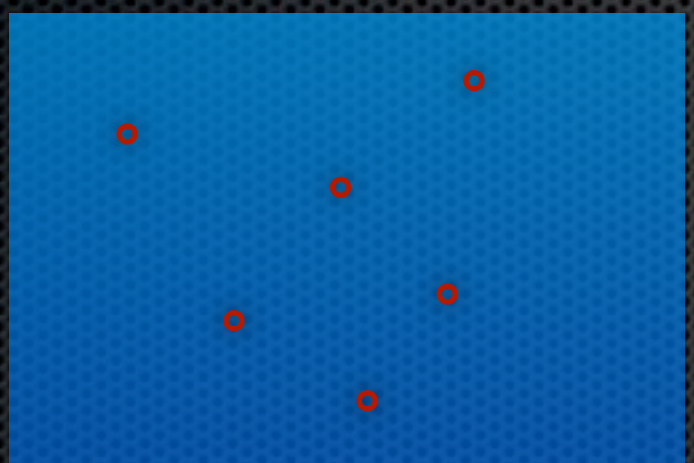

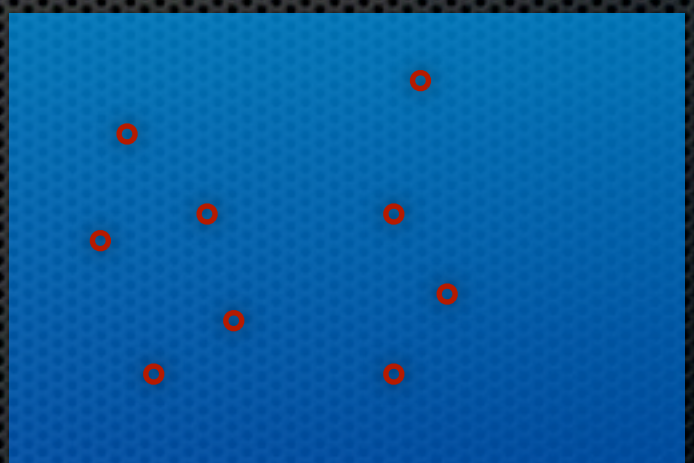

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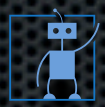

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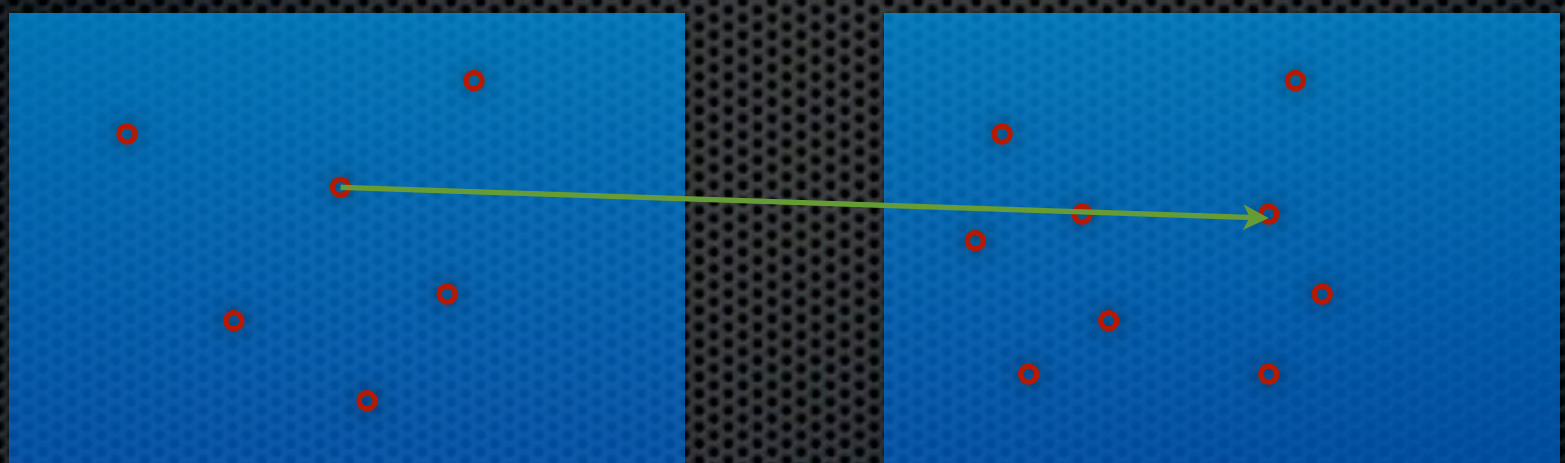

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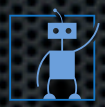

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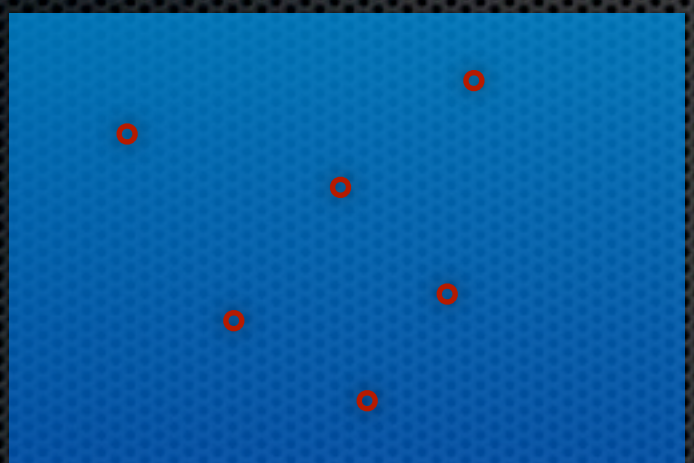

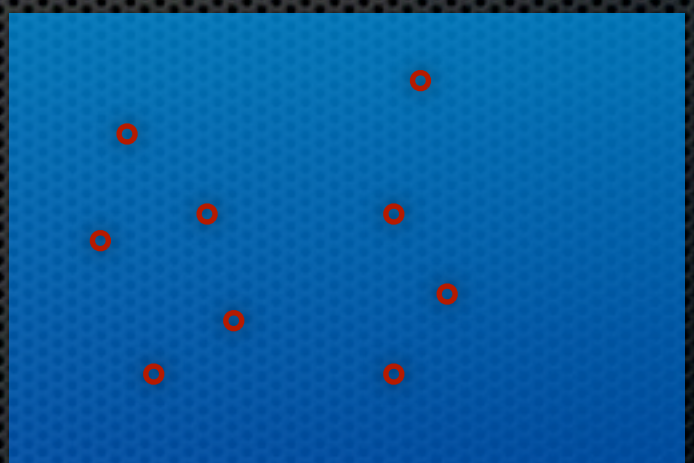

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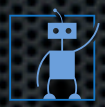

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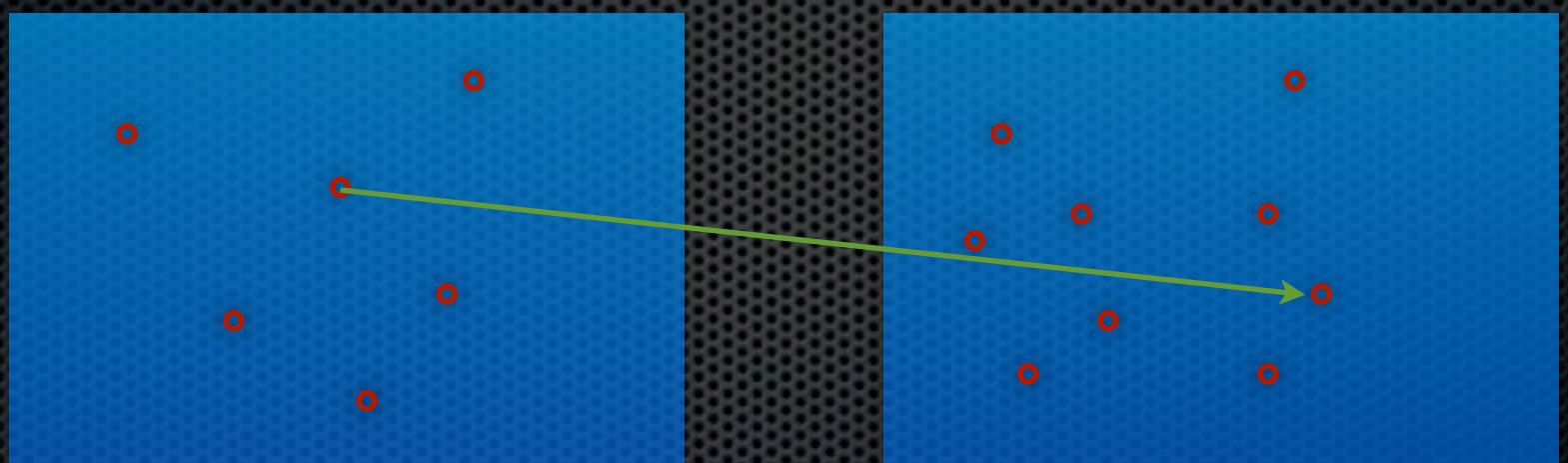

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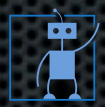

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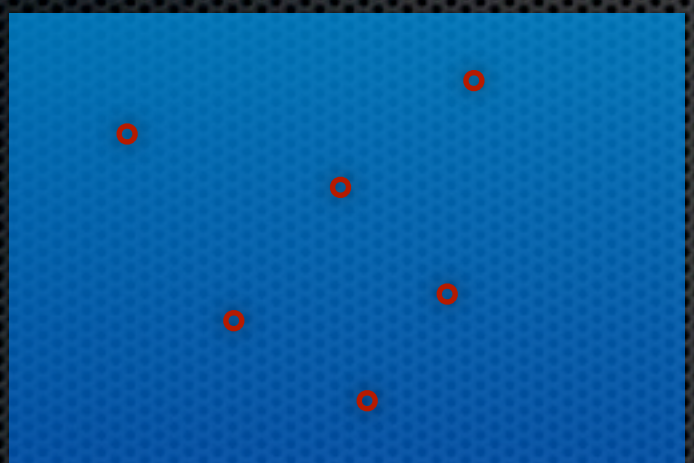

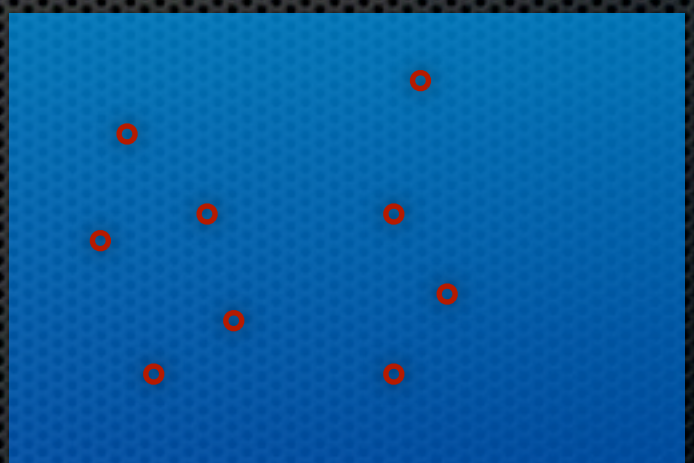

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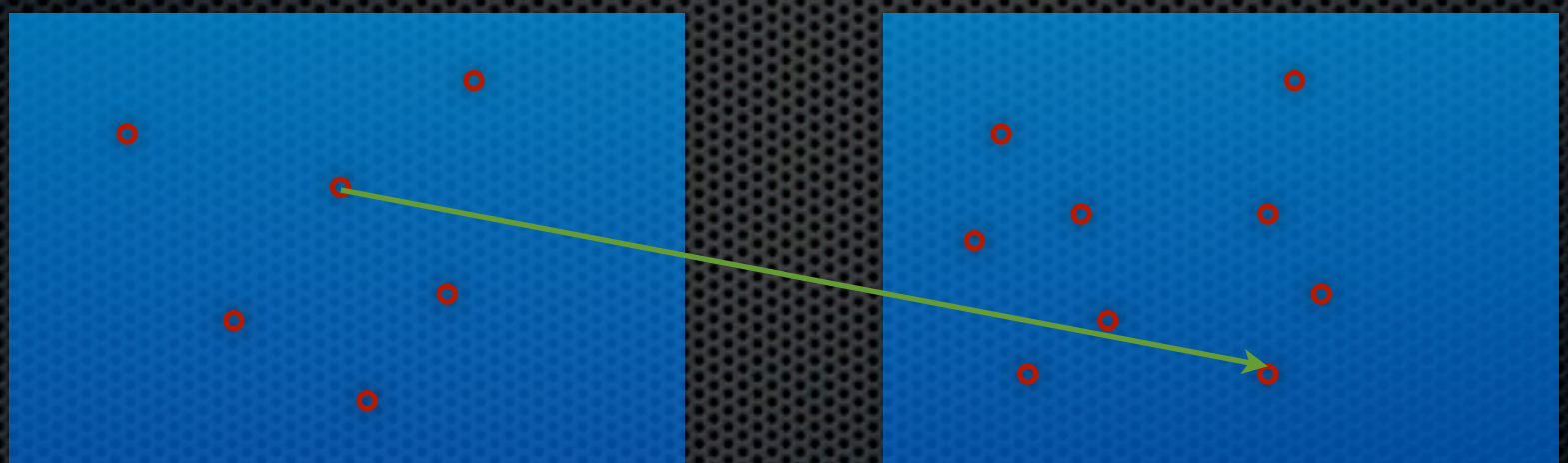

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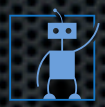

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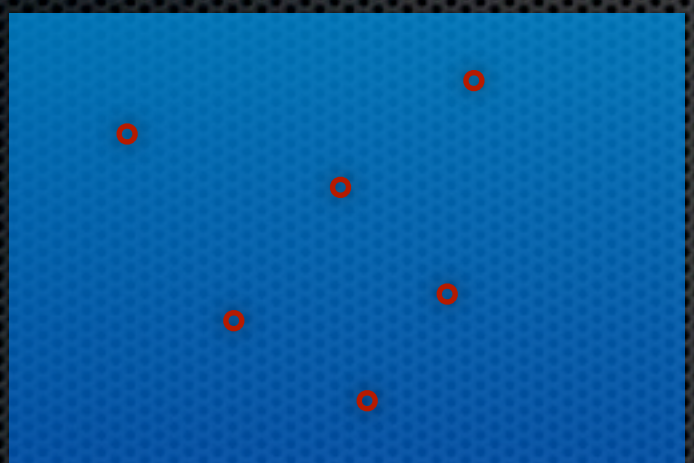

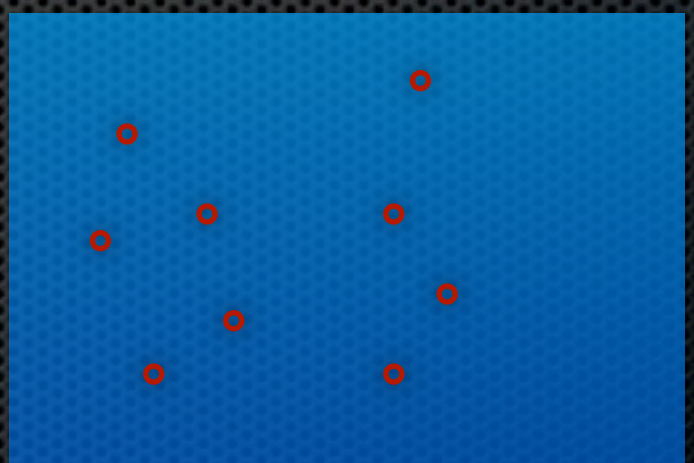

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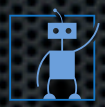

Robotics and
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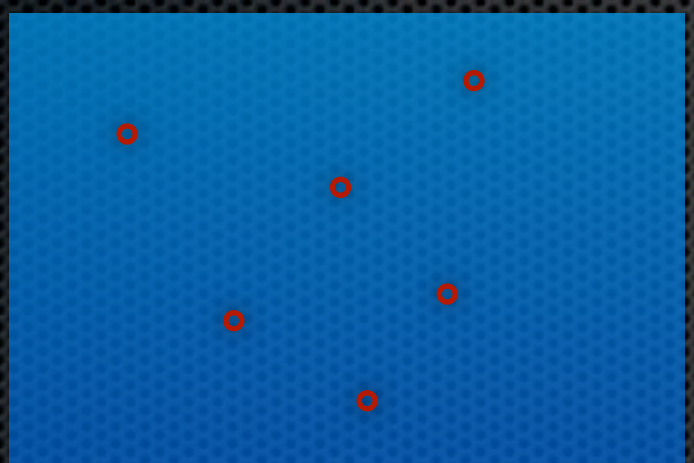
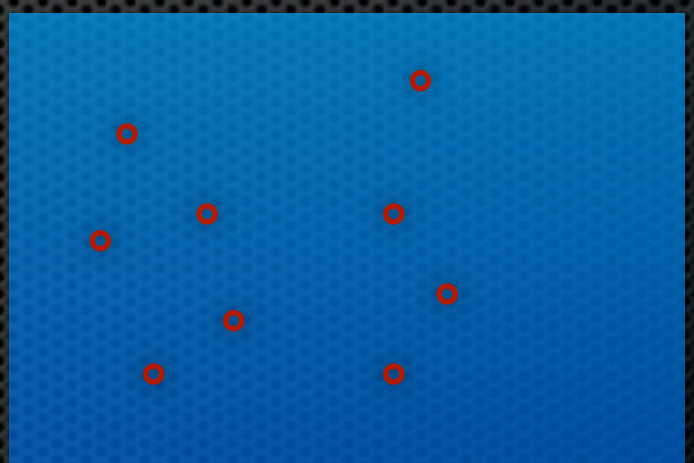




- Keep the best match (or a list of the best matches - see exercise sheet)

Homography DLT

Robotics and
Embedded Systems

- Calculate the transformation that best describes the observed feature matches
- Given 2d matches $\{\mathbf{x}_i \leftrightarrow \mathbf{x}'_i\}$
- Calculate homography such that

$$\mathbf{x}'_i = H\,\mathbf{x}_i$$

Homography DLT

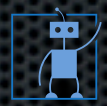
Robotics and
Embedded Systems

$$H\mathbf{x}_i = \begin{pmatrix} \mathbf{h}^{1\top}\mathbf{x}_i \\ \mathbf{h}^{2\top}\mathbf{x}_i \\ \mathbf{h}^{3\top}\mathbf{x}_i \end{pmatrix}$$

$$\mathbf{x}'_i = (x'_i, y'_i, w'_i)^\top$$

$$\mathbf{x}'_i \times H\mathbf{x_i} = \begin{pmatrix} y'_i\mathbf{h}^{3\top}\mathbf{x}_i - w'_i\mathbf{h}^{2\top}\mathbf{x}_i \\ w'_i\mathbf{h}^{1\top}\mathbf{x}_i - x'_i\mathbf{h}^{3\top}\mathbf{x}_i \\ x'_i\mathbf{h}^{2\top}\mathbf{x}_i - y'_i\mathbf{h}^{1\top}\mathbf{x}_i \end{pmatrix}$$

Homography DLT



Robotics and
Embedded Systems

$$\begin{bmatrix} \mathbf{0}^\top & -w'_i\mathbf{x}_i^\top & y'_i\mathbf{x}_i^\top \\ w'_i\mathbf{x}_i^\top & \mathbf{0}^\top & -x'_i\mathbf{x}_i^\top \\ -y'_i\mathbf{x}_i^\top & x'_i\mathbf{x}_i^\top & \mathbf{0}^\top \end{bmatrix} \begin{pmatrix} \mathbf{h}^1 \\ \mathbf{h}^2 \\ \mathbf{h}^3 \end{pmatrix} = \mathbf{0}$$

$$\begin{bmatrix} \mathbf{0}^\top & -w'_i\mathbf{x}_i^\top & y'_i\mathbf{x}_i^\top \\ w'_i\mathbf{x}_i^\top & \mathbf{0}^\top & -x'_i\mathbf{x}_i^\top \end{bmatrix} \begin{pmatrix} \mathbf{h}^1 \\ \mathbf{h}^2 \\ \mathbf{h}^3 \end{pmatrix} = \mathbf{0}$$

$$A_i\,\mathbf{h} = \mathbf{0}$$

Homography DLT

Robotics and Embedded Systems

- Every match generates an A_i
- Stack all A_i together to get a matrix A
- At least 4 matches are needed
- Solve for $A\mathbf{h} = \mathbf{0} \quad \text{s.t.} \quad ||x|| = 1$
- Special problem - solve using SVD

$$\text{SVD}(A) = U\Sigma V^\top$$

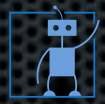
- Solution is the last column of V

Homography DLT

Robotics and Embedded Systems

- Current solution dependent on the scale of the points
- Normalization of the points needed
- Compute similarity transform T for the points $\mathbf{x}_i$ to a new set of points $\tilde{\mathbf{x}}_i$ with centroid $(0,0)^\top$ and average distance $\sqrt{2}$ to the origin
- Do the same for the points $\mathbf{x}'_i$ giving the transformation T'
- Compute the homography $\tilde{H}$ for the matches $\tilde{\mathbf{x}}_i \leftrightarrow \tilde{\mathbf{x}}'_i$
- Denormalize and get $H = T'^{-1}\tilde{H}T$

Homography to pose



Robotics and Embedded Systems

- Given the camera calibration and an estimate for the homography find the rotation and translation of the planar template

$$H = K[r_1\, r_2\, t] \quad G = K^{-1}H$$

$$l = \sqrt{||G_1||||G_2||}\; R_1 = \frac{G_1}{l},\; R_2 = \frac{G_2}{l},\; T = \frac{G_3}{l}$$

$$c = R_1 + R_2,\; p = R_1 \times R_2,\; d = c \times p$$

$$R_1' = \frac{1}{\sqrt{2}}\left(\frac{c}{||c||} + \frac{d}{||d||}\right),\; R_2' = \frac{1}{\sqrt{2}}\left(\frac{c}{||c||} - \frac{d}{||d||}\right)$$

$$R_3 = R_1' \times R_2'$$