Detection, Rectification and Segmentation of Coplanar Repeated Patterns

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Motivation

- Repetitive patterns are ubiquitous in images
- Unless considered, they usually decrease vision algorithm performance

Coplanar Repeats: Problem Formulation

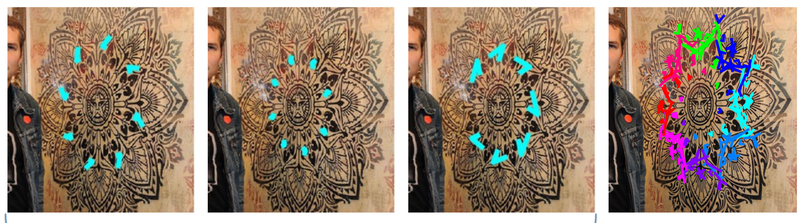
- Very *general definition* of a repeat; a single condition required:
  mapped by rigid intra-planar transforms
- No regularity of repeats required, e.g. in a lattice
- No special image structure needed other than repetition, e.g.:
  no parallel scene lines, axial symmetries or homologies needed
- We cover cases where:
  repeats cover only a small part of the image
  there are only a few repeats imaged

Contributions

- Automated method for coplanar repeat detection, rectification up to a similarity and pixel-level segmentation
- Linear geometric constraints and the necessary configurations of repeats for successive levels of rectification
- Generative model of repeated patterns inferred:
  motif, intra-plane mappings, rectification and lens distortion
- Reduce SIFT variance by geometric refinement of features

Repeats, Motifs, Instances and Patterns

Repeat: a photometrically consistent cluster of local affine frames satisfying a scale constraint (cf. Affine Rectification)
Motif: a spatially coherent collection of features
Instance: motif placed by one intra-planar mapping
Pattern: all instances of a motif in a single plane



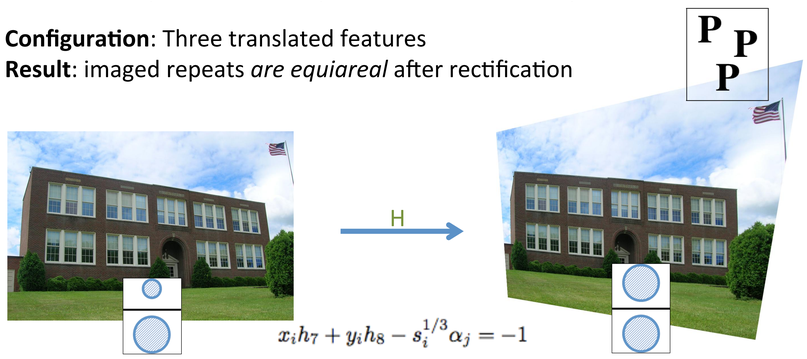
Repeats

Pattern with color-coded Instances

Affine Rectification

Constraint: equiareal scene repeats means rectified repeats are equiareal.

Configuration: Three translated features
Result: imaged repeats *are equiareal* after rectification

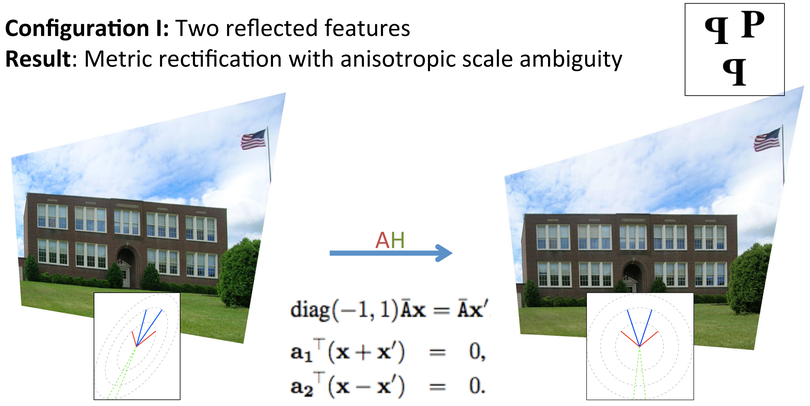


$$x_i h_7 + y_i h_8 - s_i^{1/3}\alpha_j = -1$$

Metric Rectification

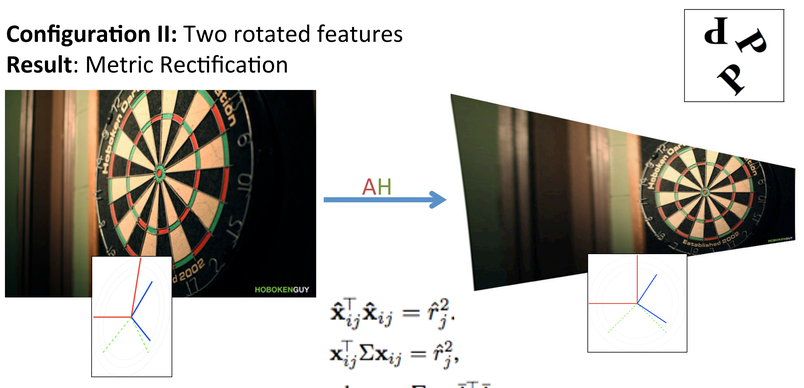
Constraint: congruent scene extents means rectified repeats have congruent extents

Configuration I: Two reflected features
Result: Metric rectification with anisotropic scale ambiguity



$$\mathrm{diag}(-1,1)\bar{\mathbf{A}}\mathbf{x} = \bar{\mathbf{A}}\mathbf{x}'$$
$$\mathbf{a_1}^\top(\mathbf{x}+\mathbf{x}') = 0,$$
$$\mathbf{a_2}^\top(\mathbf{x}-\mathbf{x}') = 0.$$

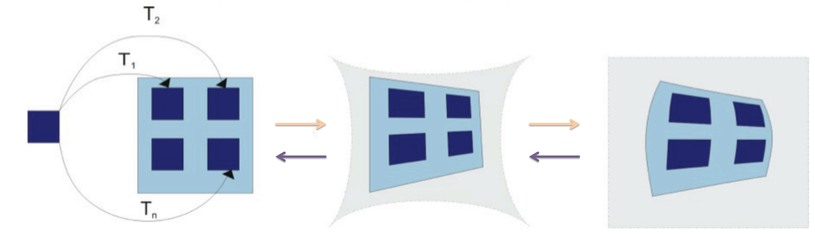
Configuration II: Two rotated features
Result: Metric Rectification



$$\hat{\mathbf{x}}_{ij}^\top \hat{\mathbf{x}}_{ij} = \hat{r}_j^2.$$
$$\mathbf{x}_{ij}^\top \Sigma \mathbf{x}_{ij} = \hat{r}_j^2,$$
$$\text{where} \quad \Sigma = \bar{\mathbf{A}}^\top \bar{\mathbf{A}}.$$

Generative Model

- Repeated pattern is explicitly modeled in rectified space
- Lens distortion estimated as a nuisance parameter
- Input to inference algorithm is ONLY an *unannotated image*
- Distance from reprojected model to imaged pattern minimized



Reprojection
Inference

$$\min_{\hat{\lambda},\hat{\mathbf{H}},\hat{\mathbf{T}}_j,\hat{\mathbf{v}}_i} \sum_{i=1}^{N} \sum_{j:\exists \mathbf{u}_{ij}} d(\mathcal{L}_{\hat{\lambda}}(\hat{\mathbf{H}}^{-1}\hat{\mathbf{T}}_j(\hat{\mathbf{v}}_i)), \mathbf{u}_{ij})$$

Lens Distortion | Rectification | Motif Positioning | Measurements

Pattern Estimation

- Estimate rectification and pattern jointly from an image
  1. SIFTs extracted from image and clustered
  2. Rectification estimated from linear constraints
  3. Clusters verified against scale constraint to make repeats
  4. Geometric hashing of LAFs in rectified space to construct motifs
- Refine pattern, rectification and model lens distortion by minimizing reprojection error of model

Rectifiations With Segmentations