Geometry-based Repetition Detection for Urban Scene

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Related Work

Sparse Feature Matching
[Loy et al. 06, Schindler et al. 08, Zhao et al. 11, ...]

Pixel-level Matching
[Liu et al. 04]

Model Template Matching
[Korah et al. 08, Müller 07, ...]

Projective, possibly non-planar, possibly 1D
Motivations

• Symmetry = Multiple Views
  – Different viewpoints
  – Not exactly symmetric in 2D due to projective transformations

• Symmetry + Geometry
  – Geometry-guided symmetry detection
  – Symmetry-based 3D dense reconstruction
Geometric Priors in Urban Scenes

- Planarly repeating structures
  - Repeating along vanishing point directions
  - Sometime only in one direction
  - Providing strong constraints for matching
Geometric Priors in Urban Scenes

- Coexisting 3D translational and reflective symmetry
  - Repeating structures are mostly reflective symmetric
  - Providing a strong constraint for repetition detection
Symmetry-based Planar Reconstruction

- Vanishing Point (VP) detection
  - Extract VPs based repeating features and line segments
  - Entropy-based refinement for better quality of symmetry

Repeating SIFT features

Distribution of horizontal distances between feature pairs

Perspective View

Rectified View
Symmetry-based Planar Reconstruction

- Vanishing Point (VP) detection
  - Extract VPs from repeating features and line segments
  - Entropy-based refinement for better quality of symmetry

![Repeating SIFT features](image1)

![Hist. of horizontal distance](image2)

![Hist. of Vertical distance](image3)
Initializing Repeating Regions

- Coexisting translational and reflective symmetry
  - Intervals between symmetry axes are half of repetition
  - Very robust to outliers
Propagating with Robust Matching

• Use proportional patch size
  – Robust to the scale changes of repetition
• Use SIFT descriptor for patch matching
  – Robust for small perspective changes
Salient Repeating Regions

- Finding salient boundaries
  - Translational symmetry often occurs in only one direction
  - Minimum repetition Intervals
  - Scoring based on SIFT distance ratio

\[
\frac{\text{dist. of interval } I}{\text{2nd smallest from dist. of interval } (I, I/2, I/3, \ldots)}
\]

Good if no smaller intervals match

Bad if smaller intervals match
Analyzing Variations

• Decompose the repetition regions
Detecting Vanishing Points

Detection Walkthrough
Detection Experiments
Detection Experiments

Robust to viewpoint changes
Quantitative Evaluation

- Zürich Building Database (ZuBuD)
  - 201 building, 5 images per building (excluding 282)
  - 96%: successful vanishing point detection.
  - 70%: full detection of major repetition regions
Scene Recognition

• Single Feature Image Retrieval
Repetition for Scene Recognition

• Single Feature Image Retrieval

• Retrieval Evaluation

SIFT-like Descriptor
Where Pixel-level Geometry Helps?

- Recognition, hole filling, symmetrization, ...
The Geometry of 3D Repetition

• Multiview Geometry

• From 3D to 2D rectified images
  – Simple transformation
    \[(x, y)^T = \left(\frac{aX}{Z} + b, \frac{cY}{Z} + d\right)^T\]
  – Repeating pixels
    • Lie on the same scanlines
    • Disparity-like repetition interval
      \[I_Z = \frac{a}{Z}\]
Dense Reconstruction

Repetition interval map $f(p)$

Energy function

$$E(f) = E_{data}(f) + E_{smooth}(f) + E_{repetition}(f)$$

$f(p - f(p))$ and $f(p + f(p))$ are similar to $f(p)$
Dense Reconstruction

Repetition interval map $f(p)$

Energy function $E(f) = E_{\text{data}}(f) + E_{\text{smooth}}(f) + E_{\text{repetition}}(f) + E_{\text{sym}}(f)$
Applications

• Using symmetry and 3D geometry together
  – More accurate using of symmetry
  – Allows to copy correct pixels within the single image

• Applications
  – Hole filing according to repetition or reflection
  – Ortho-rectified images (invariant representation)
Ortho-rectified Image

Median representation  Ortho-rectification based on dense reconstruction
Conclusions

• Exploiting the synergy with multiview matching
  – Robust matching by using dense SIFT grids
  – MRF-based optimization
  – From sparse to dense

• Geometry facilitates symmetry
  – Exploiting geometric priors of urban scenes
  – Using coarse planar geometry to guide 3D symmetry detection
  – Combining symmetry and 3D geometry for applications

• Symmetry leads to geometry
  – The symmetry-based planar reconstruction (VP).
  – The symmetry-based dense reconstruction
Thank you