Detecting Large Repetitive Structures with Salient Boundaries

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Changchang Wu
UNC-Chapel Hill, USA
ccwu@cs.unc.edu

Jan-Michael Frahm
UNC-Chapel Hill, USA
jmf@cs.unc.edu

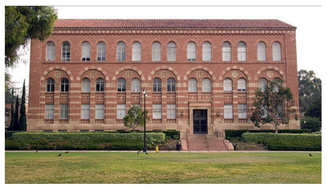
Marc Pollefeys
ETH-Zürich, Switzerland
marc.pollefeys@inf.ethz.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Repetition Detection

In urban photos, regions of repeating elements are often **large**.

- Large appearance variations between elements due to occlusions, reflections, depth changes, or actual structural differences, etc




Key Observations

- Repetitions happen along Vanishing Point (VP) direction(s)
  - Allows our repetition-based VP refinement
- Reflective symmetry along the horizontal direction
  - Enables our boundary selection deploying the coexistence of repetition and reflective symmetry
- Possible lack of repetition/symmetry in the vertical direction
  - Determine the boundaries according to the repetition in the perpendicular direction with a novel repetition quality measurement

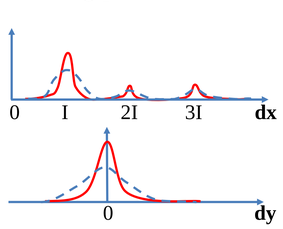
Algorithm Outline

1. Vanishing point detection and image rectification
2. Finding possible repetition intervals and symmetry axes
3. Determining regions for each new repetition interval

Repetition-based VP Refinement

- The horizontal/vertical differences of the matched feature pairs should have histograms with only a few strong peaks.
- Similar for symmetrical feature pairs and edge segments
- **Entropy**-based optimization of vanishing point

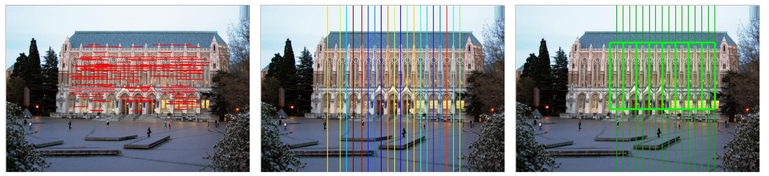
Example of matched feature pairs along VP directions



Histogram of coordinate differences (**dx** and **dy**) in rectified image; The optimization seeks strong narrow peaks (red vs. blue)

Repetition Intervals and Symmetry Axes

- The distances between repeating symmetry axes are equal to half of the repetition interval (width of repeating element)



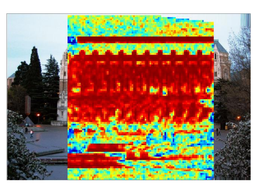
- Initialize repetition regions from groups of repeating axes

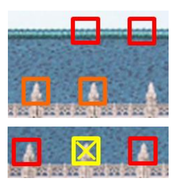
Determining Boundaries of Repetition Region

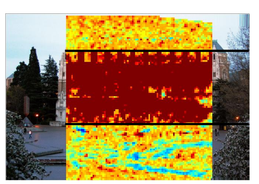
- **Evaluate patch similarity for repetition**
  - Adaptive patch size proportional to the repetition interval
  - Robust comparison by using upright SIFT descriptor (GPU)
  - ***D(x, I)*** denotes the distance at location **x** for interval **I**
  - Propagate regions according to the similarity measurements
- **Distinguish with integer multiples of repetition**
  - Choose a set of offsets $T = \{0, \pm I/2, \pm I/3, ...\}$
  - Compute a set of distances $V = \{D(x, I + t) \mid t \in T\}$
  - Repetition quality measurement based on distance ratio

$$f(x, I) = \min(\alpha \frac{V_{(2)} + \sigma}{D(x, I) + \sigma}, 1)$$

where α is a ratio parameter, and σ is the variance parameter

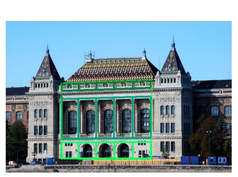
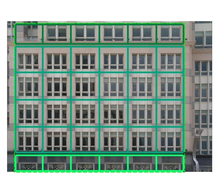
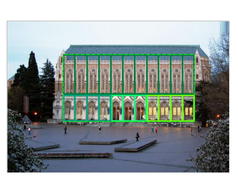

Similarity


Ambiguity

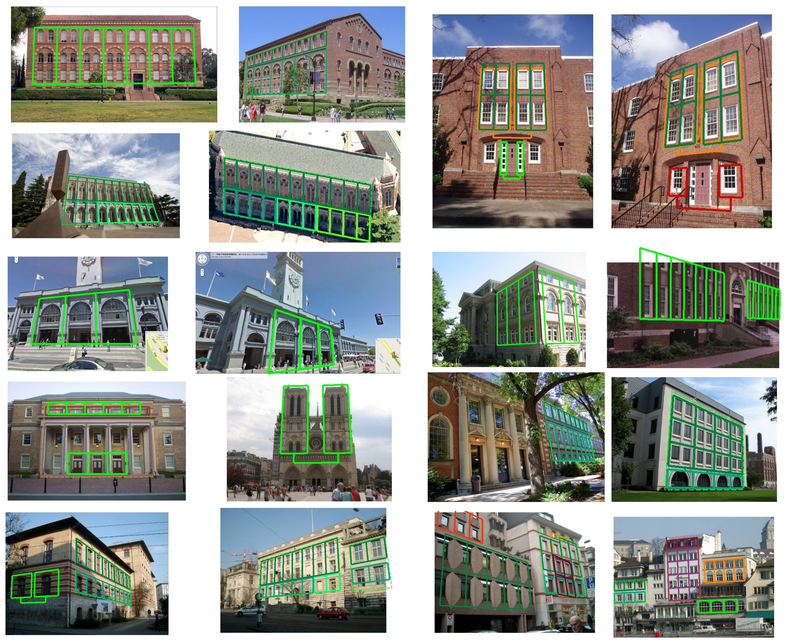

Repetition Evaluation

- Determine vertical boundary for non-repeating direction

- **Further decomposition of repetition regions**
  - Divide regions at multiple vertical locations
  - Find repetition along the vertical repetitions
  - Decompose regions according to continuation of repetition

Qualitative Results



Quantitative Evaluation

- Evaluation of our repetition detection on the Zürich Building Database (ZubuD) : 1005 images; 5 images per building.
  http://www.vision.ee.ethz.ch/showroom/zubud/

Category (excluding 282 manually discarded images)	#	Percentage
No detection due to VP detection failure	25	4%
No correct detection due to other algorithmic limitations	34	5%
Partial Detection; Missing major repetitions	88	12%
Full detection of all major repetitions; Some boundaries errors	67	9%
Full detection of all major repetitions; Good boundaries	509	70%

- Single feature image retrieval on ZubuD.

- Describe repeating elements by 4x4 or 8x8 gradient histogram
- Query closest image for every element (Consider correct if a retrieval belong to the other 4 images of the same building)
- Use the standard SIFT feature as a baseline for comparison