Repetition-based Dense Single-View Reconstruction

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Single Image 3D Reconstruction

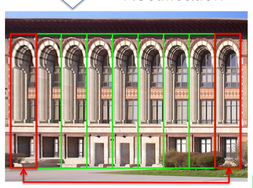
Overview

1. Dense correspondence of repeating pixels within a single image.
2. Exploiting constraints of 3D repetition and 3D reflective symmetry.
3. Modeling the high-level constraints as regular energy functions.

Non-planar Repeating Structures

- The 3D symmetries are projectively transformed to 2D.
- Each element is a different view of the common 3D structure.

Homography Rectification



2D symmetrization? The 2D elements are not perfectly reflective-symmetric.

2D element copying? Each element is still different in the rectified images.

Outliers challenge reconstruction and other applications.

Geometric relationship

Let the camera be at the origin and the 3D structure repeat along X, then the transformation from 3D geometry to the rectified image is

$$(x, y)^T = (\frac{aX}{Z} + b, \frac{cY}{Z} + d)^T$$

And the repetition interval in the rectified image is

$$I_Z = \frac{a}{Z}$$

The position of reflective symmetry axis depends on the depth

$$x = \frac{a(X_0 + \frac{i}{2})}{Z} + b = (X_0 + \frac{i}{2})I_Z + b$$

Optimization framework

Dense estimation of repetition interval f=Iz instead of depth Z

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

Data term: repetitive color pattern

The corresponding pixels should have similar appearances

$color(p \pm f(p))$ are similar to $color(p)$

Penalize the color differences, and employ robust dissimilarity measure to handle the challenging appearance variations

Repetition term: repetitive 3D structure

The repeating pixels should have similar labels (depths)

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

Penalize the depth differences between the corresponding pixels

$$E_{repetition} = \omega_{rep} \sum_{q_y = p_y,\ R_f(q,q)=1} G(p,q)\, \rho(f(p) \neq f(q))$$

$|p_x - q_x| \in \{f(p),\ f(q)\}$

only if p,q have similar color

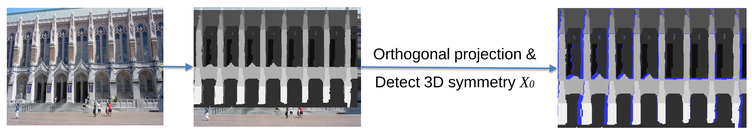
The pixel pairs are dynamic due to the depth dependency, but the function can be mapped to a fixed neighborhood as follows

$$E_{repetition} = \omega_{rep} \sum_{|q_x - p_x| \in L,\ q_y = p_y} R_f(p,q)\, G(p,q)\, \rho(f(p) \neq f(q))$$

The repetition term is regular and can be optimized by α-expansion.

Reflective-symmetry term

Reflective symmetry can be enforced similar to repetition and the 3D symmetry parameter X_0 is additionally required.



Algorithm

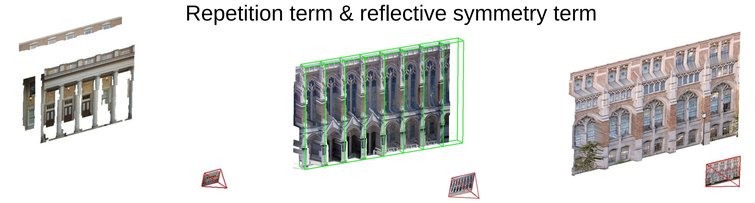
1. Use graphcut to solve f without the reflective symmetry tem,
2. Find the refined interval range from f,
3. Re-optimize the labeling f on the refined interval range,
4. Extract the symmetry position parameter X_0 from f ,
5. Include the reflective symmetry term and re-optimize.

Reconstruction Results

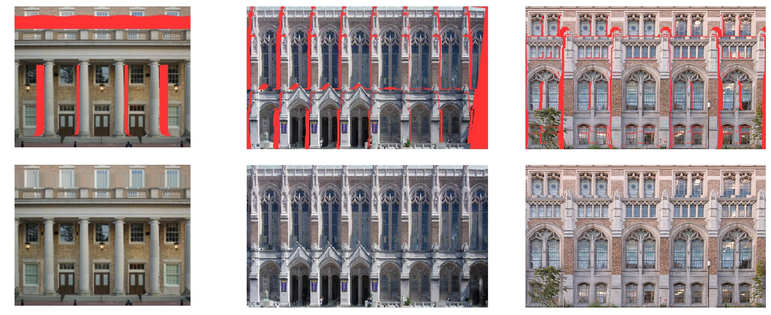
No symmetry constraints

Repetition term

Repetition term & reflective symmetry term

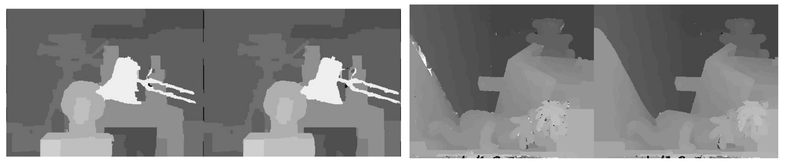


Orthogonal Rectification



Symmetric Stereo as 3D Repetition

Combine the stereo image pairs (L, R) to a single *repetition* image [R, L]



Symmetrically enforces the consistency between multiple disparity maps