Coupled Structure-from-Motion and Symmetry Detection for Urban Facades

Duygu Ceylan  Niloy J. Mitra  Youyi Zheng  Mark Pauly
3D Reconstruction of Urban Scenes

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
3D Reconstruction of Urban Scenes

CityEngine

urban design

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
3D Reconstruction of Urban Scenes

CityEngine

urban design

content creation

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
3D Reconstruction of Urban Scenes

CityEngine
urban design

CubeCities
data visualization

NextSpace

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
3D Reconstruction of Urban Scenes

CityEngine

urban design

CubeCities

data visualization

Google Maps

content creation

mapping and navigation

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3D Reconstruction of Urban Scenes

CityEngine

urban design

cubeCities

data visualization

Google Maps

content creation

Microsoft Bing Maps

mapping and navigation

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Image-based Reconstruction

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Correspondence search

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Image-based Reconstruction

correspondence search

structure-from-motion (SfM)

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Image-based Reconstruction

correspondence search

structure-from-motion (SfM)

dense reconstruction (PMVS)

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Correspondence Problem

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Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Artifact Types
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standard output (Bundler + PMVS)

desired output (ours + PMVS)

poor/noisy output

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Artifact Types

standard output (Bundler + PMVS)

poor/noisy output

desired output (ours + PMVS)

incorrect number of repeating elements

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Related Work

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Related Work

internet images:

Bundler (Snavely et al. ‘2006)
Related Work

internet images:

Bundler (Snavely et al. ‘2006)

global relations:

Zach et al. ‘2010

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Related Work

internet images:

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Related Work

internet images: 

Bundler (Snavely et al. ‘2006)

global relations:

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duplicate structures:

Jiang et al. ‘2012

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Related Work

internet images:

Bundler (Snavely et al. ’2006)

duplicate structures:

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global relations:

Zach et al. ‘2010

Cohen et al. ‘2012

Wilson et al. ‘2013

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
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Main Observation: Joint Detection & SfM

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
‘Grid’ Matching

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Local & Global Alignment

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Global Grid Alignment

unknown
global grid

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Global Grid Alignment

unknown global grid

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Global Grid Alignment

unknown global grid

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Local Alignment

original image pair
Local Alignment

original image pair

detected 2D grids

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
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original image pair

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Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
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alignment ~ shifts in rows/columns

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original image pair

detected 2D grids

alignment ~ shifts in rows/columns

20 supporting feature matches

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Local Alignment

original image pair

detected 2D grids

alignment ~ shifts in rows/columns

51 supporting feature matches

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Local Alignment

original image pair

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alignment ~ shifts in rows/columns

51 supporting feature matches

image matching graph

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

image matching graph

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Global Alignment

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image matching graph
Global Alignment

image matching graph
Global Alignment

image matching graph

\[ \text{total shift in rows/columns} \neq 0 \]
\[ \text{inconsistent loop} \ L_i \]
Global Alignment

\[ \chi_e \in [0, 1] \]

image matching graph

total shift in rows/columns \( \neq 0 \)

inconsistent loop \( L_i \)

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

\[ \chi_e \in [0, 1] \]

image matching graph

\[
\min \{ \chi_e \} \quad \sum_{e \in E} w_e \chi_e
\]

subject to \[ \sum_{e \in L_i} \chi_e \geq 1 \]

linear programming (CVX)

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

Initial graph
Global Alignment

initial graph

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Global Alignment

initial graph

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

initial graph

iteration 3

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Global Alignment

initial graph

iteration 3

iteration 6 (final iteration)

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Symmetry-Aware Bundle Adjustment

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Symmetry-Aware Bundle Adjustment
Symmetry-Aware Bundle Adjustment

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Symmetry-Aware Bundle Adjustment

$P + T_{hor}$

$P + T_{ver}$

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

input images
Results

input images

Bundler + PMVS

Symmetry-aware SFM + PMVS

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

Bundler + PMVS

input images

Symmetry-aware SFM + PMVS

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

Bundler + PMVS

input images

Symmetry-aware SFM + PMVS

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

input images

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Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

Coupled SFM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Results

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Comparisons

input images
Comparisons

Zach et al. '2010 + PMVS

Symmetry-aware SFM + PMVS

input images

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Comparisons

Zach et al. ‘2010 + PMVS

Symmetry-aware SFM + PMVS

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Comparisons

input images

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Comparisons

Jiang et al. ‘2012 + PMVS

Symmetry-aware SFM + PMVS

input images
Comparisons

input images

Jiang et al.'2012 + PMVS

Symmetry-aware SFM + PMVS

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Applications: Image Editing

image 1

original images (7-by-4 grid)  edit-1 (9-by-5 grid)  edit-2 (5-by-3 grid)

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Applications: Occlusion Removal

image 1  image 2  image 3

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Summary

... input images
Summary

input images

partial 2D grids
Summary

input images

partial 2D grids

global optimization
Summary

input images

partial 2D grids

global optimization

complete 2D symmetry information

camera parameters + 3D symmetry information
Limitations & Future Work

insufficient discriminating features
Limitations & Future Work

insufficient discriminating features

our method  Bundler

Coupled SfM and 3D Symmetry Detection for Urban Facades, Ceylan et al. (ACM TOG 2014)
Limitations & Future Work

insufficient discriminating features

our method  Bundler  irregular/rotational symmetries

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