Factored Facade Acquisition using Symmetric Line Arrangements

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3D Reconstruction of Urban Scenes

Google Earth
Microsoft Visual Earth

urban design
mapping and navigation

content creation
virtual tours

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
State of the Art

Multi-View Stereo
State of the Art

Multi-View Stereo

Furukawa et al.
CVPR’07
State of the Art

Multi-View Stereo

Furukawa et al.
CVPR’07

Furukawa et al.
CVPR’09

Sinha et al.
ICCV’09

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State of the Art

Multi-View Stereo

Furukawa et al.  
CVPR’07

Furukawa et al.  
CVPR’09

Sinha et al.  
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Wu et al.  
CVPR’11

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State of the Art

Multi-View Stereo

Furukawa et al. CVPR’07
Furukawa et al. CVPR’09
Sinha et al. ICCV’09
Wu et al. CVPR’11

Other Data Sources

Zheng et al. Siggraph’10
Li et al. ICCV’11

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State of the Art

Multi-View Stereo

- Furukawa et al. CVPR’07
- Furukawa et al. CVPR’09
- Sinha et al. ICCV’09
- Wu et al. CVPR’11

Other Data Sources

- Zheng et al. Siggraph’10
- Li et al. ICCV’11
- Xiao et al. Siggraph’08

Procedural Modeling

- Muller et al. Siggraph’08

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Challenges

tall buildings
Challenges

tall buildings

textureless regions
Challenges

tall buildings

strong variation in illumination

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Challenges

- tall buildings
- textureless regions
- strong variation in illumination
- reflective surfaces

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Our Algorithm
Our Algorithm

input images

output reconstruction

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Our Algorithm

input images

3D lines

output reconstruction

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Our Algorithm

input images

3D lines

plane fitting

output reconstruction

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Our Algorithm

input images

3D lines

plane fitting

structure detection

output reconstruction

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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
3D Line Reconstruction

2D edges

multi-view stereo on the edges

3D lines

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3D Line Reconstruction

2D edges

3D lines

input image

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3D Line Reconstruction

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3D Line Reconstruction

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3D Line Reconstruction

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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Candidate Plane Generation
Candidate Plane Generation

Pick a pair of lines
Candidate Plane Generation

Pick a pair of lines

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Candidate Plane Generation

Pick a pair of lines

Coplanar?
Candidate Plane Generation

Pick a pair of lines

Coplanar? yes

Generate 3D plane
Candidate Plane Generation

Pick a pair of lines

Coplanar?

yes

Generate 3D plane

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Candidate Plane Generation

Pick a pair of lines

Coplanar?

yes

Generate 3D plane

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Candidate Plane Generation

Pick a pair of lines

\[\text{Coplanar?}\]

yes

Generate 3D plane

Find inlier lines

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Candidate Plane Generation

Pick a pair of lines

Coplanar?

yes

Generate 3D plane

Find inlier lines

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Candidate Plane Generation

- Pick a pair of lines
  - Coplanar?
    - yes
    - Generate 3D plane
    - Find inlier lines

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Candidate Plane Generation

Pick a pair of lines

Coplanar?

yes

Generate 3D plane

Find inlier lines

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Candidate Plane Generation

- Pick a pair of lines
- Coplanar?
  - yes
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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Candidate Plane Generation

- Pick a pair of lines
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  - yes
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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Image Segmentation

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Image Segmentation

What is the most likely plane assignment for each pixel?
What is the most likely plane assignment for each pixel?

\[ E = \sum_{p \in I_i} E_{data}(h_p) + \alpha \sum_{\{p,q\} \in N_p} E_{smooth}(h_p, h_q) \]
What is the most likely plane assignment for each pixel?

\[ E = \sum_{p \in I_i} E_{data}(h_p) + \alpha \sum_{\{p,q\} \in N_p} E_{smooth}(h_p, h_q) \]
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Image Segmentation

What is the most likely plane assignment for each pixel?

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\]
What is the most likely plane assignment for each pixel?

\[
E = \sum_{p \in I_i} E_{data}(h_p) + \alpha \sum_{\{p,q\} \in N_p} E_{smooth}(h_p, h_q)
\]

Markov Random Field (MRF) Optimization

Kolmogorov Pami’06

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Refined Segmentation

input

MRF optimization

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Refined Segmentation

input

MRF optimization

plane intersections

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Refined Segmentation

input

MRF optimization

plane intersections

user correction

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User Assistance
User Assistance
User Assistance

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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Symmetry Detection

Wu et al. CVPR’10

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Symmetry Detection

Wu et al. CVPR’10

user-guided selection
Symmetry Detection

Wu et al. CVPR’10

user-guided selection

texture-based similarity

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Symmetry Detection

Wu et al. CVPR’10

user-guided selection

texture-based similarity

feature-line similarity
Symmetry Detection

\[ \alpha \cdot + \beta \cdot \]

Wu et al. CVPR’10

user-guided selection

texture-based similarity

feature-line similarity

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Symmetry Refinement

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Symmetry Refinement

\[
\begin{align*}
\vdots & \\
\cdots t & \\
\vdots & \\
\cdots (k-2)t & \\
\cdots (k-1)t & \\
\end{align*}
\]
Symmetry Refinement

\[
\begin{align*}
\text{Line Fitting} \\
&= t \\
&= (k-2)t \\
&= (k-1)t
\end{align*}
\]
Symmetry Refinement

\[
\begin{align*}
\vdots \quad t \\
\end{align*}
\]

Line Fitting

\[
\begin{align*}
\vdots \quad t \\
(k-2)t \\
(k-1)t \\
\end{align*}
\]

Transformation Optimization

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Structure Completion

input

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Structure Completion

input

initial detection
Structure Completion

input

initial detection

initial refinement

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Structure Completion

input

initial detection

initial refinement

projected 3D lines

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Structure Completion

input
initial detection
initial refinement
completion

projected 3D lines
Structure Completion

- Input
- Initial detection
- Initial refinement
- Completion

Projected 3D lines

2D lines

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Structure Completion

input

initial detection

initial refinement

projected 3D lines

2D lines

completion

final refinement:
Structure Completion

input

initial detection

initial refinement

projection 3D lines

2D lines

final refinement:

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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Procedural Depth Refinement

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Procedural Depth Refinement

no user edit
Procedural Depth Refinement

no user edit

window extrusion

Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Procedural Depth Refinement

no user edit  window extrusion  beam extrusion

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Factored Facade Acquisition Using Symmetric Line Arrangements, Ceylan et al.
Summary

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Results
Results
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Comparison to PMVS

input

PMVS
Furukawa et al. ’09

PMVS + Poisson

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Comparison to PMVS

Input

PMVS
Furukawa et al. ’09

PMVS + Poisson

Repetition detection

Our reconstruction

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More Results
More Results
More Results

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Limitations
Limitations

insufficient lines
Limitations

- insufficient lines
- variations in repetitions
Limitations

- insufficient lines
- variations in repetitions
- curved features

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Limitations

- insufficient lines
- curved features
- variations in repetitions
- no repetitions

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What’s Next?

building colonies

similar architecture style

Structure-from-Motion

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