Image-based Modeling

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Overview

■ Introduction
■ From pixels to 3D points
  ■ Structure from motion
  ■ A quasi-dense approach
■ From 3D points to objects
  ■ Small-scale objects
    ■ Smooth surfaces, Hairs, Trees
  ■ Large-scale buildings
    ■ Façade, Buildings, Cities
■ Conclusions
Introduction

- Computer vision
  - 3D reconstruction from images
  - One of the fundamental vision problems
- Computer graphics
  - Modeling: creating 3D digital models
    - Interactive methods (using softwares like Maya)
    - Use scanners
  - Use photographs → image-based modeling
    - For existing objects
    - Photorealistic models
    - Can be automated
Modeling/3D reconstruction applications

- TV/movie post-production, special effects,
- Virtual realities, 3D game creation
- Photogrammetry
- Robotics navigation
- ...
- Modeling the world:
  - Google Earth, Virtual Earth!
One example of small-scale object

take images (1 of 35)
3D mesh model
Rendered by Maya
One example of large-scale object
Two challenging components:

- How to get 3D points and camera positions from 2D pixels? (geometry computation or structure-from-motion (SFM))

- How to get 3D objects from unstructured 3D points? (object modeling)

Objects are of different natures:
- Smooth objects (surface reconstruction)
- Curvilinear objects (hair modeling)
- Complex fine details (tree modeling)
- Large-scale objects (city modeling)
Structure from Motion
Standard Sparse SFM

- Sparse feature detection (points of interest, or SIFT)
- Heuristic Initial matching of feature points by local image similarities
- Correspondence using RANSAC with minimum algebraic solution
- Auto-calibration
- Optimization of cameras and points (bundle adjustment)

There are textbooks (Faugeras, Hartley/Zisserman) and commercial softwares for sparse SFM.
A Quasi-dense approach

- Dense (per pixel) reconstruction is impossible
- Standard Sparse (feature) reconstruction is insufficient

- Quasi-dense: re-sampled (un-interpolated) disparity maps

captured 26 images

3D points and camera positions

A Quasi-Dense Approach to Surface Reconstruction from Uncalibrated Images
Lhuillier and Quan, IEEE PAMI 2005
Advantages of Quasi-dense:

- Hand-held camera (uncalibrated)
- Fully automatic computation
- Robust and accurate (the example is impossible with other existing methods)
- Pave the way for further object modeling (with sufficient density of points cloud, often impossible with sparse)
Object Modeling
Structuring points into objects!

SFM

Modeling
Surface reconstruction

- Model a wide variety of relatively smooth objects
- Prior is ‘smoothness’
- Mathematically well studied:
  - Implicit surface
  - Variational principle
  - Level-set implementation
Hair Modeling

- Difficult due to insufficient image resolution
  - Typically 500*500 pixels for 50,000 hair fibers
- Only Hair strands, group of hair fibers, are visible
Hair modeling approach

- Prior model: a curve approximated by a polyline
- Constraint: Polyline Growth by following edge orientation
Examples, fiber by fiber, 300K fibers

Modeling Hair from Images, Wei, Ofek, Quan, Shum, Siggraph 2004.
Tree modeling

- Trees are ubiquitous but difficult to model
  - Complex geometry and topology
  - Fine texture details

relative leaf size

Tree spectrum
But, trees have self-similar structure: a natural generative model for both leaves and branches.

All leaves are similar: a generic model for all leaves of a type of plants.
Example

Each leaf has individual geometry and texture.

one of the 35 input images  
recovered model

Image-based Plant Modeling,
- But, trees have self-similar structure: a natural generative model for both leaves and branches
- All leaves are similar: a generic model for all leaves of a type of plants
- The branches are self-similar, a kind of fractal!
One of the 18 input images   Recovered tree model

“This is probably the first image-based tree modeling method that produces a quality that could be adequate for movies. Earlier work produced results that were suitable for virtual reality applications, but not really anything that could be confused with a real image. Here, that seems within reach!” from one siggraph reviewer.

Image-based Tree Modeling,
Provisional summary:

- generative rules
- generic models
- Data(image)-driven
Large-Scale Object Modeling
City → buildings → façades

- Challenging ‘large-scale’ buildings vs ‘small-scale’ objects
- Spatial constraints for capturing
- Scale and automation
Prior knowledge on buildings and façades

- Generic shape:
  - rectangle (approximation at a given scale, the ground level street-view)

- Generative rules:
  - rectangular boxes $\rightarrow$ rectangles $\rightarrow$ nested rectangles with different offsets
Basic ideas: facade by facade

- Initialization as a flat rectangle in space
- Decomposition:
  - Dividing recursively the facade into small rectangular patches (building blocks)
  - Regularize the depth (quasi-dense 3D point)
- Augmentation by quasi-dense
- Completion (texture refetching)

*Image-based Façade Modeling, Xiao, Fang, Tan, Zhao, Ofek, and Quan, SIGGRAPH ASIA 2008.*
Image-based Façade Modeling

Paper ID: 0273
Image-Based Façade Modeling
Example for Hennepin avenue:
Comparison with Virtual Earth models
Example of Canton street

614 images by a handheld camera
Large-scale $\rightarrow$ full automation

- Interactive $\rightarrow$ automatic
- Segmentation is the key
- A fully automatic approach to building modeling
Classification and segmentation

Five classes: buildings, sky, ground, vegetation, the others

Input image → Over-segmentation → Classification (single view) → Segmentation (multi-view)
Multiple View Semantic Segmentation for Street-view Images
Pipeline overview

- (scene) classification and segmentation
- (building block) decomposition scheme
- (façade) structure analysis and modeling
Building partition: using vertical lines

- Detection of lines
- Match only horizontal and vertical lines
  → using vanishing points
- Reconstruct only vertical lines
  → for the lateral motion of the camera
Building partition → façades

Decompose the buildings into small modelable blocks or facades
Façade modeling: Patch reconstruction and ortho composition

• Over-segmentation [Felzenszwalb and Huttenlocher 2004].
  Estimate centroids
  Estimate normal directions
• Ortho-image space (object space)
Patch-reconstruction and Ortho-composition

Depth map
Texture map

→ From single image

Input image  Ortho image

→ From multi image
Façade modeling: Structure analysis

- Joint segmentation
- Shape regularization
Façade modeling: final results

Image-based Street-side City Modeling,
Xiao, Fang, Zhao, Lhuillier, and Quan, SIGGRAPH ASIA 2009.
Image-based Street-side City Modeling

Paper ID: 0238
Façades → buildings → cities
Conclusion

- An image-based approach to 3D
  - At the intersection of vision and graphics
  - Scale (small and large) and automation
- Methodology:
  - Generative rules
  - Generic models
  - Data(image)-driven
New book

*Image-based Modeling*,
Long QUAN,
*Springer-Verlag*,
2010.

- Part I Geometry: fundamentals of multi-view geometry
- Part II Computation: from pixels to 3D points
- Part III Modeling: from 3D points to objects