Feature-Enhancing Aerial LiDAR Point Cloud Refinement

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Outline

- Introduction
- Approach Overview
- Implementation Details
- Evaluation
- Conclusion and Future Work
- Acknowledgements
Why Refinement?

Defects of raw point clouds
- Noise
- Under-sampling

Visual artifacts in applications
- Grainy planes
- Gaps and holes
- Bumpy boundaries

Direct Rendering
Challenges of Aerial LiDAR Points

- Sparse sampling density
- 2.5D nature

Image courtesy to Qian-Yi Zhou
Preliminary Definitions

Normal discontinuous feature
- Discontinuities in normals
- The underlying surface is still continuous

Position discontinuous feature
- Discontinuities in positions
- The underlying surface breaks
Related Work

* **Feature preserving bilateral filtering** [Mederos2003] [Duguet2004] [Sun2007] [Nociar2010] [Huang2012]
  * Cannot handle position discontinuous features

* **Explicit feature smoothing approaches** [Pauly2003] [Daniels2007] [Zhou2008]
  * Replace points as lines/curves

From [Huang2012]
Approach Overview

**Input**

* An unoriented, piece-wise smooth aerial LiDAR point cloud of a single building

**Output**

* A new set of oriented points
* Providing
  * Smoothed noise
  * Filled gaps and holes
  * Enhanced normal discontinuous features
  * Enhanced position discontinuous features
Approach Overview (Cont.)

Approach

- Explicitly extract and regularize position discontinuous features
- Two-step framework
  - **Smoothing**: handles noise
  - **Up-sampling**: handles under-sampling
**Position Discontinuous Feature Refinement**

- **Detection**: local environment analysis

- **Boundary direction (B. direction) estimation**
  - The direction of the underlying line formed by boundary points only
  - PCA over neighbors
Step 1: Smoothing

* Bilateral filtering
  * The estimate for a point is the weighted average of prediction from neighboring points
  * The weight of a neighbor depends on
    * Spatial distance (spatial weight)
    * Normal/B. direction difference (influence weight)

* Two stage:
  * Smooth normals/B. directions
  * Smooth positions under the guidance of the filtered normals/B. directions
Smoothing for All Points

(a) Input noisy points
(b) Normal estimation
(c) Normal smoothing
(d) Position smoothing
Smoothing for Boundary Points

(a) Input noisy points
(b) B. direction estimation
(c) B. direction smoothing
(d) B. position smoothing
(e) Output points
Step 2: Up-sampling

- Local gap detector: local environment analysis
- Bilateral projection operator: preserve features

(a) Locate gap  (b) Find end point  (c) Interpolate new point
Up-sampling

(a) Input noisy points
(b) Smoothed points
(c) Interior up-sampling
(d) Boundary up-sampling
Feature Enhancing Up-sampling

Features can be enhanced if up-sampling is restrained to regions near features.

(a) Smoothed points
(b) Interior enhancing
(c) Boundary enhancing
(d) Output points
Evaluation Outline

* Robustness
* Stability
* Versatility
* Extensibility
* Comparison with previous work
* Performance
* Applications
Robustness to Noise

* The smoothing quality does not degrade much as the noise increases

<table>
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<th>Data set</th>
<th>Interior-MD</th>
<th>Interior-SD</th>
<th>Boundary-MD</th>
<th>Boundary-SD</th>
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MD: mean distance
SD: standard deviation
Robustness to Non-homogeneous Point Density

* Achieve global uniform sampling with a single parameter
* Both inner and outer boundaries are well preserved
Stability

* Most normal and position discontinuous features are sharply recovered for data sets with vastly different densities.
Versatility

* Effective to buildings with various roof shapes and complexity
Extensibility

- Extensible to objects other than buildings
- Extensible to large-scale data
Comparison with Point-Based Refinements

* Comparable quality on non-boundary points
* Obviously less errors on boundaries
**Comparison with Geometry Modeling**

- Comparable quality on straight boundaries
- Better quality on curved boundaries

(a) Ground truth image  (b) Original points  (c) Geometry models  (d) Refined points
Performance

- Smoothing and up-sampling are fast

<table>
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<tr>
<th>Data set</th>
<th>IP-N</th>
<th>SM-T</th>
<th>US-T</th>
<th>US-N</th>
<th>EU-T</th>
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IP-N: number of input points; NE-T: time for normal estimation; SM-T: time for smoothing; US-T: time for up-sampling; UP-N: number of points after up-sampling; EU-T: time for feature enhancement up-sampling; OP-N: number of output points. Time is measured in seconds.
Applications

* Our approach provides
  * smoother planes
  * no gaps
  * sharpened both normal and position discontinuous features
* It is a useful pre-process to improve visual quality of
  * direct point rendering
  * surface reconstruction (e.g. APSS and RIMLS)
Conclusion

* Explicitly extract and regularize position discontinuous features
* The smoothing step filters noise while preserves features
* The up-sampling step fills gaps while enhance features
* Experiments show improved rendering and surface reconstruction results
Future Work

* To improve performance: parallelize each refinement operation

* To improve quality:
  * incorporate other information such as aerial images
  * add more restricted geometric assumptions as in urban modeling

* Incorporate refinement into real-time city-scale point cloud visualization
Acknowledgements

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