Large-scale efficient extraction of 3D roof segments from aerial stereo imagery

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TU Delft:
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Mentor #2: Tom Commandeur
Co-reader: Pirouz Nourian

Readaar:
Sven Briels
From: Aerial stereo imagery
To: 3D roof segments

- For large area: Municipalities & Provinces
Relevance: PV potential & Asbestos

READAAR:

- Photovoltaic potential
  - Number of panels and orientation
  - Solar panel yield

- Detection of asbestos
  - Asbestos illegal in 2024
  - Estimated 120km$^2$
  - 1000 asbestos related deaths yearly
Current method READAAR has its limitations

- Based on gridded LiDAR
  - Not always available outside NL
  - Expensive to gather

- Potential improvement using aerial stereo imagery
LiDAR vs stereo

- Color
- Density
- Gaps/noise
LiDAR vs stereo

- Color
- Density
- Gaps/noise
Goal: Large-scale efficient extraction of 3D roof segments using only aerial stereo imagery

1. Scalability & Efficiency:
   – Municipalities/provinces
   – Fully automatic
   – Within reasonable time

2. 3D roof segments:
   – Watertight building models not required

3. Aerial stereo imagery
   – Not dependent on LiDAR data
Related work: Model vs data driven

- **Model-driven** (Fitting primitives from library)
  - Watertight roofs
  - Limited to shapes in library

- **Data-driven** (Segmentation of pointcloud/image)
  - Roofs of any shape
  - Not watertight
Related work: Segmentation

• Directly searching planes
  – RANSAC
  – Hough transform

• Image segmentation based on color/normals
  – Thresholding
  – Region growing
  – Watershed

• Clustering normals
  – K-means
  – Mean-shift
Literature study conclusions

1. Data-driven approach
   - Any shape
   - Watertight building models not required

2. Potentially useful algorithms for large-scale applications
   - Thresholding
   - Watershed
   - Mean-shift

3. Two step segmentation approach (first color than orientation)
   - Exploiting color
   - Dealing with gaps/noise
   - Efficient
Methods:

- All processing steps are per building
- This Ensures scalability
Methods: Clip, rectify & match

Left View  Right View  Disparity
Method: Conversion to point cloud
Methods: Color segmentation

Left View

Gradient Magnitude

Watershed
Methods: Cluster color segments

Normal x component

Normal y component

Mean-Shift clustering of color segments based on orientation
Methods: Height jumps

Disparity based on plane models

Height Jumps
Methods: Reconstruction

Vectorize & Cut with Footprint

3D roof segments
Quality assessment:

- **True Positive (TP):** >50% overlap
- **False Positive (FP):** <50% overlap
- **False Negative (FN):** Not detected
Quality assessment:

- **Completeness** = \( \frac{|TP|}{|TP|+|FN|} \)

- **Correctness** = \( \frac{|TP|}{|TP|+|FP|} \)

- **Quality** = \( \frac{|TP|}{|TP|+|FP|+|FN|} \)
Results: Terraced
Results: Free-standing
Results: Industry
## Results: Segmentation quality

<table>
<thead>
<tr>
<th>Stereo</th>
<th>Comp</th>
<th>Corr</th>
<th>Q</th>
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<tbody>
<tr>
<td>Terraced</td>
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<td>64.5</td>
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<td>86.1</td>
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</table>
Results: Problems

Overhanging roofs

Shadowing effects
Results: Problems

Dormers

Roof objects (Chimneys)
Results: Computation time

- Without loading times
- Roughly 14400 buildings/hour
- Average municipality in The Netherlands has 25000 buildings

<table>
<thead>
<tr>
<th>Process</th>
<th>Time (s)</th>
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<tr>
<td>Rectification</td>
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<tr>
<td>Matching</td>
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<td>Watershed</td>
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<tr>
<td>BAG_Filter</td>
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<tr>
<td>Plane fitting</td>
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<td>Clustering</td>
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<td>Reconstruction</td>
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<td><strong>Total</strong></td>
<td><strong>0.257</strong></td>
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Results: Comparison
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<td><strong>LiDAR</strong></td>
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Conclusions/contributions

- Integration of stereo matching and roof segment extraction (scalable)
- Efficient method for extraction of 3D roof segments from aerial stereo images only
- Higher quality than the current LiDAR-based method
- Problems with shaded areas, overhanging roofs, roof objects and complicated roof shapes
Future work: Matching with neural network

- Promising results
  - Network trained with traffic situations only
  - Train network with aerial stereo images and disparity from AHN

![SGM](image1.png)  ![Neural network (Luo, 2016)](image2.png)
Future work: Integrate LiDAR

- Improve results in shaded areas
Future work: Process building blocks

- Improve results when roofs within block are similar
- Not possible for blocks with varying roof shapes
Future work: Intersect segments
Thank you for your attention