Creation of LoD1 Buildings Using Volunteered Photographs and OpenStreetMap Vector Data

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Surveying the world of tomorrow - From digitalisation to augmented reality
Outline

- Introduction
- Research Goals
- Methodology
- Field Experiments and Results
- Conclusions and Future Work
Introduction - 3D City Models

- 3D city models become increasingly popular among urban planners:
  - Noise and environmental analyses
  - Disaster management
  - Architecture and city planning

- Level of Detail – LOD1

bcgis.com
Introduction - Volunteered Geographic Information

- VGI: "Thousands of humans acting as remote sensors" (Goodchild, 2007).

- Groups of people can collect geographic data that is either difficult to automate or expensive to implement.

Map creation by walking or driving using smartphones (GPS trajectories)

Aerial/satellite imagery digitizing
Introduction – OSM

- OpenStreetMap - One of the most famous examples of crowdsourcing VGI maps with more than 3.1 million users.
- More than 6.5 million building 2D footprints, increasing by 1% monthly.
- Yet, only 1.4% of OSM buildings have height data.

OSM 3D - Buildings in Heidelberg, Germany
Research Goals

- Investigate whether collective imagery contributed by users (WWW) can be used to produce LoD1 information.
- Extract accurate building heights from single perspective images.
- Produce 3D building models (LoD1) in OSM.
Methodology

Input Data

Vanishing points detection

Calculating camera internal parameters

Building height calculation

Building footprint calculation

Corresponding building in OSM -> LoD1
Input Data– Perspective Building Images

Manhattan-world assumption: the imaged scene contains three orthogonal, dominant directions, typically corresponding to the X, Y, and Z axes.

EXIF - Exchangeable Image File format:

- Geotagging – most cameras and smart phones have a built-in GPS receiver that stores location information \([\text{lat}, \text{long}] \rightarrow [X,Y]\)
- Focal length – [pixel]
- Image size – [pixel]
Methodology

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Corresponding building in OSM -> LoD1
Orthogonal Vanishing Points Detection

• Automatically detect the 3 vanishing points based on the Manhattan-world assumption (orthogonality).
Orthogonal Vanishing Points Detection

- Several methods for vanishing point detection make use of the line segments detected in images.

Methodology

**Input Data**
- Vanishing points detection
- Calculating camera internal parameters

**Building height calculation**
- Building footprint calculation
- Corresponding building in OSM -> LoD1
Camera Internal Parameters

- **EXIF:**
  - Assume principle point is at image center:
  
  $$[u_0, v_0] = \left[ \frac{\text{Image Width}}{2}, \frac{\text{Image Height}}{2} \right]$$
  
  - Focal length in pixels:

  $$\text{new } f = \frac{\text{original } f \cdot \text{new width}}{\text{original width}}$$

- **Vanishing points:**
  - Camera principal point $[u_0, v_0]$ is at the orthocenter of the triangle, which has the vanishing points as its vertices.
  
  - Focal length is estimated using:
Methodology

Input Data

- Vanishing points detection
- Calculating camera internal parameters

Building height calculation

- Building footprint calculation
- Corresponding building in OSM -> LoD1
Building Height Calculation: Single View Metrology

- Single view metrology is used to calculate height in the “real world”.

- Cross ratio is preserved by the projective transformation of a projective line.
Building Height Calculation: Cross Ratio

- **Horizon line** - Projection of the line at infinity of the reference plane into the image \([v_1, v_2]\).

- **Vertical point** - A point at infinity in the reference direction \([v_3]\).

- **Reference** - height in meter

\[
\frac{\|t - b\|v_z - r}{\|r - b\|v_z - t} = \frac{H}{R}
\]
Building Height Calculation - Example

- Building height is 11.24 m - measured by total station (±2 cm).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Calculated Building Height [m]</th>
<th>Error [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop sign</td>
<td>2.8</td>
<td>11.4</td>
</tr>
<tr>
<td>Pedestrian&lt;sub&gt;a&lt;/sub&gt;</td>
<td>1.65</td>
<td>11.6</td>
</tr>
<tr>
<td>Pedestrian&lt;sub&gt;b&lt;/sub&gt;</td>
<td>1.55</td>
<td>11.1</td>
</tr>
</tbody>
</table>
Methodology

Input Data

Vanishing points detection

Calculating camera internal parameters

Building height calculation

Building footprint calculation

Corresponding building in OSM -> LoD1
Building footprint - Homography

- **Projective**
  
  \[
  P = \begin{pmatrix}
  1 & 0 & 0 \\
  0 & 1 & 0 \\
  l_1 & l_2 & 1
  \end{pmatrix}
  \]

  \(l_1 \) & \(l_2 \) are Horizon line parameters

- **Affine**
  
  \[
  A = \begin{pmatrix}
  1 & \frac{-\alpha}{\beta} & 0 \\
  0 & 1 & 0 \\
  0 & 0 & 1
  \end{pmatrix}
  \]

  \(\alpha\) & \(\beta\) are function of the internal parameters

- **Similarity**
  
  \[
  M = \begin{pmatrix}
  sR & t \\
  0^T & 1
  \end{pmatrix}
  \]

  Scaling, Rotation & Translation

\[
S = \frac{\text{building height in pixel}}{\text{building height in meter}}
\]
Building footprint: Homography Results
### Field Experiments and Results - Height

<table>
<thead>
<tr>
<th>Building</th>
<th>Measured</th>
<th>Calculated</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>b1</td>
<td>11.24</td>
<td>11.4</td>
<td>0.16</td>
</tr>
<tr>
<td>b2</td>
<td>11.63</td>
<td>11.56</td>
<td>-0.07</td>
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<tr>
<td>b3</td>
<td>10.95</td>
<td>11.00</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Field Experiments and Results - Footprint

- Building footprints were measured using a tape (±5 cm)

<table>
<thead>
<tr>
<th>Measured</th>
<th>Calculated via focal length</th>
<th>Calculated via EXIF focal length</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A [m]</td>
<td>B [m]</td>
<td>Focal</td>
</tr>
<tr>
<td>16.00</td>
<td>22.60</td>
<td>16.40</td>
<td>23.00</td>
</tr>
<tr>
<td>8.80</td>
<td>12.70</td>
<td>8.22</td>
<td>13.50</td>
</tr>
<tr>
<td>12.20</td>
<td>17.20</td>
<td>12.36</td>
<td>16.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.58</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>0.20</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>-0.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.06</td>
</tr>
</tbody>
</table>
Field Experiments and Results - LoD1
Methodology

Input Data

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Vanishing points detection

Corresponding building in OSM -> LoD1

Building footprint calculation

Building height calculation

Calculating building footprint calculation

From digitalisation to augmented reality

Surveying the world of tomorrow - Helsinki Finland 29 May - 2 June 2017
Corresponding building in OSM

- Estimate the distances from the building corners using the intersections with the vanishing line

\[ Dp1 = \frac{A \cdot \sin(\delta)}{\sin(\beta_1 + \gamma)} \]

\[ Dp2 = \frac{A \cdot \sin(Z1)}{\sin(\beta_1 + \gamma)} \]

\[ Dp3 = \frac{B \cdot \sin(270 - \delta)}{\sin(\beta_2 - \gamma)} \]
Corresponding building in OSM – Step 1

- Circular buffer with radius = Dp2 + GPS Accuracy (10 m) + Error (5 m)
- The circle center is the GPS coordinates from the EXIF data

- If there is only one building inside the buffer - Stop search!
Corresponding building in OSM – Step 2

- Compare between the footprints: keep the building with difference below 5 [m] for both A & B

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Dif_A [m]</th>
<th>Dif_B [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>1.87</td>
<td>6.96</td>
</tr>
<tr>
<td>3</td>
<td>0.30</td>
<td>-14.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Dif_A [m]</th>
<th>Dif_B [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.01</td>
<td>4.59</td>
</tr>
<tr>
<td>2</td>
<td>3.24</td>
<td>2.95</td>
</tr>
<tr>
<td>3</td>
<td>5.54</td>
<td>3.39</td>
</tr>
<tr>
<td>4</td>
<td>5.14</td>
<td>0.89</td>
</tr>
<tr>
<td>5</td>
<td>3.94</td>
<td>3.89</td>
</tr>
</tbody>
</table>
Corresponding building in OSM – Step 3

- Circular buffer with radius of $Dp_1$ & $Dp_3$
- The circles centers are the 2 corners
Corresponding building in OSM – Step 3

- $X$ – where the image has been taken in the field
- The difference between $X$ and the nearest intersection point is less than 4 meters
Conclusions

- Using user-generated contributed single image was found valuable to calculate and extract building height and footprint data.

- Algorithms developed are qualitative in calculating LoD1 building values with less than 1.00 m errors (for most cases) to generate 3D city models (reducing cost and work labor).

- Using accurate reference height is important, although errors are still in the range of desired output.

- Automatically Identifying and updating height data in corresponding building feature in OSM.
Future Work

- Analyze methodology and algorithms on more WWW building images.
- Update building footprints in OSM.
- Analyze more complex building shapes and footprints.
- Implement a GUI/app for photographers to automatically update OSM with building height data.
Thank you!

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