Estimation of building heights from high-resolution TerraSAR-X imagery

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- Background and objectives
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Background and objectives

- Modeling and monitoring of urban areas
  - urban planning, environmental assessment and evaluating risk from natural disasters
- Collecting features of an individual structure
  - especially the height
- High-resolution SAR images are now available

An method for estimating building heights from high-resolution SAR images
Related studies

- Recent researches for height detection
  - Measuring shadows from high-resolution optical images
  - Radiometric analysis
    - Local material information
  - Interferometric SAR (InSAR) analysis
  - Geometrical characteristic
Geometrical characteristic

\[ L = \frac{h}{\tan \theta} \]

- A building in a SAR image shows a layover from the actual position to the direction of the sensor.
Study area

- Three temporal TerraSAR-X data
- Lidar data (DSM and DEM)
### TerraSAR-X data

<table>
<thead>
<tr>
<th>Polarization</th>
<th>HH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>HighSpot</td>
</tr>
<tr>
<td>Resolution (RxA)</td>
<td>0.9 m x 1.1 m</td>
</tr>
<tr>
<td>Number of looks</td>
<td>2 x 2</td>
</tr>
</tbody>
</table>

R: 2011/10/13  
G: 2007/12/27  
B: 2007/12/05
Lidar data and pre-processing

- Lidar was taken in June 2010, with 6 cm vertical resolution and 2.0 m spatial resolution.
- SAR intensity images were geocoded according to the Lidar DEM and resampled as 0.5 m/pixel.
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Target area I (low-rise buildings)

Building height (reference)  TSX intensity image (2011/10/13)

116 buildings were select as targets
Template searching for layover

- Resize TSX image to 0.1 m/pixel
- An Initial template: between 1.5 and 2.0 m high
- Shift to the sensor direction: 0.1 m interval in height
- Thresholds for the template
  \[ \sigma > -10.5 \text{ dB (average value)} \quad \rho_L \geq 40\% \]
ID number is assigned to each building.

Searching is carried out in the order of ascending ID.

Masked the building areas and the former searched layover areas.
Result of estimation (Area I)

- 89 of 116 buildings’ heights were detected.
- The building that behinds to other one in the range direction cannot be detected.
Verification of results (Area I)

86 samples (74%)
RMS: 2.54 m

Detected height

Detected height (m)
Reference height (m)

0 5 10 15 20 25
0 5 10 15 20 25

[Images showing graphs and photographs of buildings labeled a, b, c]
Target area II (high-rise buildings)

11 buildings more than 50 m high were selected as targets
Layover of high-rise buildings

Intensity image

Phase image $\phi$ of InSAR analysis
(12/05-12/27)
Building height and phase

Building height from InSAR analysis

Stable phase cycles

\[ h = \frac{\lambda H \sin \theta}{4\pi B_\perp \cos \theta} \cdot \phi \]

\[ B_\perp = 561 \text{[m]} \Rightarrow h = 11.6 \text{[m/cycle]} \]

\[ T = \frac{\lambda H \sin \theta}{2 B_\perp} = 8.87 \text{[m]} \]

\[ \Delta \phi = \frac{4\pi B_\perp}{\lambda H \sin \theta} = 0.71 \text{[rad/m]} \]
Investigation of phase characteristics

- Thresholds for stable phase
  
  \[
  0 < \Delta \varphi < 1.3 \text{ [rad/pixel]} \quad (0.65 \text{ in theory})
  \]
  
  \[
  7 < T < 13 \text{ [pixels]} \quad (10 \text{ in theory})
  \]
Extraction of layover

Phase gradient $\Delta \phi$

GIS footprints

Potential layover

Extracted layover ($p_L > 11\%$)
Verification of results (Area I)

- 11 buildings
  RMS: 7.83 m

- Maximum error: 20.1 m
- Average error: 5.5 m
Conclusions

- Height detection was carried out from TSX images and building footprints.
  - Heights were calculated according to the lengths of layovers.
  - Two methods were proposed for low- and high-rise buildings, respectively.
  - The RMSE for low-rise buildings is 2.5 m, and the one for high-rise buildings is 7.8 m.
  - The accuracy of height detection depends on the surrounding conditions.

- In the future, the method will be more tested and improved.
Acknowledgement
The TerraSAR-X images and Lidar data used in this study were provided from 2012 IEEE Geoscience and Remote Sensing Society Data Fusion Contest.

Thank you very much!