Terrestrial laser scanning and digital photogrammetry for cultural heritage - An accuracy assessment

Timothy NUTTENS, Philippe DE MAEYER, Alain DE WULF, Rudi GOOSSENS, Cornelis STAL

Ghent University, Department of Geography, Ghent (Belgium)
3D Data Acquisition Cluster
Terrestrial laser scanning and digital photogrammetry for cultural heritage: an accuracy assessment

Alain.DeWulf@UGent.be
Timothy.Nuttens@UGent.be

Project
- Comparison of the 3D accuracies of terrestrial laser scanning versus digital photogrammetry
- For cultural heritage purposes
- Line-of-sight distances < 15 m
- Total station measurements (test set of 100 points) are considered as “truth”

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Project
- Sint-Baafs Abbey (Ghent, Belgium)
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2008-2009: Pulse laser scanner (Leica scanstation 2)
- Scanning resolution of max. 4 cm
- Laser scanning did not meet photogrammetric accuracies

2010-2011: Phase laser scanner (Leica HDS 6100)
- Different type of laser scanner
- High lateral scanning resolution (< 5 mm)
- Leica ScanStation 2

Time-of-Flight

Pulse-Based

Up to 50,000 pts/sec

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Leica ScanStation 2

Leica ScanStation 2 Prestatie Specificaties

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumenttype</td>
<td>Puls, dubbelassige compensator, laser scanner met zeer hoge snelheid, millimeermenukeurig, groot bereik en volledig rondom zicht</td>
</tr>
<tr>
<td>Bediening</td>
<td>Laptop of Tablet PC</td>
</tr>
<tr>
<td>Camera</td>
<td>Geïntegreerde digitale camera met hoge resolutie</td>
</tr>
</tbody>
</table>
| Nauwkeurigheid van individuele meting | Positie*: 6 mm
|                                | Afstand*: 4 mm
|                                | Hoek (horizontaal/verticaal): 60 yrad/60 yrad (3.8 mgon/3.8 mgon) ** |
| Spot grootte                   | Vanaf 0 - 50 m: 4 mm (FWHH-gebaseerd); 6 mm (Gauss-gebaseerd) |
| Gemodelleerd vlak precisie/ruis| 2 mm **                          |
| Meting op richtmerk            | 2 mm std. afwijking              |
| Dubbelassige compensator       | Resolutie 1', dynamisch bereik +/- 5' |
| Data integriteit bewaking      | Periodieke zelftest tijdens de werking en opstarten |
| Laser scan systeem            | 300 m bij 90%; 134 m bij 18% reflectie |
| Verlichting                    | Voldoende werkzaam bij zowel helder zonlicht als absolute donker |
| Voeding                        | 36 V, AC of DC, hot swappable    |
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Alain.DeWulf@UGent.be
Timothy.Nuttens@UGent.be

Leica HDS6100

Phase-Based

Up to 500 000 pts/sec

Key Leica HDS6100 Performance Specifications

<table>
<thead>
<tr>
<th>Instrument type</th>
<th>Compact, phase-based, dual-axis sensing, ultra-high speed laser scanner, with survey-grade accuracy and full field-of-view</th>
</tr>
</thead>
<tbody>
<tr>
<td>User interface</td>
<td>Onboard touch panel, or external notebook or Tablet PC, or PDA</td>
</tr>
<tr>
<td>Data storage</td>
<td>Integrated hard drive</td>
</tr>
</tbody>
</table>
| Accuracy of single measurement | Position: 5 mm, 1 m to 25 m range; 9 mm to 50 m range  
Distance: ±2 mm at 90° albedo up to 25 m; ±3 mm at 18% albedo up to 25 m  
±3 mm at 90° albedo up to 50 m; ±5 mm at 18% albedo up to 50 m  
Angle (Horizontal/Vertical): 123°/22°/125° (7.8 mm/7.9 mm) one sigma  |
| Spot size       | 3 mm at exit (based on Gaussian definition) + 0.22° rad divergence; 8 mm @25; 14 mm @50 m |
| Modeled surface precision**/noise | 1 mm at 25 m; 2 mm at 50 m, for 90% albedo; one sigma  
2 mm at 25 m; 4 mm at 50 m, for 18% albedo; one sigma |
| Target acquisition*** | 2 mm std. deviation |
| Dual-axis sensor | Selectable on/off; Resolution 3.6° |
| Laser scanning system | Range: 79 m ambiguity interval  
79 m @90°; 50 m @18% albedo  
Scan Rate: Up to 500,000 points/sec, maximum instantaneous rate  
Scan density: @10 m  
50 m  
“Preview” 50.6 x 50.6 mm  
250 x 250 mm  
Middle (4x) 12.6 x 12.6 mm  
62 x 62 mm  
High (8x) 6.3 x 6.3 mm  
31.4 x 31.4 mm  
Super High (16x) 3.1 x 3.1 mm  
15.8 x 15.8 mm  
Ultra High (32x) 1.6 x 1.6 mm  
7.9 x 7.9 mm |
| Laser Class     | 3R (IEC 60825-1) |
| Lighting        | Fully operational between bright sunlight and complete darkness |
| Power supply    | 24 V DC; integrated Li-Ion battery (5.5 hrs) and/or optional external DC power supply (4 hrs) or AC supply |
| Power consumption | 65 W max. |
| Temperature     | Operation: -10°C to +60°C; Storage: -20°C to +50°C |

All specifications are subject to change without notice. All +/- accuracy specifications are one sigma unless otherwise noted. ** One sigma; subject to modeling methodology for modeled surface. *** Algorithmic fit to planar HDS gray 6 white targets.
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3D DATA ACQUISITION

Alain.DeWulf@UGent.be
Timothy.Nuttens@UGent.be

Terrestrial laser scanning

- Phase-based Leica HDS6100
- Average lateral resolution of 0.5 cm
- Intensity value of reflection laser beam
- No RGB color information
- 8 circular targets on tripods
Terrestrial laser scanning

- Multiple (ca. 30) scanning positions
- Target-based registration
- Georeferencing in Lambert72 (conical projection with Hayford ellipsoid) based on total station / GNSS measurements
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- **Camera:**
  - Canon Eos 1Ds (11 Mp) full frame DSLR
  - with 24 mm lens (grand angular)
  - approx. scale of 1/500
  - pixel size approx. 3-5 mm
- **Minimum 80% overlap**
Digital photogrammetry

- Photogrammetric processing of the stereo couples using
  **Virtuoso** software

- **Relative** orientation:
  - 100 – 150 homological points per couple
  - Maximum error: ca. 1/5 of a pixel (ca. 1mm)

- **Absolute** orientation:
  - based on total station / GNSS measurements in Belgian Lambert72 conical projection
  - Maximum RMS error: 1 cm (X, Y and Z)

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Photogrammetric products: DEM and Orthorectified images
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Total station
- Georeferencing laser scanning
- Absolute orientation
- Independent test set of 100 points
- ‘Ground truth’ for comparison

Comparison – Results
- Differences between X-, Y- and Z-coordinates of test set (cm) for
  - Photogrammetry vs. total station
  - Laser scanning vs. total station
  - Photogrammetry vs. laser scanning
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### Systematic errors

**Comparison of systematic errors in the position of the control points using laser scanning and photogrammetry compared to total station measurements**

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photogrammetry vs. Total station</td>
<td>-1,00</td>
<td>-0,30</td>
<td>-1,57</td>
</tr>
<tr>
<td>Laser scanning vs. Total station</td>
<td>0,90</td>
<td>-0,53</td>
<td>0,27</td>
</tr>
<tr>
<td>Photogrammetry vs. Laser scanning</td>
<td>-1,90</td>
<td>0,20</td>
<td>-1,83</td>
</tr>
</tbody>
</table>

- Photogr. vs. total station => 1.9 cm (3D)
- Laser scanning vs. total station => 1.1 cm (3D)
- Altimetric error photogrammetry ca. 5 times higher than the altimetric error of laser scanning

### Random errors

**Comparison of accuracies (random errors) in the position of the control points using laser scanning and photogrammetry compared to total station measurements**

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photogrammetry vs. Total station</td>
<td>2,73</td>
<td>2,90</td>
<td>3,07</td>
</tr>
<tr>
<td>Laser scanning vs. Total station</td>
<td>1,53</td>
<td>1,73</td>
<td>1,30</td>
</tr>
<tr>
<td>Photogrammetry vs. Laser scanning</td>
<td>3,03</td>
<td>3,63</td>
<td>3,20</td>
</tr>
</tbody>
</table>

- Photogr. vs. total station => 5.0 cm (3D)
- Laser scanning vs. total station => 2.6 cm (3D)
- Altimetric error photogrammetry 2 times higher than the altimetric error of laser scanning
Conclusions

- Higher systematic and random error for photogrammetry (error in Z of photogrammetry even 2-5 times higher than laser scanning).

- In this cultural heritage test case with lines of sight of 5-15 m: Lateral scanning resolution of 0.5 cm enables to surpass the accuracy of digital photogrammetry with the same resolution.

Thank you for your attention

Questions?

Contact & Information:

alain.dewulf@ugent.be
Timothy.Nuttens@UGent.be

Ghent University, Department of Geography, Ghent (Belgium)
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