Terrestrial Laser Scanning: Applications in Civil Engineering

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Overview

- Laser scanning overview
- Research applications
  - geometric accuracy assessment
  - coastal monitoring
  - slope stability assessment
- Waveform laser scanning developments
- Integration with other data sources
- Remaining challenges
- Conclusions
Laser Scanning: Main Aspects

- collection of mass ‘point cloud’

- [xyz + intensity] for each target (point)
  - intensity = strength of returned signal
  - influenced by target reflectivity

- most systems collected digital imagery
  - aids in interpretation
  - useful for mapping (lidar is ‘blind’ technique)

- full waveform scanning (more later...)
System Development

Terrestrial laser scanning

parallel, but separate development

Airborne laser scanning (lidar)
Mobile Mapping Systems (MMS)

- natural extension of lidar & TLS
- tight integration of scanner, GPS, IMU
- support dynamic applications
  - e.g. road, rail, boat
Laser Scanning Research at Newcastle University
Mobile Mapping Systems

• MMS have been active research topic for ~ 20 years

• development driven by:
  – airborne systems offer poor coverage of urban environments
  – TLS can partially overcome, but only over limited spatial extents
  – demand for responsive data capture

• MMS have only recently become commercial reality
  – systems are still maturing
  – requirement for improved understanding of accuracy/precision
Assessing Geometric Quality

**StreetMapper system**
- 3 laser profilers
- mounted on high-sided van
- integrated with GPS-IMU

- commissioned by Ordnance Survey
- analysis of processed data
  - i.e. ‘customer-ready’
Test Sites & Datasets

- **two test sites (Newcastle upon Tyne)**
  1. low density residential housing
     - => good GPS scenario
  2. narrow valley: tall, tightly-packed industrial buildings
     - => worst case GPS scenario

- **5 forward, 5 reverse passes at each site (precision analysis)**

- **reference measurements**
  - RTK & static GPS measurements for vertical and planimetric assessment
Precision Assessment

- Test site 1: 0.030 m (95%)
- Test site 2: 0.046 m (95%)

Example

- N.B. poorer precision along kerb-lines

no significant difference
## Accuracy Assessment

<table>
<thead>
<tr>
<th></th>
<th>Elevation Accuracy (m)</th>
<th>Planimetric Accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Site 1</td>
<td>0.037</td>
<td>0.100</td>
</tr>
<tr>
<td>Test Site 2</td>
<td>0.029</td>
<td>0.211</td>
</tr>
</tbody>
</table>

### Elevation
- poorer results for test site 1
- some correspondence with flightlines originating in narrow streets

### Planimetry
- corner of road markings used as check points
- poorer than expected – some difficulties in identifying points in scan data
Summary of Findings

- positional quality difficult to independently assess
- analysis of individual flightlines shows largest RMSE errors in main urban canyons in test site 2
- route planning should be considered as important aspect
- quality control measures are required as routine to ensure specifications are met
- results demonstrate that MMS can be successfully used even in ‘worst case’ GPS environments
MMS for Coastal Monitoring

Riegl LMS Q560 airborne lidar system

AEROcontrol GPS/IMU

Vibration mount

Power and storage

GrafNav, AEROoffice and TerraScan for processing
Testing at Filey Bay

- 7km beach section
- Single pass coverage
### Data Validation

<table>
<thead>
<tr>
<th></th>
<th>Test Area 1</th>
<th>Test Area 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation (m)</td>
<td>0.209</td>
<td>0.200</td>
</tr>
<tr>
<td>Root mean square error (m)</td>
<td>0.222</td>
<td>0.267</td>
</tr>
<tr>
<td>Minimum (m)</td>
<td>-0.423</td>
<td>-0.595</td>
</tr>
<tr>
<td>Maximum (m)</td>
<td>0.511</td>
<td>0.644</td>
</tr>
<tr>
<td>Mean (m)</td>
<td>0.080</td>
<td>0.181</td>
</tr>
<tr>
<td>No. Points</td>
<td>37</td>
<td>26</td>
</tr>
</tbody>
</table>

- validated using post-processed RTK GPS data
- results influenced by:
  - occlusions
  - cliff-face orientation (relative to scanner)
  - vegetation effects
Summary of Findings

- well-suited to rapid assessment of dynamic environment
- more affordable than airborne techniques (e.g. lidar)
- increasingly suitable as cliffs tend to vertical

However:

- limited by access, tides, foreshore terrain
- orientation of cliff-face can cause occlusions
- defences, buildings, etc may cause obstructions/occlusions
TLS for Transport Corridors
Slope Stability

- assessing deformation and slope stability
- investigating sensitivity of TLS
- repeat scanning procedure

Haltwhistle Road Embankment

Loose material on upper slope
TLS-derived Elevation Differences
October – December 2007

- Detection of low-magnitude instability (soil creep, surface run-off)
Waveform Laser Scanning

- Record complete waveform of backscattered echo
Newcastle Waveform Scanning Research

Bristol test site:
- BMX circuit
- Mixed landscape types (320m x 275m)
Conventional ground classification algorithms

Digital Surface Model

DTM 3° Iteration angle

DTM 6° Iteration angle
Smoothing of discontinuities

DTM with waveform information

3° Iteration angle

Inclusion of low vegetation

6° Iteration angle
Waveform Digitising & MMS

- waveform digitising now a feature of MMS
- advantages for airborne systems clear (DTMs, vegetation)
- terrestrial systems have smaller footprint → less impact?
  - greatest benefits may be in vegetated areas:
Integration with Other Datasets

- **imagery**
  - often comes as standard
  - improved mapping of features and edges
  - textural information for (e.g.) building modelling

- **airborne lidar**
  - complementary data source
  - overcome occlusions and provide wider-area coverage

- **vector mapping data (e.g. OS MasterMap)**
  - inclusion of breaklines (e.g. kerbs) & features (e.g. walls) essential for accurate flood modelling
Remaining Challenges

Greatest challenge is transforming data -> information

- enormous data volumes (esp. with waveform)
- no explicit feature information (unlike imagery)
- building/feature extraction remain **major** research challenges

- fully automated workflow some way off
Conclusions

• MMS offer great potential for rapid, detailed mapping
  – numerous applications

• technique still in its infancy

• evaluation of quality (accuracy, precision) should be core element of every survey
  – particularly important for many hydrological analysis tasks

• GPS/IMU solution occupies major portion of error budget
  – mission and route planning important
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