Error Propagation in Directly Georeferenced Terrestrial Laser Scanner Point Clouds for Cultural Heritage Recording

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Introduction

- Terrestrial laser scanners (TLSs) have found application to many cultural heritage recording projects.
- However, insufficient attention has been given to point cloud precision, which is often overstated.
- Our aim was to construct a random error budget for directly georeferenced TLSs that models all sources.
- Many of the contributing random sources are common to the surveying field.
- A new probabilistic model is proposed for the angular uncertainty due to the finite laser beam diameter, which may be significant.
- The error budget for a heritage-recording case study undertaken at the UNESCO World Heritage-listed Wat Mahathat site in Ayutthaya, Thailand, is presented and analysed.

Case Study: Wat Mahathat, Ayutthaya, Thailand

- Located 8 km north of Bangkok.
- An ancient capital of Siam, Ayutthaya holds UNESCO World Heritage status for the many culturally significant Wats in the city and its environs.
- Site was scanned in order to create a three-dimensional virtual model to support education and historical interpretation.

Probabilistic Model

- The probability governing the angular position \((\theta, \alpha)\) of the range measurement is assumed to be uniform within the beam’s cross-section having diameter \(\delta\).
- The standard deviation for beamwidth is given by

\[
\sigma_\alpha = \pm \frac{\int_0^{\pi/2} \alpha \sigma_\theta d\alpha}{\int_0^{\pi/2} \sigma_\theta d\alpha} = \pm \frac{\delta}{4}
\]
Case Study (cont’d)

- Full error propagation performed on a nominal 0.1 x 0.1 m grid (57,674 points) to assess quality of the full point cloud mosaic.
- Budget includes:
  - Setup and back sight station errors from network adjustment
  - Leveling, pointing and optical centering errors
  - Observation errors
  - Beam width error
- Some of the relevant parameters (Riegl LMS-Z210)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Numerical Value</th>
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</thead>
<tbody>
<tr>
<td>Range σ</td>
<td>±(25 mm + 20 ppm)</td>
</tr>
<tr>
<td>Vertical σ</td>
<td>±0.036° (13.3″)</td>
</tr>
<tr>
<td>Horizontal σ</td>
<td>±0.018° (165″)</td>
</tr>
<tr>
<td>Laser Beamwidth (θ)</td>
<td>3 mrad (619″)</td>
</tr>
<tr>
<td>Beamwidth σ</td>
<td>±135″</td>
</tr>
</tbody>
</table>

Ayutthaya 95% error surface contours (contours in mm)

Summary

- The subject of error propagation has seemingly been a casualty of the rapid emergence of the very impressive TLS technology.
- Many of the error sources in the proposed budget are fundamental to elementary surveying.
- A model has been proposed for laser beamwidth uncertainty, which may be significant.
- The estimated precision in the Ayutthaya network was much poorer than the advertised range precision—which is often taken to be gospel—for the scanner in question.
- However, the attained precision was more than adequate for this type of recording project.
- Pre-analysis recommended for any recording project in order that realistic project specifications be set and fulfilled.

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