LIDAR Features for the Indirect Geo-Referencing of Photogrammetric Data

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• Introduction
• LIDAR and photogrammetric geo-referencing
• Integration rationale and requirements
• Co-registration problem
• Experimental work
• Conclusions and recommendations
Active and Passive Sensors

Photogrammetric Positioning

- The position and the attitude of the two camera stations have to be known (geo-referencing problem).
Photogrammetric Geo-referencing

Indirectly using control points

Directly using GPS/INS systems

Indirectly using control lines

LIDAR Geo-referencing

GPS positioning satellites

Onboard GPS Onboard IMU

GPS base station
LIDAR Positioning

\[ \hat{X}_G = \hat{X}_o + R_{\Delta \alpha, \Delta \beta, \Delta \gamma} \hat{P}_G + R_{\alpha, \beta, \kappa} R_{\Delta \alpha, \Delta \beta, \Delta \gamma} R_{\alpha, \beta, \kappa} \begin{bmatrix} 0 \\ 0 \\ -\rho \end{bmatrix} \]

- \( \hat{X}_G \): ground coordinates of object point under consideration
- \( \hat{X}_o \): ground coordinates of GPS antenna phase center
- \( \hat{P}_G \): offset between laser unit and phase center w.r.t. the laser unit coordinate system
- \( R_{\alpha, \beta, \kappa} \): rotation matrix that needs to be applied to the ground coordinate system until it is parallel to the IMU coordinate system
- \( R_{\Delta \alpha, \Delta \beta, \Delta \gamma} \): rotation matrix that needs to be applied to the IMU coordinate system until it is parallel to the laser unit coordinate system
- \( R_{\alpha, \beta, \kappa} \): rotation matrix that needs to be applied to the laser unit coordinate system until it is parallel to the laser beam coordinate system
LIDAR Characteristics

Pros:
- Direct acquisition of 3D coordinates
- Dense information from homogeneous surfaces
- Day or night data collection
- One pulse – multiple returns
- Large areas are quickly covered

Cons:
- Almost no information along breaklines
- No inherent redundancy
- Positional; difficult to derive semantic information
- Accuracy degrades with increased flying height
- Huge amounts of data
- Planimetric accuracy is worse than its vertical accuracy
Photogrammetric Characteristics

Pro:
- High redundancy
- Rich with semantic information
- Dense positional information along object space break lines

Con:
- Almost no positional information along homogeneous surfaces
- Vertical accuracy is worse than the planimetric accuracy
- Complicated and sometimes unreliable matching procedures
- Suitable daytime data collection
Integration Requirements

The exploitation of complimentary characteristics in both mapping techniques would lead to a more complete surface description from semantic and geometric aspects

Requirements:

– Precise calibration of both systems to ensure the captured datasets are free of systematic errors
– Registration of the involved datasets relative to a common reference frame

Registration Problem

Registration; generally aims at combining multiple datasets acquired by different sensors in order to achieve better accuracy and enhanced inference about the environment than could be attained through the use of a single sensor.

For LIDAR & Photogrammetry; registration is an essential prerequisite to realizing the complementary characteristics in both datasets.
Registration: Key Issues

- **Registration primitives:**
  - Distinct points, linear features, or areal features

- **Similarity measure:**
  - Ensure the correspondence of selected conjugate primitives.

- **Registration transformation function:**
  - Mathematical relationship between geometric attributes of corresponding primitives.

- **Matching strategy:**
  - Controlling framework that utilizes the primitives, the similarity measure, and the transformation function to solve the registration problem.

Registration Primitives

- Conjugate features that could be identified in both datasets.
- These features will be used for the alignment of the LIDAR and photogrammetric datasets relative to the same reference frame.
- Alternatives:
  - Points,
  - Linear features, or
  - Homogeneous regions.
Registration Primitives

- **Point primitives:**
  - It is almost impossible to correlate the laser beam footprint with the corresponding point in optical imagery.

- **Homogeneous regions:**
  - Easy to extract from LIDAR data.
  - Not straightforward to extract from photogrammetric data.

- **Linear features:**
  - Can be reliably extracted from LIDAR and photogrammetric data.
Registration Primitives: LIDAR Data

• LIDAR linear features can be extracted through either:
  – Segmentation, plane fitting, and plane intersection.
    • Utilizes the raw LIDAR data (original point clouds).
    • Very accurate.
  – Utilization of range and intensity data.
    • Requires prior interpolation of the LIDAR point clouds into a uniform grid.
    • Planimetric coordinates are derived from the intensity image while the corresponding height information is derived from the range data.
    • Less accurate.

Linear Features from LIDAR (1)

• First: Planes are fitted through homogeneous patches.
  – Surface roughness can be used to reject points that do not belong to the patch in question.
• Linear features are obtained by intersecting neighboring planar patches.
Object Selection

Patch Selection
LIDAR Linear Features

Linear Features from LIDAR (2)
Intensity/Range Image Measurements

Registration Primitives: Photogrammetric Data

Points are selected mono-scopically (no stereo measurements)
Similarity Measure and Transformation Function

• **Transformation function:** Necessary mathematical model for the co-registration (alignment) of the photogrammetric and LIDAR datasets.

• **Similarity Measure:** Mathematical constraint that describes the coincidence of photogrammetric and LIDAR primitives after the application of the registration transformation function.

The LIDAR linear features will be used as the source of control (i.e., establish the datum) for the photogrammetric model.

\[
(\vec{V}_A \times \vec{V}_B) \cdot \vec{V}_1 = 0
\]

\[
(\vec{V}_A \times \vec{V}_B) \cdot \vec{V}_2 = 0
\]
Similarity Measure and Transformation Function

- The triple product in the previous equations will ensure the coincidence of:
  - The image line, and
  - The object line after being projected into the image space.
- The triple product has an implicit assumption that the transformation function between the LIDAR and photogrammetric data is represented by 3-D similarity transformation.
  - Assumes the absence of any biases between the two data systems, which cannot be represented by such transformation.
  - The quality of fit of the final registration could be used to verify such an assumption.

Experimental Work

**Photogrammetry: Specifications of the photogrammetric datasets**

<table>
<thead>
<tr>
<th>Camera type &amp; model</th>
<th>RC10 analog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length (mm)</td>
<td>153.167</td>
</tr>
<tr>
<td># of images</td>
<td>7</td>
</tr>
<tr>
<td># of control points</td>
<td>31</td>
</tr>
<tr>
<td>Avg. flying height (m)</td>
<td>1375</td>
</tr>
<tr>
<td>Avg. base (m)</td>
<td>700</td>
</tr>
<tr>
<td>Pixel size (mm)</td>
<td>0.024</td>
</tr>
<tr>
<td>Image measurement accuracy (mm)</td>
<td>± 0.024</td>
</tr>
</tbody>
</table>

Expected accuracy (assuming one pixel measurement error)

- Planimetric (m): ±0.21
- Vertical (m): ±0.60

**LIDAR: OPTECH ALTM 2050 laser scanner with an average flying height of 975m and mean point density of 2.24 points/m2 (~0.7m point spacing).**
Analysis of Experimental Work Results

Check point analysis for LIDAR-RC10 datasets

<table>
<thead>
<tr>
<th></th>
<th>Using Control Points</th>
<th>Using LIDAR Control Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td># of control points</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td># of control lines</td>
<td>0</td>
<td>109</td>
</tr>
<tr>
<td># of check points</td>
<td>24</td>
<td>31</td>
</tr>
<tr>
<td>$\Delta X, \text{m}$</td>
<td>0.07 ($\pm$0.28)</td>
<td>-0.05 ($\pm$0.25)</td>
</tr>
<tr>
<td>$\Delta Y, \text{m}$</td>
<td>-0.05 ($\pm$0.17)</td>
<td>-0.01 ($\pm$0.16)</td>
</tr>
<tr>
<td>$\Delta Z, \text{m}$</td>
<td>-0.16 ($\pm$0.19)</td>
<td>-0.14 ($\pm$0.31)</td>
</tr>
</tbody>
</table>

Results of Experimental Work

Compatibility of the generated orthophoto with the LIDAR DEM
Conclusions

• The co-registration methodology demonstrated its efficiency and capability to combine both the LIDAR and photogrammetric datasets.

• It is sufficiently feasible to use straight line features in establishing a common reference frame for the LIDAR and photogrammetric surfaces.

• The extraction of linear features from both datasets was accurate enough for the purposes set.
Ortho-Photo Generation

Ortho-Photo & Relief Displacement
Ortho-Photo Generation

True Ortho-Photo Generation
Future Work

1. The automation of the extraction of linear features from photogrammetric and LIDAR data together with the correspondence between conjugate features.

2. The possibility of developing new visualization tools for an easier portrayal of the registration outcome. Overlay of the derived ortho-photos and LIDAR data can be used to check the quality of the registration process as well as showing the different characteristics of the involved datasets.
Future Work

3. Finally, registered multi-temporal datasets will be inspected for the possibility of developing automatic change detection techniques.