Multi-Sensor Triangulation of Multi-Source Spatial Data

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Overview

• Introduction.
• Multi-sensor triangulation.
• Multi-primitive triangulation:
  – Points.
  – Linear features.
  – Aerial features.
• Experimental results.
• Conclusions and future outlook.
Introduction

• There is a tremendous increase in data acquisition systems, which are available for the mapping community:
  – Photogrammetric systems:
    • High resolution imaging satellites.
    • Metric analog frame cameras.
    • Metric digital frame cameras.
    • Metric digital line cameras.
    • Medium-format digital frame cameras.
  – LIDAR systems.
  – GPS/INS navigation units.
• These systems provide complementary information.
• We need to provide an integrating environment of these sensors: Multi-Sensor Triangulation (MST).
Photogrammetric Systems

Frame Cameras

- RC10
- DMC
- Applanix DSS
- Kodak 14n
- Canon EOS 1D
- SONY 717

Line Cameras

- ADS 40
- IKONOS
LIDAR Systems

ALS 40 (Leica Geosystems)  OPTECH ALTM 3100
Point-Based Triangulation

\[
\begin{bmatrix}
    x_a - x_p - \Delta x \\
    y_a - y_p - \Delta y \\
    -c
\end{bmatrix}
= \lambda R^T
\begin{bmatrix}
    X_A - X_0 \\
    Y_A - Y_0 \\
    Z_A - Z_0
\end{bmatrix}
\]
Line-Based Triangulation

Photogrammetry:

Direct measurement of intermediate points on images
Line-Based Triangulation

LIDAR:

Plane fitting & intersection

manual identification of LIDAR patches with the aid of imagery
Line-Based Triangulation

LIDAR:
Manipulation of range and intensity images
Line-Based Triangulation

Direct incorporation of LIDAR lines as control in the photogrammetric BA

\[
(\vec{V}_1 \times \vec{V}_2) \cdot \vec{V}_3 = 0
\]

Line-Based Triangulation
Patch-Based Triangulation

Direct incorporation of LIDAR patches as constraints in the photogrammetric BA

Photogrammetric (A,B,C points) and LIDAR surface patches
Patch-Based Triangulation

Direct incorporation of LIDAR patches as constraints in the photogrammetric BA

Volume of the pyramid: $i, A, B, C$ should $= 0$

$$\begin{vmatrix} X_i & Y_i & Z_i & 1 \\ X_A & Y_A & Z_A & 1 \\ X_B & Y_B & Z_B & 1 \\ X_C & Y_C & Z_C & 1 \end{vmatrix} \begin{vmatrix} X_i - X_A \\ Y_i - Y_A \\ Z_i - Z_A \\ X_B - X_A \\ Y_B - Y_A \\ Z_B - Z_A \\ X_C - X_A \\ Y_C - Y_A \\ Z_C - Z_A \end{vmatrix} = 0$$
Multi-Sensor Triangulation (MST)

- Developed an integrated triangulation system.
  - Multi-sensor: Satellite imagery, aerial imagery, LIDAR and GPS/INS.
  - Multi-primitive: distinct points, linear features, and aerial features.

- Advantages:
  - Takes an advantage of the extended coverage of imaging satellites.
  - Takes an advantage of the high geometric resolution of aerial imaging systems.
  - Utilizes sparse frame imagery to improve the weak geometry of imaging satellites while reducing ground control point requirements.
  - Uses LIDAR data for photogrammetric geo-referencing.
MST: Experimental Results

DSS: Expected accuracy:
planimetric: 0.25m
vertical: 0.74m
spatial: 0.78m
MST: Experimental Results

Upper Block

DSS: Upper Block

Upper LIDAR Scan
MST: Experimental Results

Middle Block

DSS: Middle Block

Middle LIDAR Scan
MST: Experimental Results

Lower Block

DSS: Lower Block

Lower LIDAR Scan
Stereo-IKONOS with GCP Layout

IKONOS scenes and GCP layout over Daejeon, Korea
MST: Experimental Results

Examples of Tie Points
MST: Experimental Results

Examples of Tie / Control Lines
MST: Experimental Results

Example of a Control Patch
## No Ground Control Points

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<th>RMSE (m)</th>
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138 Control Lines & 139 Control Patches

Scan line direction
Configuration of 5 GCP

Scan line direction
## 5 Ground Control Points

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<th># Frames</th>
<th>GPS / LIN / PATCH</th>
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138 Control Lines & 139 Control Patches

**Scan line direction**
Configuration of 7 GCP
## 7 Ground Control Points

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<th># GCP</th>
<th># Frames</th>
<th>GPS / LIN / PATCH</th>
<th>$\hat{\sigma}_0$ (mm)</th>
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138 Control Lines & 139 Control Patches
Configuration of 40 GCP
# 40 Ground Control Points

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138 Control Lines & 139 Control Patches

**Scan line direction**
MST: Experimental Results

![Graph showing experimental results for MST. The graph plots Number of Control Points on the x-axis and RMSE, m on the y-axis. Different lines represent different conditions: NO Frames, Frame, LIN, PATCH, GPS, GPS + LIN, GPS + PATCH. The graph illustrates how the RMSE changes with the number of control points for each condition.](image-url)
MST: Experimental Results

DSS / IKONOS Ortho-photos
MST: Experimental Results

DSS / IKONOS Ortho-photos
Ortho-Photo Generation
True Ortho-Photo Generation
MST: Experimental Results

Generated Ortho-photo

Differential Rectification
MST: Experimental Results

Generated Ortho-photo

True Ortho-photo
Concluding Remarks

• The introduced methodologies are successful in:
  – Using LIDAR features for photogrammetric geo-referencing.
    • Line-based and patch-based photogrammetric geo-referencing using control derived from LIDAR data.
  – Delivering a geo-referenced imagery of the same quality as point-based geo-referencing procedures.
  – Taking advantage of the synergistic characteristics of spatial data acquisition systems.
• The triangulation output can be used for the generation of 3-D perspective views.
Recommendations for Future Work

- Automated segmentation of LIDAR data to extract the patches and linear features.
- More investigation into using the outcome from the geo-referencing procedure for the verification of the system calibration.
- Utilize the raw LIDAR measurements in the patch-based photogrammetric geo-referencing.
  - Such a utilization will allow for LIDAR system calibration.
- Quality assurance and quality control procedures for LIDAR data.
3-D Perspective View