Geometric Potential of MOMS-02/D2 Data for Point Positioning, DTM and Orthoimage Generation

Emmanuel P. Baltsavias
Institute of Geodesy and Photogrammetry, ETH Zurich

Dirk Stallmann
Institute of Photogrammetry, University of Stuttgart
Outline

1. Introduction
2. Test Data and Ground Truth
3. Sensor Model /Geometric Point Positioning Accuracy
4. DTM Generation
5. Orthoimage Generation
6. Conclusions
Introduction

• Past and current satellite-based optical sensors:
  • linear CCDs in pushbroom mode
  • across-track (SPOT) or along-track stereo (MOMS-02)
  • geometric resolution up to 4.5 m (MOMS-02)
• Future:
  • **along-track** and across-track stereo
  • geometric resolution up to 1 m
• Improved possibilities for
  • mapping
  • DTM and orthoimage generation, orthoimage maps
  • classification and feature extraction
MOMS-02 Sensor

- High resolution imaging system with along-track stereo
- 4-channel multispectral, visible and near-infrared range
- 3-line along-track stereo (fore, aft and nadir), panchromatic
- GSD nadir: 4.5 m x 4.5 m
- GSD multispectral/oblique panchr.: 13.5 m x 13.5 m
- Convergence angle, oblique-nadir: 21.4°
- Base-height-ratio: fore-aft 0.8, nadir-oblique 0.4
- Orbit mean altitude: 296 km
MOMS-02 Principle

Modular Optoelectronic Multispectral/Stereo Scanner 2
Test Data

- MOMS-02/D2 Space Shuttle Mission April/May 93
- Australia scene 17, fore - nadir - aft images
- Covered area: ca. 40 x 110 km²
- Elevation range: 200 - 300 m, few discontinuities
- Almost no vegetation and cultural features
- Data: Level 1 (radiometric corrected only)
- Image size:

<table>
<thead>
<tr>
<th></th>
<th>Pixels per line</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>nadir</td>
<td>8304</td>
<td>24122</td>
</tr>
<tr>
<td>fore/aft</td>
<td>2976</td>
<td>8121</td>
</tr>
</tbody>
</table>
Ground Truth

- Ground control points
  - ca. 80 points covering the whole image
  - measured with D-GPS
  - GPS accuracy 10 cm,
    actual accuracy 1 - 5 m (poor identification)

- 3D profile
  - 16 km long
  - 3228 DTM check points in 5-m interval
  - measured with roving D-GPS
  - accuracy 10 - 20 cm
Image Quality Problems

- grey level range: 50 grey values
- positive and negative spike noise, pattern noise
- blemished lines in nadir channel
- different brightness of the left and right part of nadir channel

Original (nadir)  
After contrast enhancement  
After preprocessing
Preprocessing

• for point measurement
  • strong contrast enhancement by Wallis filtering
• for DTM and orthoimage generation
  • noise reduction by median filter
  • contrast enhancement by Wallis filtering
  • special filters for nadir channel
Fore channel

Original image

After preprocessing
Nadir channel

Original image

After preprocessing
Control Points

Control point definition in the nadir (left) and fore (right) preprocessed images

Well defined

Poorly defined
Bundle Adjustment Software

- Kratky’s geometric sensor model
- Extended bundle adjustment for point determination and reconstruction of the exterior orientation (stereo and single images)
- Strict sensor modelling, elliptic orbit
- Sensor types: pushbroom and oscillating scanners, e.g. SPOT, Landsat 5 TM, JERS-1 OPS, MOMS-02

- Unknown parameters per image:
  6 exterior, 2 interior, 3 linear or 6 quadratic attitude rates
- Minimal number of required GCPs: 4 - 6, suggested 10
Point Positioning Accuracy

- Combination: Fore-aft
- Point measurement manually and by least-squares matching
- Refinement of pixel coordinates from residuals of bundle
- Linear and quadratic attitude rates

<table>
<thead>
<tr>
<th>Model</th>
<th>GCP</th>
<th>CHP</th>
<th>$\sigma_0$ [$\mu$m]</th>
<th>RMSE of CHPs [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\mu_X$</td>
</tr>
<tr>
<td>Q</td>
<td>20</td>
<td>45</td>
<td>3.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Q</td>
<td>10</td>
<td>55</td>
<td>2.9</td>
<td>6.7</td>
</tr>
<tr>
<td>Q</td>
<td>6</td>
<td>59</td>
<td>2.3</td>
<td>7.4</td>
</tr>
</tbody>
</table>
Summary of Point Positioning Accuracy

• Linear attitude rates 40% worse than quadratic
• 10 GCPs suffice
• With 6 GCPs solution sensitive to GCP selection
• Image point measurement with matching vs. manual
  - at least as accurate
  - faster
Fast Polynomial Mapping Functions

- Polynomial of 3° - 4° with 11 - 16 terms
- Height ...independent parameter connecting the three 2D spaces
- Much faster than rigorous transformations
- Almost equally accurate (difference < 0.1 pixel)
Automatic DTM Generation

Multiphoto Geometrically Constrained Matching

image pyramid

reference image

selected points

quasi epipolar line
Constrained Least-Squares Matching

- Matching edge points, not in epipolar line direction
- Reduced errors due to multiple solutions, radiometric differences, noise etc.
- Higher success rate and reliability
- Any scale and rotation difference can be accommodated, e.g. fore and nadir
- Any number of images simultaneously matched (not implemented yet for MOMS)
Matching Parameters

- Fore and aft, 12 x 20 km area
- Two tests: 10,000 and 18,000 match points
- Patch size 17 x 17 pixels ... 230 x 230 m -> smoothing
- Conformal geometric transformation
- 4 pyramid levels
Matching along edges: without (top) and with (bottom) constraints
Matching fore (left) and nadir (right). Top: no constraints, scale approx. = 1. Bottom: with constraints, scale approx. = 3.
• Automatic detection and deletion of blunders
  -> 2.5% and 5.8% of points rejected in the two matchings
• Flat and open terrain, some creeks
• Very little radiometric differences
  -> huge advantage of along-track stereo

Radiometric differences:
Different water reflection
DTM Accuracy

Bilinear interpolation of 2,900 GPS values in 40 m regular DTM derived from matching

Statistics of $\Delta Z$:
- $\Delta Z_{\text{mean}} = 0.6$ m
- RMSE $\Delta Z = 4.2$ m
- $\Delta Z_{\text{max}} = 13.2$ m

Errors > 8.5 m due to:
- smoothing of discontinuities
- weak texture
Triangular meshes of 10,000 match points.
DTM derived from 18,000 match points and displayed as grey level image
Orthoimage generation

• Using DTM and PMFs to derive orthoimages

• Accuracy (related also to DTM accuracy)
  • from four GCPs: RMSE 5 - 6 m in planimetry and height
  • from parallaxes between orthoimages of fore and aft channel:
    - ideally should be identical
    - 50 points over whole area and at large radiometric differences
    - max. parallax 0.6 pixel (8 m), mainly at creeks

• 3.5 min. CPU time for fore or aft channel (SUN Sparcstation 20)
3D Parallel View

Top left part of the fore channel (12 km x 20 km). Orthoimage draped over the DTM (height exaggeration factor 8)
Conclusions

• Kratky’s model:
  • mathematically strict, modelling of calibration errors
  • operationally simple, flexible (various sensors)
  • quadratic rates, 10 GCPs, point measurement by matching

• PMFs:
  • fast and accurate
  • DTM and orthoimage generation

• Results (fore-aft channel):
  • Point positioning accuracy: in X, Y, Z: 6 - 7 m
  • DTM accuracy: RMSE 4.2 m, max. 13.2 m
  • Orthoimage: ca. 0.5 pixel accuracy, fast generation
  • No systematic errors in sensor model
Future Work

• Problems of this test:
  - poor: image quality, GCP definition, calibration
  - limited data set, flat and open terrain, no reference DTM

• Further tests with MOMS-PRIRODA using
  - good GCPs and reference DTM
  - different terrain types (slope, cover)

• Use of nadir channel in the investigations
  - expectations for improved planimetric accuracy