ATOMIC input and output data

Ortho images

DTM/DSM

2D inaccurate structured road vector data

ATOMIC Automatic road centreline extraction

3D accurate structured road vector data

Classification of roads according to landcover

forest
urban
rural area
General Strategy

- Use of existing knowledge, rules and models
- Use and fusion of multiple cues about road existence
- Creation of redundancy through multiple cues to account for errors
- Early transition to object space, use of 2D and 3D interactions to bridge gaps and missing road parts
- Object-oriented approach in multiple objects (e.g. road classes)

Features, Cues and Algorithms

<table>
<thead>
<tr>
<th>Input</th>
<th>Processing</th>
<th>Features, cues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo color aerial images / orthos</td>
<td>Feature Extraction</td>
<td>zebra crossings</td>
</tr>
<tr>
<td></td>
<td>Image Matching</td>
<td>2-D straight edges</td>
</tr>
<tr>
<td></td>
<td>Image Classification</td>
<td>2-D road marks</td>
</tr>
<tr>
<td>DSM</td>
<td>nDSM Generation</td>
<td>3-D straight edges</td>
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<tr>
<td>Geodatabase</td>
<td>Information Derivation</td>
<td>3-D road marks</td>
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<tr>
<td></td>
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<td>road regions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>shadows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>vegetation</td>
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<tr>
<td></td>
<td></td>
<td>buildings</td>
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<tr>
<td></td>
<td></td>
<td>above-ground and</td>
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<tr>
<td></td>
<td></td>
<td>ground objects</td>
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<tr>
<td></td>
<td></td>
<td>road geometry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>road attributes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>road topology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>landcover</td>
</tr>
</tbody>
</table>
How ATOMI road extraction works

a. Straight edge extraction
b. Removal of irrelevant edges
c. Detection of Parallel Road Sides
d. Evaluation of Missing Road Sides
e. Bridging Gaps
f. Linking Road Sides to Extract Roads

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Test site in Switzerland

Geneva 7km²
Aerial Film 50cm (summer ‘98)
IKONOS PSM 100cm (May ‘01)
Quickbird PSM 70cm (July ‘03)
Manually measured reference data from 50cm orthophotos

Results from Geneva (yellow VECTOR25, black result)

50cm Aerial Film  100cm IKONOS  70cm QUICKBIRD
Quality evaluation of the results of Geneva

<table>
<thead>
<tr>
<th>Quality measures</th>
<th>Aerial 50cm</th>
<th>IKONOS-PSM 100cm</th>
<th>Quickbird-PSM 70cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness</td>
<td>90.89%</td>
<td>54.22%</td>
<td>72.68%</td>
</tr>
<tr>
<td>Correctness</td>
<td>95.36%</td>
<td>81.22%</td>
<td>89.58%</td>
</tr>
<tr>
<td>Length of reference (km)</td>
<td>50.72</td>
<td>50.72</td>
<td>50.72</td>
</tr>
<tr>
<td>Length of extraction (km)</td>
<td>48.35</td>
<td>33.87</td>
<td>42.16</td>
</tr>
<tr>
<td>RMS error (m)</td>
<td>x 0.62</td>
<td>y 0.93</td>
<td>x 0.81</td>
</tr>
<tr>
<td>Mean error (m)</td>
<td>x 0.07</td>
<td>y -0.73</td>
<td>x -0.44</td>
</tr>
<tr>
<td>Process time (s)</td>
<td>1510</td>
<td>992</td>
<td>924</td>
</tr>
</tbody>
</table>
Results from Geneva

- The system achieved good results with the 50cm aerial film imagery with 90% of rural roads extracted.

- The performance (mainly the completeness) of the satellite data was inferior to aerial imagery, especially the 1m IKONOS imagery.

- In the satellite data, higher class (wider) roads were usually extracted, while most lower class (narrower) roads were not. This is because of ATOMI’s algorithm requirement of min. 3 pixels road widths was not fulfilled.

- The smaller GSD of Quickbird made more roads visible and the road surface and road edges were clearer. But compared to aerial film the completeness was lower.

- With smaller GSD, correctness and accuracy do not deteriorate much, but completeness yes.

Building Extraction, Ikonos, Melbourne

- 19 roof corners measured by GPS
- Measured in mono and stereo in all three images of Melbourne

Results from stereo images and 6 GCPs (RMSE):

RPCs: XY = 0.7m
Z = 0.9m
Building Extraction

Aerial Photography (1:15,000) /Ikonos 1m Pan Stereo

- Omission of 15% of buildings (small & large)

Produced with CyberCity Modeler

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Building Extraction

3D Model of University of Melbourne Campus from Ikonos 1m PAN Stereo

Produced with CyberCity Modeler

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Building Extraction

Aerial Photography (1:15,000)  Ikonos Stereo  Ikonos Nadir Pan-Sharp.

Conducive to building feature measurement

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Building Extraction

Aerial Photography (1:15,000)  Ikonos Stereo  Ikonos Nadir Pan-Sharp.

Ikonos stereo of questionable value to building feature measurement in this case

---

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Building Extraction

Ikonos Stereo

Aerial Photography (1:15,000)

Ikonos Nadir Pan-Sharp.

Ikonos stereo of questionable value to building feature measurement in this case

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High-Resolution Satellite Imagery Precision Processing Software SAT-PP (ETHZ)

Main Features of SAT-PP:
- High-Resolution Satellite Imagery (HRSI): ≤ 5 m Geometrical Resolution
- Joint Sensor Model for IKONOS, QuickBird, SPOT, ALOS/RPISM and etc.
- Specially Designed Image Matching Procedure for Linear Array Imagery

Software SAT-PP: New Processing Methods / Products for HRSI

Input
Imagery with Supplementary Data
- IKONOS
- QuickBird
- SPOT ……
GCPs

SAT-PP
- Image Orientation
- Image Matching
- Feature Collection
- 3D City Modeling
- Image Pan-Sharpening
- DTM & Ortho-Image Generation

Products
- DSM / DTM
- Ortho-Images
- Pan-Sharpened Images
- 3D Vector Data
- Digital Image Maps
- 3D City Models

……

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Main Features of SAT-PP:

- **Project and Data Management**
  - Multi-sensor HRSI data support, including IKONOS, QuickBird, SPOT and ALOS/PRISM
  - Image enhancement with an edge-preserving adaptive smoothing filter

- **Image Orientation**
  - Manual and semi-automated GCP / tie point measurement in multi-image environment
  - Both rigorous sensor models and generalized sensor models such as rational function models (RFM), affine projection model and projective direct linear transformation model (DLT)
  - On-line quality control and error analysis with interaction of graphics elements

- **Quasi-Epipolar Resampling for Stereoscopic Feature Collection and Automated DSM / DTM Generation**

- **Automated DTM / DSM Generation**
  - A hybrid image matching procedure, which exploits the characteristics of linear array imagery and its image geometry, is used to produce dense, precise, and reliable results for DSM / DTM generation

---

Main Features of SAT-PP:

- **Orthorectification Image Generation**

- **Image Pan sharpening**
  - Fully automated sub-pixel image registration between multi-spectral and panchromatic imagery
  - Enhancement of the visual information of multispectral imagery by fusing it with the detailed spatial information of panchromatic imagery

- **Feature Collection and Semi-Automated 3D City Modelling**
  - Works in stereoscopic and multi-image monoscopic mode
  - Features can be collected manually or semi-automatically
  - Mono-plotting with existing terrain data
  - Works with semi-automatic 3D city modeling software CyberCity Modeler™
Application Case 1: IKONOS Geo Product; Hobart, Australia

Semi-Automated GCP Measurement

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Application Case 1: IKONOS Geo Product; Hobart, Australia

## Orientation Results of IKONOS Triplet

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of GCPs (CPs)</th>
<th>RMS in East (m)</th>
<th>RMS in North (m)</th>
<th>RMS in Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLT without RPCs</td>
<td>124 + 0</td>
<td>0.36</td>
<td>0.52</td>
<td>0.73</td>
</tr>
<tr>
<td>With RPCs</td>
<td>1 + 123</td>
<td>0.49</td>
<td>0.35</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>4 + 120</td>
<td>0.48</td>
<td>0.36</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>124 + 0</td>
<td>0.45</td>
<td>0.35</td>
<td>0.84</td>
</tr>
</tbody>
</table>

DSM Accuracy Test Results:
(Checked by more than 100 Feature (GPS) Points)
RMS: 0.9 m

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Application Case 1: IKONOS Geo Product; Hobart, Australia

Ortho-Image Overlaid with Collected Features & Contours

Visualization of 3D City Model

Application Case 2: IKONOS Geo Product; Thun, Switzerland

Shadow Area

Original IKONOS Image            Enhanced IKONOS Image

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Application Case 2: IKONOS Geo Product; Thun, Switzerland

Matched Ridge Lines

Image Overlaid with Matched Line Features

5 m Grid DSM Generated from 5 IKONOS Images

Vegetation

Thun City

Image Orientation Accuracy:
RMS-X: 0.48 m
RMS-Y: 0.82 m
RMS-Z: 0.79 m

DSM Accuracy Test Results:
(With 2 m Reference DSM generated from LiDAR)
Whole Area: RMS: 4.8 m
City Area: RMS: 2.9 m
Open Area: RMS: 1.3 m
Application Case 3: SPOT5-HRS Imagery; CNES-ISPRS Study Team

Image Orientation Results: (43 GCPs)
RMS-X: 6.48 m; RMS-Y: 3.28 m; RMS-Z: 1.85 m

Application Case 1: SPOT5-HRS Imagery; CNES-ISPRS Study Team

DSM Accuracy Test Report

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Application Case 4: SPOT5 Across-Track 2.5 m Stereo; Bamiyan, Afghanistan

Image Orientation Accuracy:
RMS-X: 1.2 m; RMS-Y: 2.1 m
RMS-Z: 1.8 m

Visualization of 20 m DTM

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The Great Buddha

3D Visualization of the Bamiyan Area
(SPOT DSM overlaid with 1 m IKONOS Image)

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Application Case 5: QuickBird 0.7 m Stereo 1B Product; Yokohama, Japan
Application Case 5: QuickBird 0.7 m Stereo 1B Product; Yokohama, Japan

Image Pan-Sharpening: Enhance the visual information of multispectral imagery by fusing it with detailed spatial information in panchromatic imagery.

3D modeling and visualization of cultural heritage sites from high-resolution satellite imagery.

Application example of High Resolution Satellite Images
Motivation

- Modeling of large cultural heritage areas can be required for monitoring, visualization, documentation or cartographic mapping
- C.H. areas are often located in areas not easily accessible or in problematic countries
- (High-resolution) satellite imagery offer a great alternative to standard aerial photo for mapping purposes
Cultural Heritage sites from space

Quickbird over Peru

High-Resolution satellite data

- Almost instant availability
- Large area coverage
- Increasing resolution
- Different products (PAN, multispectral, stereo, ...)
- High costs

Scene orientation (strict sensor model vs. RPCs)

\[ \text{DTM/DSM generation} \]

\[ \text{Visualization} \]
UNESCO has recently started the OPEN INITIATIVE, a partnership with different space agencies to support and assist in the monitoring and documentation of World Heritage sites, natural hazards and for the sustainable development using satellite data.

=> great interest (not only in the scientific community) towards mapping from satellite data.

Different sensors available with resolution less than 5 m (QuickBird, IKONOS, SPOT-5/HRG, IRS-1C/1D, ...)

Satellite data used for documentation and visualization of the C.H. area of Bamiyan, Afghanistan.

**The Bamiyan project**

1. DTM generation from high-resolution satellite images
2. Generation of tourist / geographic information system
3. 3D Modeling of the Great Buddha of Bamiyan
   
   [Gruen et al., 2002, 2003]
4. 3D modeling of the 2 empty niches
   
   [Gruen et al., 2004]
5. Mapping and visualization of frescos
   
   [Remondino et al., 2004]
Cultural heritage site of Bamiyan

- ca 200 km N-W of Kabul
- ca 2500 m altitude
- Valley in the middle of silk road
- One of the major Buddhist areas
- 3 larger Buddha statues
- Nowadays 8 protected areas
Cultural heritage site of Bamiyan

SRTM DTM
NASA-Wind

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Cultural heritage site of Bamiyan from space

1. DTM from satellite images

1. **SPOT 5** - HRG stereo pair
   - for DTM generation
   - 2.5 m ground resolution
   - 60x60 km coverage

2. **IKONOS** Geo image mosaic
   - only for texture mapping
   - 1m ground resolution
   - ca 12x18 km coverage

7 GCP measured with GPS available
   (master station, rover station)
DTM Generation with SAT-PP Software (ETHZ)

High-Resolution Satellite Imagery Precision Processing
[Zhang and Gruen, 2004]

1. SPOT 5 - HRG stereo pair (B/W)
   - orientation with RPCs
   - DTM 20 m raster grid

2. IKONOS Geo image mosaic (color)
   - orientation with RPCs
   - DTM 5 m raster grid

<table>
<thead>
<tr>
<th>Source</th>
<th>RMSE East (m)</th>
<th>RMSE North (m)</th>
<th>RMSE Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKONOS</td>
<td>0.56</td>
<td>0.48</td>
<td>-</td>
</tr>
<tr>
<td>SPOT Image Pair</td>
<td>1.22</td>
<td>2.01</td>
<td>1.50</td>
</tr>
</tbody>
</table>

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DTM Visualization

- DTM 20 m raster grid
  - 49x38 km²

DTM data visualization / animation

- 20 m grid = 4.6 million points
  - B/W SPOT texture = ca. 435 MB

- 5 m grid (interpolated) = ca. 12 million points
  - B/W IKONOS texture = ca. 300 Mb
  - Color IKONOS texture = ca. 900 Mb

- 3D views with ARCGIS - ARC Scene

- Flight-over with ERDAS - Virtual GIS
DTM Visualization

- 20 m grid SPOT texture
- 5 m grid IKONOS texture

DTM with SPOT texture

- Rock Cliff with Buddha Niches
DTM with IKONOS texture

Niche of the Great Buddha

Niche of the Small Buddha

Rock cliff with Buddha niches

Ghulghulah, old Bamiyan city
DTM - Anaglyph view

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DTM data visualization/animation

Video - DTM with SPOT texture

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DTM data visualization/animation

Video - DTM with IKONOS texture

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2. Geographic / Tourist Information System

- Generation of new maps: contours, slopes, hydrology, settlements, ...
- Generation of documentation information system
- Manual extraction of features / layers from ortho-images
- ARC VIEW and ARC Scene
GIS data in ARCScape

- Easy to handle data in 3D
- Extrude 2D features vectors into 3D objects
- Flight-over
- 3D Analysis

Rivers, Streets and House extraction
**Bamiyan: new cartography**

- Russian Map (1970’s)

**Summary of Bamiyan project**

- Modeling of the whole cultural heritage area of Bamiyan for documentation and visualization purposes
- Different types of images (satellite, metric, tourist) for landscape modeling and ‘lost objects’ computer reconstruction
- Satellite data as only possibility for the landscape mapping and for the generation of new / updated cartography
- Potentiality of satellite imagery for documentation & visualization of C.H. areas
Some conclusions on use of HR for base geodata extraction

- Very high geometric potential
- GCPs very crucial, with smaller GSD requirements for GCP quality rise; GCPs with GPS preferable over use of GCPs from orthoimages and maps.
- Accuracy for well-defined points
  - planimetry: down to 0.3 m (ca. 1/3 of GSD)
  - height: down to 0.5 m (ca. 1/2 of GSD)
- DSM generation (no manual editing, best case)
  - maximum point density up to ca. 2-3m
  - accuracy (along track): 1-4 m depending on terrain slope and land cover. For open terrain 1 m or even less feasible.
  - certain loss of details due to area matching and pixel size

Some conclusions

- Interior orientation errors become important for high accuracy applications, need for in-flight calibration
- Orthoimages with submeter accuracy can be produced even with suboptimal DSMs / DTMs and GCPs. Accuracy can reach 0.5 GSD
- Extraction of objects (buildings, roads) limited by resolution. A 0.5 m GSD would be desirable for rather complete extraction of such objects.
- Accuracy of object extraction (manual or automatic) can be less than 1 GSD
Some conclusions

• Increased number of HR satellites expected next period, with more spectral channels and smaller GSD

BUT

• Will prices fall (espec. for stereo)?
• Will image availability improve?
• Will marketing and licencing policies improve?
• Will area covered by each image increase?

Greatest hopes with state-supported systems (e.g. ALOS) and low-cost large-area images, and small low-cost HR satellites.