Integration of image analysis and GIS - examples

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INTEGRATION OF IMAGE ANALYSIS AND GIS - EXAMPLES

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- Problems addressed in literature
- Examples from the project ATOMI, ETH Zurich
- Other examples (mainly from the ISPRS WG Integration of Image Analysis and GIS and the Joint ISPRS/EARSeL Workshop, Valladolid, June 1999; all full papers available at www-datafusion.cma.fr/sig/meeting/workshopprog99.html)
- Conclusions
Problems addressed in literature

- differences between land use (GIS) and land cover (images)
- lacking procedures for interpretation and quality control of fused images
- fusion and the mixed pixels problem
- distortion of spectral properties with pixel based fusion techniques
- different levels of quality regarding geometric accuracy and thematic detail
- fusion of multitemporal data, change detection
- differences in spatial, spectral resolution (centre and width of band), also polarisation for radar
- generalisation, different levels of abstraction
- models of objects are simplistic, not general enough; on the other hand generic models are too weak
Problems addressed in literature (2)

- different representations even for the same object or object class (roads, road networks)
- different data structures (e.g. raster, vector, attribute)
- lack of accuracy indicators for the components to be fused (even though often RMS and rough estimates should be available)
- data are often inhomogeneous, i.e. acquired by different methods, several analysts
- algorithms to fuse information are restrictive (Bayesian approaches and Dempster-Shafer reasoning)
- rules/models differ spatially (e.g. buildings in Europe differ from those in developing countries) and in time (old buildings differ from new buildings)
- architecture of systems, complexity
- gap between research and practise (which is typical for not matured R&D areas).
Knowledge-based vector map update - Project ATOMI

(see also paper by Eidenbenz et al. in Congress proceedings)

Input

- vectorised 1:25,000 topomaps (roads, buildings)
  - buildings automatically vectorised
  - roads semi-automatically
  - data topologically structured and edited (but errors still exist)
  - map update cycle 6 years, imagery for update 2 years older
  - RMS: ca. 5 m, max. error ca. 12.5 m

- aerial images (B/W or color, 1:30,000 / 15 cm lens, 1:15,000 / 30 cm lens, 14 and 28 µm, 60%/25% forward / side overlap)

- national DTM (DHM25, 25 m grid, 2-3 m RMS in "Mittelland", 5-7 m RMS Alps)

- DSM derived by matching from images (Match-T)

- possibly orthoimages
Knowledge-based vector map update - Project ATOMI

Output

- More accurate planimetry (1 m RMS) for road centerlines and building outlines
- For buildings only major structures of outline, e.g. with length > 2m
- Height (1-2 m RMS) for road centerlines and one characteristic (?) point for roofs
- Results conformal to landscape model (reality!) not cartographic one
- Delivery of semi-operational, off-line program for production
- High accuracy but even more important RELIABILITY e.g. 70-80% correct AND reliable results, 20-30% with manual editing
- First step: improve existing vector data, find deleted objects
- Second step: find new objects
ATOMI - General Strategy

- Separate in detection and “reconstruction” (for buildings)
- Use multiple images (but 2 if possible), go in 3D as early as possible
- Revisit low-level processes, e.g. extract fainter edges
- Combine 2D image features (more complete) and 3D
- Use various cues about the existence of objects (DTM, DSM, color, texture, shadows, edges, context, knowledge etc.)
- Achieve complementarity AND redundancy of cue information
- Check local consistency on multiple levels, e.g.
  - fit of matched edges
  - fit of neighbouring extracted roads
  - fit of roads and buildings
ATOMI - General Strategy

- Use object-oriented approaches and object hierarchies, e.g. road network (highways, 1, 2, 3, etc. class; possibly join some classes)
- Separate objects in different subclasses depending on terrain landuse and relief, e.g.
  roads: in forest, forest border, open mountainous, open rural, suburban, urban, city center (such fine division maybe not necessary)
- For each subclass adapt:
  - domain knowledge
  - methods
  - strategy
  - tolerances
  - reliability indicators
ATOMI - General Strategy

- Use of rules and knowledge
  - domain knowledge
  - laws, regulations, specifications etc.
  - knowledge derived and accumulated during the processing (weighted with reliability) and validation
- Knowledge used to
  - constrain search space
  - check consistency of solution -> used also for reliability indicators
  - select and weight attributes for the objects
  - constrain the values that these attributes can take
ATOMI - General Strategy

- Problems
  - knowledge incomplete, partly erroneous, no quality indicators
  - there are always exceptions!
  - temporal and spatial variability of "knowledge"
  - how to map the knowledge to the given cartographic objects
  - the problem of class definition
  - representation, structure and storage in computer of all data
- Thus, knowledge
  - never used strictly
  - deviations are accounted for by accumulation of much evidence
- Additional major problem: combination of cues, solution of conflicts
- Generalisation of roof outline. Shift of vectorised map data with respect to image.
VEC25 Examples - Buildings

Left: New houses, scale differences at middle left, wrong connection of 2 houses (bottom right), funny structure bottom right. Top right: Vector data with almost no overlap with house. Bottom right: Rotated vector data. Non existing house.
Combination of 4 (left) and 3 (right) houses to one. Strange (not possible) roof outline.
Examples - Buildings

Roofs occluded by trees and shadows.
Left: shadows on majority of road edge, vectors on trees, red road, no definition of road edge. Center: road stops, more vector points at curves. Right: yellow zebra stripes, road partly on railway tracks, poor crossing definition.
Left: nonexisting roads, vectors on trees / cars/ house. Middle: very difficult road at bottom left, crossing definition at top. Right: crossing definition
VEC25 Examples - Roads and Buildings

New roads (and buildings!).
Left: crossing definition, new road. Right: missing roads, road edge definition, crossing definition.
VEC25 Examples - Roads

Left: nonexisting road. Left middle: forest occlusion. Right middle: road at forest border. Right: funny road vector.
VEC25 Examples - Roads

Left: forest border, agricultural road with grass/dirt in the middle. Right: forest occlusion, forest border.
Left: forest occlusion, different road spectral properties. Right: forest border, partly one or no road side visible.
Open rural area, relatively easy cases. Right: road sector at the center right totally occluded.
Knowledge-based Road Extraction

(see also paper by Zhang and Baltsavias in Congress proceedings)

General Strategy

Input data from L+T

Road design rules, other knowledge

Database for road network
- Class
- Road type
- Road marks
- Geometry with 3D info
- Width
- Length
- Horizontal & vertical curvature
- Topology info
- Landcover

Image processing

Partial results

Knowledge Base
Cue combination

- Results
- Accuracy estimation

Controller
Knowledge-based Road Extraction / Key Steps

Stereo color aerial images

Feature extraction Image matching

3D straight lines
- 2D road regions
- Shadows
- Road marks, cars, …

Hypothesis generation and verification

3D road reconstruction

2D image analysis

Subclass attribute derivation

- Road attributes
- Landcover
- Slope

Knowledge Base

VEC25 and other input data

Image matching

2D image analysis

Subclass attribute derivation
Use of Knowledge in Matching

- Restrict edge extraction in buffer around VEC25
- Restrict search space along an epipolar band (using DTM or DSM)
- Use similar edge orientation (- $\Delta$\kappa)
Visual check of matching results

Left image patch and lines

Right image patch and lines

One line in left image

Candidates ... in red

Correct matches ... in yellow

White ... Extracted lines
Blue  ... Matched lines
Matching Results

<table>
<thead>
<tr>
<th>No. lines in L</th>
<th>No. lines in R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>97</td>
</tr>
<tr>
<td><strong>&gt;=5.0 pixel</strong></td>
<td>81</td>
</tr>
<tr>
<td><strong>unmatchable</strong></td>
<td>35</td>
</tr>
<tr>
<td><strong>found match</strong></td>
<td>41</td>
</tr>
<tr>
<td><strong>wrong match</strong></td>
<td>1</td>
</tr>
</tbody>
</table>
3D Road Extraction

**Strategy**

- Removal of irrelevant lines ➞ knowledge (DTM/DSM, classification)
- Finding 3D parallel lines ➞ knowledge (DTM, shadows, trees)
- 2D image evaluation ➞ knowledge (training areas, edge orientation, shadows, road stripes, car position with respect to road)
- Spatial reasoning using knowledge
- 2D and 3D interactions ➞ knowledge
Road buffer
Road direction
Road slope

Removal of
irrelevant lines

3D parallel
check

2D image
evaluation

Possible Road Sides that are Parallel (PRSP)

Graph
Representation

Checking relation
between PRSPs

Gap

Search graph
Link PRSPs

Extracted Road

ROAD BUFFER
ROAD DIRECTION
ROAD SLOPE

Removal of irrelevant lines

3D parallel check

2D image evaluation

Possible Road Sides that are Parallel (PRSP)

Graph Representation

Checking relation between PRSPs

Gap

Search graph Link PRSPs

Extracted Road
User Interface
Road and Low-Level Cues

Road image & edges

DSM-DTM in the region

Image classification (ISODATA, 5 Classes; Black: road region White: shadow)
Q_Klass road with part of opposite sides visible (but not overlapping)

(a) road appearance, VEC25 and lines in buffer

(b) image classification

(c) DSM-DTM
Q_Klass road: both road side invisible or undefined

(a) road appearance, VEC25 and straight lines in buffer

(b) image classification

(c) DSM-DTM
Road Extraction Results

Classification result

Extracted straight lines

Relevant 3D lines

Found 3D parallel lines, and extracted road centerline
Road Extraction Results

Suburban area

Rural area, unpaved road
Road Extraction Results

Suburban area

Rural area
Road Extraction Results

(a) appearance, VEC25 and straight lines in buffer

(b) image classification

(c) results by developed method
Advantages of Road Extraction Method

- Integration of knowledge processing of colour image data and existing digital geographic database
- Use of knowledge as much as possible to increase success rate and reliability of the results
- Creation of hypothesis in 3D
- Work in 2D image and 3D space, and use of 2D and 3D interactions
- Spatial reasoning by incorporating multiple knowledge and multiple cues
General System Flowchart

Locate relevant straight lines

- Finding PRS
- Finding SRS

Spatial reasoning

- Graph operation

VEC25 info (width, shape, length)

- Linking

Extracted roads

- Reliability measurement

Update knowledge base

Network generation
Ongoing work: Challenging Image Understanding task
Road extraction in very complex areas

Where are the correct roadsides and road centerlines?

How to find them?
ATOMI - Building Detection / DSM Generation

(see also paper by Niederoest in Congress proceedings)

DSM, 2m grid,
28 µm images
Building Detection: Blob Extraction

Classification result without mask (left), result using a mask from blob detection (right).
Building Detection: Refinement of Blobs

Part of the left aerial image (left); classification result with vegetation objects (middle); blobs with unique identification numbers shown with different grey values.
Building Detection: Refinement of Blobs

Normalized DSM before elimination of height values caused by vegetation (left); after elimination (right).
In the two examples above the left image shows the approximation from VECTOR25, the right images shows the translated and rotated result (derived using centres of gravity and main edge directions.)
K-means classification (left); roof surfaces inside the blob (middle); main roof surfaces after connecting small surfaces to big ones (right).
Building Coarse Model with Planar Surfaces

Left: planar fit using DSM points and 3-D edges. Simple house models where method works.
Data Fusion for Resolution Enhancement (Hill et al., 1999)

- Multispectral dataset (low resolution)
- Fusion procedure
- Panchromatic band (high resolution)
- Multispectral dataset (high resolution)
### Comparison of image “sharpening” methods (Hill et al., 1999)

<table>
<thead>
<tr>
<th>Pan 5m</th>
<th>Multi 25m</th>
<th>True image 5m</th>
<th>LCM</th>
<th>HFM</th>
<th>Brovey</th>
<th>IHS</th>
</tr>
</thead>
</table>

![Image Comparison](image-url)
Fusion of DEMs from optical and SAR data (Honikel, 1999)
## Fusion of DEMs from optical and SAR data (Honikel, 1999)

<table>
<thead>
<tr>
<th>DEM</th>
<th>Test site 1</th>
<th>Test site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>InSAR</strong> (ERS-1)</td>
<td>Signed average: 1.0m, Average: 3.7m, RMS: 4.7m, Correlation: 0.61</td>
<td>Signed average: -2.9m, Average: 11.3m, RMS: 14.9, Correlation: 0.54</td>
</tr>
<tr>
<td><strong>Stereo-optical</strong> (SPOT)</td>
<td>Signed average: 1.9m, Average: 6.0m, RMS: 7.9m, Correlation: 0.7</td>
<td>Signed average: -2.3m, Average: 6.8m, RMS: 9.3, Correlation: 0.66</td>
</tr>
<tr>
<td><strong>Fused</strong></td>
<td>Signed average: 1.4m, Average: 3.2m, RMS: 4.0m</td>
<td>Signed average: -2.2m, Average: 4.9m, RMS: 6.5m</td>
</tr>
</tbody>
</table>

Single sensor and fused DEM errors (reference DEM - generated DEM)
Interrelated Segmentation and Classification (Schneider/Steinwendner, 1999)

- Image
  - Radiometric calibration
    - Calibrated images
      - Pixelwise classification
        - Seed image
          - Initial segmentation parameters
            - Segmentation
              - Objects
                - Knowledge base
                  - Mixed pixel elimination
                    - Redefine segmentation parameters
                      - Refined classification
                        - Objects
                          - Single pixels left?
                            - Yes
                              - No
                                - Thematic map

Interrelated Segmentation and Classification (Schneider/Steinwendner, 1999)

Left intermediate, right final result
Image to Map Registration (Archangel Project)

Data 1
- Extract polygonal features
  - Initial registration
  - Match polygons
    - Extract conjugate points
    - Apply correction
    - Match linear features
    - Extract linear features
    - Refine match

Data 2
- Extract polygonal features

From Dowman/Dare, 1999
Image to Map Registration (Archangel Project)

Left: ATKIS data. Right: SPOT image with extracted polygons and ATKIS motorways and road polygons overlain (from Dowman/Dare, 1999).
Maps and laser data for building reconstruction for focus of attention and coarse initial modelling.
Combination of Laser and CIR for urban classification (Haala/Walter, 1999)

Maximum likelihood classification based on CIR and laser data.
Combination of Laser and CIR for urban classification (Haala/Walter, 1999)

Orthoimage.

Classification without (left) and with (right) using shadow areas.
Improved landuse classification by combining imagery and digital DB (Kunz, 1999)
Knowledge-based landuse classification

Image detail from the test area ‘Karlsruhe-Nord’.

Detected vegetation-free pixels.
Knowledge-based landuse classification

Triangulation network using vegetation-free pixels
Knowledge-based landuse classification

Selection and fusion of valid triangles to segments

Geometric overlap of DLM (black) and segments.
Knowledge-based landuse classification

Overlapping DLM and segmentation object.

Resulting disjoint objects.
Semantic net for the classification

scene

settlement bst
forest bst
water bst
reject bst

interface level

contour kon kon kon kon

object bst

primitive kbst

object relational Database

Semantic net for the classification
Conclusions

- Phot. and RS - acknowledged disciplines for GIS data collection
- GIS data gain importance for image analysis in Phot. & RS

⇒ certain exchange of the rather discipline-specific algorithms in all 3 fields

⇒ algorithms are used in a competitive and a supplementary manner

but fusion of algorithms and furthermore general information fusion is still at the very beginning

- Data fusion systems (have to be?) developed for specific applications
- Mapping business: “Systems which we could use in our day-to-day activities of maintaining geospatial datasets”