Vector, Map, and Image Registration and Conflation

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Outline

- Introduction & Motivation
- Our approach: AMS-conflation
  - Overview
  - Vector and imagery conflation
    - Techniques
    - Experimental results
  - Map and imagery conflation
    - Techniques
    - Experimental results
- Related Work
- Conclusion
Introduction

- Geospatial data sources have become widely available.
- Automatically and accurately integrating two spatial datasets is a challenging problem.
  - Focus on resolving spatial inconsistencies (positional inconsistencies) to align datasets.

| Road network (in vector format) | Orthoimagery (in raster format) | Street maps (in raster format) |
Motivation: Vector and Imagery Integration

- **Challenges**
  - Different projections, accuracy levels, resolutions result in spatial inconsistencies

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**Name:** Stanley Smith  
**Address:** 125, Gabriel Dr.  
**City:** St. Louis  
**State:** MO  
**Phone:** (314)955-4200  
**Lat:** 38.5943572  
**Long:** -90.4265843  
**Range:** 20 – 500  
**Zip:** 63103

**Road Name:** Gabriel Dr  
**Range:** 20 – 500  
**Lat:** 38.5943572  
**Long:** -90.4265843  
**Zip:** 63103
Motivation:
Vector and Imagery Integration in Google Earth

D.C.

Ft. Campbell, KY (only zoom into 1m/p)
Motivation: Parcel Vector and Imagery Int. in Zillow
Motivation: Map and Imagery Integration

Integration Challenge
- Different geographic projections and accuracy levels
Motivation: Map and Imagery Integration

Another Integration Challenge

Some online maps are not geo-referenced
Motivation: No Map and Imagery Int. in Google Earth

Google’s hybrid view of map and imagery (like vector-imagery integration)

Our approach:
Map-Imagery integration (MapQuest map)

Transportation Raster Map (showing Metro-Links and streets)

Population Density Map (showing Population Density and Streets)
Motivation: The Status of the Art

Traditionally, the problems of vector-imagery and map-imagery alignment have been in the domain of GIS and Computer Vision.

In GIS literature
- The alignments were previously performed manually
  - Commercial products: MapMerger; Able R2V; Intergraph I/RASC; ESRI ArcGIS

In Computer Vision literature
- The alignments were performed automatically based on image processing techniques
  - Often required significant CPU time
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Aligning Geospatial Data Using Conflation Technique

Conflation: Compiling two geo-spatial datasets by establishing the correspondence between the matched entities (control point pairs) and transforming other objects accordingly.
Our Approach: AMS-Conflation

Automatic Multi-Source Conflation

Exploiting multiple sources of geospatial information to automatically align data

- Automatically exploiting information from each of the sources to be integrated to generate accurate control point pairs
- Exploited geospatial information from one data source can help the processing of the other source
AMS-Conflation:
Exploit Inferred Information from the Data Source

Inferred information from the data source

Detected edges

Classified road pixels

• Connectivity: 3
• Orientations: 1°, 90°, 180°
AMS-Conflation: Exploit Metadata about the Data Source

Metadata about the data source

Geo-coordinates
Resolution

Road widths

Resolution (or map scale)
AMS-Conflation:
Exploit Peripheral Datasets to the Data Source
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AMS-Conflation to Align Vector and Imagery

Lat / Long

Filtering Technique

Intermediate control points

Final control points

Control Point Detection

Triangulation and Rubber-Sheeting
Aligning Vector and Imagery:
Finding Control Point Pairs Using Localized Template Matching (LTM)
Aligning Vector and Imagery: Filtering Control Point Pairs Using Vector Median Filter (VMF)
Conflating Imagery and Vector Data Using Rubber-Sheeting [Saalfeld’88]
Conflation Results:

MO-DOT+ High-resolution USGS Color Image

- Red lines: Original MO-DOT
- Blue lines: Conflated lines
Conflation Results:
NAVSTREETS+ High-resolution USGS Color Image

- Red lines: Original NAVSTREETS roads  - Yellow lines: Conflated lines
Parcelizer: Parcel-Imagery Alignment

Filtering Technique

Intermediate control points

Final control points

Control Point Detection

Triangulation and Rubber-Sheeting

Lat / Long

Lat / Long

Lat / Long

Lat / Long
Finding Control Points in Parcelizer:
Finding Feature Points from Vector Parcel

Assumption*:
- Road regions are distinguishable from other parcels
Finding Control Points in Parcelizer:
Finding Feature Points from Vector Parcel

- Why not find the central-lines, then find the feature points
  - Difficult to trace parallel lines (segments)
  - Still need to determine feature points from central lines
  - Time consuming
Finding Control Points in Parcelizer: Finding Corresponding Points from Imagery

- Localized Template Matching (LTM)

1. Classify image pixels as road pixels (based on learned data)
2. Original road-sides around the area
3. Inferred template based on original road-sides
4. Compare

Control point pair
Aligning Parcel with Imagery by RubberSheeting

- The control point are further filtered to gain higher precision, then use rubbersheeting technique to align these two datasets.
Evaluation

Using road-buffer method

- Red lines: Reference roads (roadsides)
- Blue lines: Reference roads (centerlines)

**Completeness**: the percentage of the reference roads for which we generated conflated lines

\[
\frac{\text{Length of matched reference roads}}{\text{Length of reference roads}}
\]

**Correctness**: the percentage of correctly conflated lines with respect to the total conflated lines

\[
\frac{\text{Length of matched conflated lines}}{\text{Total length of conflated lines}}
\]

**Positional Accuracy**: the percentage of conflated roads within \(x\) meters to the reference roads
Results:

US Census TIGER/Lines roads+ B/W Image

<table>
<thead>
<tr>
<th></th>
<th>Original TIGER/Lines</th>
<th>Conflated TIGER/Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness</td>
<td>37.9%</td>
<td>84.7%</td>
</tr>
<tr>
<td>Correctness</td>
<td>31.3%</td>
<td>88.49%</td>
</tr>
</tbody>
</table>

Positional Accuracy

Yellow Lines: Conflated TIGER/Lines
Red Lines: Original TIGER/Lines
## Results:

**NAVTEQ NAVSTREETS+ High-res Image**

<table>
<thead>
<tr>
<th></th>
<th>Original NAVSTREETS</th>
<th>Conflated NAVSTREETS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Completeness</strong></td>
<td>44.9 %</td>
<td>74.4 %</td>
</tr>
<tr>
<td><strong>Correctness</strong></td>
<td>47.9 %</td>
<td>85 %</td>
</tr>
</tbody>
</table>

### Positional Accuracy

![Positional Accuracy Chart]

- Blue Lines: Conflated NAVTEQ NAVSTREETS
- Red Lines: Original NAVTEQ NAVSTREETS
Aligning Parcel Vector Data with Imagery

Blue Lines:
Conflated Parcel Vector Data

Red Lines:
Original Parcel Vector Data
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Map with Unknown Coordinates

Detect Intersection Points On the Map

Point Pattern Matching & Map-Imagery Conflation

Geo-referenced Imagery

Vector-Imagery Conflation

Points On the Imagery/ Vector Data
Finding Intersection Points on Maps

- Difficult to identify intersection points automatically and accurately
  - Varying thickness of lines
  - Single-line map v.s. double-line map
  - Noisy information: symbols and alphanumeric characters

- Proposed a technique to detect intersections in [acm-gis'04]
- Our primitive technique is further improved in [Chiang et al. acm-gis’05]

Maps → Isolate map data by automatic thresholding and trace parallel lines

Remove noisy information by separating lines and characters

Apply morphological operator

Points → Recognize intersections by checking line connectivity

Detect intersections

Lines → Find Corners (using OpenCV)
Finding Intersection Points on Maps: Results

- Some noisy points will be detected as intersection points.
- Our geo-spatial point matching algorithm can tolerate the existence of misidentified intersection points.
Point Pattern Matching: Overview

- Distribution of feature points is the *fingerprint* of the spatial dataset
- Find the mapping between these points to get a set of control point pairs

How to solve the point sets matching problem:
- A geometric point sets matching problem
- Find the transformation $T$ between the layout (with relative distances) of the two point sets

80 points

Example: $(x,y) = (83,22)$

400 points

Example: $(lon,lat) = (-118.407088,33.92993)$
Point Pattern Matching: Finding the Transformation

Transformation = Scaling + Translation

- Transforms most points on map to points on imagery
- Find matching point pairs to solve this transformation
Point Pattern Matching

- Pick a pair of points in first dataset
Point Pattern Matching

- Pick two random points in the second dataset as potential matching candidates
Point Pattern Matching

- Apply the same transformation to the other points
- Repeat this for a different pair until enough points are matched.
Geospatial Point Pattern Matching (GeoPPM):

- Exploit geospatial properties to reduce the search space of PPM
  - Connectivity of an intersection: the number of intersected roads
  - Orientations of intersected road segments
  - Map scale
  - Point density and localized distribution of the points

Connectivity: 3; Orientations: 0, 90, 270
GeoPPM: Exploit Connectivity

Light Green: Impossible candidates for $P_1$
Dark Green: Possible candidates for $P_1$
GeoPPM: Exploit Orientation

Dark Green: Possible candidates for $P_1$
Light Green: Impossible candidates for $P_1$
GeoPPM: Exploit Angles between Points

Some of the possible candidate pairs for $P_1, P_2$
Some of the impossible candidate pairs for $P_1, P_2$
GeoPPM: Exploit Density between Points

Some of the possible Candidate pairs for $P_1, P_2$
Some of the impossible Candidate pairs for $P_1, P_2$
GeoPPM: Localized Distribution of the Points
GeoPPM: Localized Distribution of the Points
GeoPPM: Localized Distribution of the Points
Aligning Maps and Imagery

- Using matched point pattern to align maps with imagery by rubber-sheeting
Aligning Maps and Imagery

- Using matched point pattern to align maps with imagery by rubber-sheeting
Experimental Setup:
Two Areas with various Maps/Imagery
Results
Evaluation:

- The conflated map roads v.s. the corresponding roads in the imagery
  - Use TIGER maps for evaluation
  - Compare conflated map roads with reference roads (manually plotted roads)
    - Completeness/ Correctness /Positional Accuracy
Evaluation: The Performance of Map-Imagery Conflation

Completeness/Correctness

Positional Accuracy

Disp. from reference roads (m)

Original TIGER map
Conflated TIGER map
An Example Application Based the Conflated Data

Some swimming pools
An Example Application Based the Conflated Data

What is the address of this pool owner?
An Example Application Based the Conflated Data

480 Kenwood Dr, Lemoore, CA 93245
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### Related Work

**Vector to vector conflation** based on corresponding features identified from both vector datasets (in GIS domain)

- [Walter et al. 99]: Matching features (e.g. intersection points or polygons) at geometry level
- [Cobb et al. 98]: Matching features both at spatial/non-spatial level
- [Chen et al. 06]: Matching two road networks using GeoPPM

**Vector to imagery conflation**

- Utilizing matched **polygons** [Hild et al. 98]
- Utilizing matched **lines** [Filin et al. 00]
- Utilizing matched **junction-points** [Flavie et al. 00]

All above solutions

- Require lots of CPU time
- Utilize vector data only for verifying detected features not for extracting features
Related Work

**Raster to raster conflation:**

To the best of our knowledge, there is no research addressing the problem of automatic conflation of maps and imagery.

**Related work of imagery-imagery conflation**

- Sato et al. [Sato 01] proposed an edge detection process was used to determine a set of features that can be used to conflate two image data sets.
  - Their work requires that the coordinates of both image data sets be known.
- Dare et al. [Dare 00] proposed multiple feature extraction and matching techniques.
  - Need to manually select some initial control points.
- Seedahmed et al. [Seedahmed 02] proposed an approach extract features from imagery by Moravec feature detector and obtain transformation parameters by investigating the strongest clusters in the parameter space.
  - Require lots of CPU time.
- Commercial products: Able R2V and Intergraph I/RASC.
  - Need to manually select all control points.
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AMS-Conflation

Automatic Vector to Imagery Conflation
- Road Vector to Black-White Imagery Alignment [sstd'03]
- Road Vector to Color (High-resolution) Imagery Alignment [stdbm'04] [GeoInformatica'07]
- Parcel Vector to Color (High-resolution) Imagery Alignment [sstd'09]

Automatic Map to Imagery Conflation [ng2i'03a] [acm-gis'04] [acm-gis'05] [GeoInformatica'08]

Automatic Vector to Vector Conflation [sstdbm'06]