Road Segmentation by Exploiting Road Vector Data

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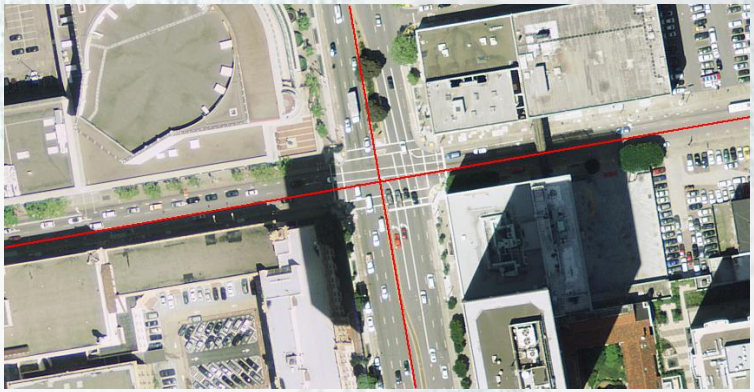
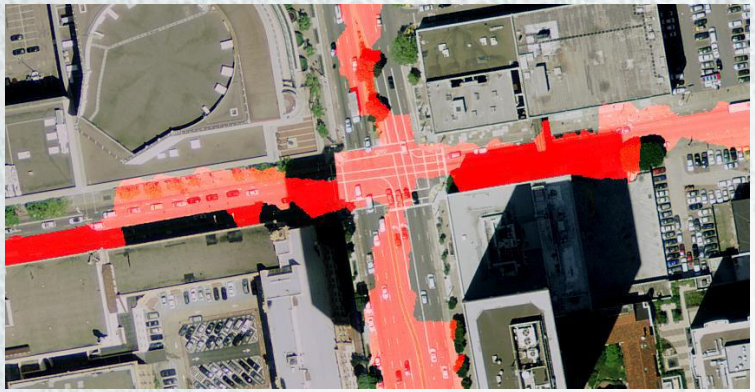
Introduction

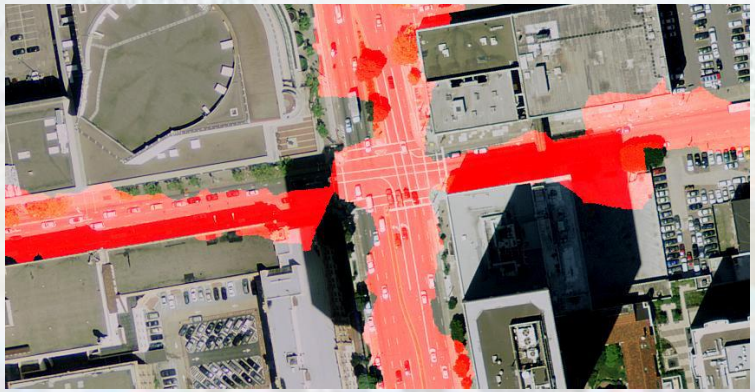
- Segmenting road regions from high resolution aerial images is important (building and update GIS, providing contextual information for image analysis) yet challenging (large variations on road surfaces).
- Although a large number of methods for road extraction have been proposed, reliable performance is still difficult to achieve, especially for high resolution images containing complex scenes.
- Road vector data are widely available from various online cartographic resources (Google Map, OpenStreetMap, etc.).
- Vector data can provide supervision for segmenting road regions.

Straightforward approach

- How to utilize vector data for supervised road segmentation is not a trivial problem.



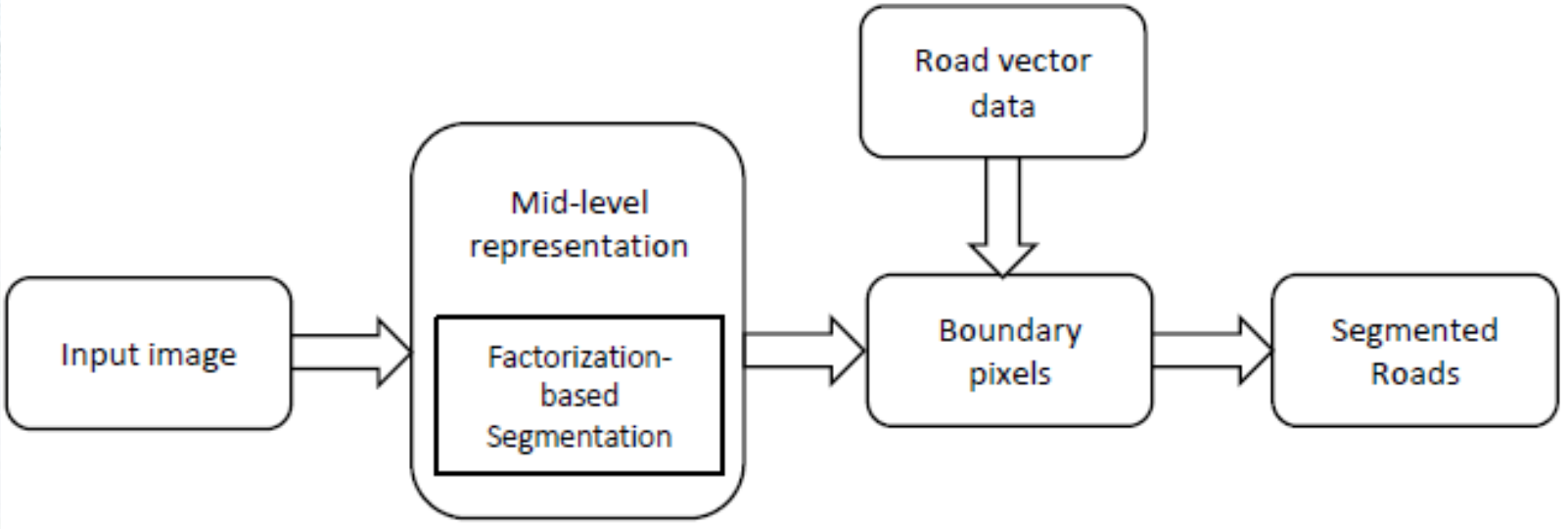




Proposed method

- The proposed method relies on a basic but distinctive feature of roads – parallel road edges. The distribution of the boundary locations with respect to road vectors are exploited to identify road edges.

- System overview



Local spectral histograms

- **Given an image window W and a bank of filters $F^{(\alpha)}$, $\alpha = 1, \ldots, K$, a spectral histogram consists of histograms of filter responses**

$$H_{\mathrm{W}} = \frac{1}{|\mathbf{W}|}\left(H_{\mathrm{W}}^{(1)}, H_{\mathrm{W}}^{(2)}, \ldots, H_{\mathrm{W}}^{(K)}\right)$$

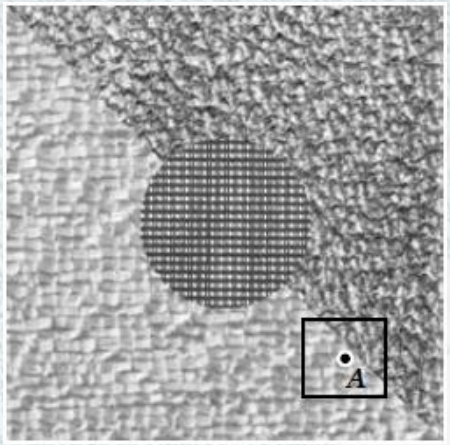
  - $H_{\mathrm{W}}^{(\alpha)}$ is the histogram of a filter response

- **A local spectral histogram is computed from a square window centered at a pixel. The size of the window is called integration scale.**

- **Spectral histograms can characterize both texture and nontexture regions.**

Image model

- Assume that spectral histograms within homogeneous regions are approximately constant.



- The feature of a near-boundary pixel location can be approximated by a linear combination of the representative features weighted by the corresponding area coverage.

- Each feature in an image can be regarded as a linear combination of all representative features weighted by the fractional area coverage in the local window.

Image model - continued

- **An image model to associate each feature with the representative features**

$$\mathbf{Y} = \mathbf{Z}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$$

- $\mathbf{Y} = [Y_1\ Y_2\ \ldots.\ Y_m]$ where Y_i is the feature vector of pixel *i*
- $\mathbf{Z} = [Z_1\ Z_2\ \ldots.\ Z_r]$ where Z_i is one representative feature
- $\boldsymbol{\beta} = [\beta_1\ \beta_2\ \ldots.\ \beta_m]$ where β_i is the weight vector of pixel *i*
- $\boldsymbol{\varepsilon}$ is a matrix representing noise

- **Segmentation is formulated as a factorization problem.**

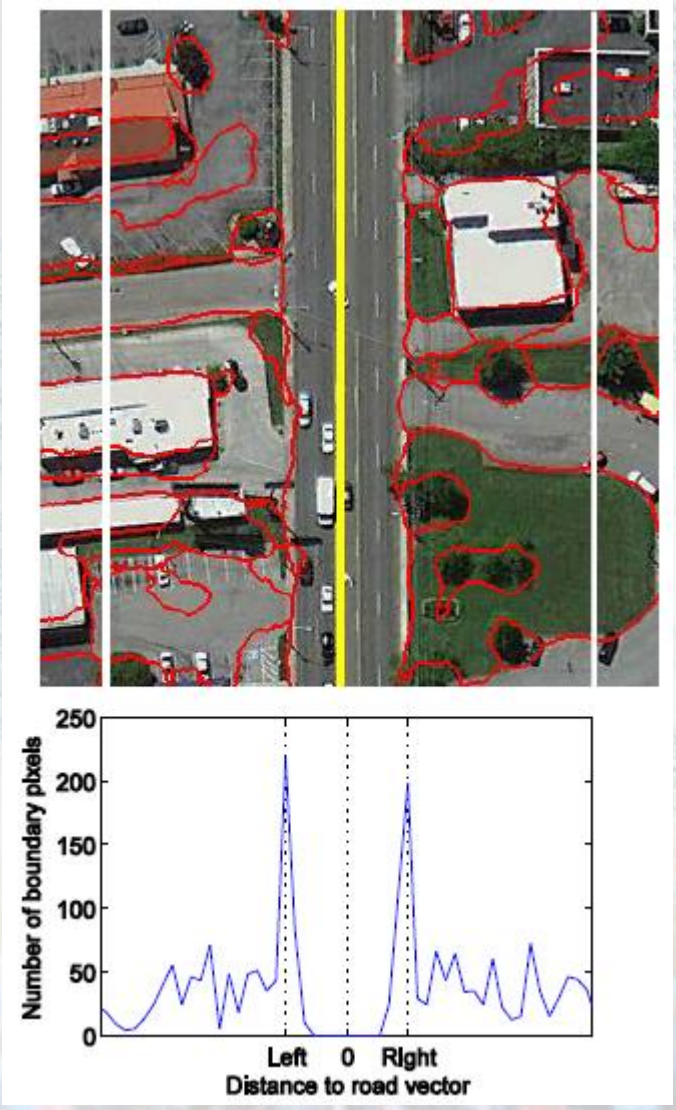
- **When Z is given, segmentation can be obtained by least squares estimation** $\hat{\boldsymbol{\beta}} = \left(\mathbf{Z}^T\mathbf{Z}\right)^{-1}\mathbf{Z}^T\mathbf{Y}$

Factorization-Based Segmentation

- Apply singular value decomposition (SVD) to obtain factored matrices with low rank.
- The number of segment equal to the effective rank of the feature matrix, which can be estimated from the singular values.
- SVD gives the subspace all features reside in, which greatly reduces feature dimensions and leads to the estimation of representative features.
- A nonnegative matrix factorization technique is used to ensure nonnegativity constraints.

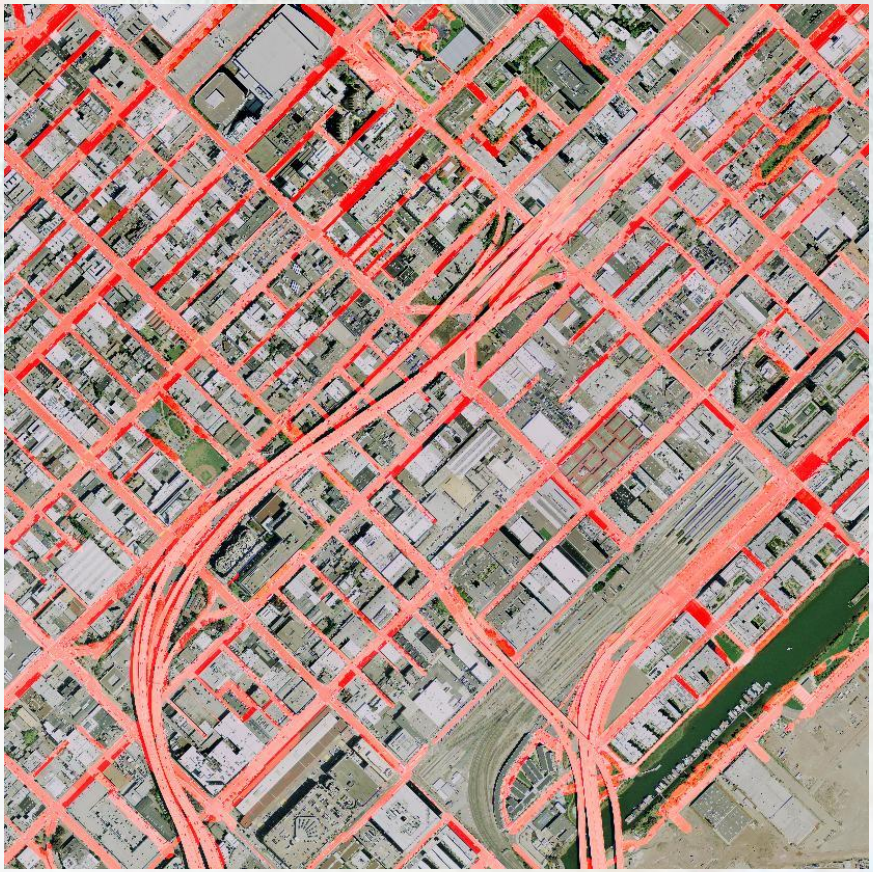
Finding Road Edges

- In aerial images, road edges tend to have more visible boundaries parallel to road vectors.
- Compute the distance from each boundary pixels in a search space to the line segment in vector data, and assign all the distances to bins of a histogram.
- A road edge is a straight line at the distance corresponding to the highest peak in the histogram.



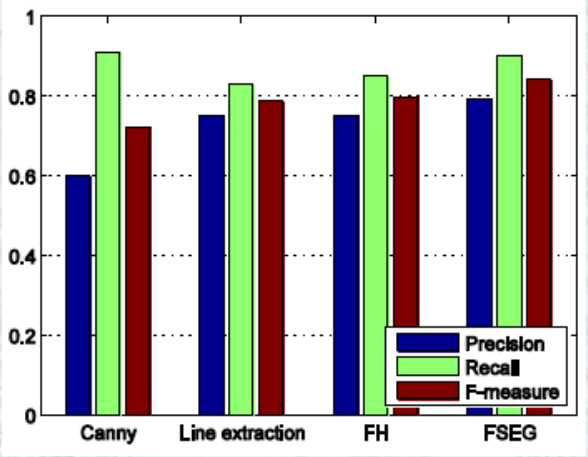
Experiments

- Two 5000×5000 aerial images covering complex urban scenes. Vector data are from OpenStreetMap.



Comparison

- Choose three different methods to produce boundaries, including Canny edge detector, straight line extraction, and the Felz-Hutt graph-based region merging algorithm.



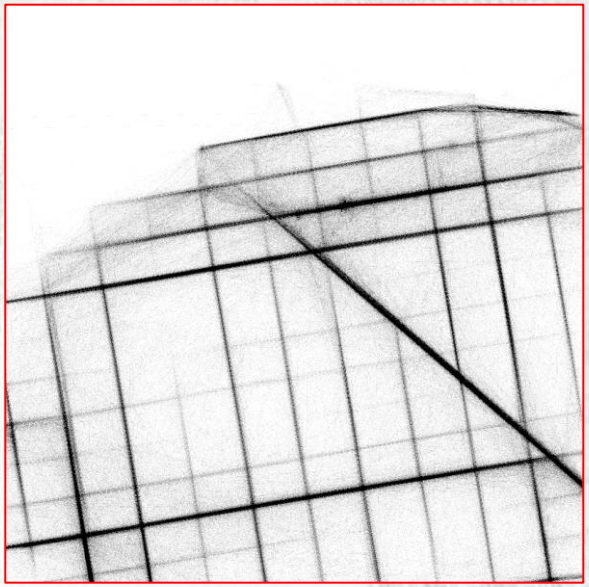
- The factorization-based algorithm achieves the best F-measure thanks to the effective use of texture information that helps identify the boundaries with high saliency.

Road segmentation using GPS traces

- **GPS receivers are widely deployed in everyday vehicles.**
- **To reduce manual work, we can replace road vector data with GPS traces of vehicles.**
- **Segment road using GPS traces**
  - Filter out noisy GPS traces based on image information.
  - Extract and prune the medial axis to form the road network.
  - Use the generated road network as the vector data to segment road regions

Experimental results

- GPS data are from over 500 taxi cabs in one month.



GPS traces

Road network

Road region

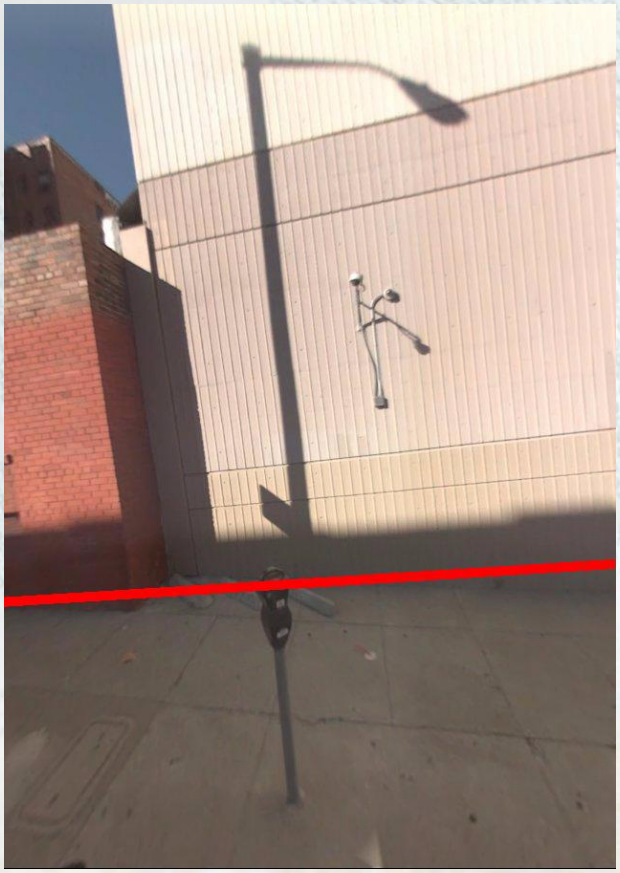
Road segmentation in street view

- Google streetview images are collected by a moving vehicle. The location information and camera parameters are available.

- The road edges identified in aerial images can be converted into edges in streetview images, which leads to segmenting road regions in streetview images.

Experimental results

Front



Right

Conclusions

- We present a simply and effective method that segments road regions with assistance of road vector data.
- The proposed method works reliably on real world data containing complex road structures.
- With additional data sources, the method can be further extended to produce useful results.