Feature Extraction and Simplification from colour images based on Colour Image Segmentation and Skeletonization using the Quad-Edge data structure

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Outline

- Motivation and problem statement
- Salient features of this research
- Results
- Conclusions

Motivation

Automated feature extraction can help in:

- Map feature digitization in a GIS environment
- Map updates
- Linear feature extraction from satellite imagery
- Linear features for automated image matching
- Robotic vision

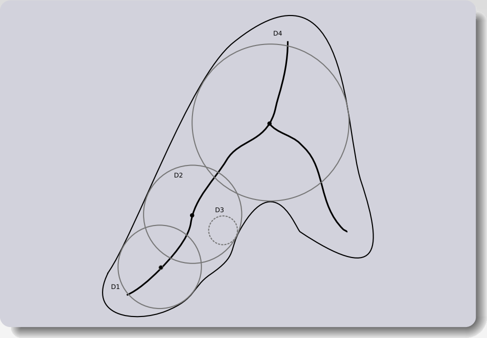
Research Objectives

1. To design a methodology to automate feature extraction from colour images.
   - Study existing Voronoi diagram / Delaunay graph based skeletonization algorithms.
   - Extend skeleton extraction algorithm by Anton et al. to colour images.
2. Development of an interactive system for automated centreline extraction from digital colour images.

What is a Skeleton?

A skeleton of an object can be described as its centreline.

More formally, a skeleton is the locus of the centre of maximal inscribed discs.



Existing Methods

- Raster based processing to extract centerline.
- Mainly process binary images.
- Do not preserve topology and mediality simultaneously.

Example

- Morphological thinning
- Distance transform

Existing Methods

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Example

Grayscale and colour images are processed by thresholding.

Existing Methods

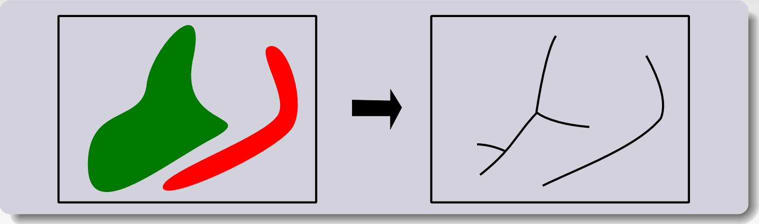
- Raster based processing to extract centerline.
- Mainly process binary images.
- Do not preserve topology and mediality simultaneously.

Example

Thinning does not guarantee mediality while Distance transform does not ensure connectivity.

Points Addressed in This Research

- Computation of vector skeletons without any intermediate raster skeletons.
- Colour images are appropriately processed by utilizing colour image segmentation algorithm.
- Voronoi diagram based skeletons preserve topology as well as geometry.



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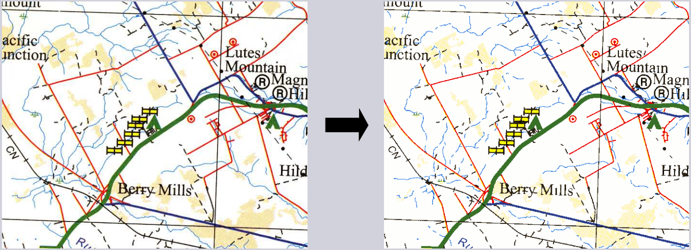

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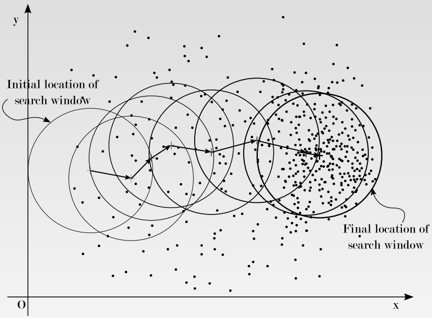
Mode seeking using mean shift algorithm



The final window location gives the local maxima of the distribution

Image segmentation

Mean shift algorithm can be applied to segment images. Following general procedure is used:

1. Definition of segmentation parameters
2. Definition of search window
3. Mean shift algorithm
4. Removal of detected feature
5. Iterations
6. Determining initial feature palette
7. Determining final feature palette
8. Postprocessing

Image Segmentation using Mean Shift Algorithm

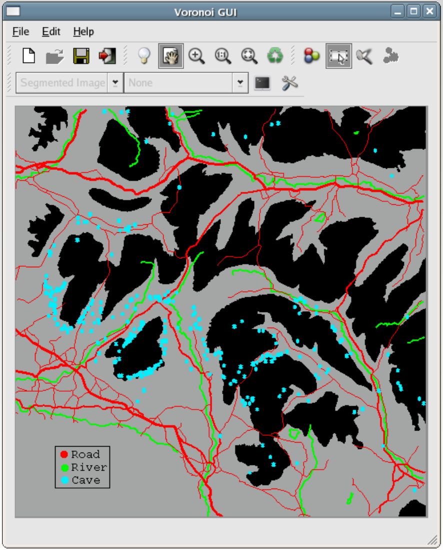
Image segmentation results

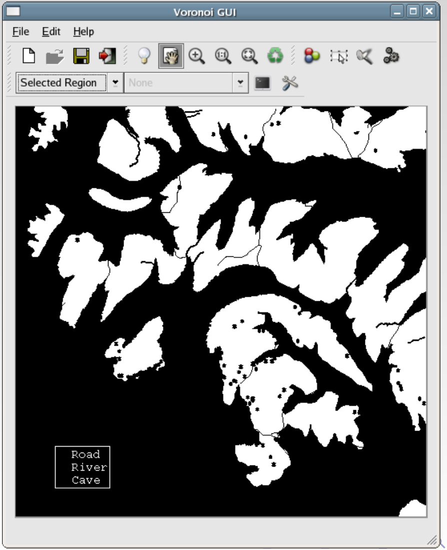
Photograph taken From Proposal "Decision support for flood event prediction and monitoring project"

Image Segmentation using Mean Shift Algorithm

Image segmentation results

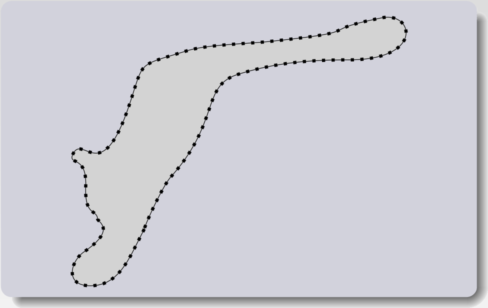
All objects or one object selected from the segmented image





Sampling object boundaries

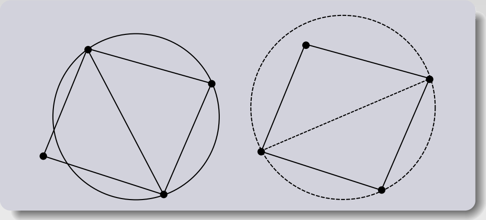
Sampling is done before any further processing.
The sampled points are then used to compute the Delaunay triangulation and the Voronoi diagram.



This can be achieved by edge detection. Edge pixels are calculated using morphological edge detection from the binary image of the selected object.

Computation of the Delaunay Triangulation

The **Delaunay triangulation** of a set of points is a triangulation such that no point in P is inside the circumcircle of any triangle of the triangulation.



Incircle criterion:

$$H(p_a, p_b, p_c, p_d) = \begin{vmatrix} 1 & x_a & y_a & x_a^2 + y_a^2 \\ 1 & x_b & y_b & x_b^2 + y_b^2 \\ 1 & x_c & y_c & x_c^2 + y_c^2 \\ 1 & x_d & y_d & x_d^2 + y_d^2 \end{vmatrix}$$

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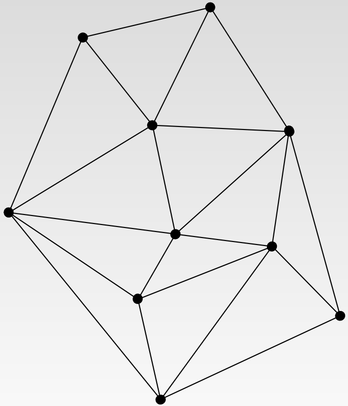
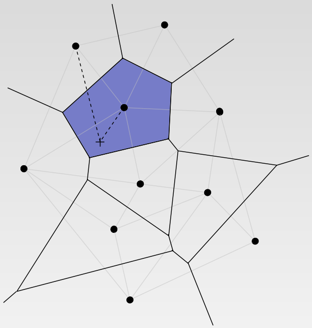


Computed using the **incremental algorithm**.

Computation of the Voronoi Diagram

Voronoi diagram is an irregular (polygonal) tessellation of space that adapts to spatial objects. They are synthesis of raster and vector model.

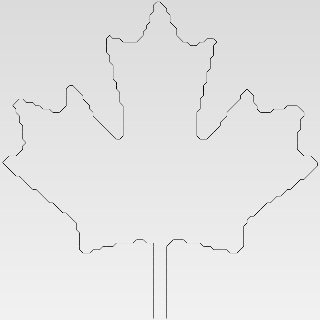


The Voronoi region of point p_i is given by:

$$V(p_i) = \{x | \, \|x - x_i\| \leq \|x - x_j\| \; \text{for } j \neq i, j \in I_n\}$$

Extraction of Crust (Boundary)

Any Delaunay edge that has a circle that does not contain the vertices of its dual Voronoi edge belongs to the **Crust**.



Extraction of Skeleton

Any Voronoi edge whose dual Delaunay edge is not a part of the crust and that falls inside the object under consideration, belongs to the **Anti-crust**.

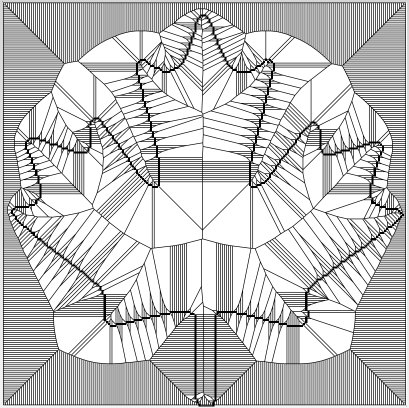
Conditions for a Voronoi edge e to be a part of the skeleton:

Corresponding Delaunay edge e' does not belong to the Crust

And

Voronoi edge e' lies completely within the binary object I

Extraction of Skeleton

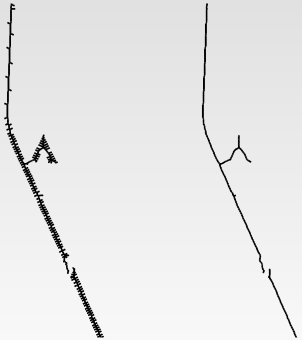


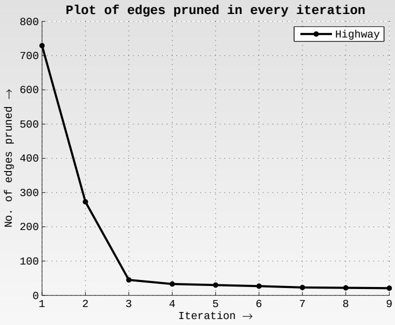
Pruning is required to get rid of the extraneous “hair” from the anti-crust!

Pruning

The extraneous edges are a result of the perturbations introduced in the sample points due to raster sampling.

A smooth skeleton can be generated from the anti-crust by removing leaf edges iteratively. Two to three levels of pruning is sufficient in most cases.





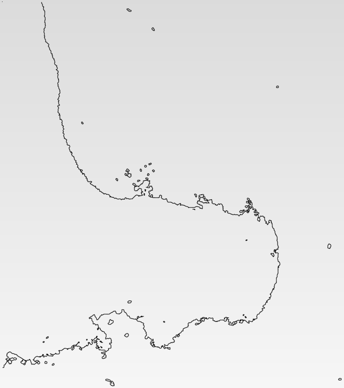
Satellite Imagery

Hebrides west coast

Results

Satellite Imagery

Saychelles beach



Results

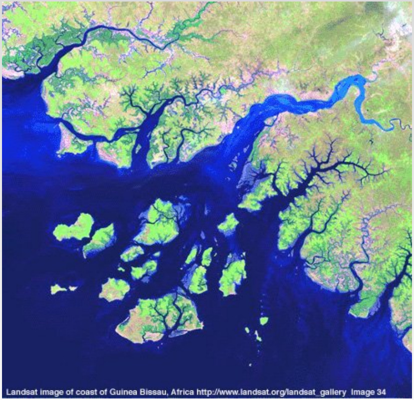
Satellite Imagery

Saychelles beach

Results

Satellite Imagery

Guinea Bissau coast



Limitations

- The skeletons may not be well connected due to the presence of clutter in the original map.
- Extra features need cleaning.

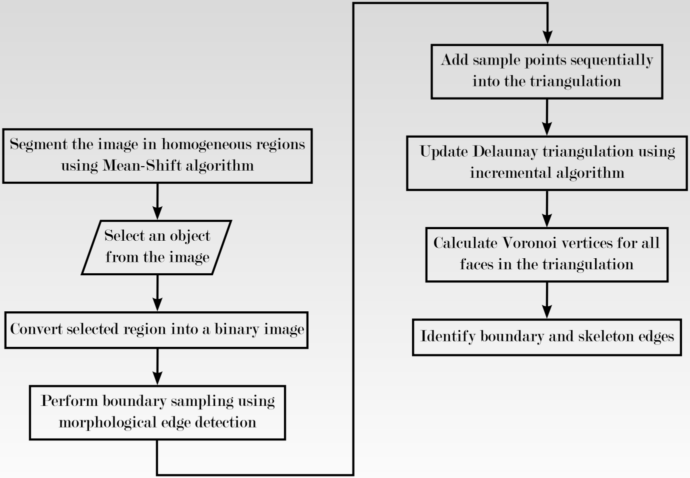
Conclusions

- Previous research on skeleton extraction using Voronoi diagrams has been successfully extended to colour images.
- A methodology to automate various parts of digitization from scanned maps has been suggested.
- An interactive software application has been developed to digitize features from colour images.
- Applicability of the designed method to process satellite imagery has been shown.

Thank You

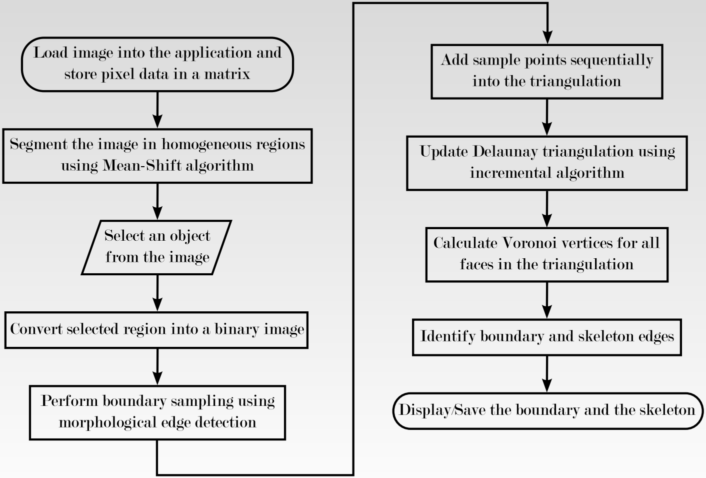
Methodology

Autonomous system for feature digitization from colour images



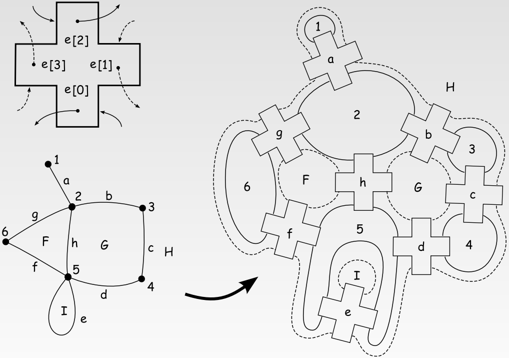
Methodology

Autonomous system for feature digitization from colour images



Quad-Edge Data Structure

- A Quad-edge simultaneously represents a graph and its dual.
- Dual of a mesh exchanges faces and vertices.
- The edges of the graph are directed and there are four such edges representing two symmetric edges from both the graph and its dual.



Quad-Edge Data Structure

Two atomic operators for navigation:

- **Rot()** points to a 90^o counterclockwise rotated edge.
- **Onext()** points to the next counterclockwise edge sharing the same origin with the current edge.

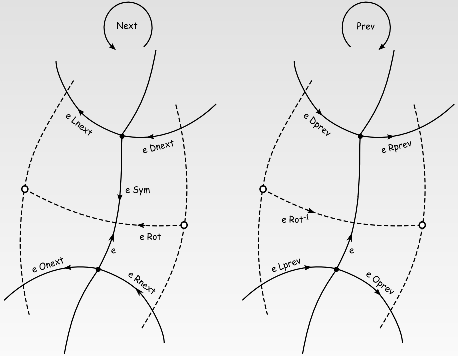
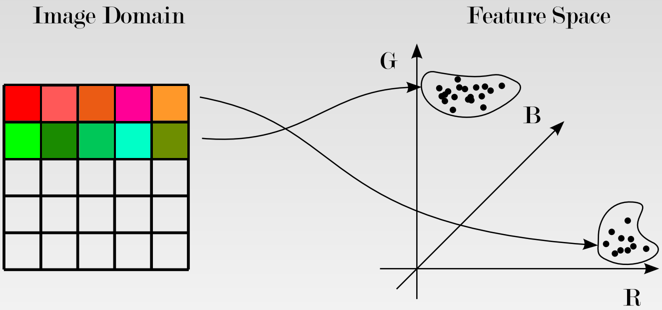


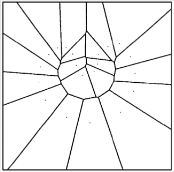
Image Space to Feature Space

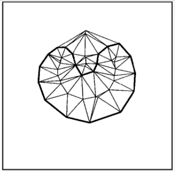
Clustering is done in **Feature Space** using **Mean Shift algorithm**. Conversion from Image Space to Feature Space is performed before clustering.



Crust Condition

[Amenta et al., 1997]:
Let S be a finite set of points in a plane, and let V be the vertices of the Voronoi diagram of S. Let S' be the union $S \cup V$, and consider the Delaunay triangulation of S'. An edge of the Delaunay triangulation of S' belongs to the *crust* of S if both of its endpoints belong to S.





Crust Condition

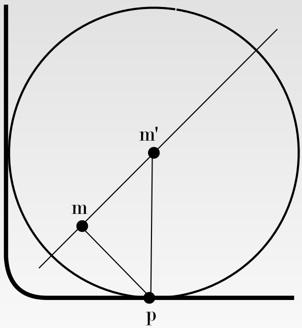
One step formulation by Christopher Gold:

$$(s-q)\cdot(s-r)*(p-q)\cdot(p-r) \geq -(s-r)\cdot v*(p-q)\cdot v$$

Where, edge(q,r) is the Delaunay edge under the test and edge(p,s) froms the dual Voronoi edge. v is a vector 90^o clockwise from $(r-q)$.

Sampling Condition

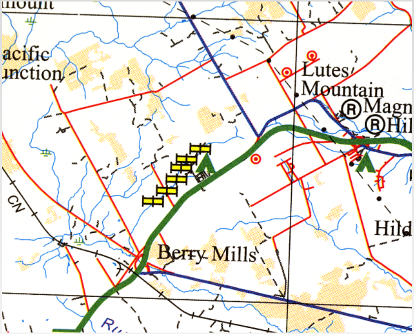
Let F be a smooth curve and $S \subset F$ be a finite set of sample points on F. The sampling should be done such that the distance from any point p on F to the nearest sample $s \in S$ is at most a constant factor r times the *local feature size* at p, which is defined as the distance from p to the *medial axis* of F.

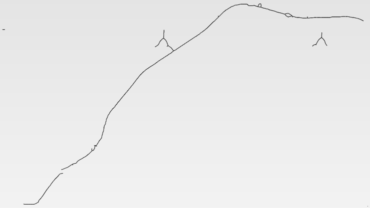


Distance $d(p, m)$ defines the local feature size.

Colour Scanned Maps

National highway

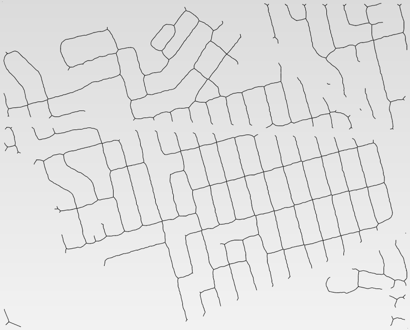




Results

Colour Scanned Maps

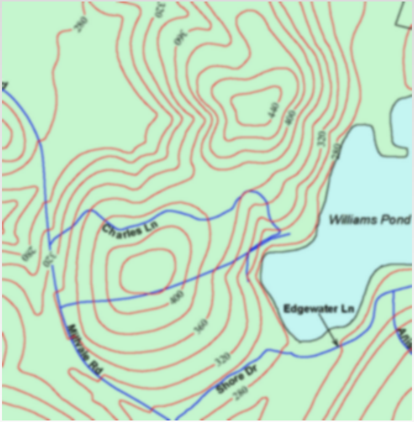
Urban roads



Results

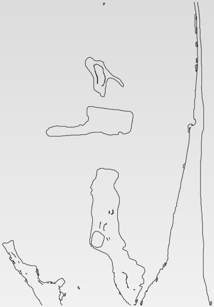
Colour Scanned Maps

Elevation contours



Colour Scanned Maps

Flood polygons(100 years)



Future Work

- Computer assisted feature labelling (using *Optical Character Recognition*)
- Connecting broken lines