Automatic Extraction of Linear Features from LiDAR and Imagery

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Motivation

Extraction of linear features from imagery is important in applications such as:

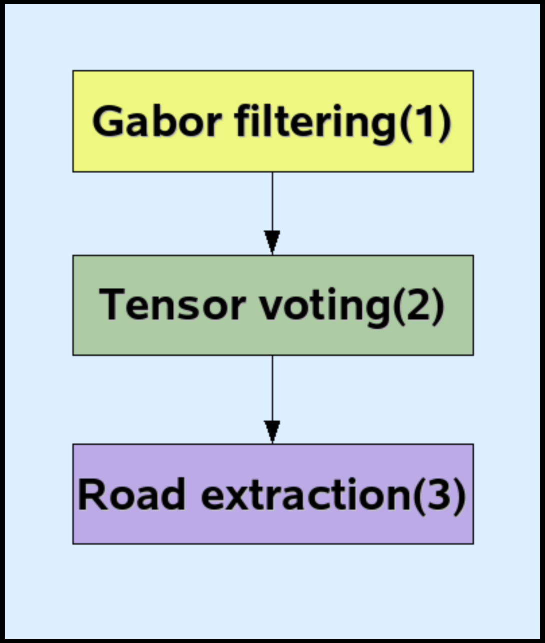
- transportation,
- waterways networks,
- civilian, intelligence and military operation

Related Work

- Considerable amount of work which can be separated into three main categories:
    1. Pixel-based (edge detection, road detection)
    2. Region-based (clustering, segmentation)
    3. Knowledge-based
- Both semi-automatic and automatic systems were proposed which deal with different types of data.

Proposed method

Integrated solution that merges the power of perceptual grouping theory (Tensor Voting, Gabor filtering) and classification with image-cues under a unified framework to address the problems of linear feature detection and classification.



Gabor filtering

Extract orientation and frequency information, resulting in maps that contains only features of special interest. A gabor function is spatial frequency domain is given by,

g(x, y) = c(x, y) × e(x, y)

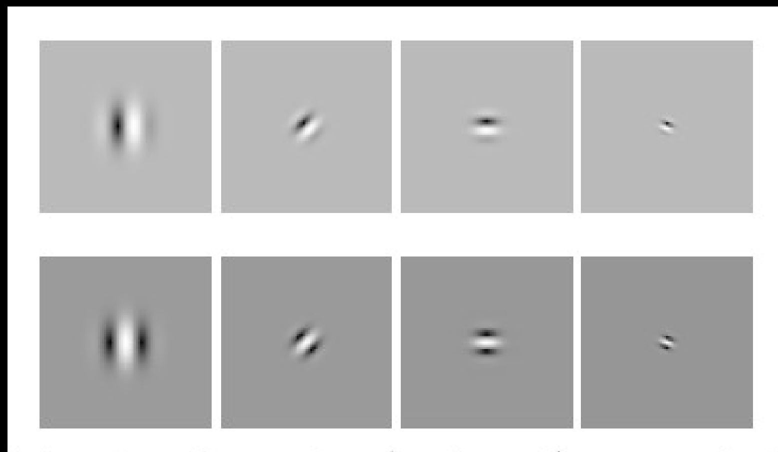
c(x,y) is a complex sinusoidal, known as the carrier and

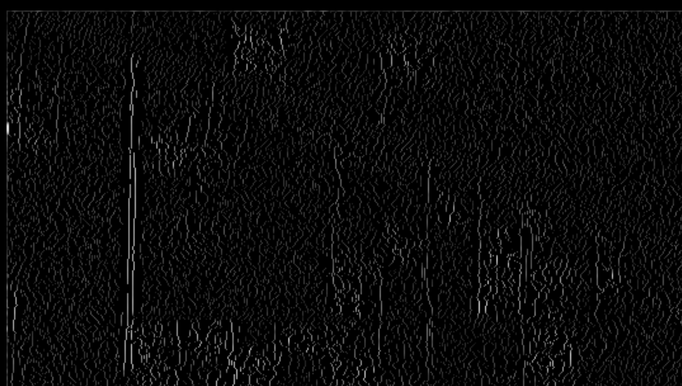
$$c(x, y) = e^{j(2\pi(u_0 x + v_0 y) + \phi)}$$

e(x,y) is a 2D Gaussian function, known as the envelope.

$$e(x, y) = Ae^{(-\pi(s_x^2(x - x_0)_\theta^2 + s_y^2(y - y_0)_\theta^2))}$$

Gabor filtering





Tensorial Representation

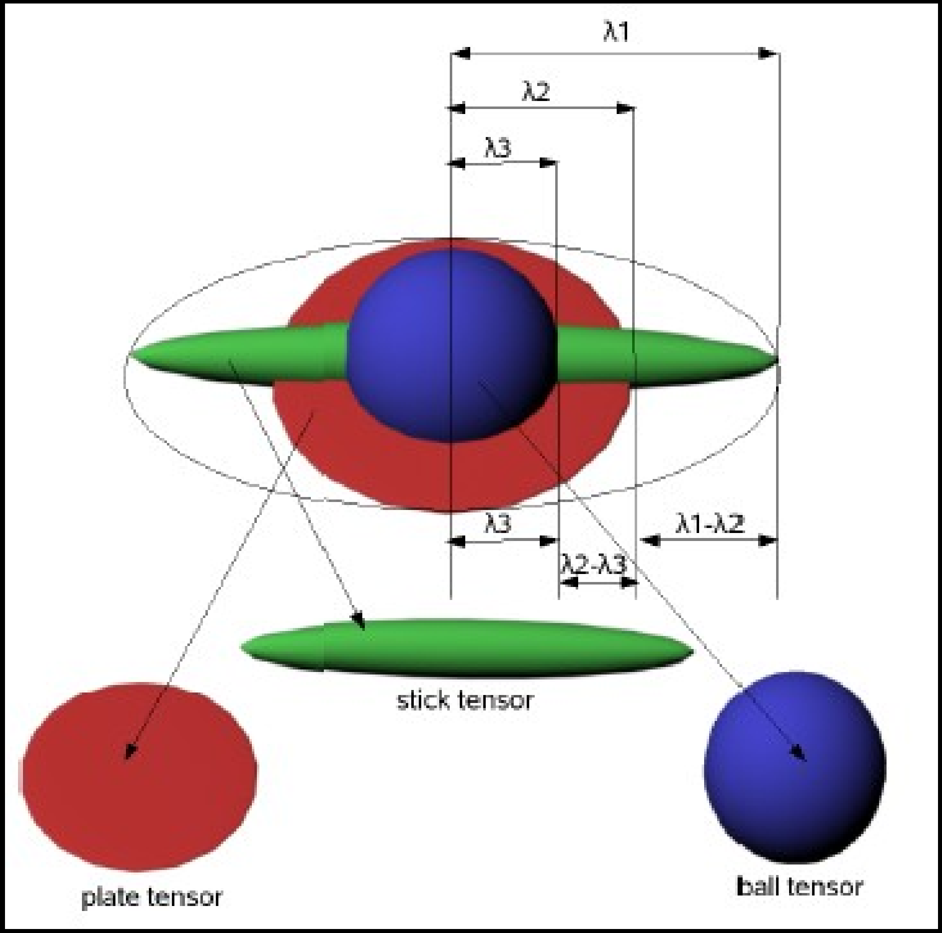
- Based on tensor calculus.
- A point is encoded as a second order symmetric tensor which captures the geometric information for every possible feature type – surface, curve, point- and its confidence, saliency.

$$T = \begin{bmatrix} \vec{e}_1 & \vec{e}_2 & \vec{e}_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \vec{e}_1^T \\ \vec{e}_2^T \\ \vec{e}_3^T \end{bmatrix}$$

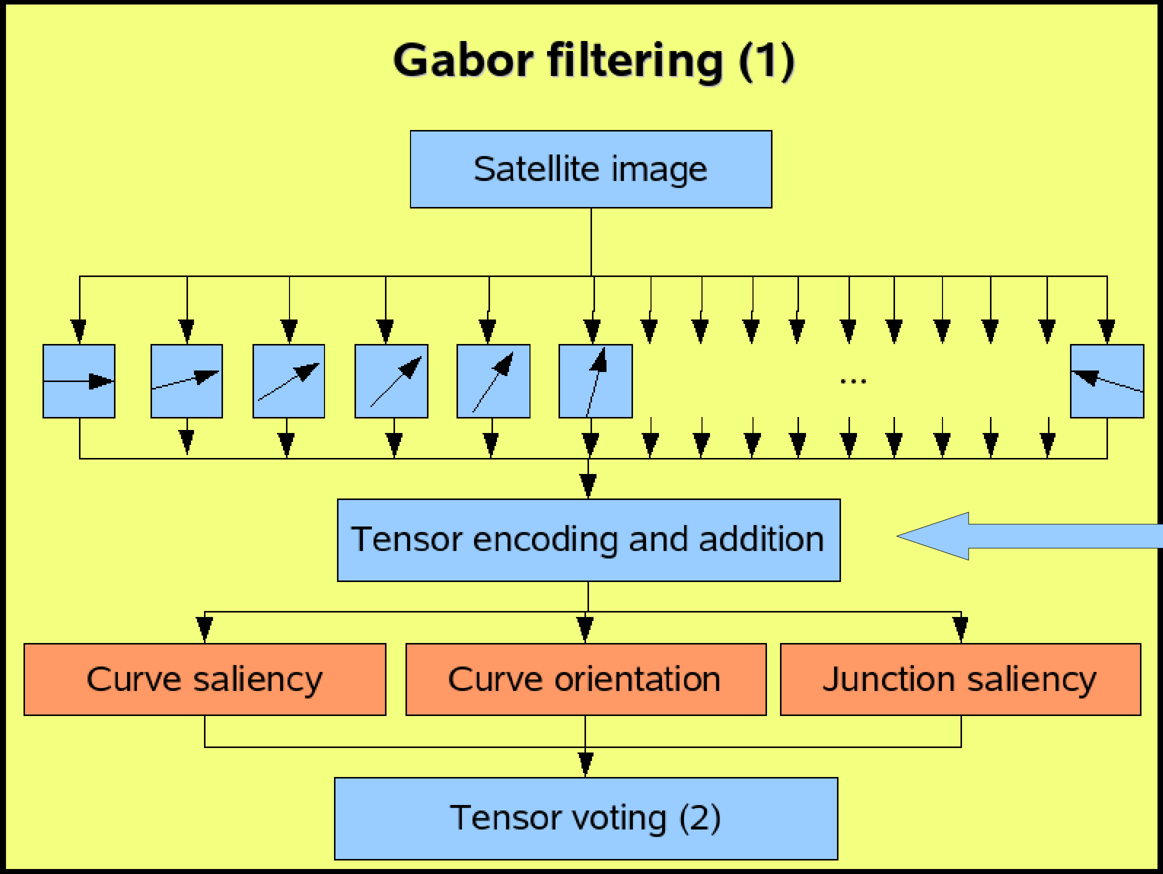
$$T = \lambda_1 \vec{e}_1 \vec{e}_1^T + \lambda_2 \vec{e}_2 \vec{e}_2^T + \lambda_3 \vec{e}_3 \vec{e}_3^T$$

Tensorial Representation

Spectrum theorem: Any tensor can be expressed as a linear combination of three singular tensors (ball, plate, stick).



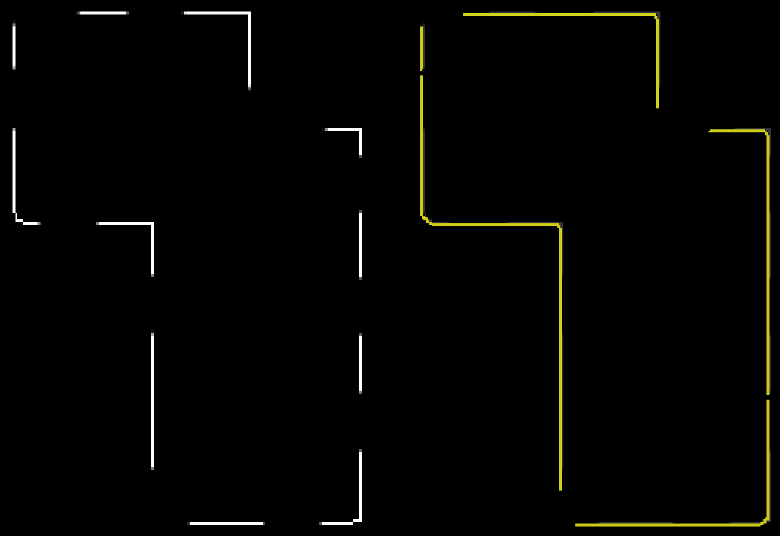
Tensor encoding & addition

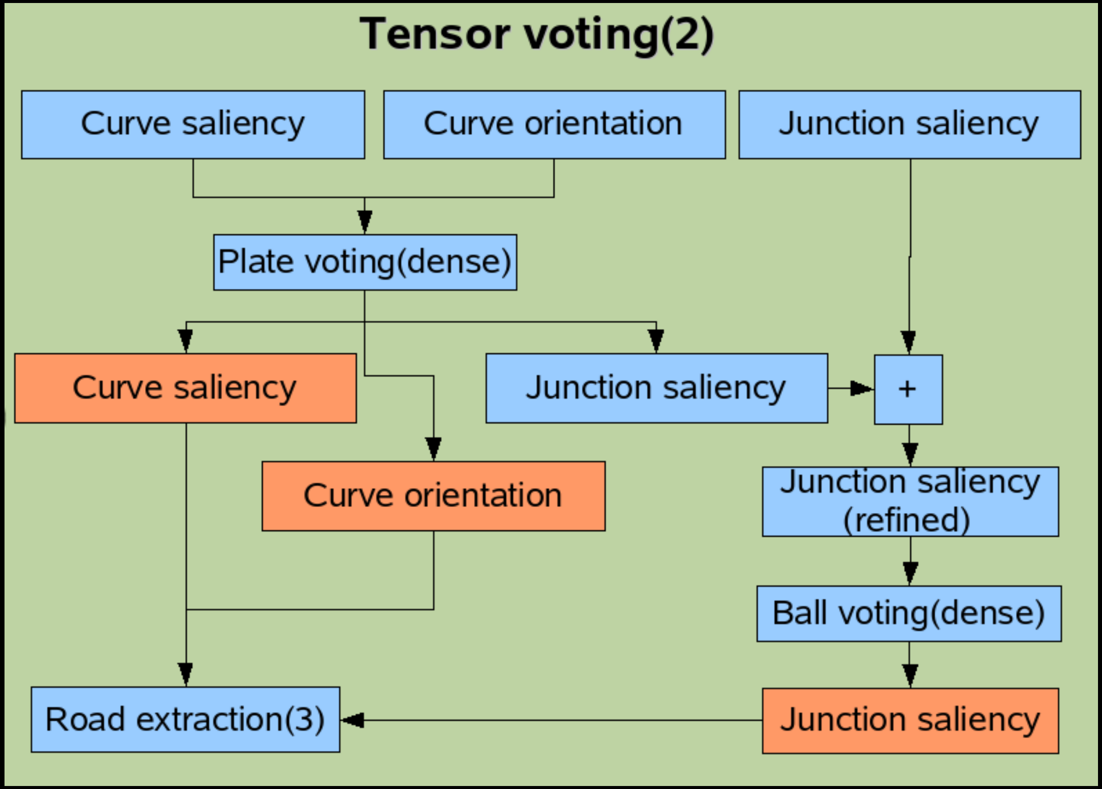


$$T_{gabor} = \sum_{i=0}^{8} ((G_i \otimes I)_{x,y} * T_{x,y,i})$$

Tensor Voting

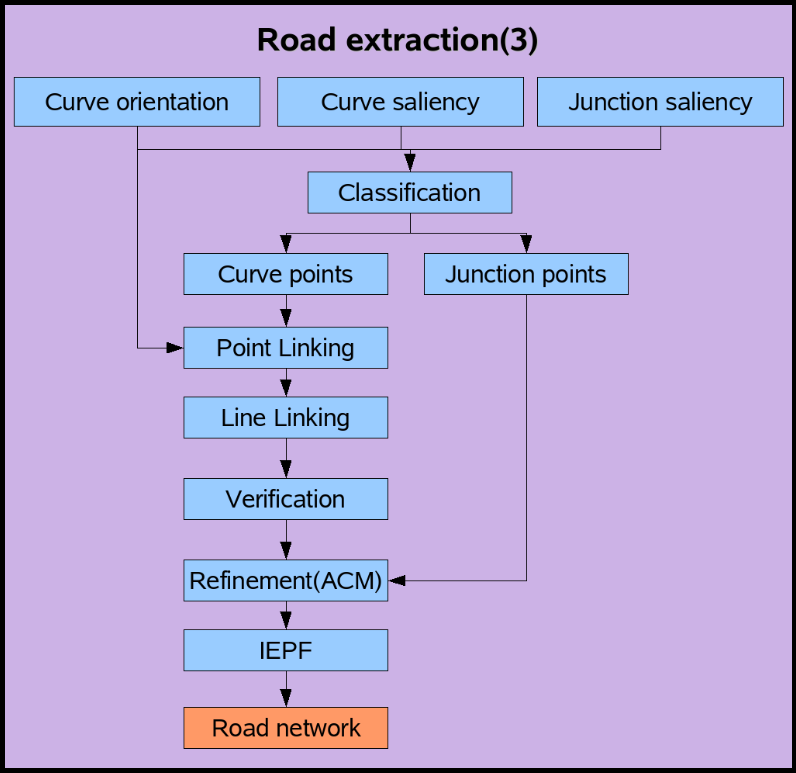
- Framework for perceptual grouping and segmentation.
- Uses linear tensor voting for the communication
- Deals with noisy and incomplete data





Road Extraction

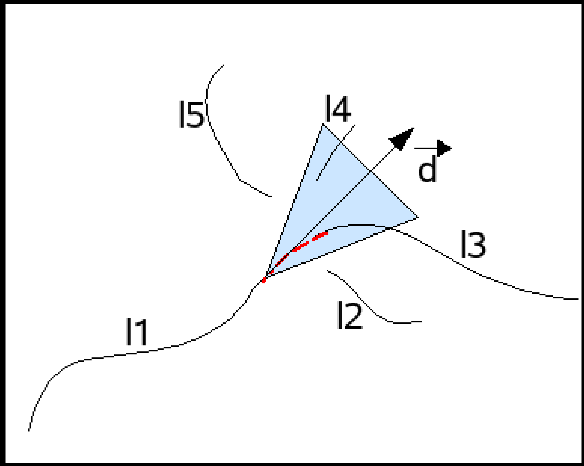
- Point linking
- Line linking
- Verification
- Refinement
- Approximation



Road Extraction

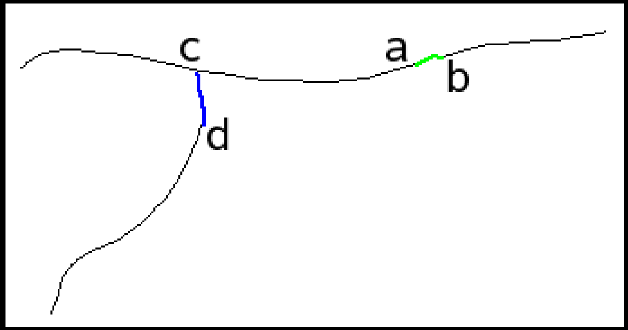
- Point linking

$$f(x,y) = argmin(w_d * D_{(x,y)} + w_\theta * O_{(x,y)} + w_s * (1 - S_{(x,y)}))$$



- Line linking
  - 1st phase

$$f'(x,y) = argmin(w_d * D_{(x,y)} + w_\theta * O_{(x,y)} + w_m * m_{(x,y)}))$$



  - 2nd phase: Perform line voting

Road Extraction

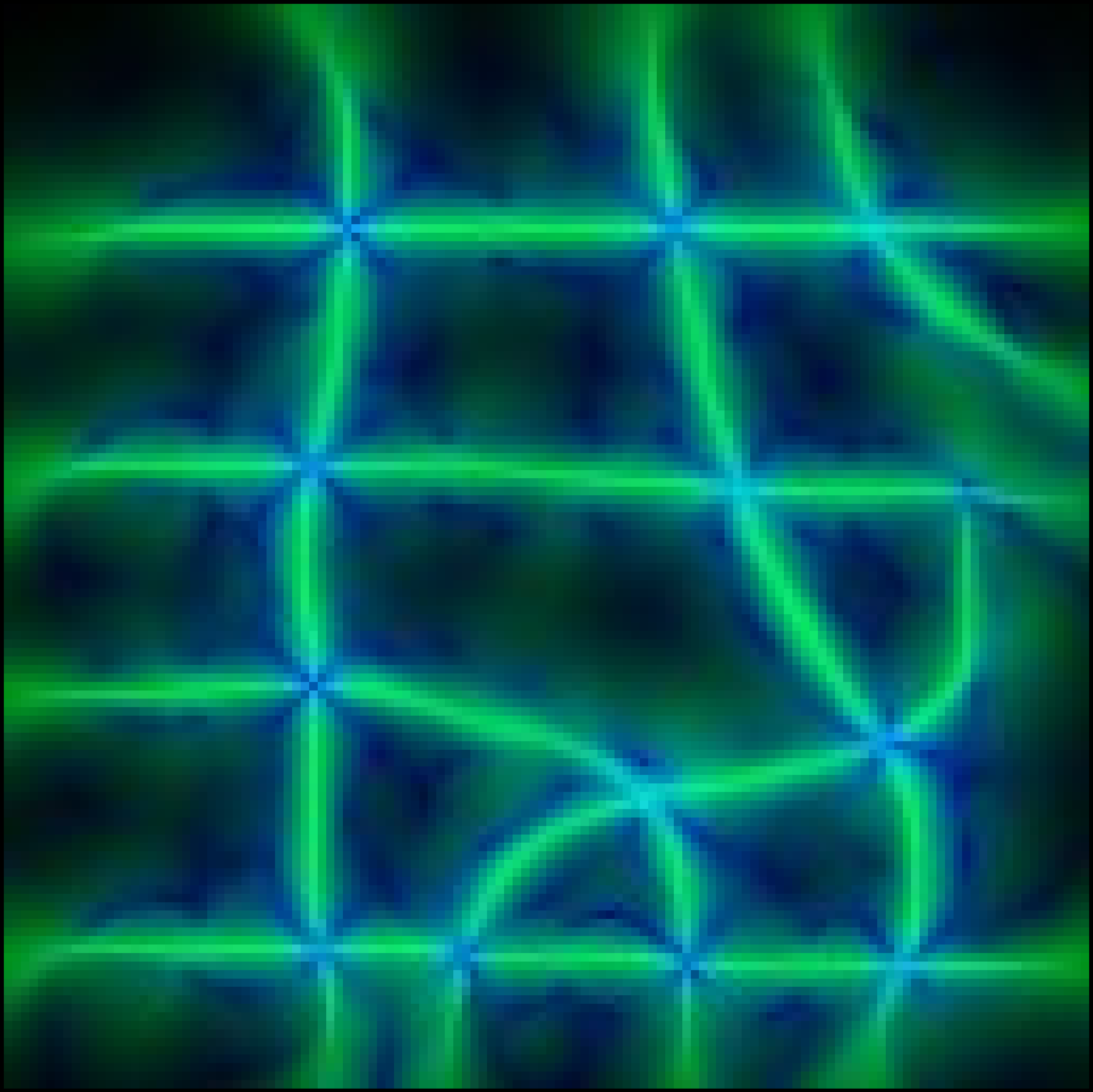
- Verification
  - Longest connected line network is chosen to be the road network-topological characteristic.
- Refinement
  - Active Contour Model (a.k.a snakes)

$$E_{total} = \int_0^1 [a(s) * E_{elasticity}(v(s))ds + b(s) * E_{stiffness}(v(s)) + c(s) * E_{image}(v(s))]ds$$

- Approximation
  - Approximate lines to reduce number of points using Iterative End-Point Fit (IEPF)

Results

Results



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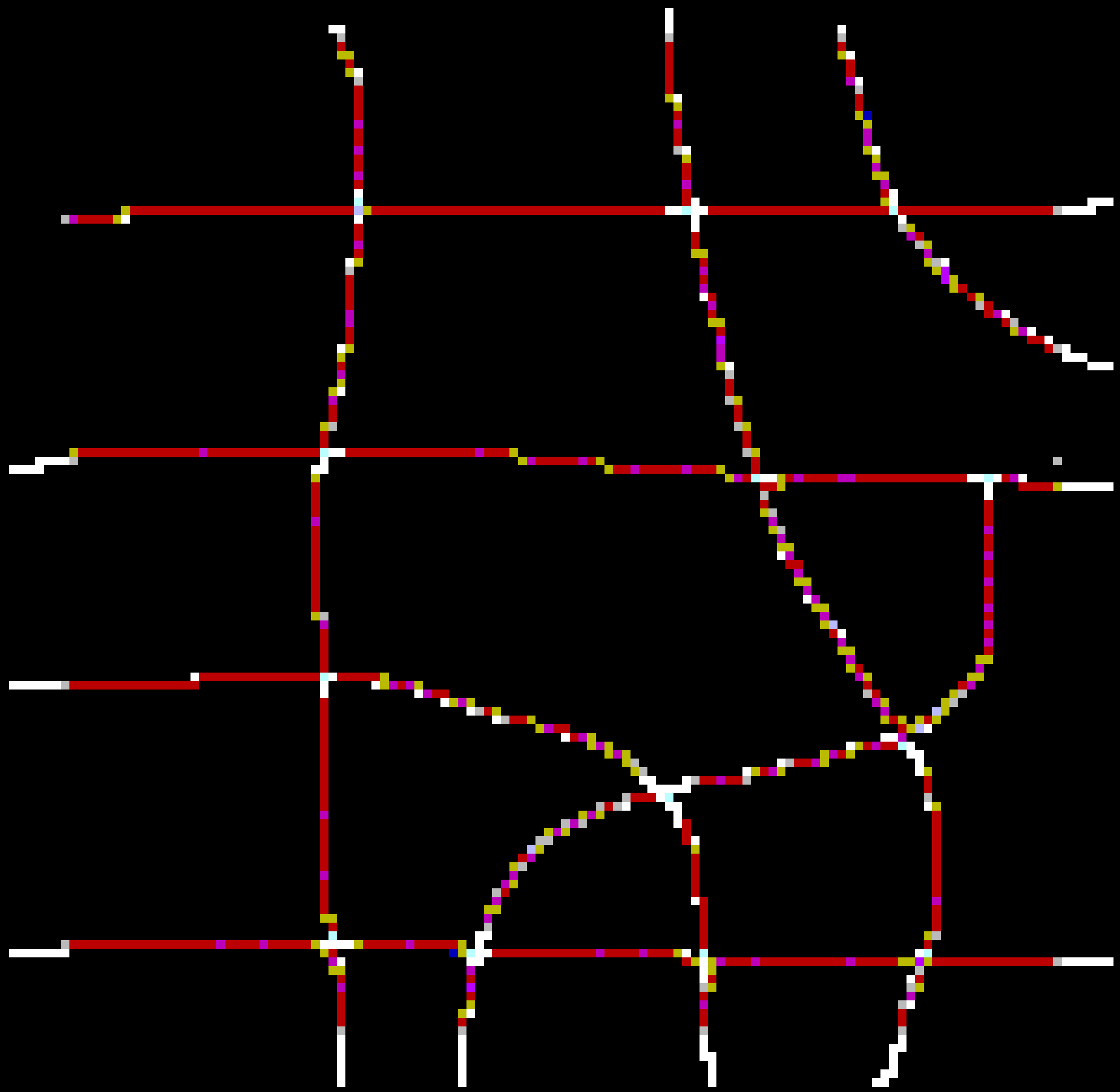

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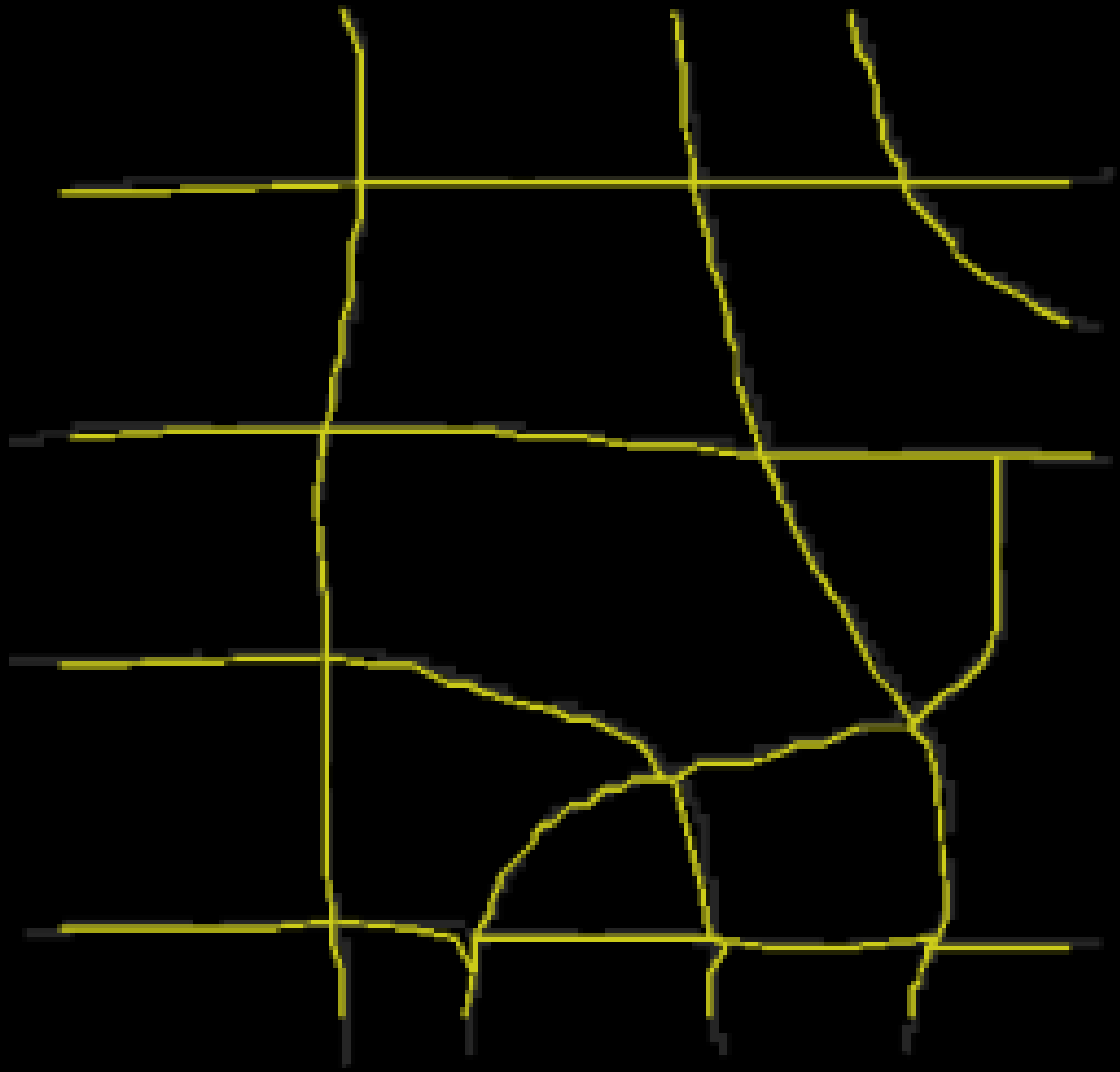

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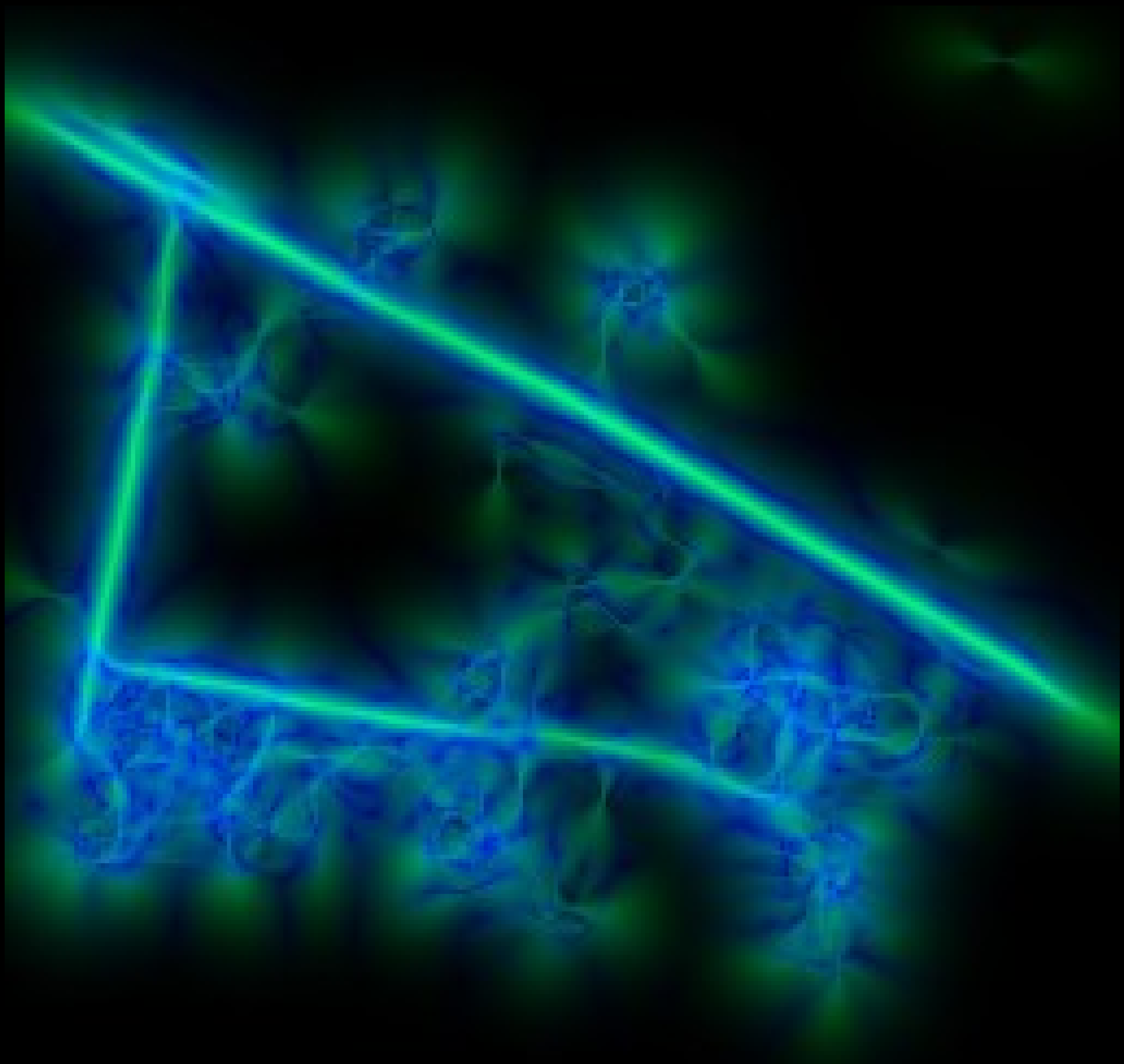

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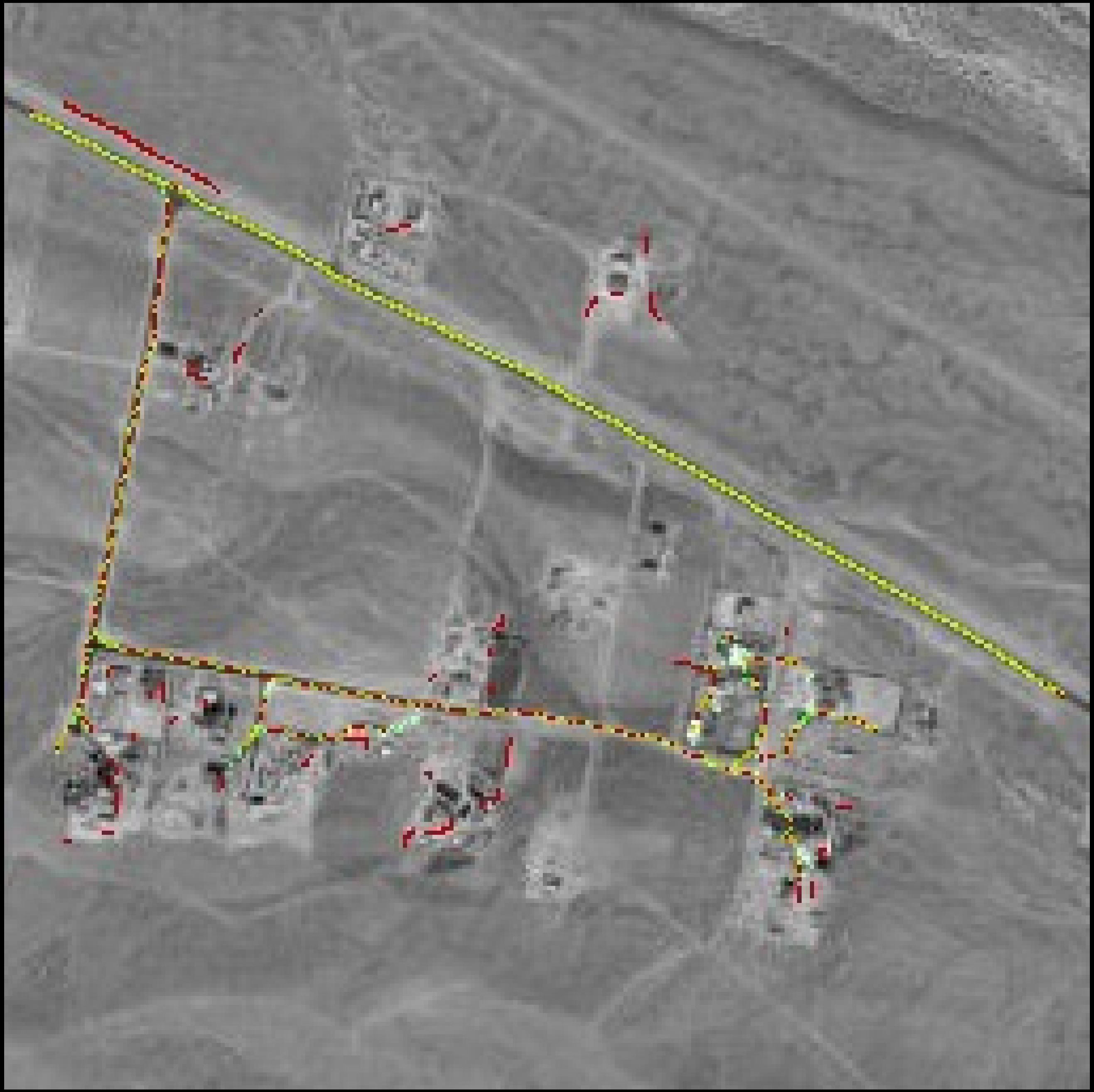

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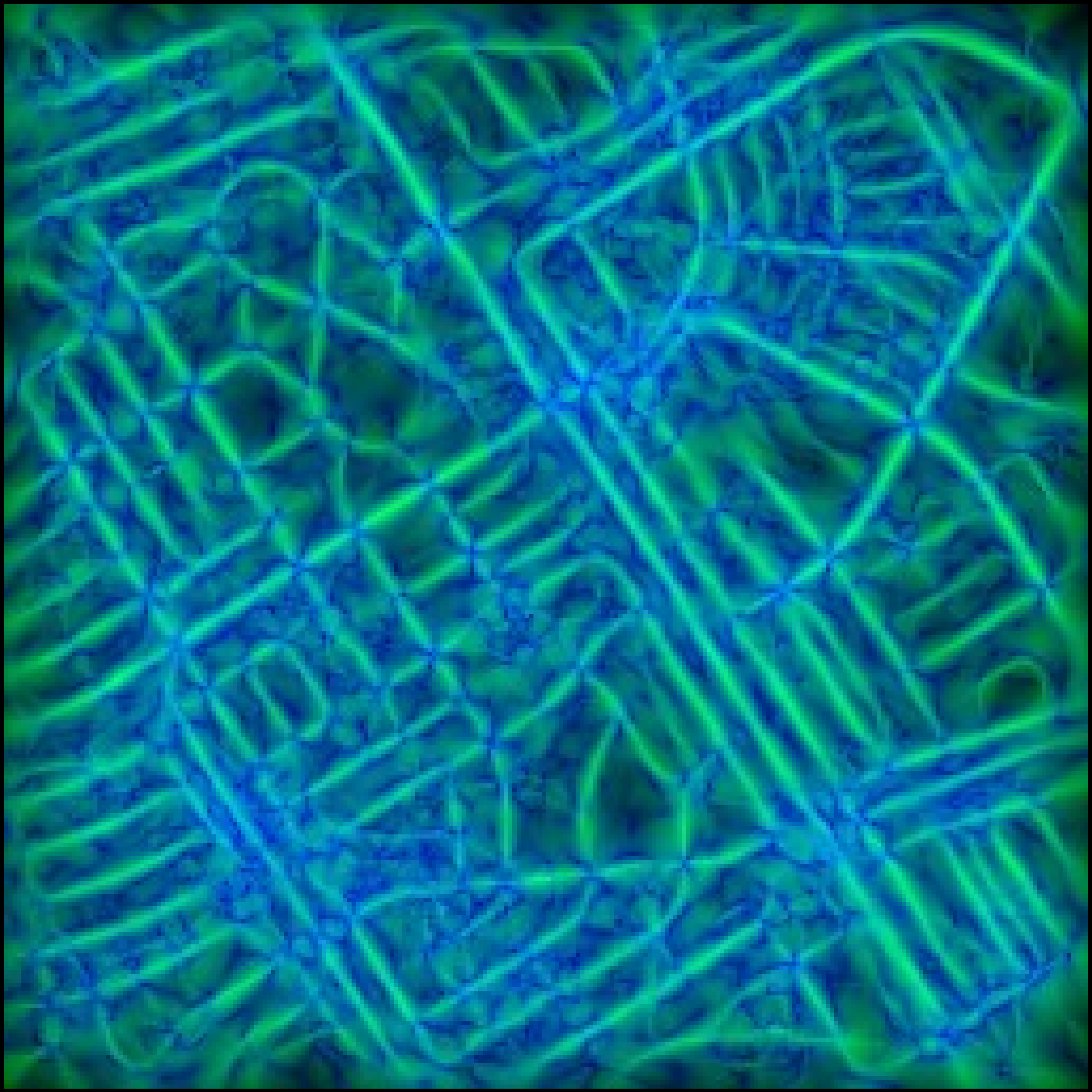

Results

Conclusion

- ➔ An integrated solution for automatic linear feature extraction from LiDAR and satellite imagery.
- ➔ The system has no data dependencies. Combining Gabor filtering and Tensor Voting eliminates the need for thresholds.
- ➔ Can deal with noisy and incomplete data.
- ➔ Missing information is recovered based on perceptual grouping theories.

Thank you!