A Model-Based Approach to Finding Tracks in SAR CCD Images

Tu-Thach Quach, Rebecca Malinas, Mark W. Koch

Sandia National Laboratories, ALBUQUERQUE, NM 87185-1163

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Introduction

- Track detection in SAR CCD imagery has applications in surveillance, search and rescue
- Difficult due to various sources of noise: SAR speckle, radar shadow, vegetation, weather phenomena
- Existing techniques require user cues and assume only a single track is present, cannot detect multiple tracks in an image
- Our approach is fully automatic, can detect multiple and overlapping tracks in an image, and can correctly identify images with no tracks present

Technical Approach

- **Given:** Set of n 2D points $\mathrm{X} = \{\mathrm{x}_1, \mathrm{x}_2, \ldots, \mathrm{x}_n\}$ that are likely to belong to tracks
- **Track model:** points as set $\mathrm{C} = \{\mathrm{c}_1, \mathrm{c}_2, \ldots, \mathrm{c}_n\}$ of m curves, where distances of points to curves (distance from point to projection on curve) are zero-mean Gaussian with standard deviation σ
- **Likelihood model:** Gaussian mixture with mixing coefficients π_j:

$$L(\mathcal{X}|\mathcal{C}) = \prod_{i=1}^{n} \sum_{j=0}^{m} \pi_j L(x_i|c_j) \quad (1)$$

- c_0 is "noise curve"—case where no true tracks are present
- For $j > 1$

$$L(x_i|c_j) = \frac{1}{||c_j||} \left(\frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{-||x_i - c_j||^2}{2\sigma^2} \right) \right) \quad (2)$$

where $||c_j||$ is the length of curve c_j and $||x_i - c_j||$ is Euclidean distance from point x_i to curve c_j

- For $j = 0$,

$$L(x_i|c_0) = l_{\mathrm{noise}} \quad (3)$$

where l_{noise} is a constant

- **Objective:** Bayesian Information Criterion (BIC)

$$B(\mathcal{X}|\mathcal{C}) = -2\log(L(\mathcal{X}|\mathcal{C})) + k\log(n) \quad (4)$$

where k is the number of degrees of freedom of the model, *i.e.,*

$$k = \sum_{j=1}^{m} |c_j| + m \quad (5)$$

$|c_j|$ = # degrees of freedom of curve c_j, m = # mixing coefficients

- This cost maximizes likelihood while penalizing model complexity

- **Algorithm:**
  1. Set $\mathcal{C} = \emptyset$, $B_{\min} = B(\mathcal{X}|\mathcal{C})$
  2. Find a line segment c through $\mathcal{X}$
  3. If $B(\mathcal{X}|\mathcal{C} \cup c) < B_{\min}$
     (a) Set $\mathcal{C} = \mathcal{C} \cup c$, $B_{\min} = B(\mathcal{X}|\mathcal{C})$
     (b) Remove points assigned to $\mathcal{C}$ from $\mathcal{X}$
     (c) Repeat step 2.
  4. Refine $\mathcal{C}$ and the model parameters iteratively until convergence
  5. Merge segments in $\mathcal{C}$ to form curves

- Finding lines: find initial lines via RANSAC. Project associated points onto each line. Determine line segment endpoints via mean shift
- Merging curves: effectively search over all possible mergings of detected segments for configuration with lowest BIC

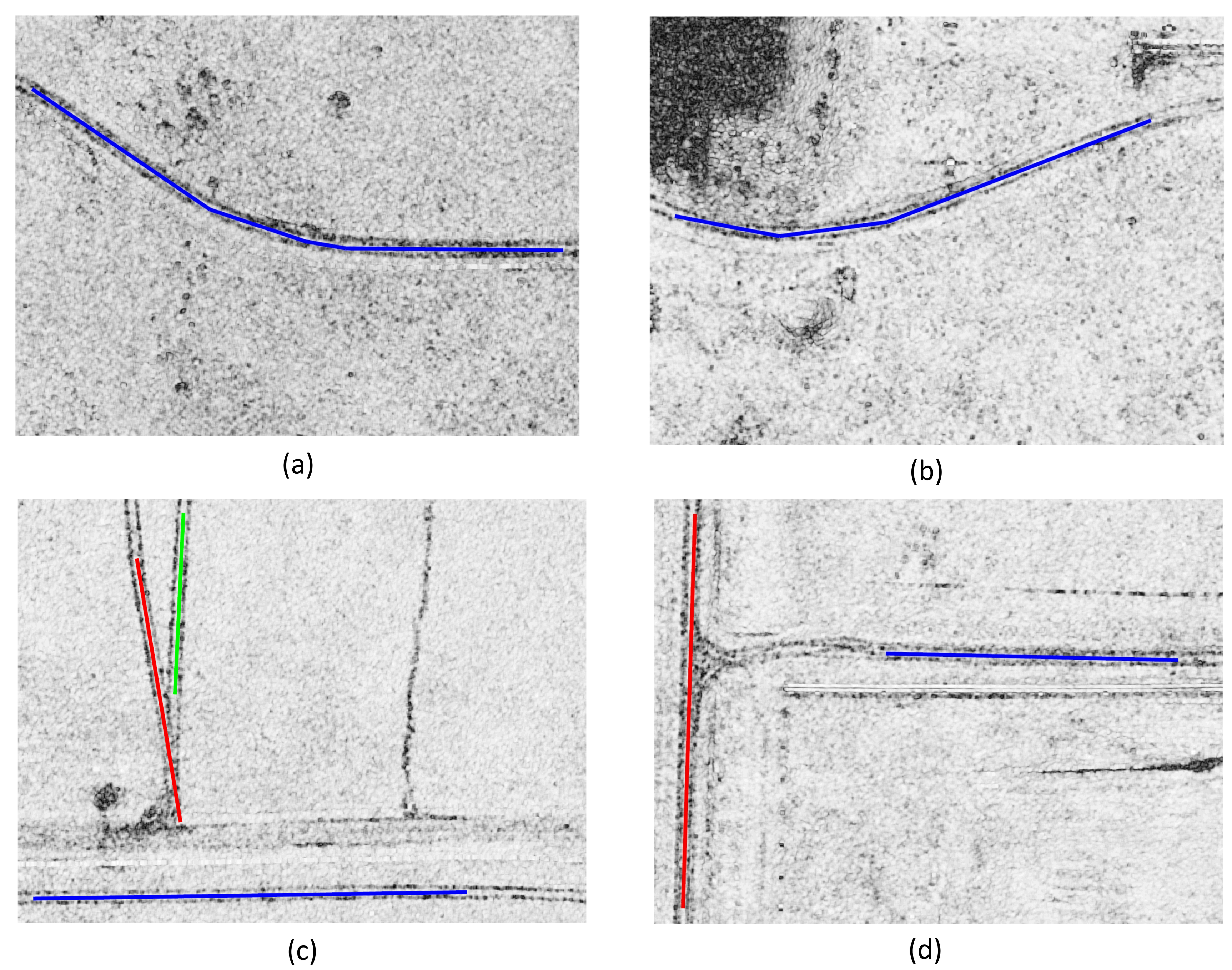

Figure 1. Track finding results on real SAR CCD images.

Validation

- Algorithm evaluated on set of 40 real 600x800 CCD images containing simulated parallel vehicle tracks
- Simulated tracks randomly generated and placed in images by adding Gaussian phase shifts along track trajectories in non-reference SAR image
- Three different versions of image set with three different track thicknesses: *light, medium, dark*
- Same model parameters used for all three versions: σ=4, $l_{noise}=\frac{1}{600*800}$

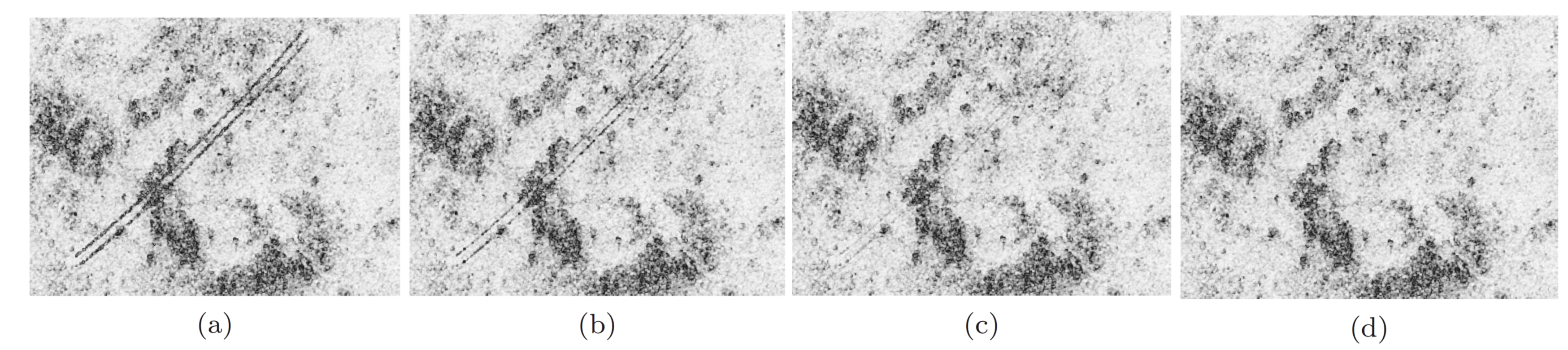

Figure 2. Example test images: (a) *dark, (b) medium,* (c) *light,* and (d) original CCD image. Each set consists of 40 images of size 600x800 containing various track curvatures and background clutters. Average track length is 705 pixels.

- Performance metric: $\frac{TP}{TP+FN+FP}$ (6)
  where TP= # true positives, FN=# false negatives, FP=# false positives

Results

	Mean	Median	Std. Dev.
dark	0.9721	0.9872	0.0471
medium	0.8352	0.9108	0.1812
light	0.2631	0.2623	0.2495

- Algorithm also tested on CCD background images without simulated tracks added – algorithm correctly declared no tracks present in all but two test images. In these two images, there were track-like structures present in the CCD image

Future Work

- Improved algorithm for extracting set of likely track points
- Improved algorithm for merging detected segments

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