Target Detection in High-Resolution 3D Radar Imagery

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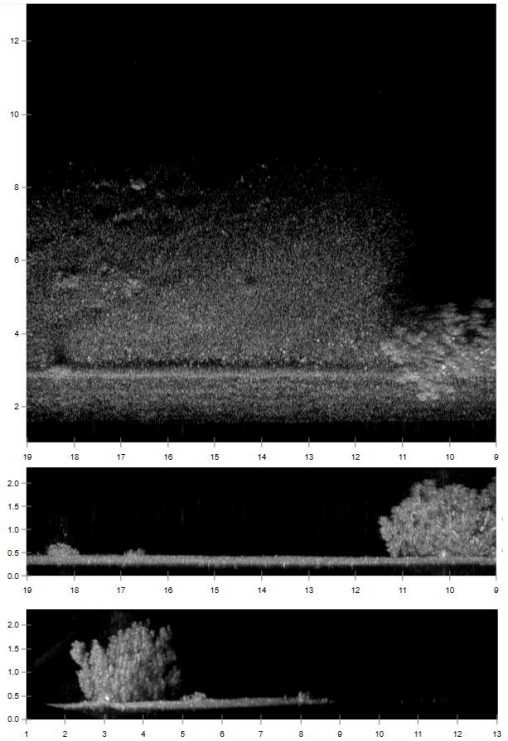
Outline

- The Stalker system
  - Holographic 3D radar image reconstruction
- Methodology
  - 2D & 3D prescreeners
    - Energy
    - Size-contrast filter
    - Prescreener fusion
  - Tiger scoring system
- Results
- Conclusion

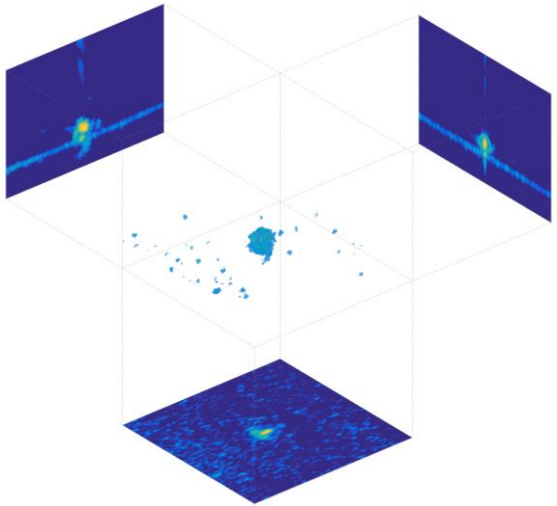
The Stalker System

- Stalker is a high-resolution 3D radar imaging system for roadside target detection
  - Operates in the low Ku-band
  - Spatial resolution of approximately 1 cm^3
  - Wide dynamic range
  - Advanced motion-compensation allows vehicle motion of 10 km/hr
- Datasets consist of 10m x 10m regions ~2m high
  - 1000 x 1024 x 186 voxels
  - 1.5 GB for each 3D image

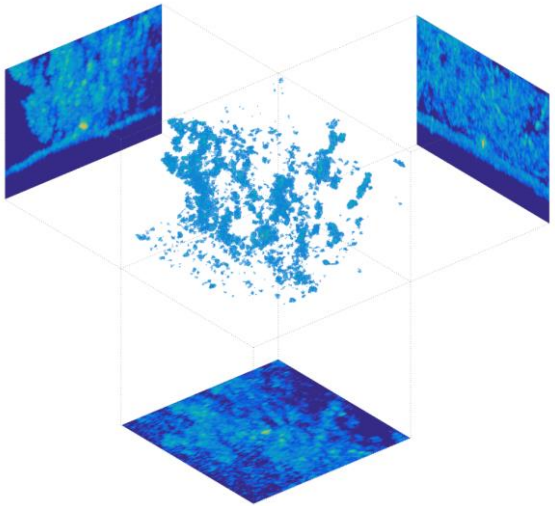


Target Examples

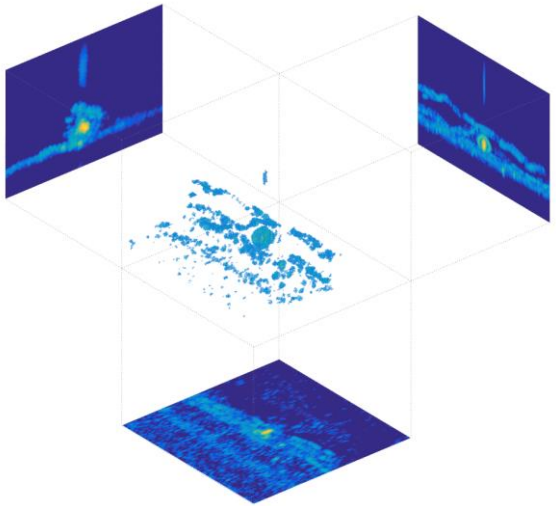
Unconcealed



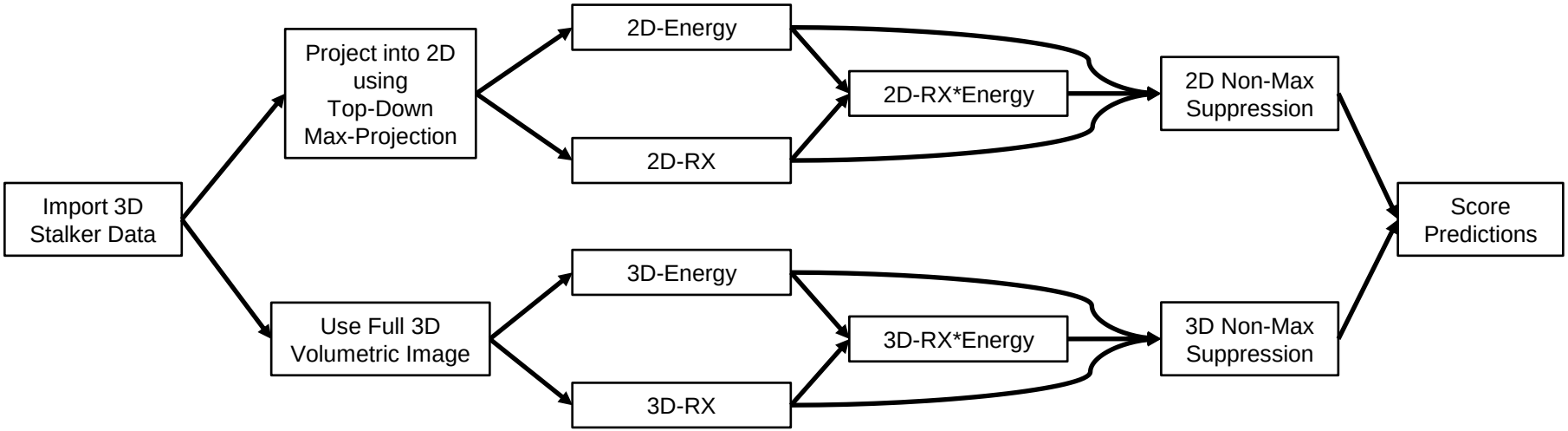
Bush



Ironwood

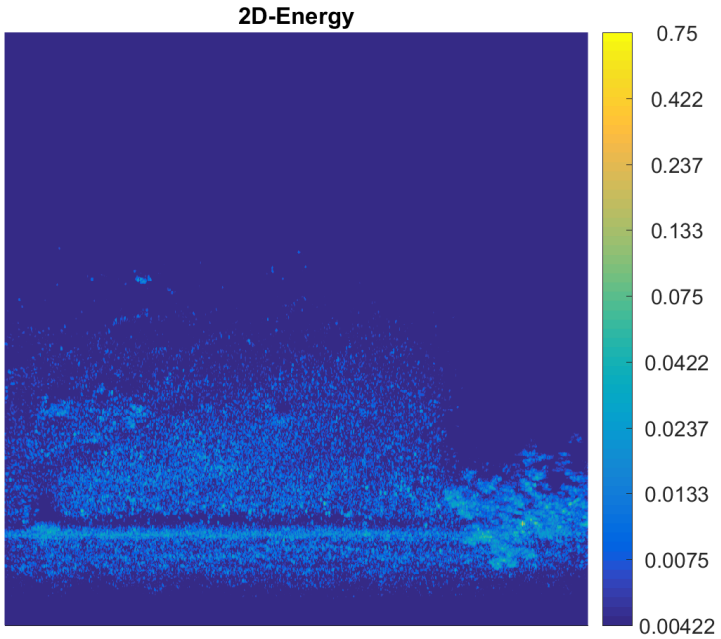


Processing Overview



2D-Energy Prescreener

- Use the top-down max-value projection
- Get alarm locations using non-max suppression:
  - Find the pixel with the highest intensity value
  - Mark an alarm at that location with the given confidence
  - Set all neighbor pixel intensities within a 1 meter radius to zero
  - Repeat until the entire image is covered

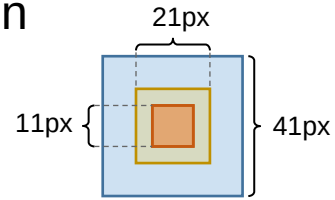


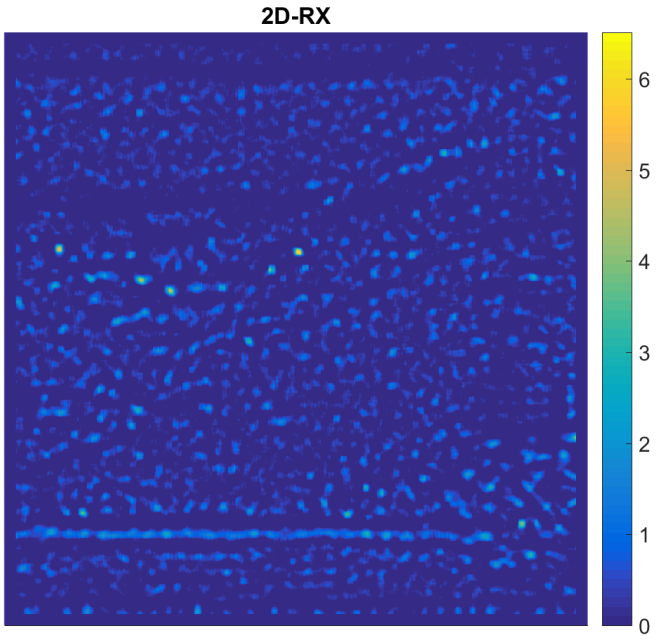
2D-RX Prescreener

- Local anomaly detector using sliding windows
  - (μ_p, σ_p) : Mean value and SD of the inner window
  - (μ_q, σ_q) : Mean value and SD of the outer annulus
  - Compute positive unidimensional Mahalanobis distance

$$\max\left(0, \frac{\mu_p - \mu_q}{\sigma_q}\right)$$

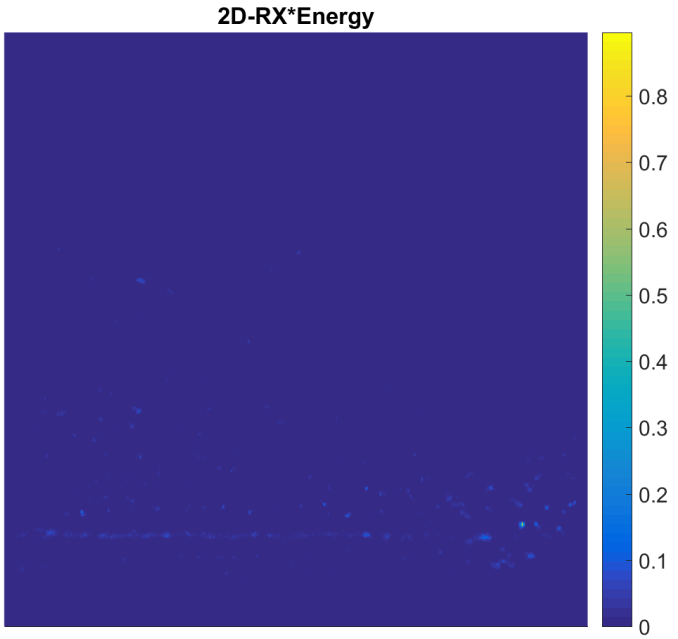
- Use non-max suppression to get alarms
- Fast to compute using integral images





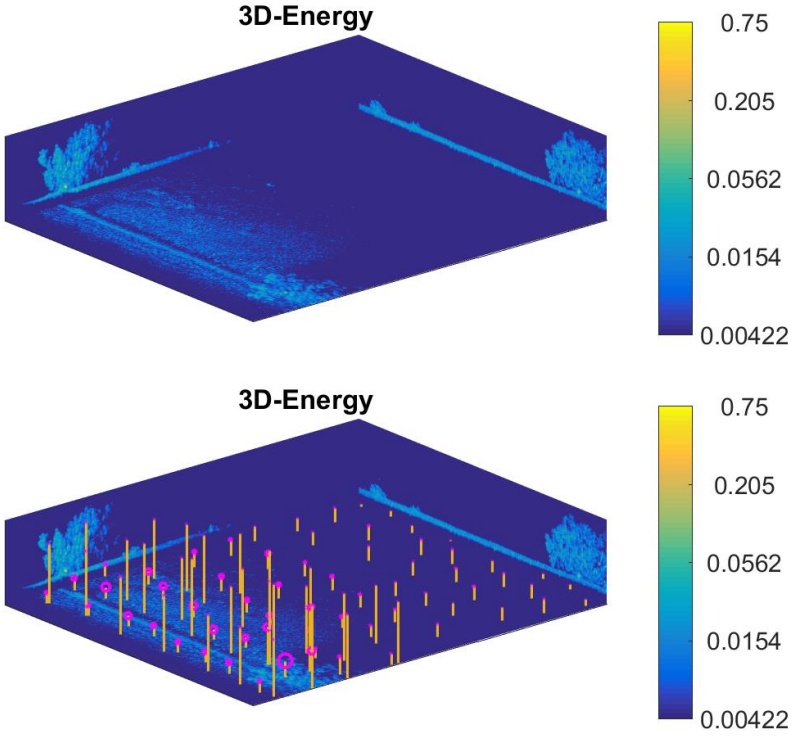
2D-RX*Energy Prescreener

- Multiply the output of the RX and energy prescreeners
- Reduces strength of RX confidence where there is low energy
- Only high where energy and RX both have high confidence
- Use non-max suppression to get alarms



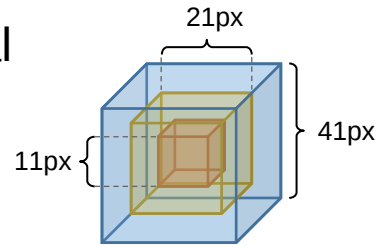
3D-Energy Prescreener

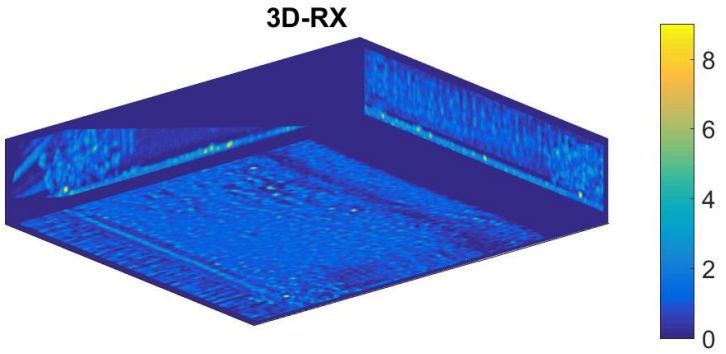
- Same approach as the 2D-Energy prescreener
- Use non-max suppression in 3D to get alarm locations
- Each alarm has an x, y, and z coordinate in the 3D image
- Circle size is proportional to alarm confidence

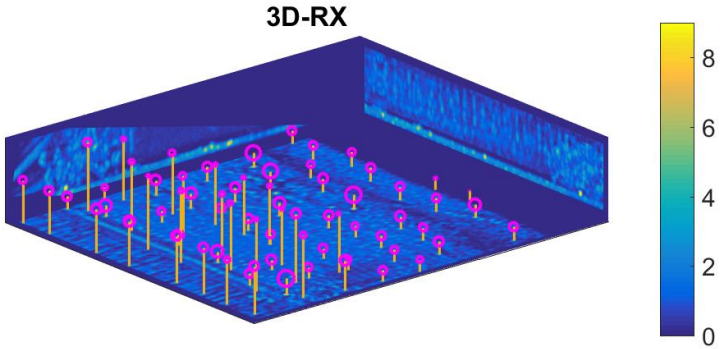


3D-RX Prescreener

- Extend the 2D-RX filter design to 3D
- Compute the filtered 3D image
- Get alarms using non-max suppression
- Use 3D integral images to compute

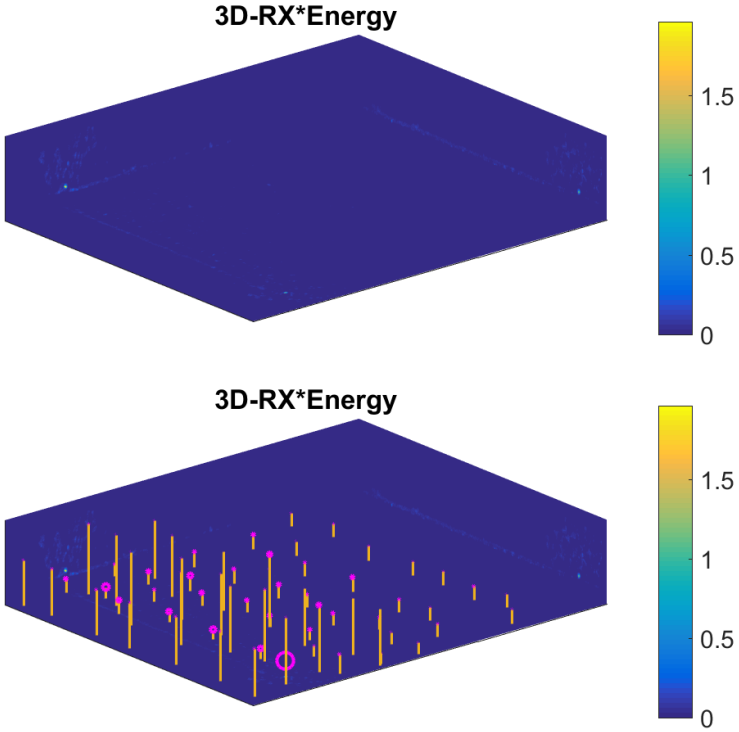






3D-RX*Energy Prescreener

- Multiply the 3D-Energy and 3D-RX confidence values together
- Only locations with high confidence in both energy and RX will have high output
- Get alarms using non-max suppression



Tiger Scoring System

- Developed to standardize comparisons between the detection results of multiple algorithms
- Combines multiple runs with confidence level averaging
- Produces several informative diagrams
  - ROC curves
  - Alarm offsets
  - Sorted alarm confidence
  - Image table of minimum FAR to detect each target

Blind Testing

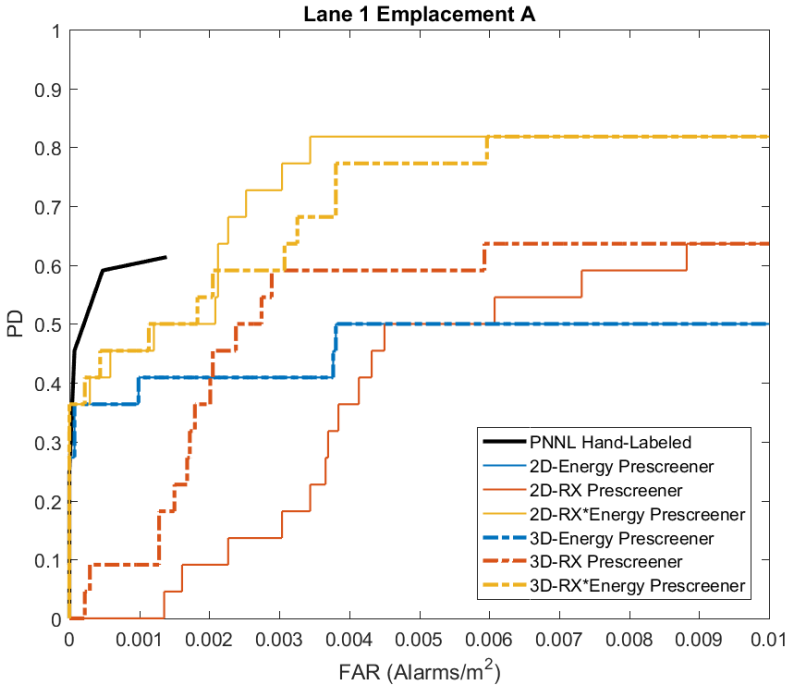
- Roadside explosive hazards were placed
  - Within bushes
  - Partially buried in the embankment

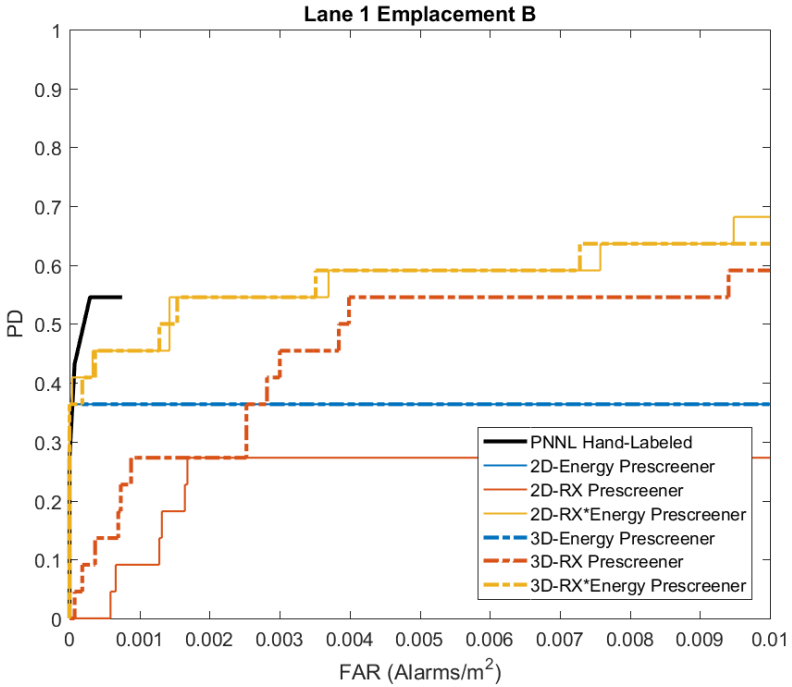
- Blind test by US Army on 2 lanes, each with 2 different emplacements
  - Two runs for each configuration
  - Results averaged by confidence

- A separate, but similar dataset was used to develop these methods

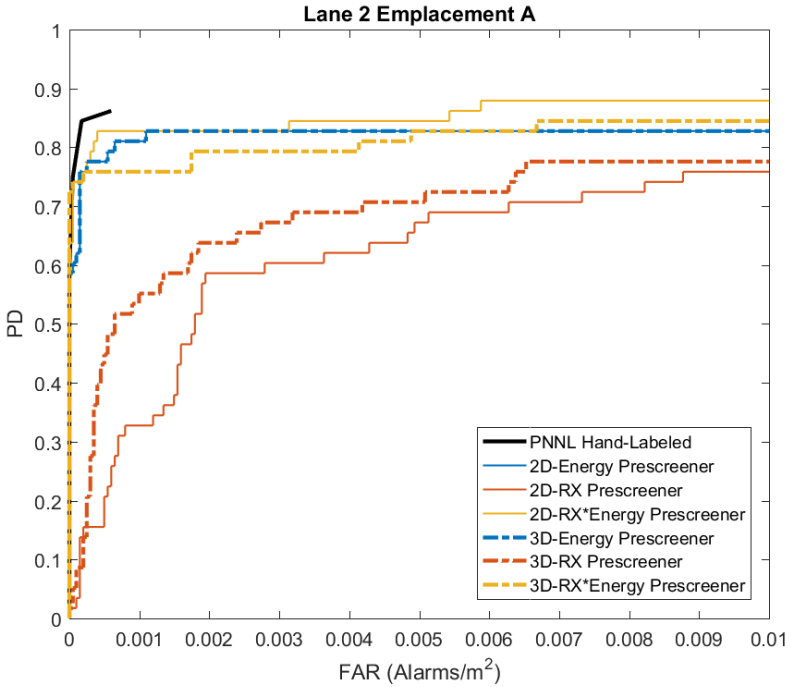
Lane #	Emp.	Length	Runs	# of Targets
1	A	1 km	2	11
1	B	1 km	2	11
2	A	1 km	2	29
2	B	1 km	2	29

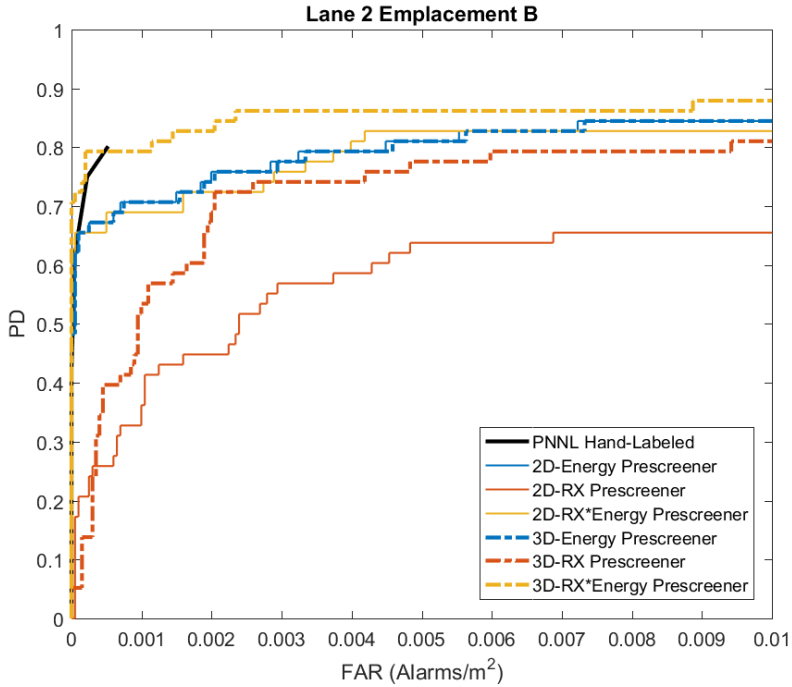
Prescreener Comparison





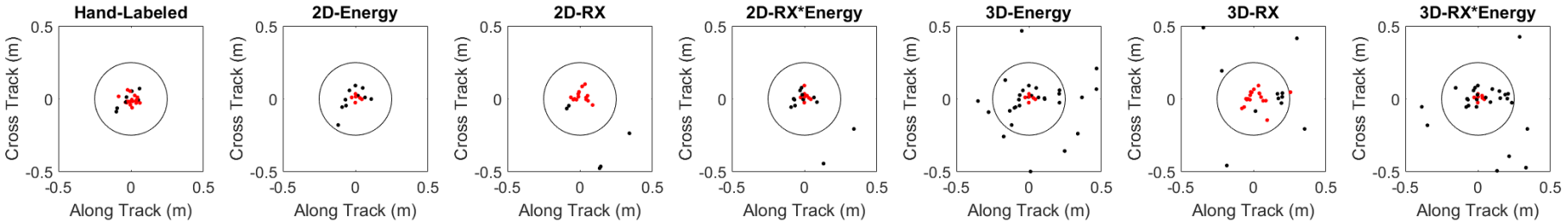
Prescreener Comparison



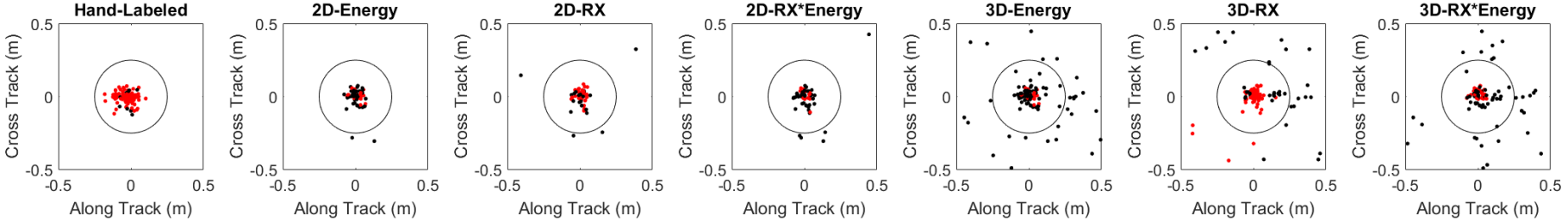


Alarm Offsets

Lane 1:

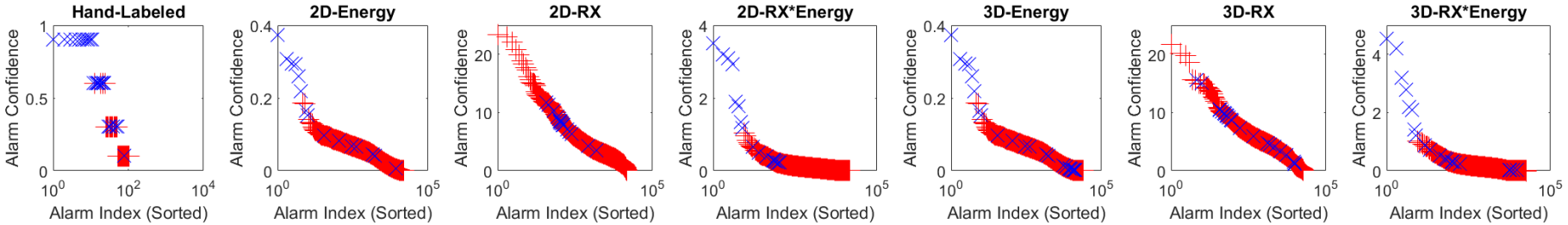


Lane 2:

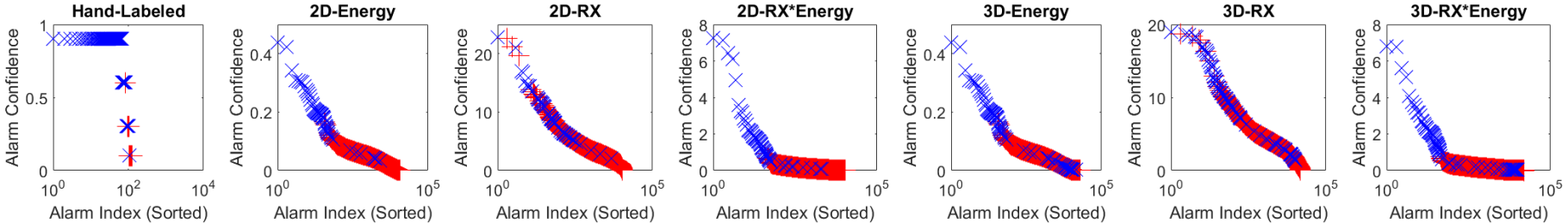


Sorted Confidence Values

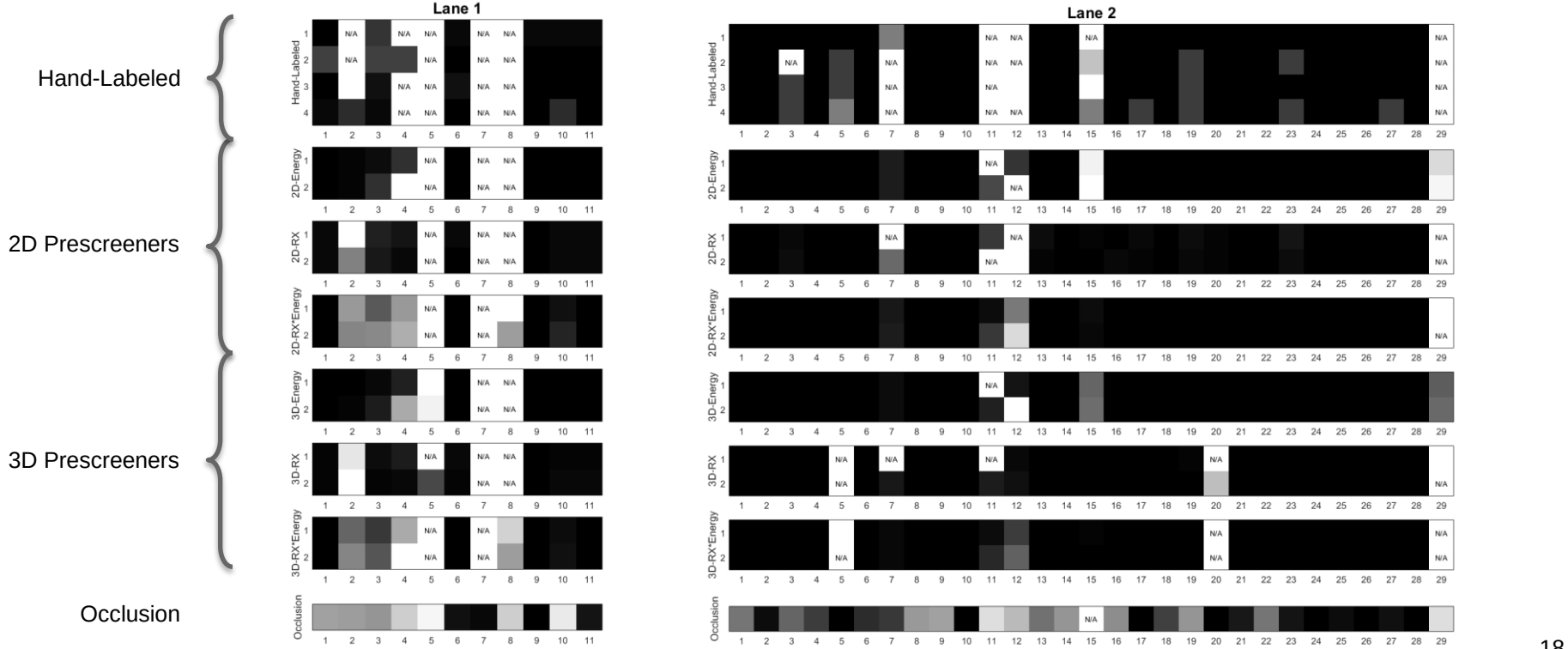
Lane 1:



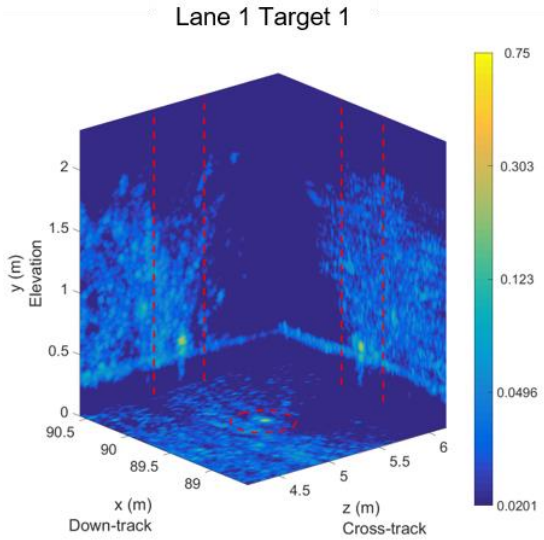
Lane 2:

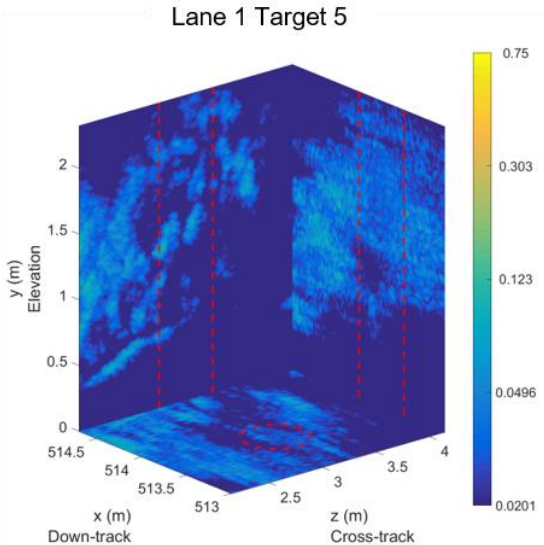


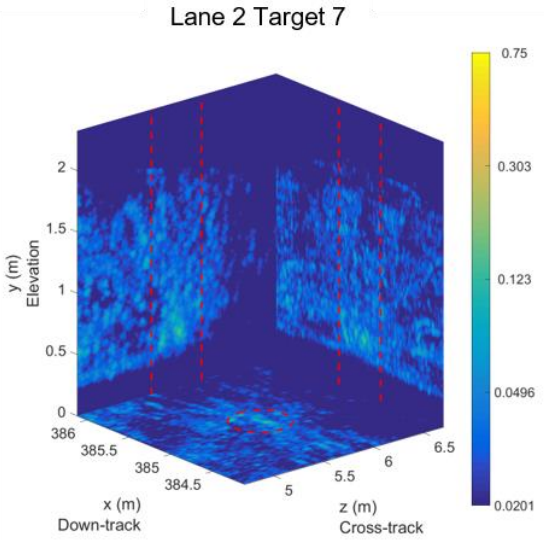
Minimum FAR to Detect Targets



Target Examples







Conclusions

- Stalker 3D radar imagery is very useful for detecting roadside explosive hazards
- Noticeable improvement by fusing RX and Energy prescreeners
- Competitive with human-level performance
- The Tiger scoring system gives insight into results
  - Detailed comparison between methods
  - Helps identify difficult targets

Next Steps

- Improve upon the prescreener results
  - Extract features based on 3D data
  - Build classifiers
  - Algorithm/classifier fusion

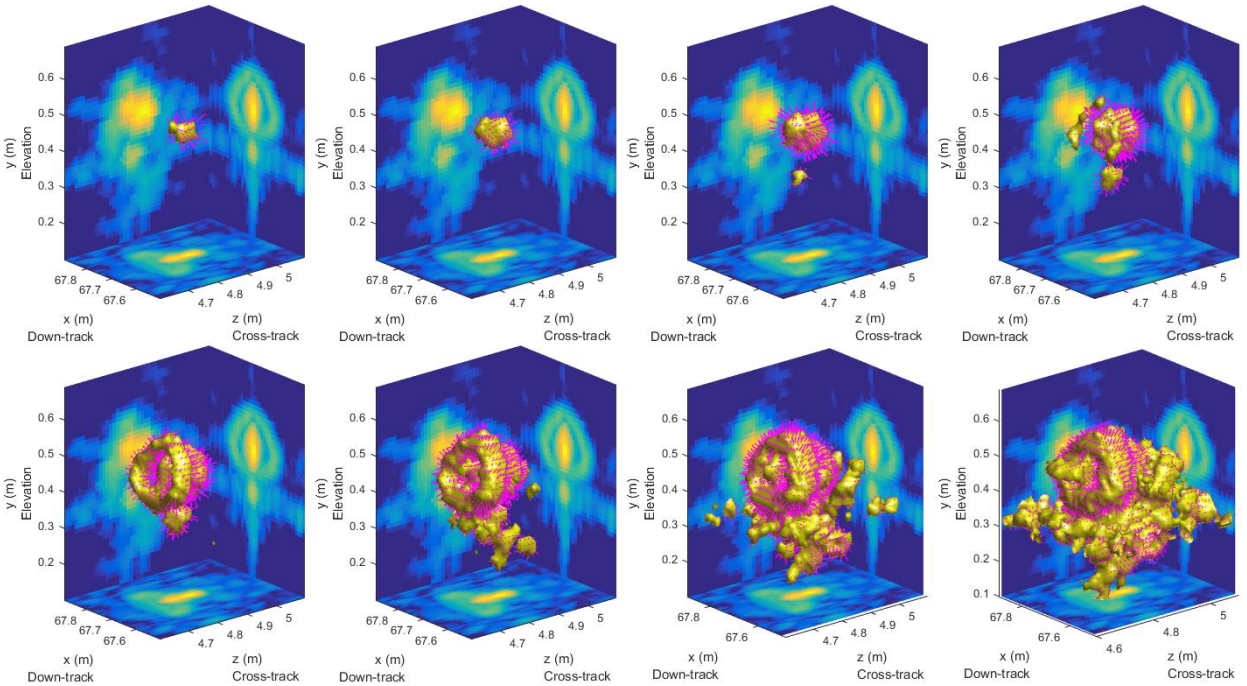
- Working on…
  - Features based on histograms of isosurface normal orientation vectors (HISNOV)
  - Characterizes the shape of the data

Isosurface Normal Vectors

The gradients are by definition perpendicular to any given isosurface.

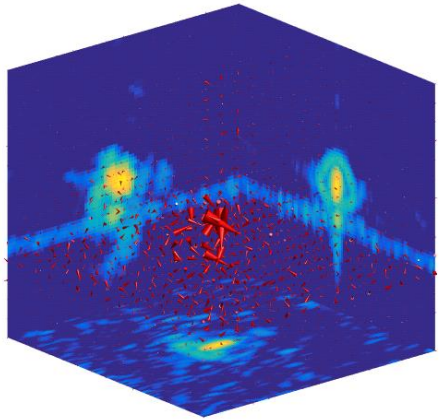
The negative gradients give the outward-pointing isosurface normal vectors.

The isosurface morphs into different shapes as the threshold changes.

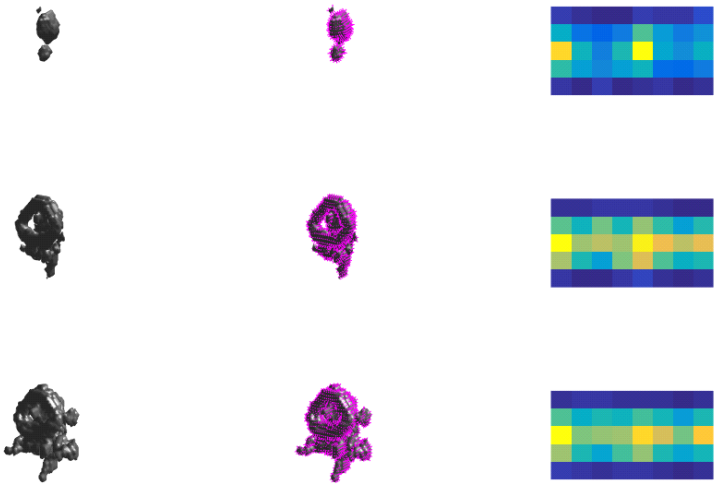


HISNOV Examples

3D Gradients



Isosurfaces

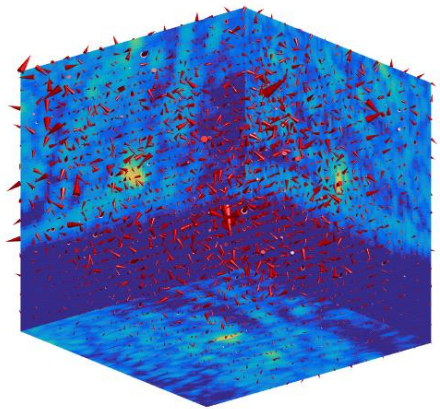


Normals

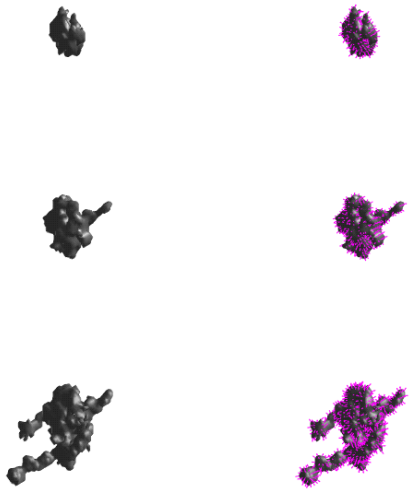
Histograms

HISNOV Examples

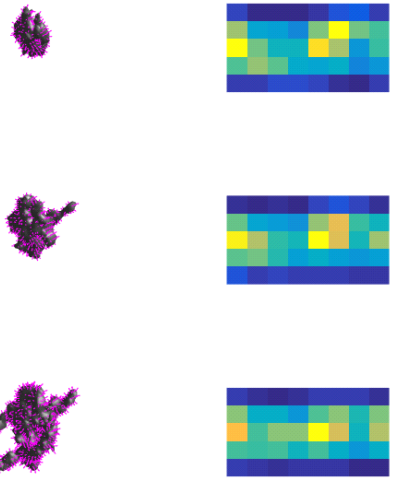
3D Gradients



Isosurfaces



Normals



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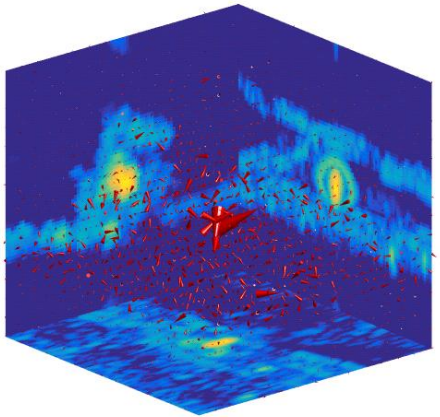
3D Gradients



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