Anomaly detection schemes in complex-valued SAR imaging

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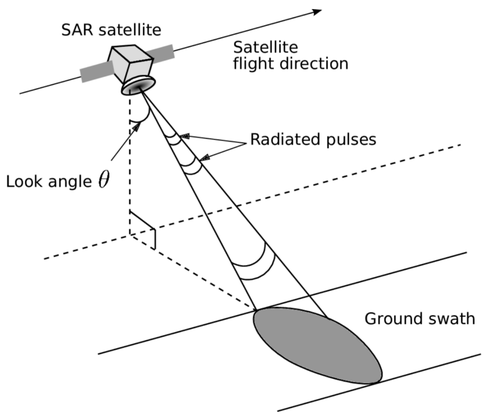
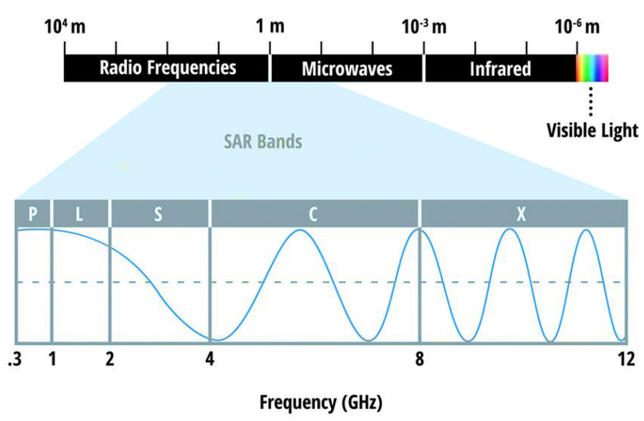
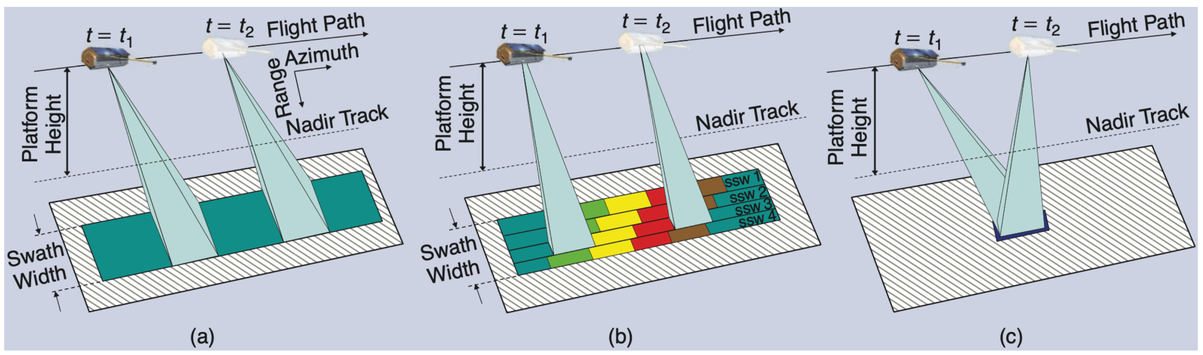
Synthetic Aperture Radar

Synthetic Aperture Radar *(SAR)* is a sensing device that collects data actively by sending electromagnetic pulses and recording the back-scattered signals. SAR sensors exploit frequency bands from 300MHz to 12GHz.



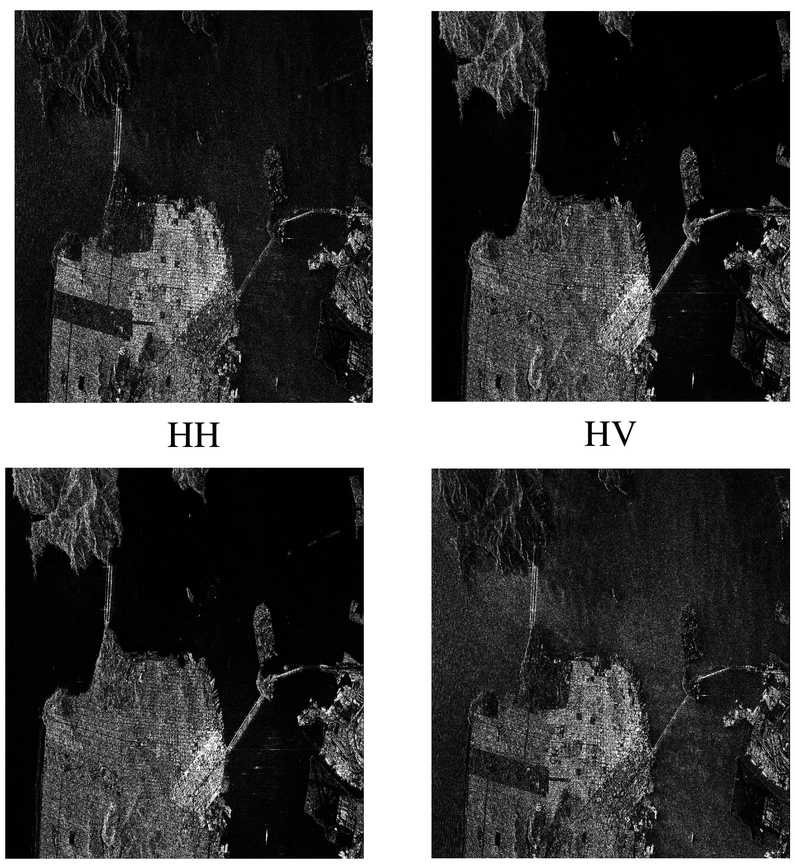


SAR can be mounted on satellites *(Spaceborne)* for large-scale observations and on aircraft, drones or helicopters *(Airborne)* for smaller-scale imaging. It usually observes Earth's surface in 3 ways:



(a) Stripmap (b) ScanSAR (c) Spotlight [3]

SAR systems leverage the polarization properties of electromagnetic waves to enable advanced imaging techniques known as *PolSAR*. Horizontal *(H)* and Vertical *(V)* are the most common polarization states. *PolSAR* use combinations of transmit - receive polarizations:



HH HV VH VV

Sentinel-1 Quadrature Polarization images over San Francisco bay.

References

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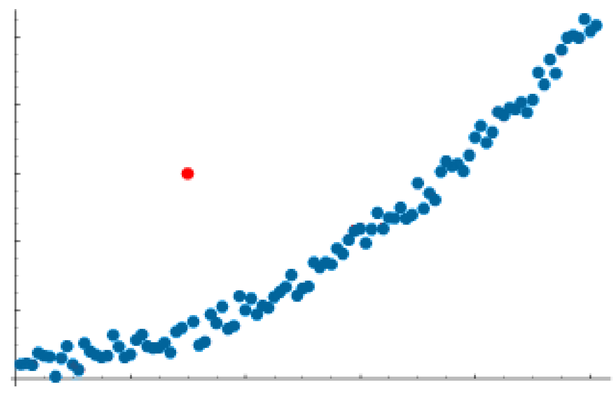
[3] A. Moreira, P. Prats-Iraola, M. Younis, G. Krieger, I. Hajnsek, and K. P. Papathanassiou. A tutorial on synthetic aperture radar. *IEEE Geoscience and remote sensing magazine*, 1(1):6–43, 2013.

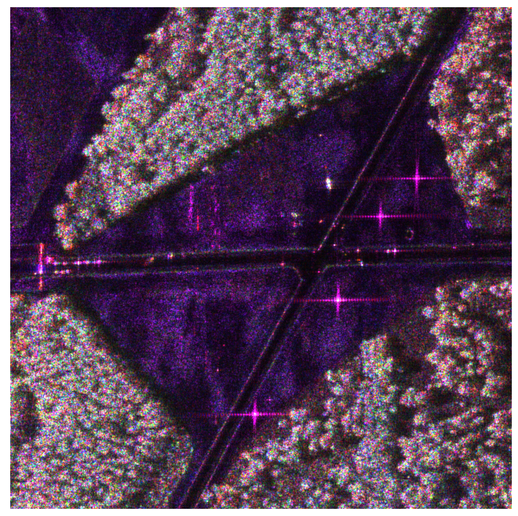
[4] M. Muzeau, C. Ren, S. Angelliaume, M. Datcu, and J.-P. Ovarlez. Self-supervised learning based anomaly detection in synthetic aperture radar imaging. *IEEE Open Journal of Signal Processing*, 3:440–449, 2022.

Anomaly detection

Anomalies refer to observations that deviate significantly from the expected data pattern.



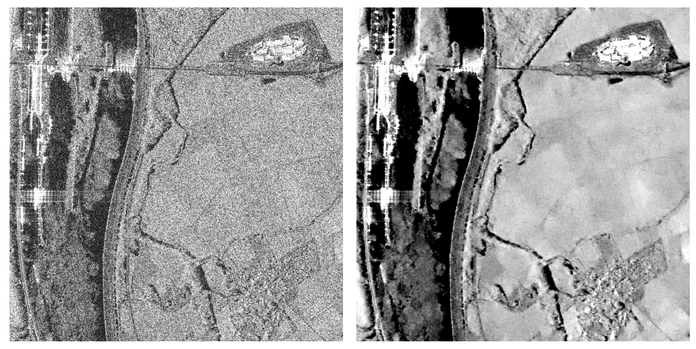
In SAR images, an anomaly is often represented by an unusual very bright spot with unknown signatures or characteristics.



ONERA SETHI L-band image with anomalies. They could be vehicles, metal debris, etc.

Challenges

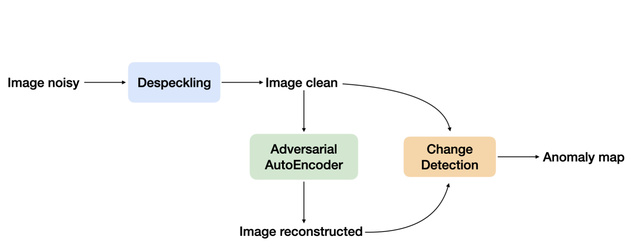
→ Speckle noise
→ Complex-valued SAR signals
→ Limited label data



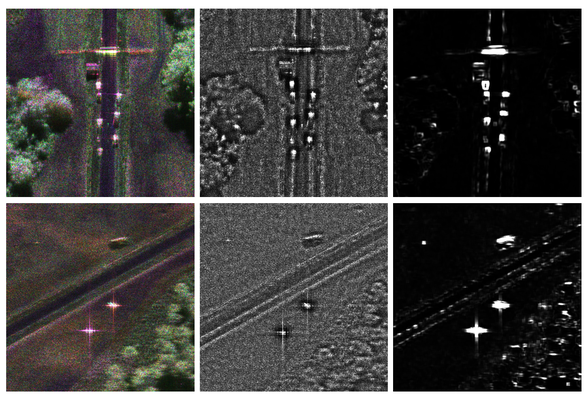
SAR despeckling with MERLIN[1]

Anomaly detection methods

To separate anomaly from the clutter, we can rely on *Statistical* or *Machine Learning* approaches. Muzeau et al.[4] has proven that using an *Adversarial AutoEncoder* produces a clearer anomaly map than *Reed-Xiaoli* statistic detector.



Anomaly detection scheme suggested by Muzeau et al.[4].



Raw Reed-Xiaoli AAE

Complex-valued neural networks

What is CVNNs?

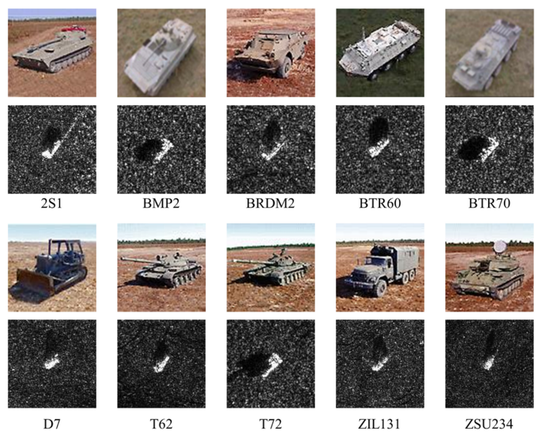
Complex-Valued Neural Networks *(CVNNs)* are a type of neural network where weights, inputs, activations, and outputs can be represented as complex numbers rather than traditional real numbers.

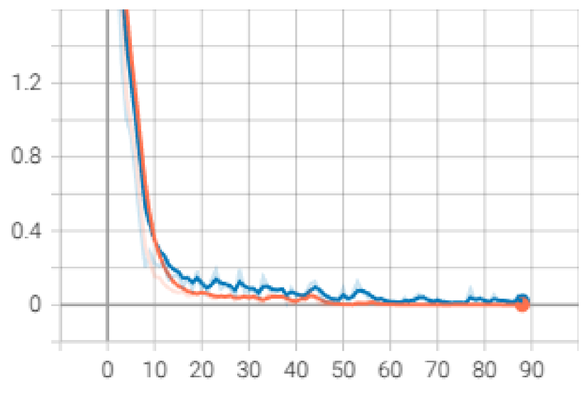
Developments

We have developped ***torchcvnn***, a Pytorch-based framework for easy experiments with state-of-the-art Complex-valued Neural Network (paper in submission). https://github.com/torchcvnn/torchcvnn

Experimentations

The MSTAR *(Moving and Stationary Target Acquisition and Recognition)* dataset is a benchmark in SAR imaging and automatic target recognition [2].





Very close train and validation loss

Complex-valued ResNet-18 achieves an accuracy of 99.8% on 16 classes of the MSTAR dataset.

Discussion

- Push further Max Muzeau's PhD work with Complex-valued Neural Network
- Develop SAR despeckling complex-valued network