A Location Scale Based CFAR Detection Framework for FOPEN SAR Images

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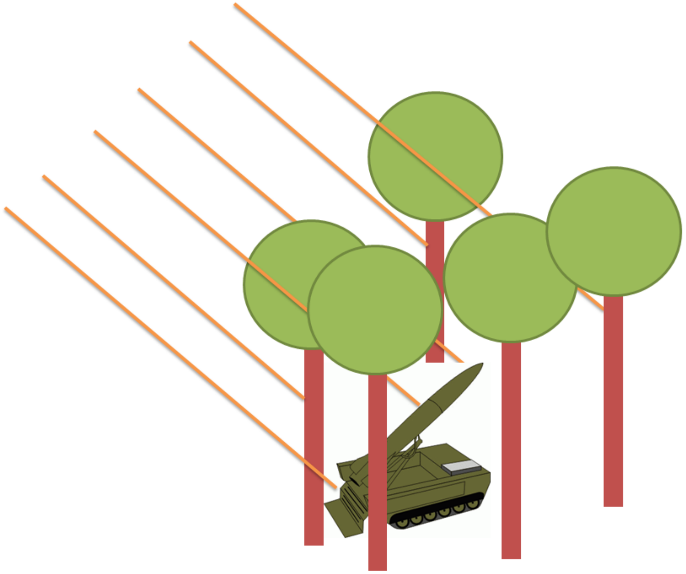
Outline

- Introduction
- Multi-Model CFAR Detection in LS Environment
- Background Characterization
- Performance analysis on Real Data
    - Extended Target Detection
- Conclusions

Introduction



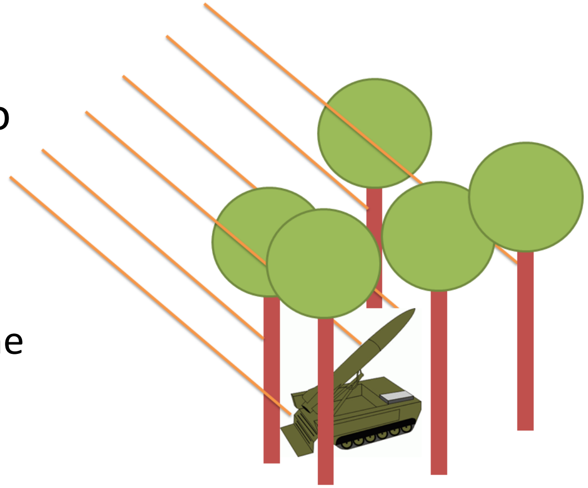
- Foliage Penetrating (FOPEN) Radar Imaging is a technique with high potential in defence applications thanks to its capability to see through foliage canopies;
- Due to the nature of the imaged scene, different challenges from "traditional" SAR images arise;
- The presence of threes, whose trunks reflect with relatively high intensity the radar signal, represents one of them;
- Threes reflection contributes to the clutter return that become more difficult to model;
- This makes difficult the application of standard detection techniques.

Introduction

- For this specific family of background a general and closed form model is not available;

- However a statistical approach is desirable thanks to its reliability and capability to include control on performance;

- The problem of target detection consists of deciding on the possible presence of a target in a signal (i.e. SAR Image).



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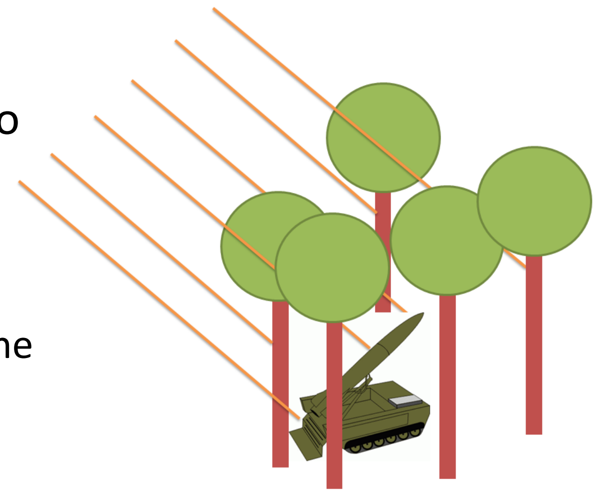

- The detection problem can be formulated in the form of the following hypothesis test:

$$\begin{cases} H_B: \quad X = B \quad \text{Target absent} \\ H_T: \quad X = T \quad \text{Target present} \end{cases}$$

Where X is the random variable and T denotes the threshold value.

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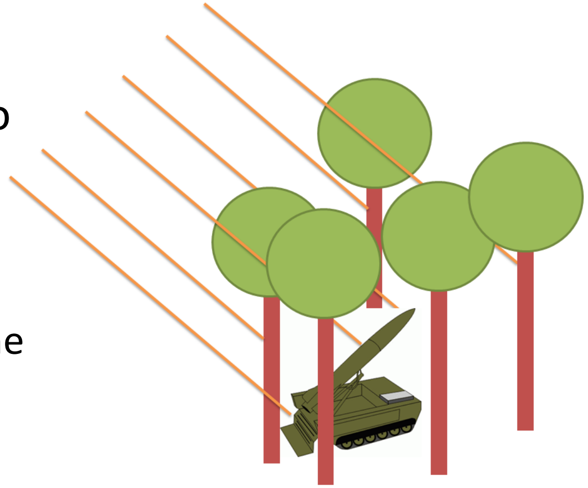

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- In this work we propose a Constant False Alarm Rate algorithm for detection of targets in foliage able to adapt the threshold and the distribution model to deal with this particular background type;

Multi-Model CFAR Detection in LS Environment

- A general solution to the CFAR problem exists if the clutter distribution is of a Location-Scale family or if a parameter-free transformation can be found a general distribution in a Location-Scale type

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$$X = \theta_S X_0 + \theta_L$$

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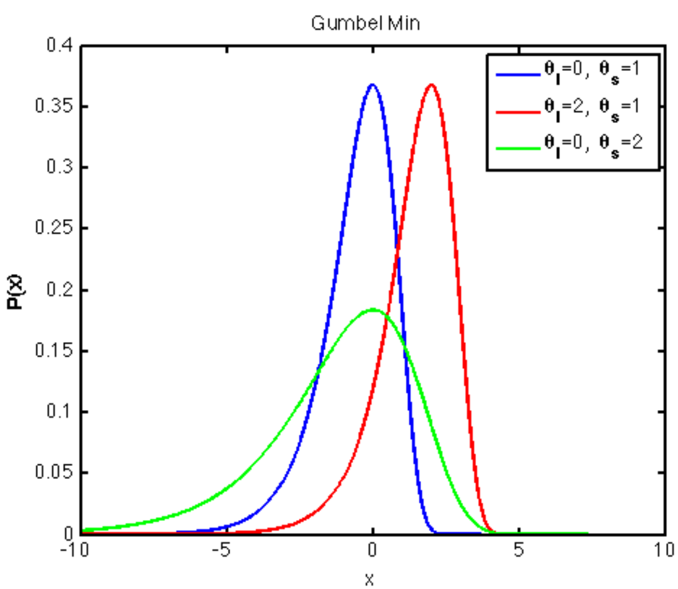
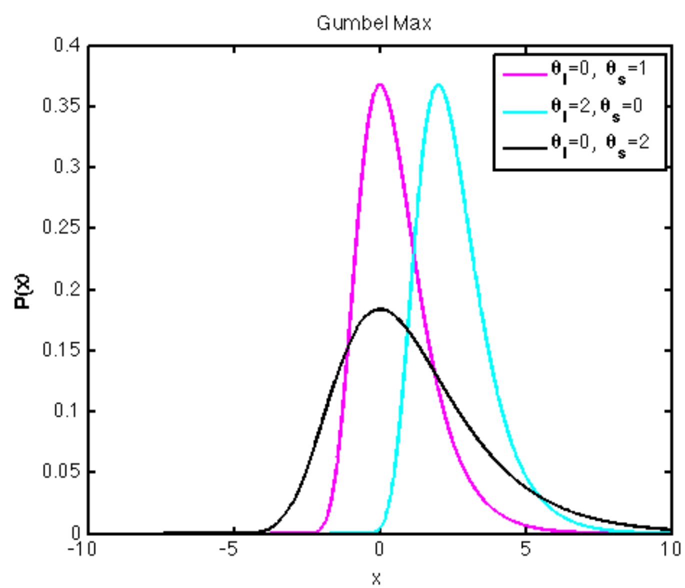
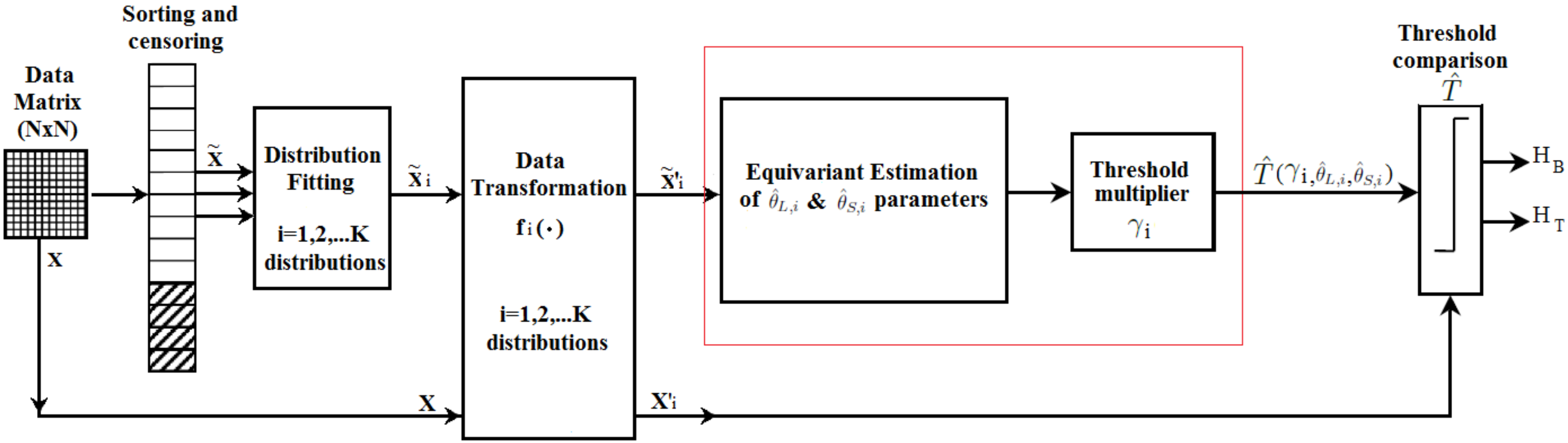


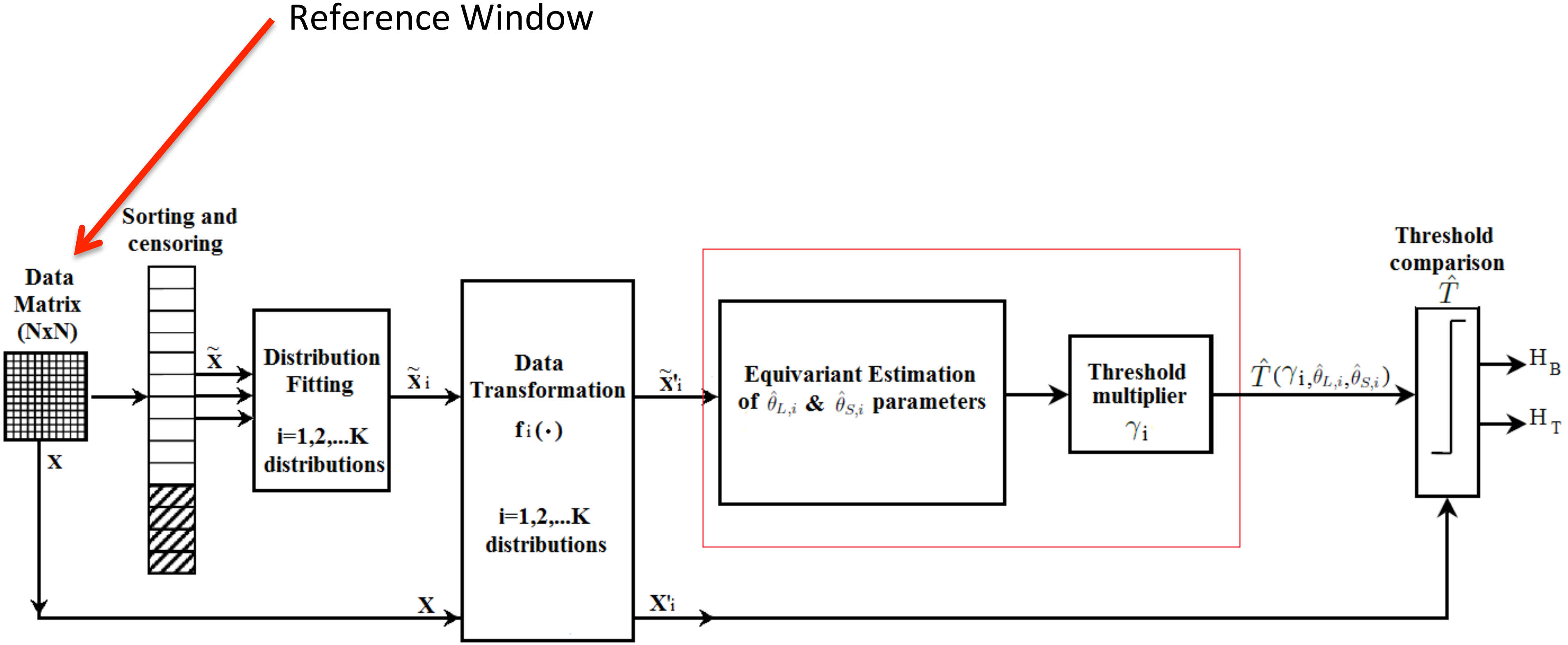


Multi-Model CFAR Detection in LS Environment



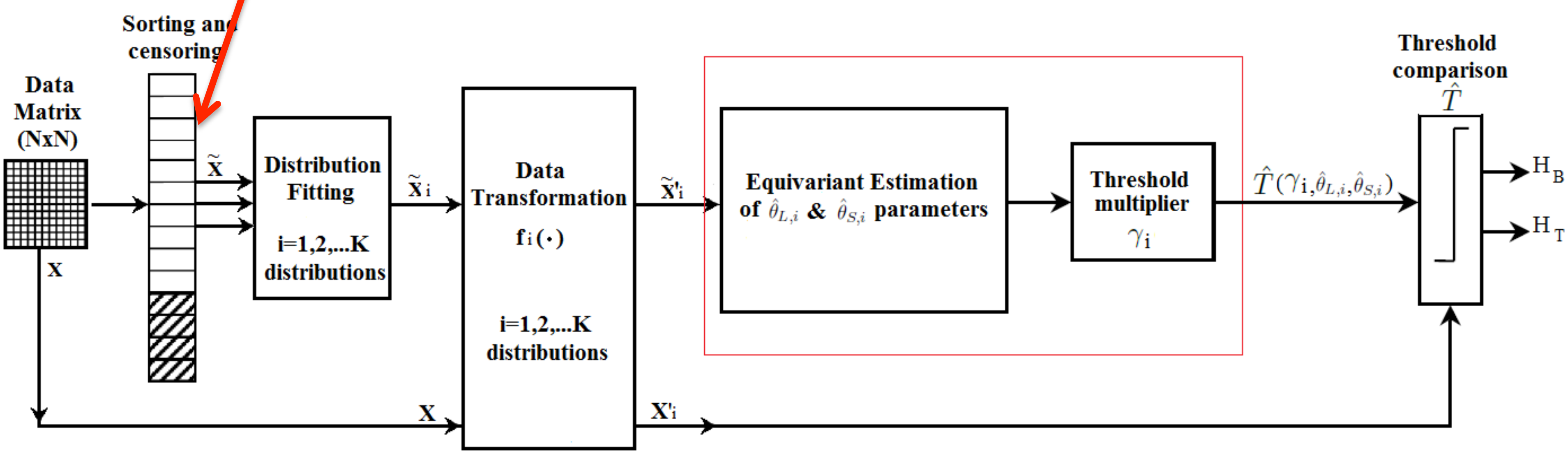
Multi-Model CFAR Detection in LS Environment

Reference Window



Multi-Model CFAR Detection in LS Environment

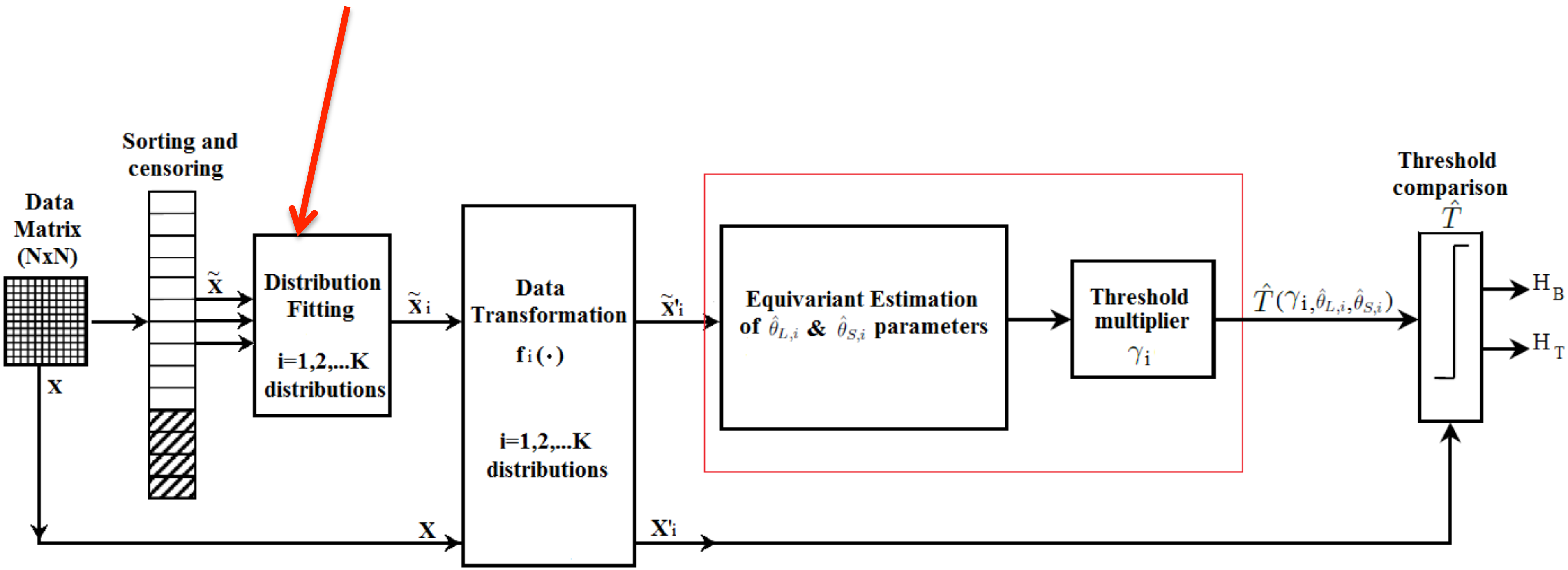
Censoring to avoid target self masking in the distribution parameters estimation process



The pixels with highest values in the reference window are removed to avoid bias in the threshold estimation.

Multi-Model CFAR Detection in LS Environment

Background Characterization using Lilliefors Test

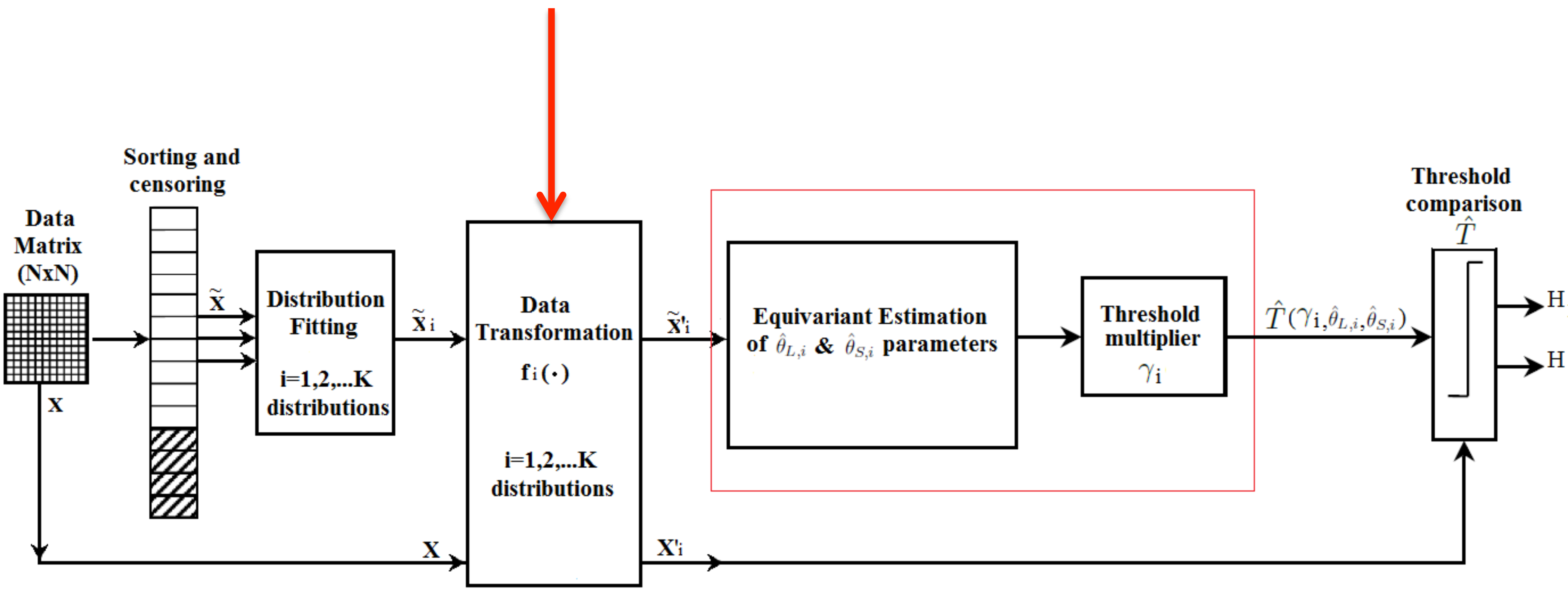


The background model is selected based on the location-scale distribution model that fits better the data or its non-parametric transformation;

Lilliefors test is a modified Kolmogorov-Smirnov test that is non-parametric and applicable in the unknown parameter case.

Multi-Model CFAR Detection in LS Environment

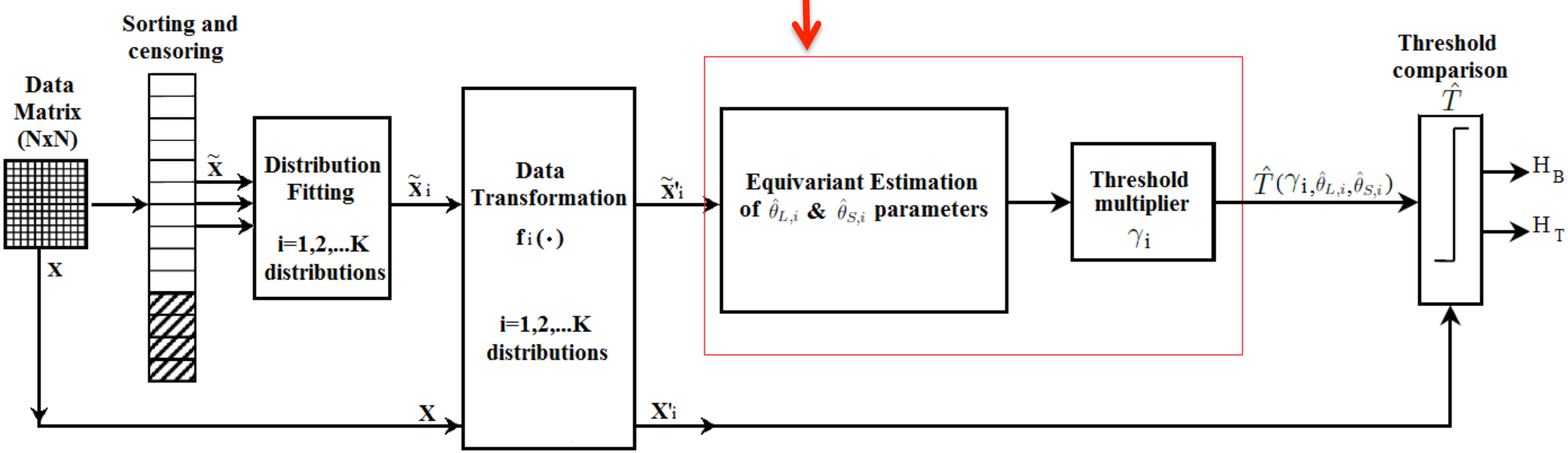
Data transformation to make them LS



As the selected distribution might not be LS, then the data must be transformed to become LS.

Multi-Model CFAR Detection in LS Environment

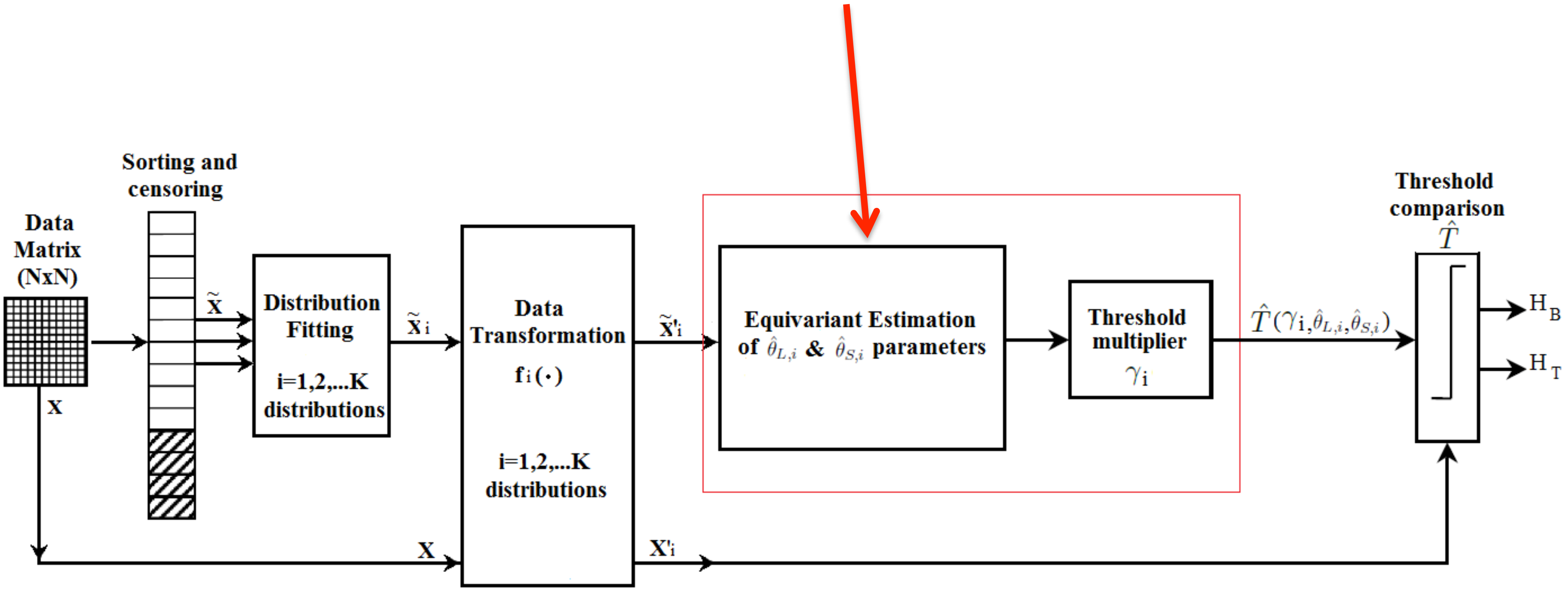
Model Specific block



The parameter estimators depends on the statistical model adopted;

Multi-Model CFAR Detection in LS Environment

Location and Scale Parameters Estimation

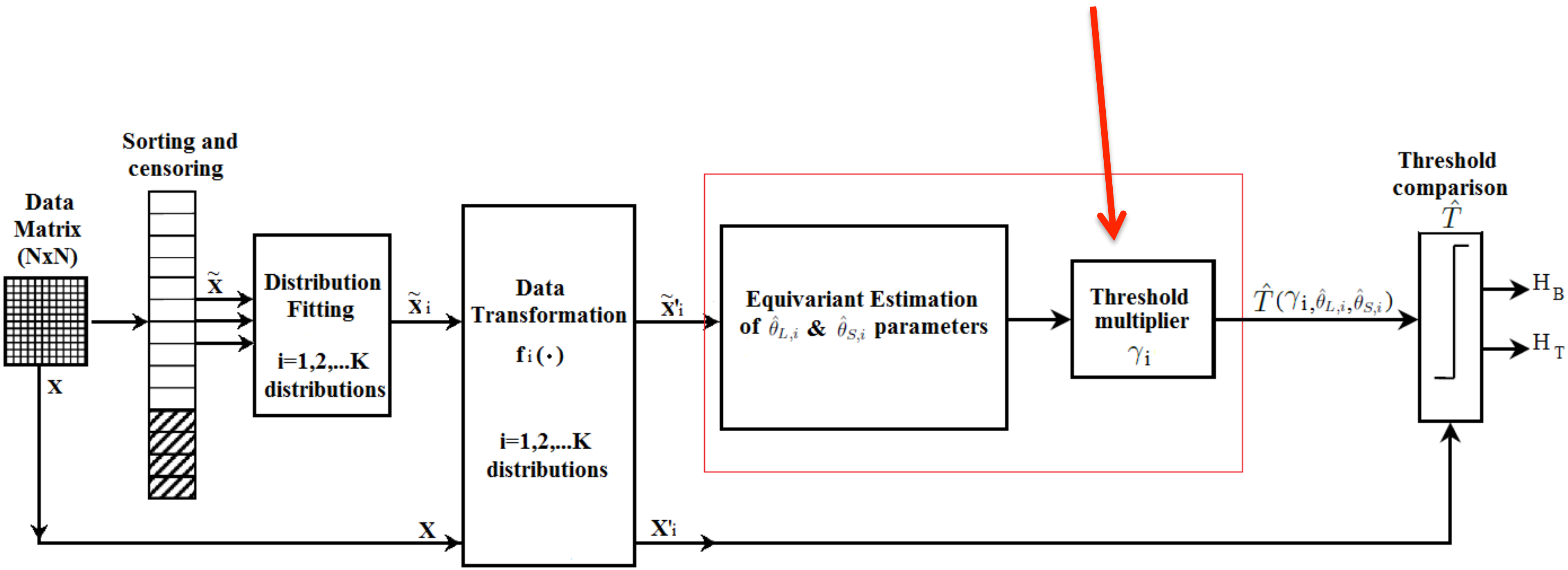


The Best Linear Unbiased Estimators are used to estimate location and scale parameters, minimizing the variance with unbiasedness constraint.

$$\begin{pmatrix} \hat{\theta}_{L,i} \\ \hat{\theta}_{S,i} \end{pmatrix} = \left(\mathbf{H}_i^T \mathbf{C}_{0,i}^{-1} \mathbf{H}_i\right)^{-1} \mathbf{H}_i^T \mathbf{C}_{0,i}^{-1} \tilde{\mathbf{X}}'_{\mathbf{i}}, \qquad \mathbf{H}_i = (\mathbf{1}\ \boldsymbol{\mu}_{0,i})$$

Multi-Model CFAR Detection in LS Environment

Treshold multiplier



The threshold multiplier ensures the false alarm probability for the given parameters and is the solution to the equation

$$P_{FA} = Pr\left\{ \frac{\tilde{X}'_i - \hat{\theta}_{L,i}}{\hat{\theta}_{S,i}} > \gamma_i \middle| H_B \right\}$$

Multi-Model CFAR Detection in LS Environment

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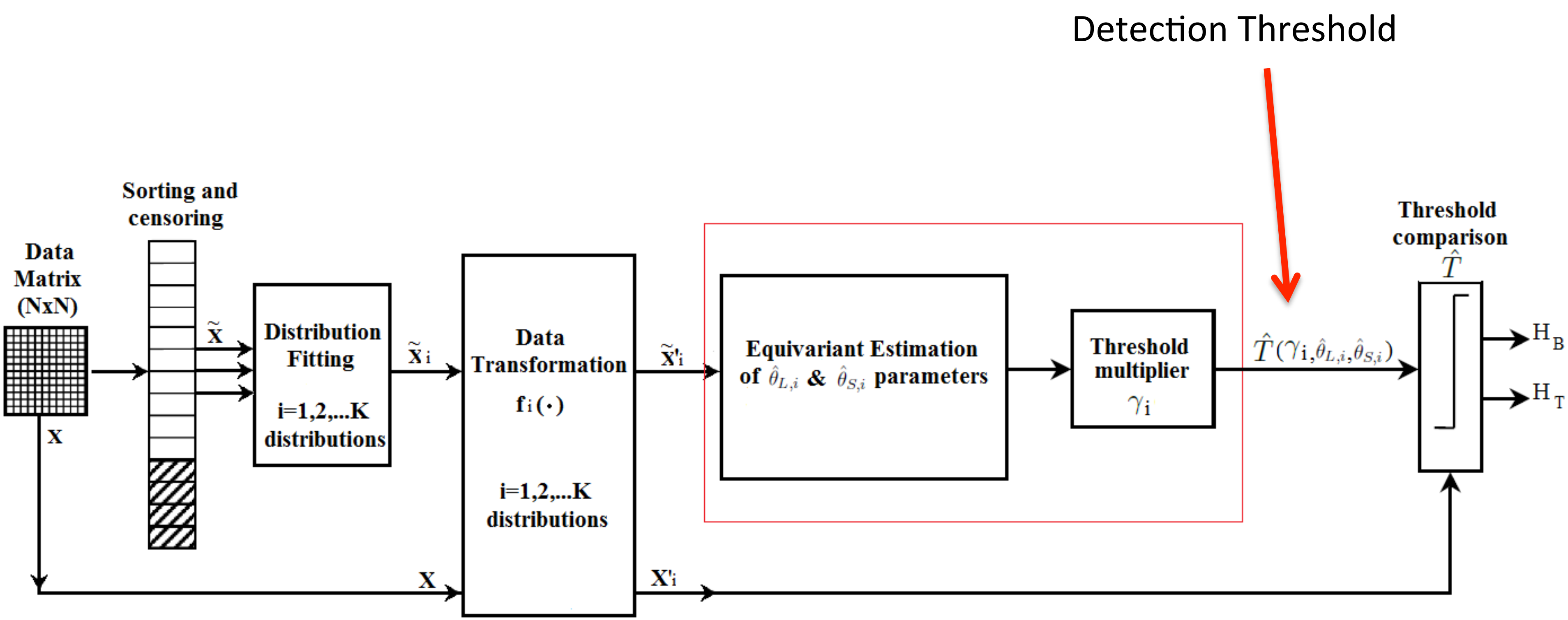
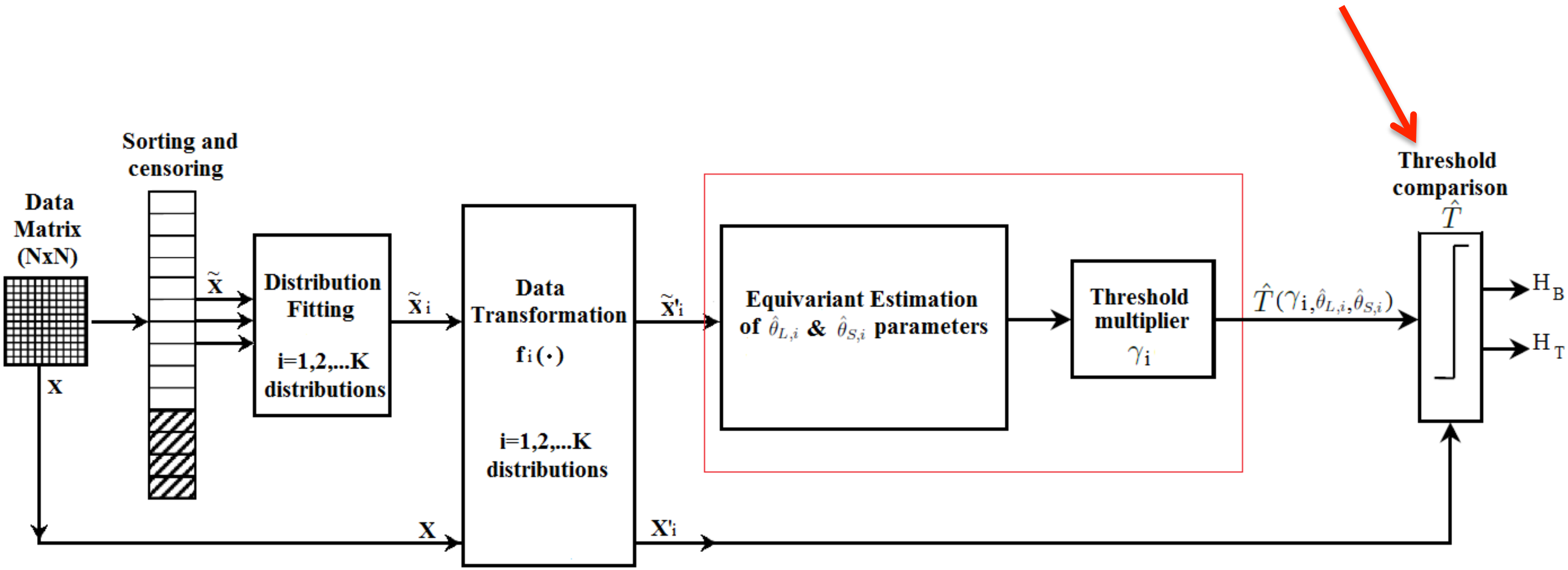


The adaptive threshold is then obtained as

$$\hat{T}\left(\gamma_i, \hat{\theta}_{L,i}, \hat{\theta}_{S,i}\right) = \hat{\theta}_{S,i}(\tilde{\mathbf{X}}'_{\mathbf{i}})\,\gamma_i + \hat{\theta}_{L,i}(\tilde{\mathbf{X}}'_{\mathbf{i}}).$$

Multi-Model CFAR Detection in LS Environment

Decision



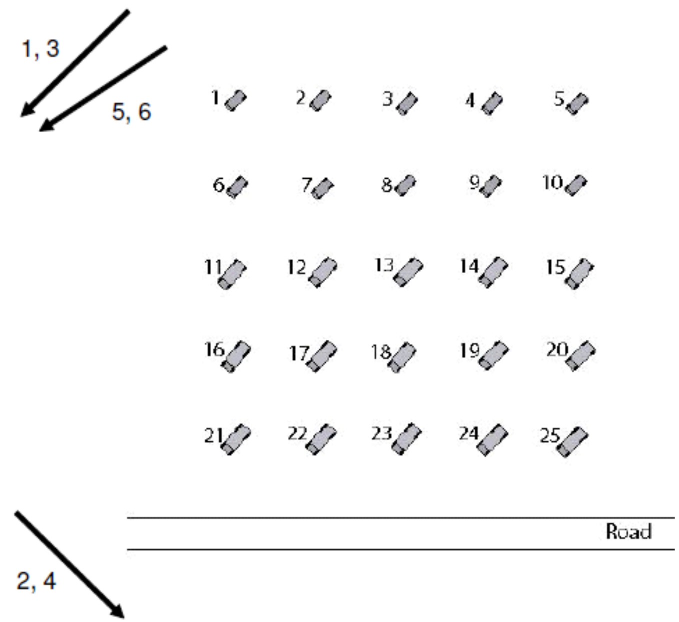
The threshold is compared with the uncensored data to perform the detection

$$X_i' \underset{H_B}{\overset{H_T}{\gtrless}} \hat{T}\left(\gamma_i, \hat{\theta}_{L,i}, \hat{\theta}_{S,i}\right)$$

Background Characterization

- A requirement of the proposed framework is that the background models are Location-Scale or Location-Scale transformable;

- The Carabas II dataset (intensity only) has been used for model selection and for performance analysis;



Background Characterization

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- Due to the presence of trees in the scenario distributions with light and heavy tails are preferred;
- The two distributions that resulted to provide the best fit are:

The Gumbel for Maximum distribution, whose CDF is:

$$F\left(\mathbf{x};\theta_L,\theta_S\right) = exp\left[-exp\left(-\frac{x-\theta_L}{\theta_S}\right)\right] \quad \theta_L \in \mathbb{R} \;\; \theta_S > 0$$

and the Weibull distribution with CDF:

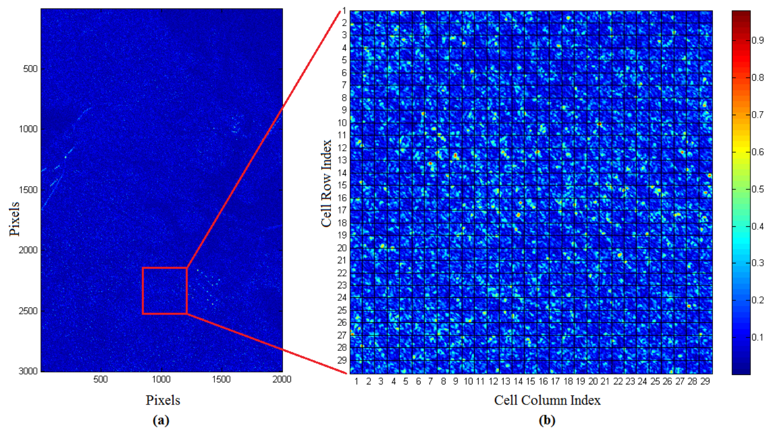
$$F\left(\mathbf{x};\kappa,\lambda\right) = \begin{cases} 1 - e^{-\left(\frac{x}{\lambda}\right)^k}, & \text{if } x \geq 0, \\ 0, & \text{if } x < 0. \end{cases}$$

whose natural logarithm is a Gumbel for Minimum distribution, so it can be transformed in LS-type.

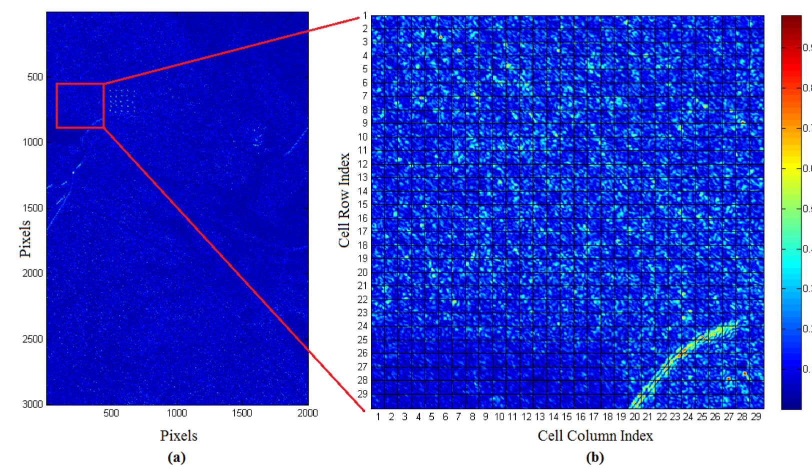
Background Characterization

- For both high and low density forest the Lilliefors test was used in a single and multi-model approach;

High density Forest



Low density Forest



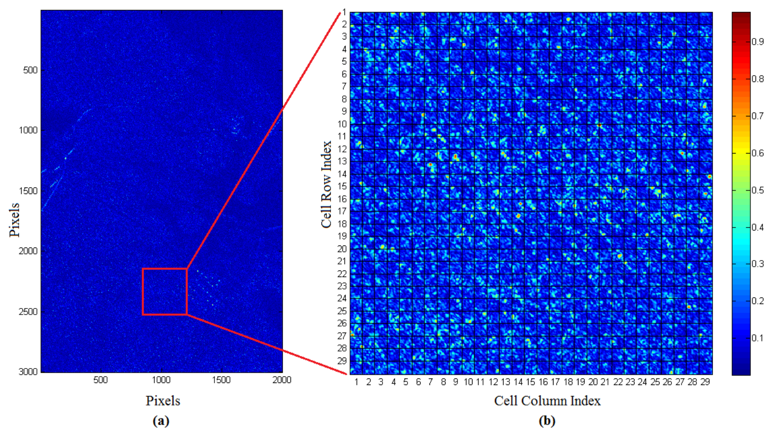
Gumbel Maximum	Multi-Model
96.91%	98.57%

Weibull	Multi-Model
97.50%	99.16%

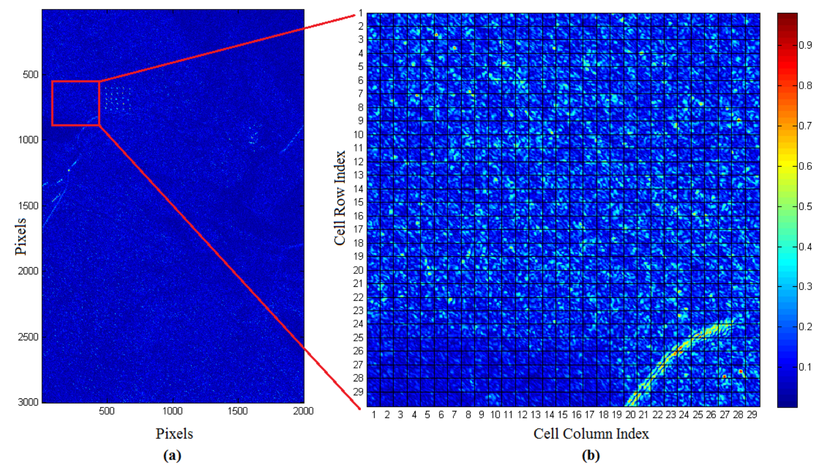
CFAR Performance

- In order to verify the CFAR property, the detection is performed in the target free areas (nominal $P_{fa} = 10^{-4}$);

High density Forest



Low density Forest



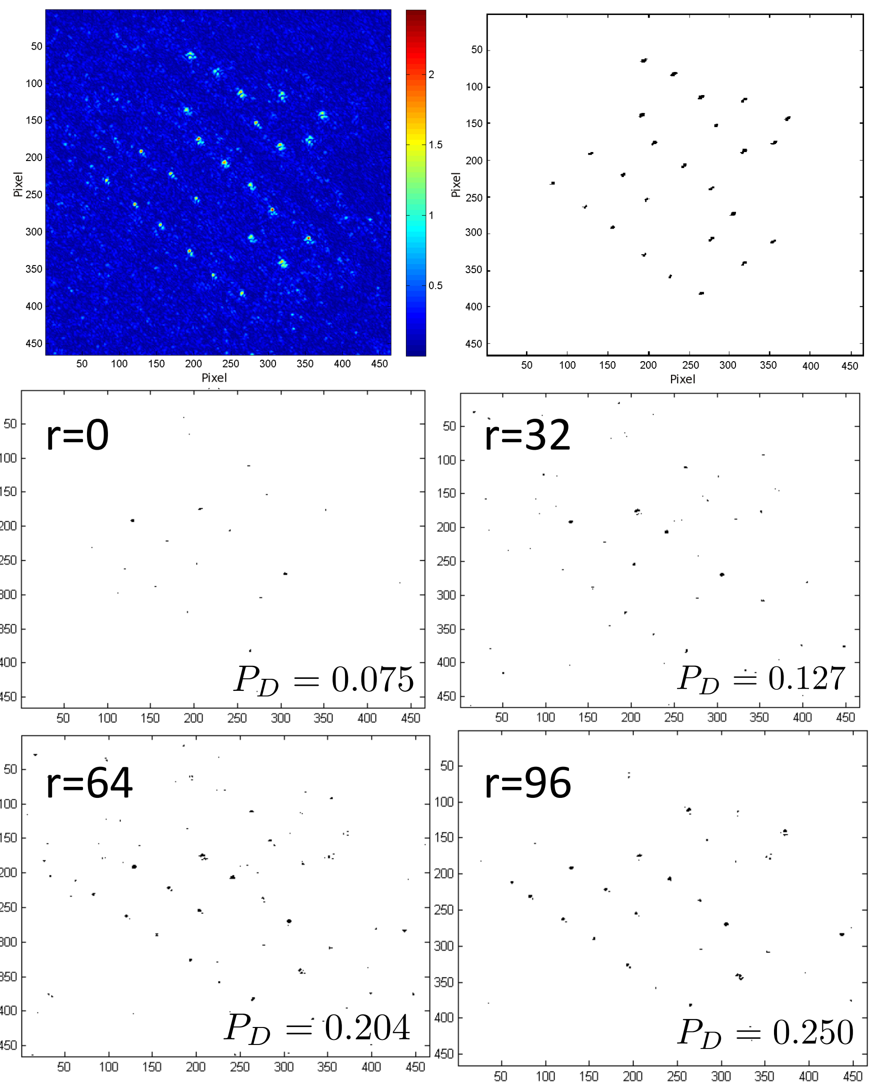
Censoring Depth	P_{fa}
0	1.03×10^{-4}
32	8.64×10^{-4}
64	6.70×10^{-4}
96	6.61×10^{-4}
128	6.19×10^{-4}

Censoring Depth	P_{fa}
0	5.08×10^{-5}
32	1.43×10^{-4}
64	1.52×10^{-4}
96	6.01×10^{-5}
128	8.32×10^{-5}

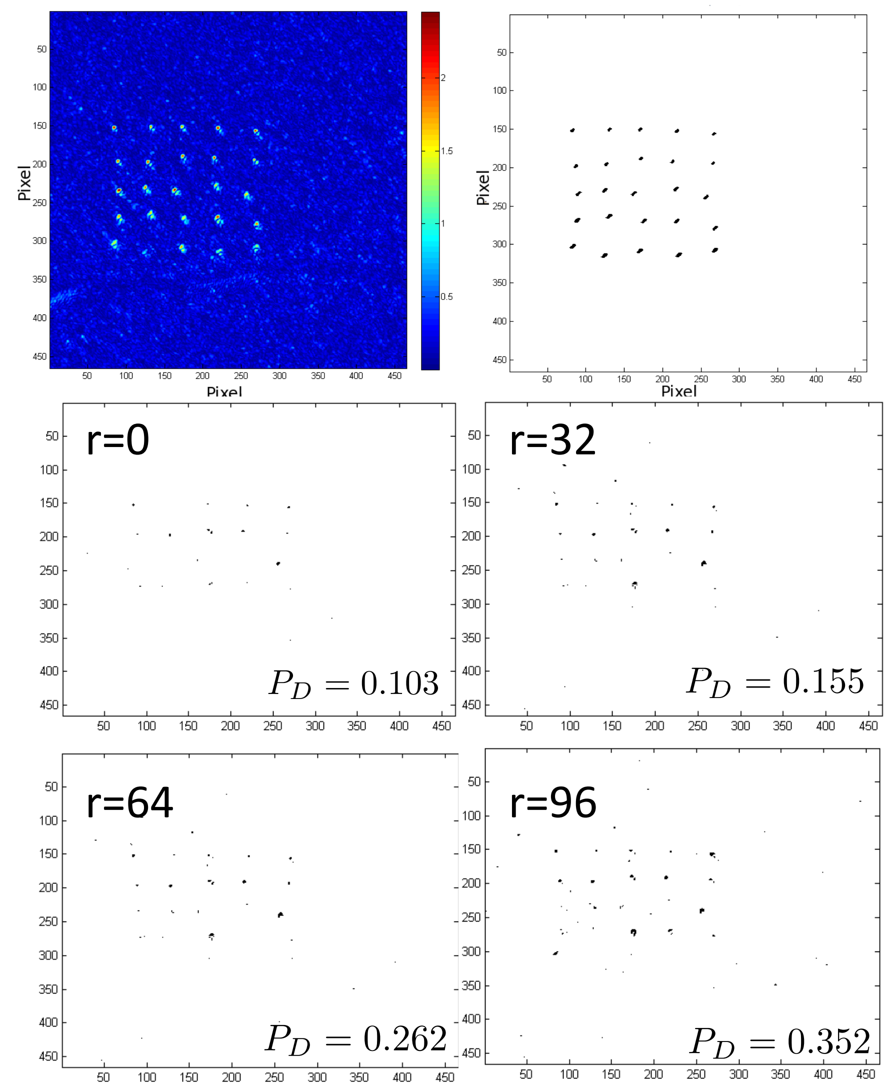
Detection Performance

- In order to verify demonstrate the capability to detect targets, the algorithm is tested on the area containing vehicles hidden in foliage (nominal $P_{fa} = 10^{-4}$);

High density Forest

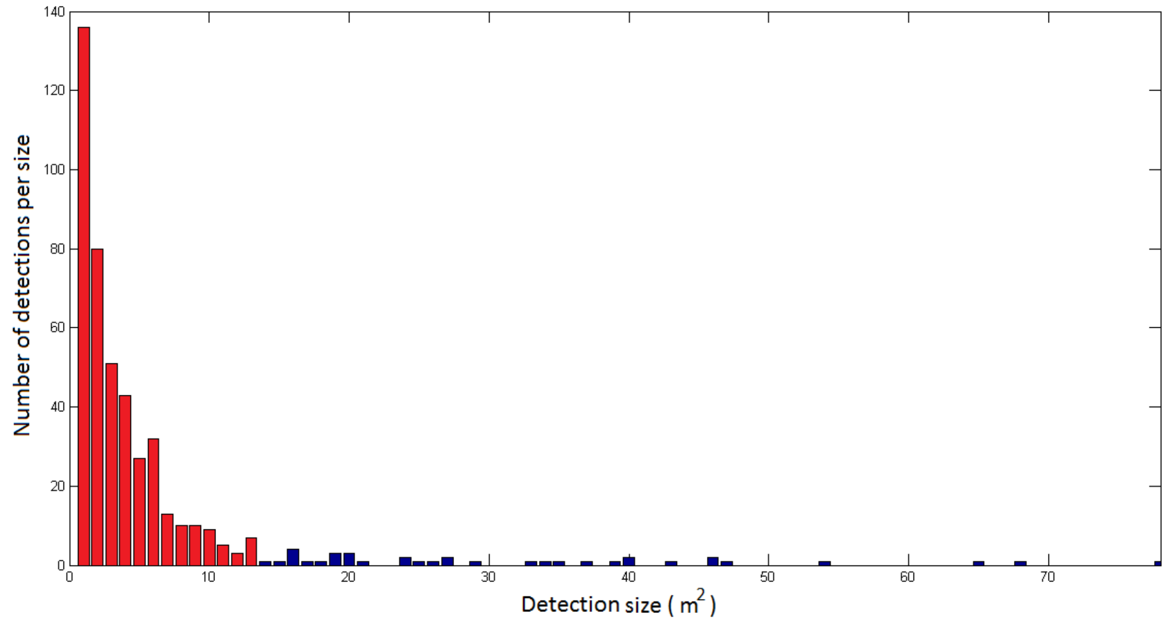


Low density Forest



Extended Target Detection

If a clustering and a threshold on the target size are applied the probability of detection can be improved with mitigation of higher false alarms.



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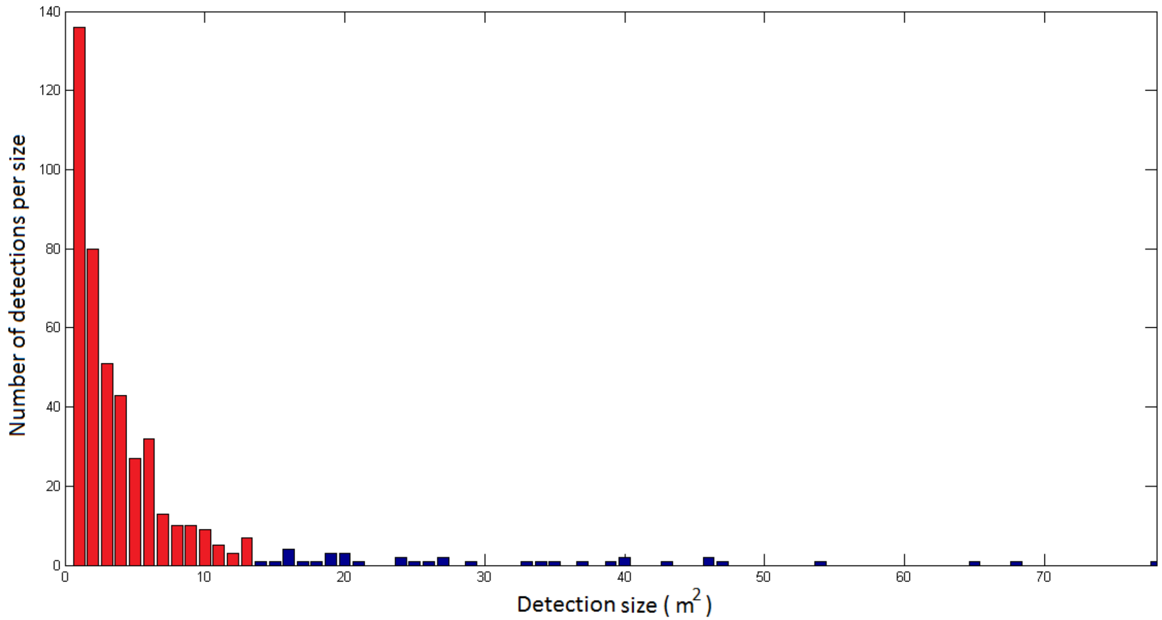
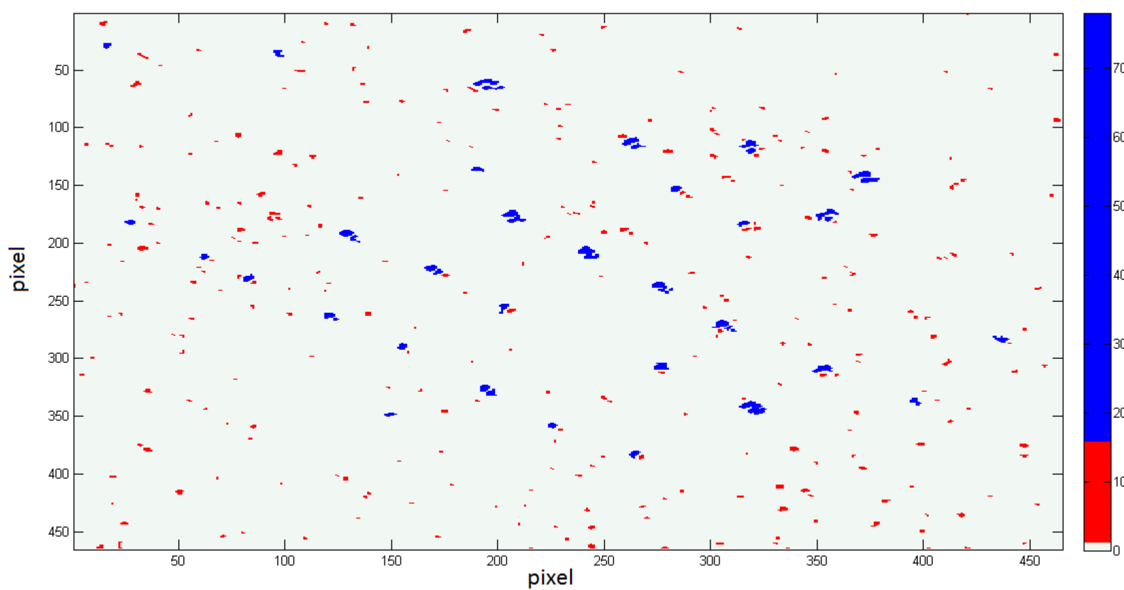
Nominal $P_{fa} = 10^{-2}$	P_D	P_{fa}
No Clustering	0.5804	1×10^{-2}
Clustering	0.5804	3×10^{-3}

1 miss only = 96% of extended targets are at least partially detected.





Conclusion

- A framework for CFAR detection in Foliage Penetration SAR images has been proposed;
- The proposed approach adapts both background model and threshold in order to maintain the CFAR property;
- The CFAR and detection performance have been assessed on real data with two forest densities;
- The framework demonstrated to successfully provide a control on the false alarm probability;
- The detection probability can be improved by exploiting domain knowledge information as in the case of extended target detection;
- Future work will deal with the extension of the framework to coherent CFAR detection.

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