

22<sup>nd</sup> Mine Action Symposium  
25 March 2026, Split, Croatia

# ANOMALY DETECTION METHODS FOR UXO AND LANDMINE EXTRACTION ON MULTIBAND IMAGES

Ivan Racetin<sup>1</sup>, Andrija Krtalić<sup>2</sup>

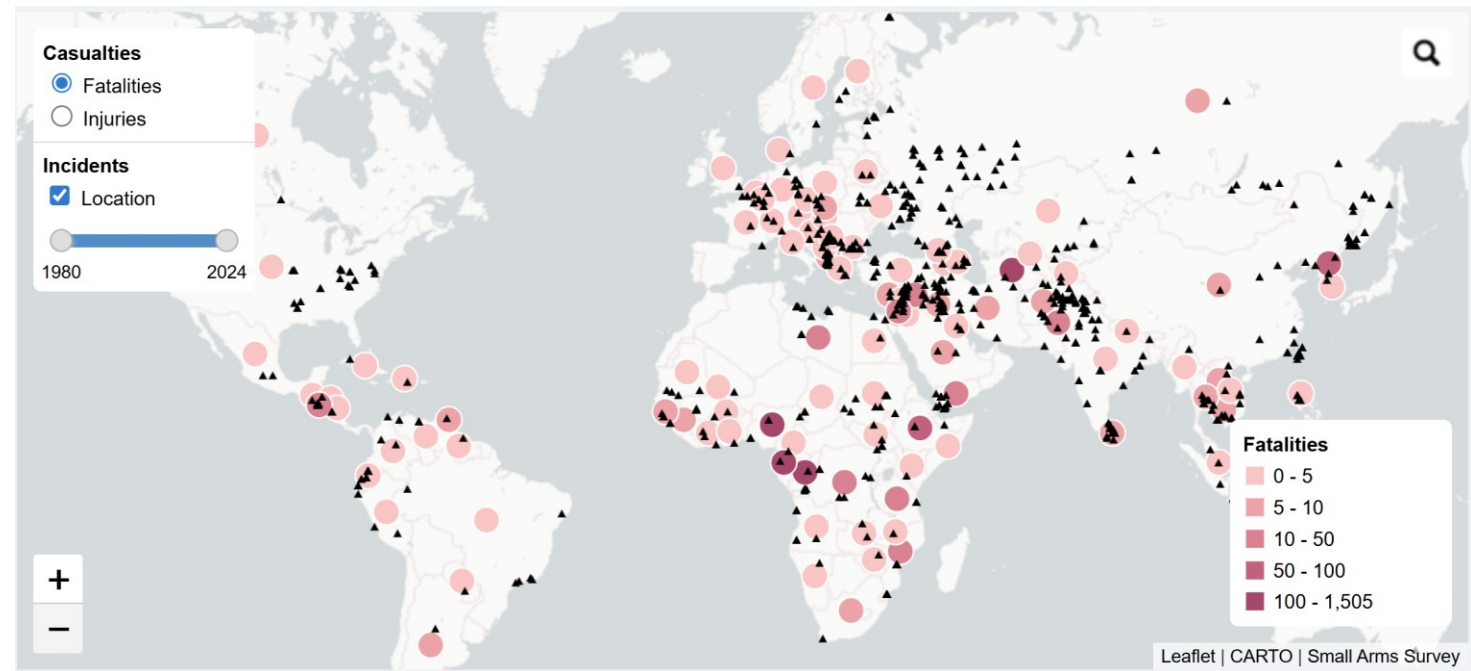
<sup>1</sup> Faculty of Civil Engineering, Architecture and Geodesy, Chair of Geodesy and Geoinformatics,  
University of Split, Croatia, [ivan.racetin@gradst.hr](mailto:ivan.racetin@gradst.hr)

<sup>2</sup> Faculty of Geodesy, Institute for Cartography and Photogrammetry, Chair of Photogrammetry  
and Remote Sensing, University of Zagreb, Croatia, [andrija.krtalic@geof.unizg.hr](mailto:andrija.krtalic@geof.unizg.hr)



# MOTIVATION: CONTEXT

- Small Arms Survey: 1979 - 2021, 636 incidents of Unplanned Explosions at Munitions Sites occurred in more than 100 countries, resulting in 30,883 casualties
- The global landmine crisis intensified dramatically in 2023, with 5,757 recorded casualties, a 22% increase from the previous year
- 2025:
  - for the first time, Estonia, Finland, Latvia, Lithuania, and Poland initiated legal steps to withdraw from the Mine Ban Treaty
  - Lithuania became the first country ever to withdraw from the Convention on Cluster Munitions



<https://www.smallarmssurvey.org/database/unplanned-explosions-munitions-sites-uems>



# MULTIBAND IMAGE ANALYSIS IN SUPPORT OF UXO AND LANDMINE EXTRACTION

Significant research has been done on remote sensing methods to support demining operations and explosive ordnance detection, tackling various passive and active sensors operating in different portions of electromagnetic spectrum.

General problem in development of algorithms for UXO and landmine detection on multiband images is a lack of standardized reference datasets for model training and validation.

Information retrieval step in an image analysis can be done by two general approaches:

- 1) Classification or
- 2) Target detection:
  - a) Spectral signature-based detection (spectral matching): supervised learning that requires a-priori data about targets
  - b) **Anomaly detection**: unsupervised learning methods that do not require data about target spectral signatures



# ANOMALY DETECTION

The mathematical framework for anomaly detection arises from signal detection theory and statistical hypothesis testing.

A selection between two disjunct hypotheses needs to be made: a pixel belongs to the prevailing background, or pixel belongs to sparse anomaly.

$$\hat{H}(\underline{x}) = \begin{cases} H_0: & \text{target absent ( } \underline{x} \text{ is a background pixel )} \\ H_1: & \text{target present ( } \underline{x} \text{ is a target pixel )} \end{cases}$$

In this research, standard anomaly detection methods **Cluster-based anomaly detectors** (CBAD), **Orthogonal Subspace Projection** (OSP) and **Reed-Xiaoli** (RX) were implemented and tested



# UXO REFERENCE SPECTRA

Reference spectra of UXOs that were used in this work is described in works of Bajic et al<sup>1,2</sup>.

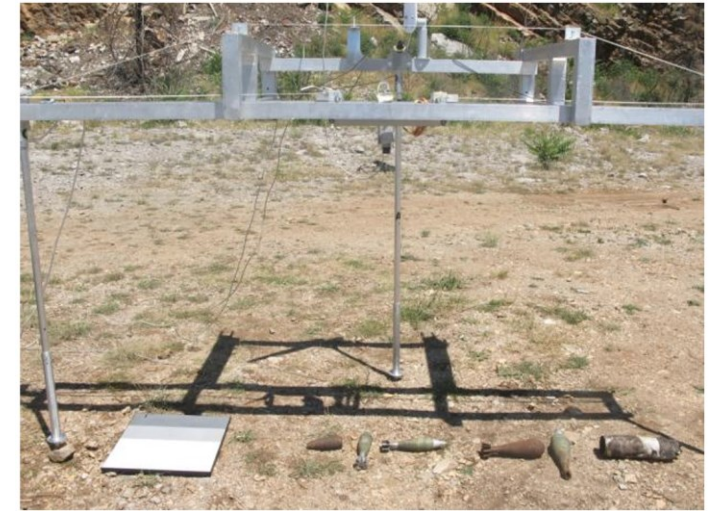
Hyperspectral linear scanner ImSpector V9 was used for data collection, and raw data was further corrected for radiometric and atmospheric effects.

Reference spectrum of each explosive ordnance was determined as an average of its spatial pixels, resulting in one reference spectrum in visible and near-infrared region for twelve selected explosive ordnances.

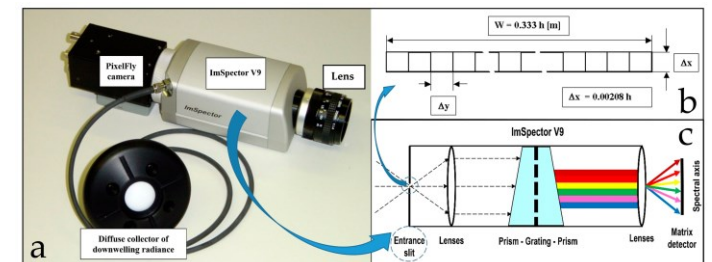
<sup>1</sup> Bajić, M.; Ivelja, T.; Krtalić, A.; Tomić, M.; Vuletić, D. The multisensor and hyper spectral survey of the UXO around the exploded ammunition depot, of the land mines test site vegetation. In Proceedings of Proceedings of 10th International symposium HUDEM, Sibenik, Croatia; pp. 91-96.

<sup>2</sup> Bajic, M.; Ivelja, T.; Brook, A. Developing a Hyperspectral Non-Technical Survey for Minefields via UAV and Helicopter. Journal of Conventional Weapons Destruction 2017, 21.

<sup>3</sup> Krtalić, A.; Miljković, V.; Gajski, D.; Racetin, I. Spatial Distortion Assessments of a Low-Cost Laboratory and Field Hyperspectral Imaging System. Sensors 2019, 19, 4267. <https://doi.org/10.3390/s19194267>



Acquisition of UXO reference spectra. Figure from Bajic et al.<sup>1</sup>



Hyperspectral linear scanner ImSpector V9. Figure from Krtalic et al.<sup>3</sup>



# LANDMINE REFERENCE SPECTRA

Reference spectra of four landmines (VS 50, PMN, VS-2.2, PMD-6) in visible, near-infrared and shortwave infrared portions of electromagnetic spectrum (250-2500 nm) were acquired from work by Makki<sup>1</sup>.

In that work, a high-resolution spectroradiometer was used to collect calibrated reflectance data.



Four landmines VS 50, PMN, VS-2.2, PMD-6 were used in this research. Figure from Makki et al.<sup>1</sup>

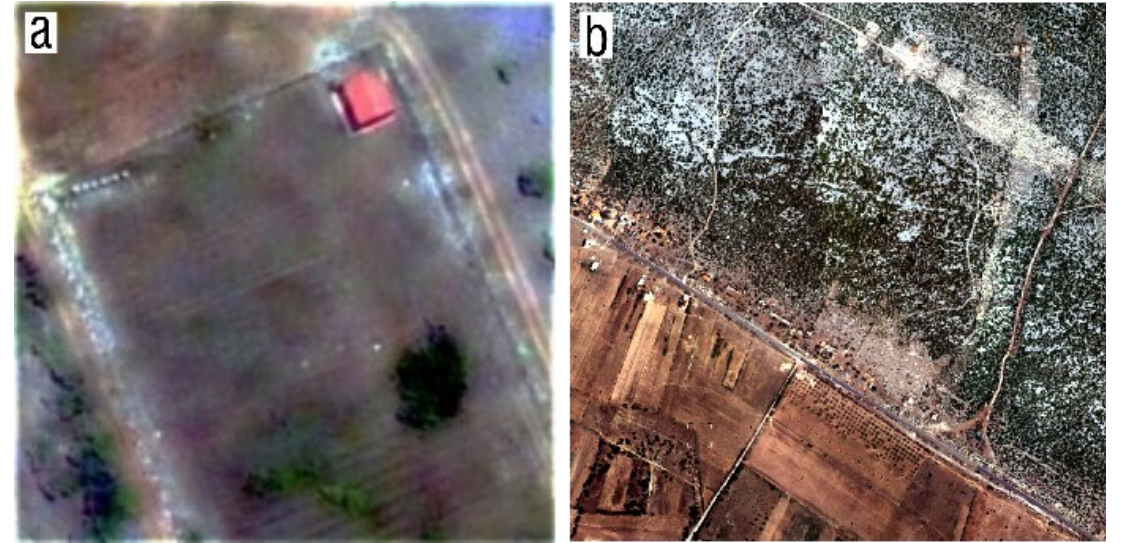
<sup>1</sup> Makki, I.; Younes, R.; Francis, C.; Bianchi, T.; Zucchetti, M. A survey of landmine detection using hyperspectral imaging. ISPRS J. Photogramm. Remote Sens. 2017, 124, 40-53, doi:10.1016/j.isprs.2016.12.009.



# TEST DATASETS

As a basis for implementation of landmine and UXO spectra, aerial scene of Pristeg area acquired by multispectral system Daedalus 1268 and scene of Benkovac mine test area acquired by hyperspectral Cubert UHD 185 were used.

Reference spectra of both landmine and explosive ordnance samples were resampled to spectral bands of sensors used in the study, namely Cubert UHD 185 and Daedalus 1268 using Nearest Neighbour method.



(a) RGB composite of Cubert UHD 185 hyperspectral cube of Benkovac test area<sup>1</sup>, (b) RGB composite of Daedalus 1268 multispectral image of Pristeg area.

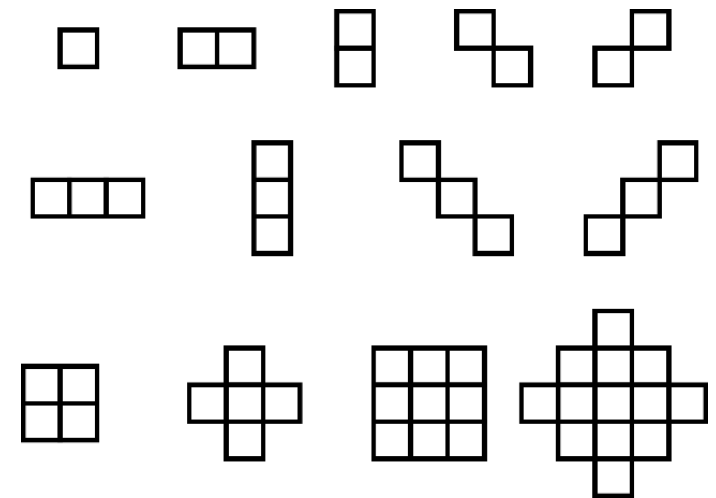
<sup>1</sup> Bajic, M.; Ivelja, T.; Brook, A. Developing a Hyperspectral Non-Technical Survey for Minefields via UAV and Helicopter. Journal of Conventional Weapons Destruction 2017, 21.



# UXO AND LANDMINE SIMULATION

To simulate the shape of the landmines and UXOs on the scenes, thirteen characteristic shapes were defined, from one-pixel, linear shapes (up to 3 pixels in length) to rectangular 3x3 and circular 5x5 shapes.

Synthetic test datasets and accompanying ground truth were generated using Mersenne Twister pseudorandom generator to choose the desired shape and position of implemented landmine and UXOs on the scene. Therefore, test datasets were created by replacing original pixel values with reference spectra of landmines and UXOs.

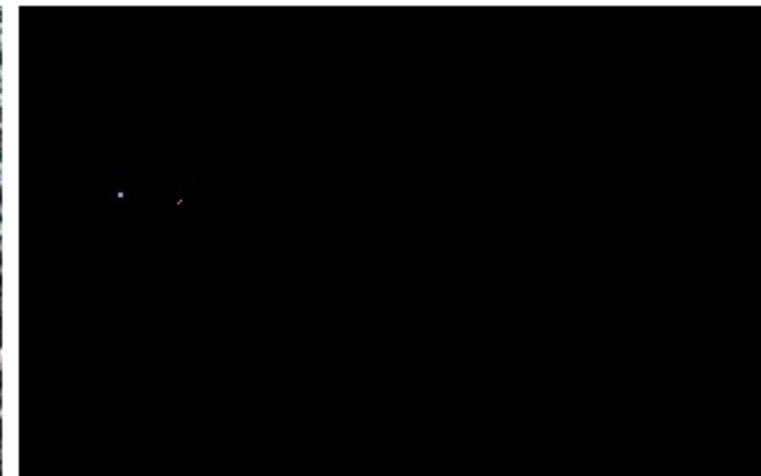
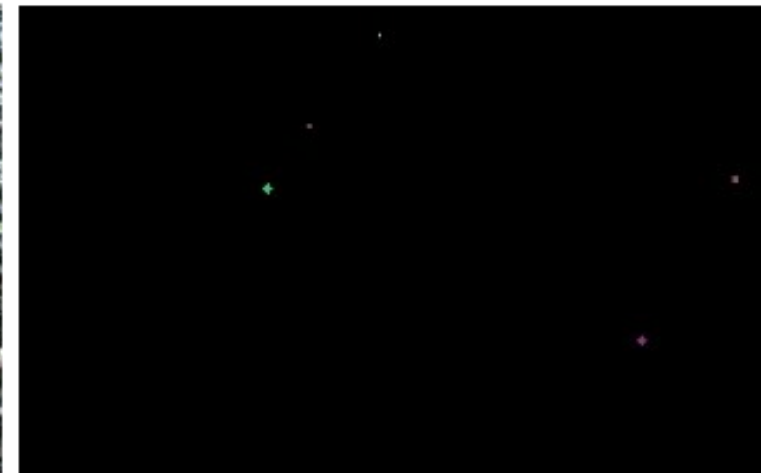


Geometric shapes of simulated landmines and UXO



# UXO AND LANDMINE SIMULATION

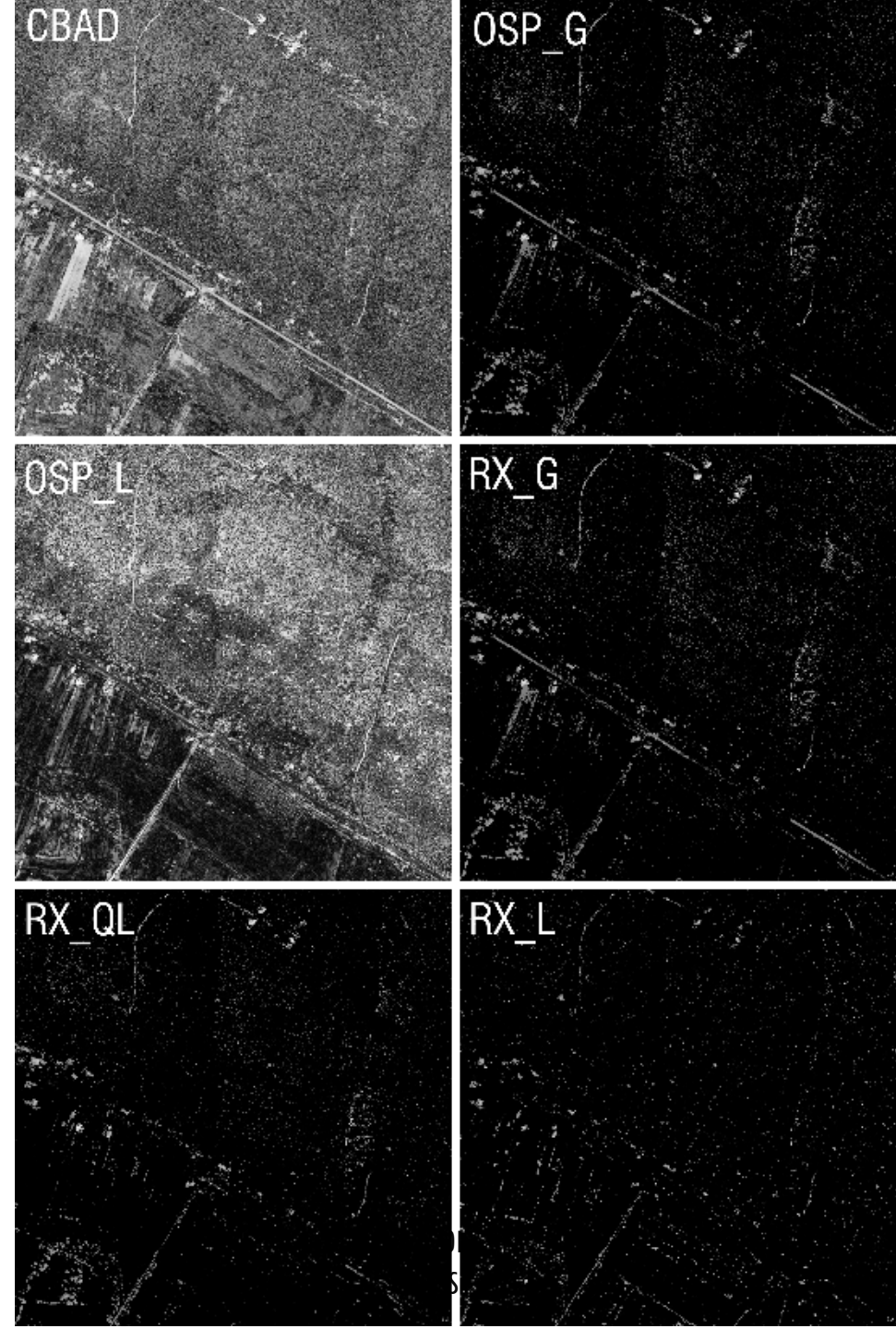
For each of two scenes, six scenarios were simulated. Landmines and UXOs were simulated separately, varying share of replaced pixels at 0,001%, 0,01% and 0,1% of total image pixels.



# IMPLEMENTATION OF ANOMALY DETECTORS

- global RX AD (RX G)
- local RX detector (RX L)
- quasi-local RX detector (RX QL)
- cluster-based anomaly detector (CBAD)
  - K-Means
- local orthogonal subspace projection AD (OSP L)
  - Principal Component Analysis
- global orthogonal subspace projection AD (OSP G)
  - Principal Component Analysis

\* Mahalanobis distance was used as a detection statistic

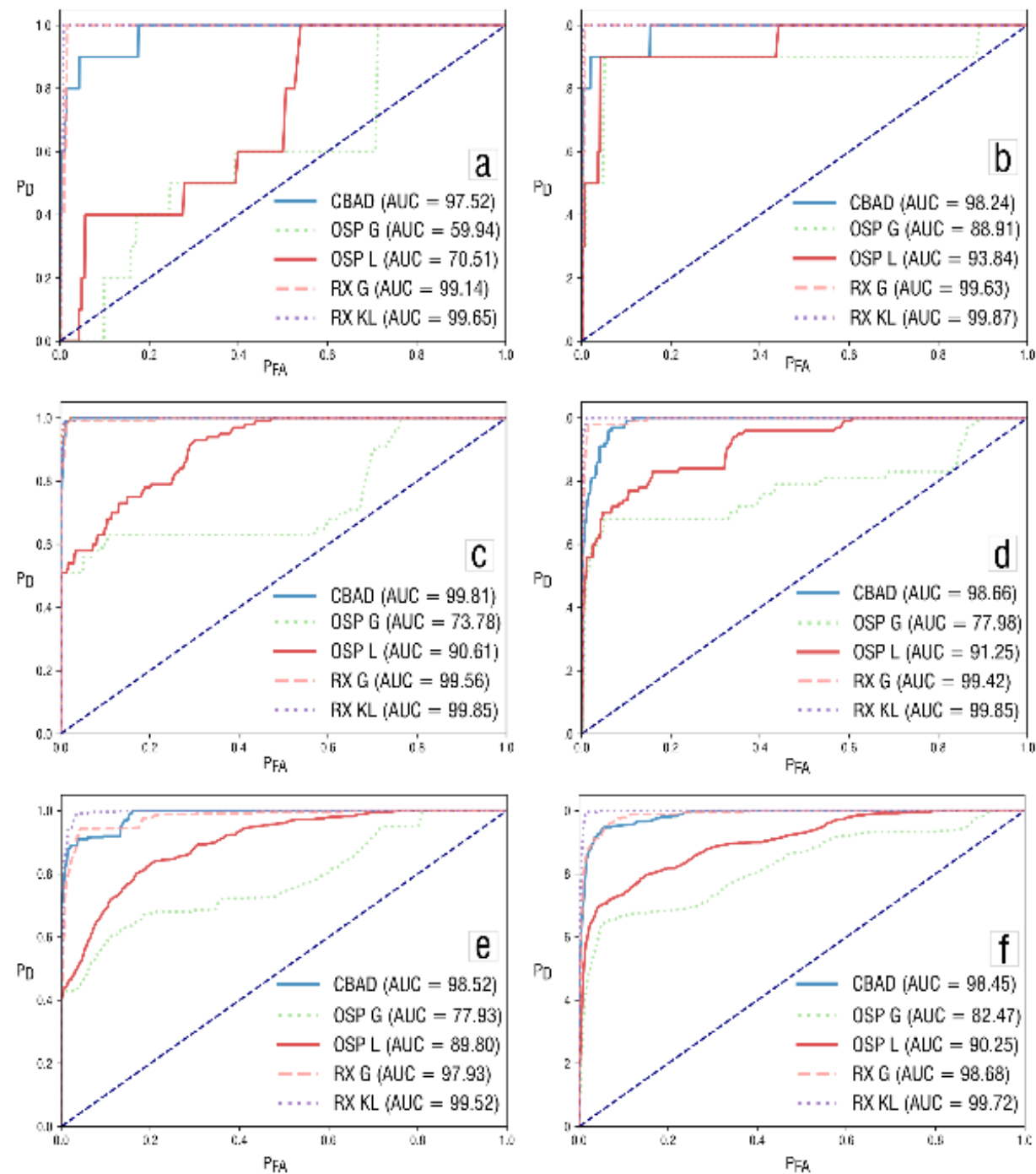


# RESULTS ON HYPER SPECTRAL DATASET

Although large window sizes were used for local methods (10x pixels than number of bands), it was not possible to invert covariance matrix due to rank defect for local RX AD in hyperspectral dataset.

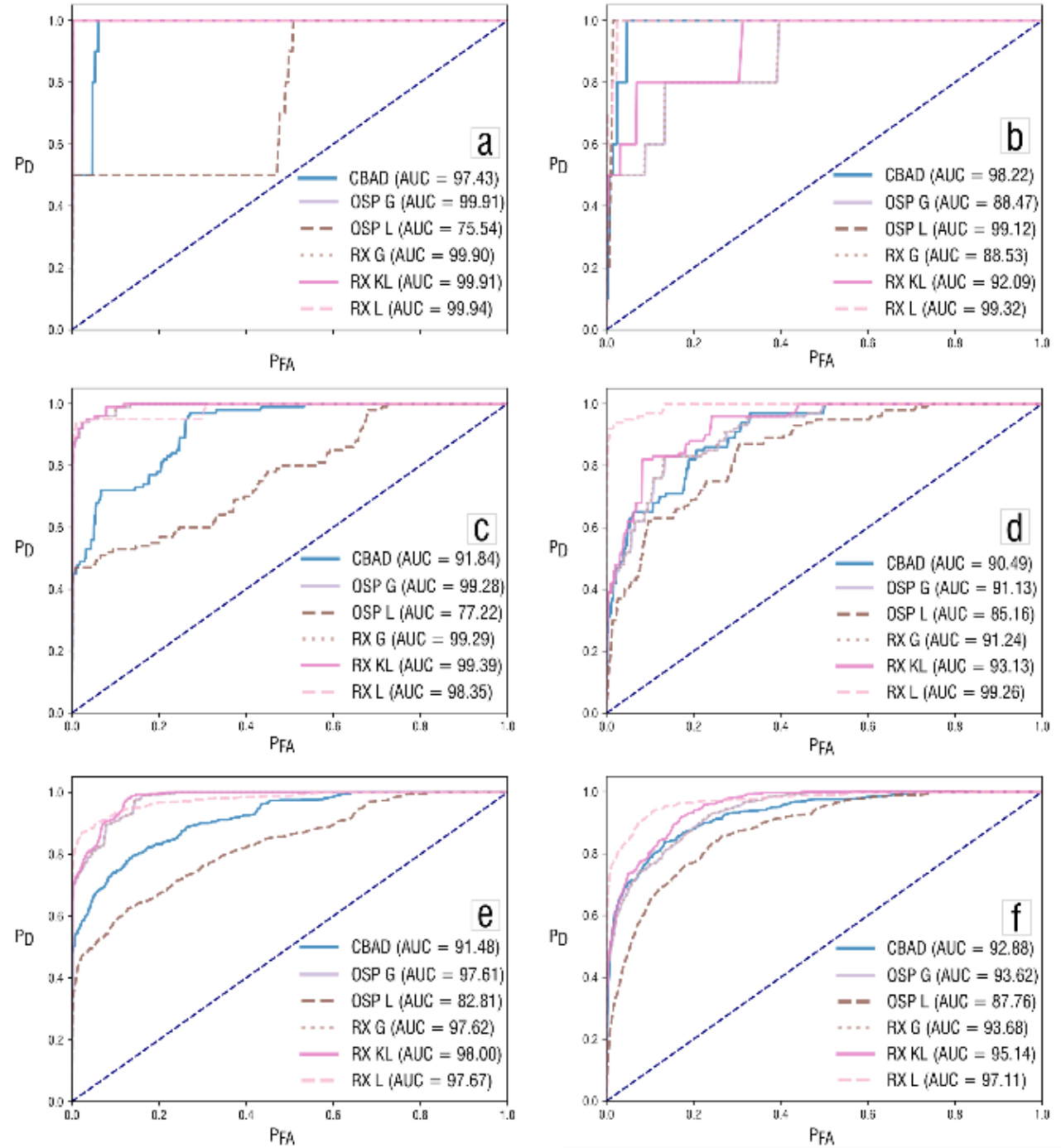
Among tested ADs on hyperspectral dataset RX QL achieved the highest AUC of 99.74, followed by RX G with 99.06 and CBAD with 98.53.

Experimental ROC curves and AUC values of all implemented ADs on the hyperspectral image. The left column represents scenarios with landminines: (a) 0.001%, (c) 0.01%, and (e) 0.1%. The right column represents scenarios with UXOs: (b) 0.001%, (d) 0.01%, and (f) 0.1%



# RESULTS ON MULTISPECTRAL DATASET

For multispectral dataset, local RX detector showed the highest average AUC value of 98.61, followed by RX QL with 96.28, RX G 95.04 and OSP G with 95.00.



Experimental ROC curves and AUC values of all implemented ADs on the multispectral image. The left column represents scenarios with landmines: (a) 0.001%, (c) 0.01%, and (e) 0.1%. The right column represents scenarios with UXOs: (b) 0.001%, (d) 0.01%, and (f) 0.1%

# RESULTS

The lowest AD performance was noted for OSP L in scenario with 0.001% landmines on hyperspectral dataset, while the single highest AUC score achieved RX L in the same scenario but on multispectral dataset.

ADs showed slightly higher performance on multispectral (93.88) than on hyperspectral (92.38) test scenarios.

Regarding target type, in landmine scenarios AUC score of 93.15 was achieved, with 1 percent higher result of 94.15 was exhibited in UXO scenarios.



# CONCLUSION AND FUTURE STEPS

This paper evaluated six common anomaly detection methods on hyperspectral and multispectral test dataset created by synthetically simulating landmine and UXO targets.

Achieved average AUC scores higher than 95 for selected ADs indicate potential for application in humanitarian demining.

However, as the performance was evaluated on synthetic dataset, additional tests must be conducted in more realistic and demanding conditions.

- **Therefore, a project proposal is currently submitted to Croatian Science Foundation call for proposals to develop, test and validate methods in relevant scenarios.**

Furthermore, perspective ADs should be developed to work in online mode to support real-time on-flight processing and successful detection of explosive ordnances.



22<sup>nd</sup> Mine Action Symposium  
25 March 2026, Split, Croatia



Ivan Racetin, [ivan.racetin@gradst.hr](mailto:ivan.racetin@gradst.hr),  
Andrija Krtalić, [andrija.krtalic@geof.unizg.hr](mailto:andrija.krtalic@geof.unizg.hr)

