Accelerated Extinction Profiles for Anomaly Detection in Fluvial Ecosystems

Javier López-Fandiño[1], Dora B. Heras[1], and Francisco Argüello[2]

[1]Centro Singular de Investigación en Tecnoloxías Intelixentes (CiTIUS)

[2]Departamento de Electrónica e Computación.

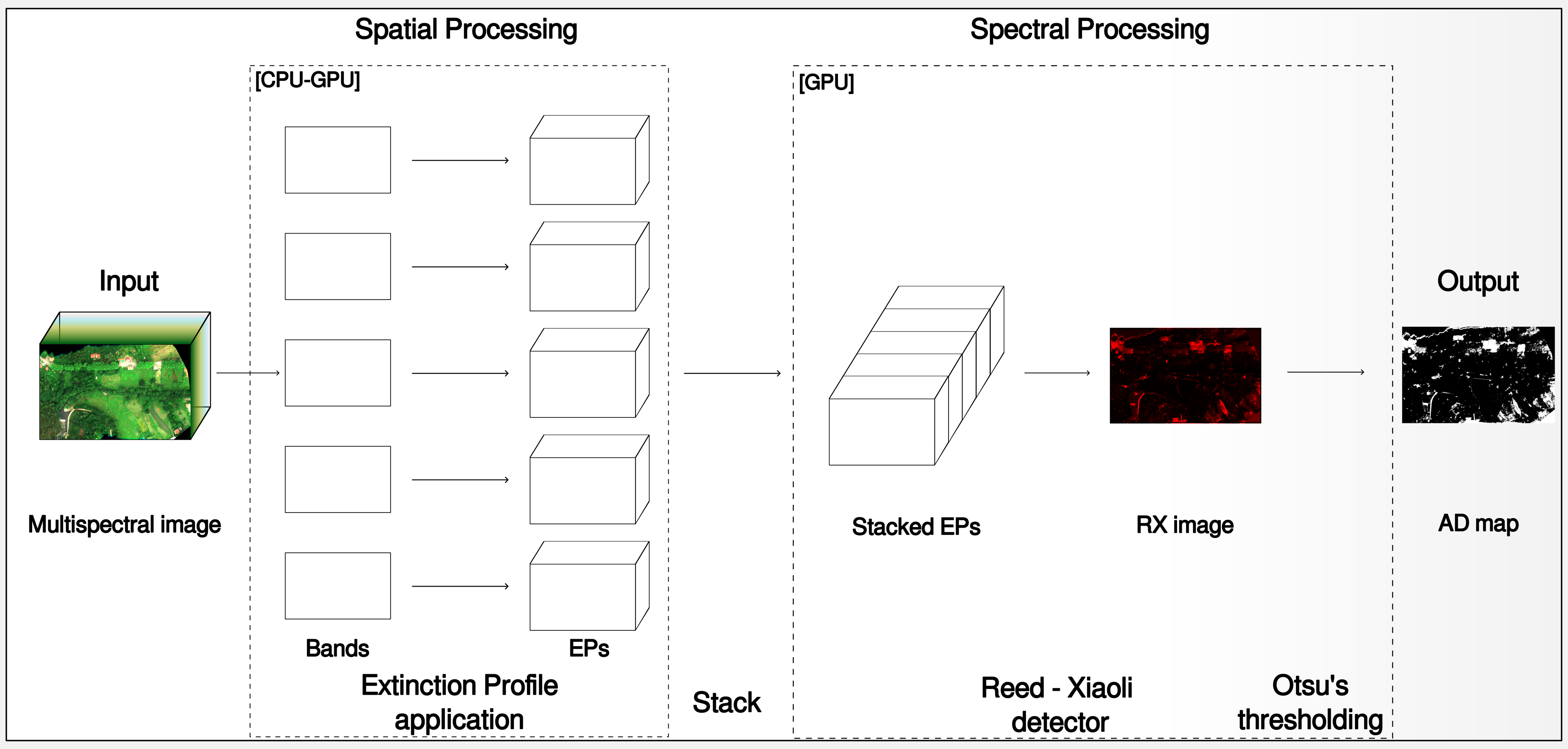
Universidade de Santiago de Compostela

23th International Conference Computational and Mathematical Methods in Science and Engineering

2023 CMMSE

New multispectral sensors, which are capable of capturing high resolution images through low altitude drone flights, offer access to a wealth of information about the Earth's surface at a significantly lower cost than other imaging devices. The process of identifying unexpected patterns within an image that do not conform to the expected behavior is known as anomaly detection (AD). When applied to fluvial ecosystem monitoring, this involves detecting the existence of small constructions or roads that allow automatic alarms to be produced for the people in charge of monitoring the ecosystem. The extraction of spatial information is a critical step in AD, since it determines the final quality of the AD and it is a computationally expensive processing. In this work, Extinction Profiles (EP) are selected to perform a multilevel implicit segmentation of the image, thus extracting the spatial information of relevance. A computationally efficient implementation of the EP-based spatial extraction of information for multidimensional images is proposed in this paper, as it is a basic step in the detection of anomalies in natural ecosystems. The proposed method takes advantage of heterogeneous computing to perform the task in a reduced execution time.

Anomaly Detection Scheme



EP Algorithm:

Input: Image band.
Output: EP of band.
Parameters: Nº of extrema to be kept at each level of EP.

Opening

- Max-tree computation:
  - Reorder image and indexes. < GPU >
  - Get parents of each node (union-find). < CPU >
  - Compute node array. < CPU >
- Compute extinction values. < CPU - GPU >
- For each level in EP: < OpenMP >
  - Calculate extinction filter. < CPU - GPU >
  - Get filtered image. < GPU >

Negate image < GPU >

Closing

- Max-tree computation:
  - Reorder image and indexes. < GPU >
  - Get parents of each node (union-find). < CPU >
  - Compute node array. < CPU >
- Compute extinction values. < CPU - GPU >
- For each level in EP: < OpenMP >
  - Calculate extinction filter. < CPU - GPU >
  - Get filtered image. < GPU >

RX Algorithm:

Input: Stacked EPs.
Output: RX Image.

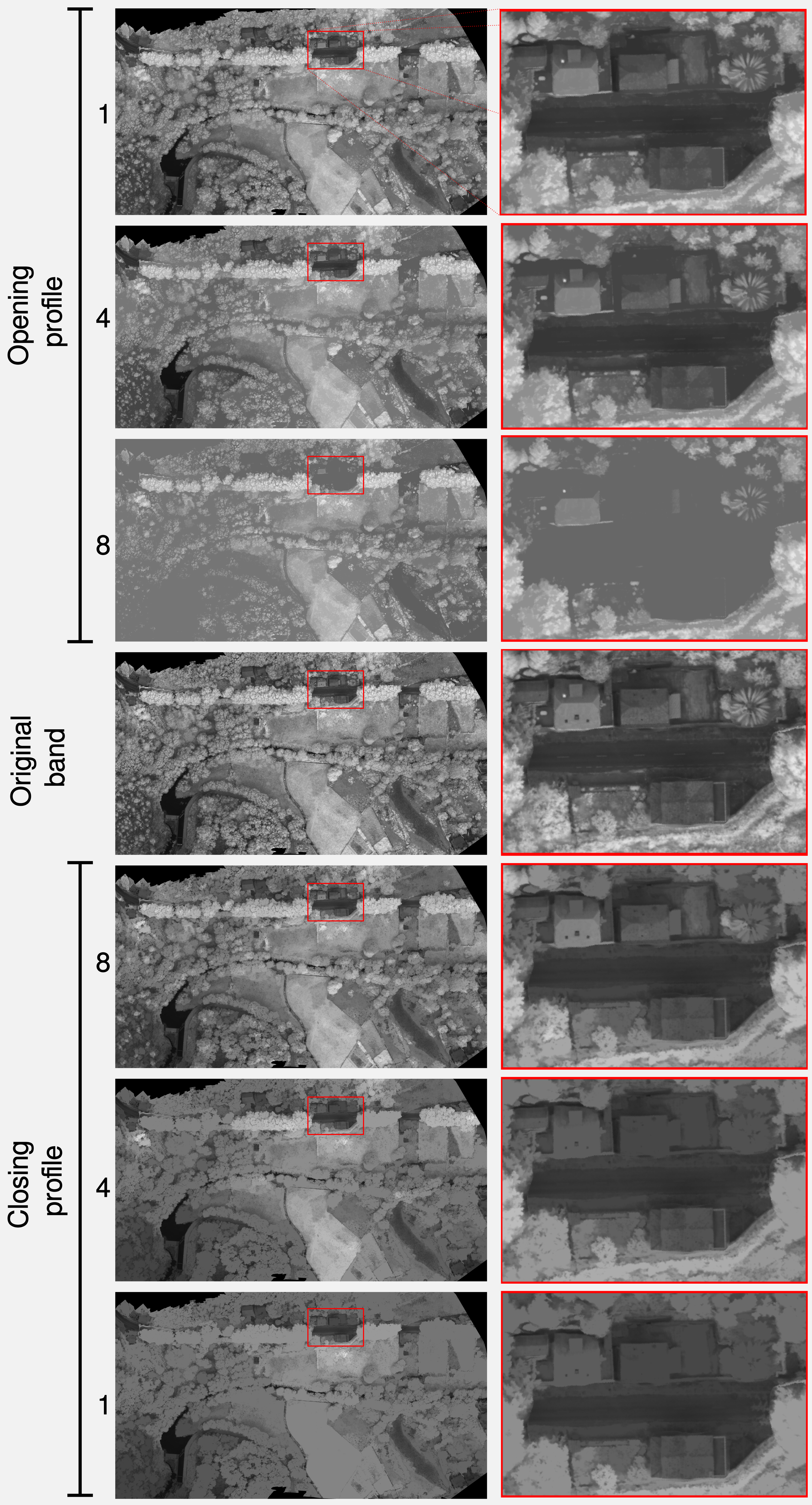
- Compute mean vector. < GPU >
- Compute covariance matrix. < GPU >
- Invert covariance matrix. < GPU >
- Compute Mahalanobis distance. < GPU >

Otsu's thesholding Algorithm:

Input: RX image.
Output: AD map.

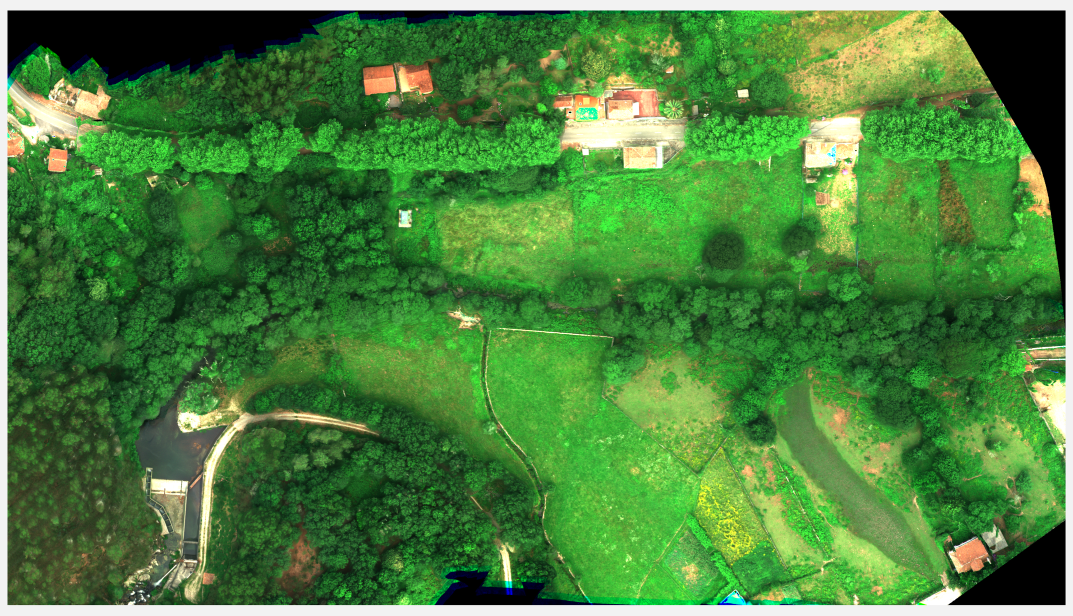
- Rescale image between [0, 255]. < GPU >
- Compute image histogram. < GPU >
- Calculate threshold value by Otsu's method. < GPU >
- Generate binary image regarding the threshold. < GPU >

Extinction Profile of one band



Extinction filter at different levels — Detail of anomalies

Oitavén River Dataset



RGB color composition

Reference data of anomalies

Dataset description

- Spatial dimensionality: 2141 x 3807
- Spectral dimensionality: 5 bands
- Reference data pixel distribution:
  - Number of anomalies: 321710
  - Number of non anomalies: 7829077
  - Percentage of anomalies: 3.95 %
  - Percentage of non anomalies: 96.05 %

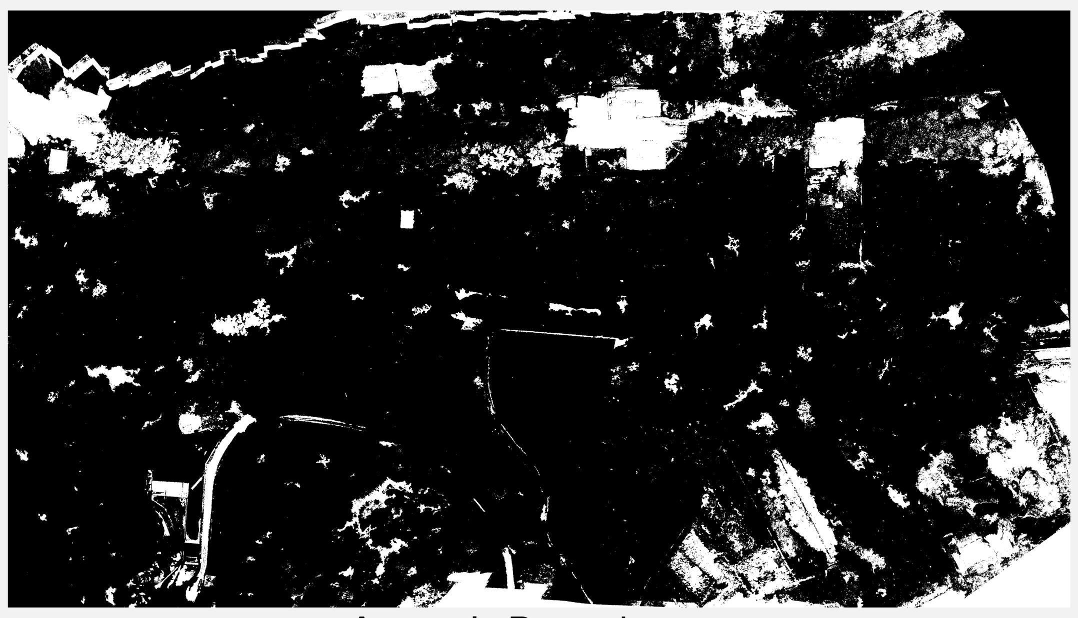
Sensor information

- Sensor: MicaSense RedEdge multispectral camera mounted on a custom UAV.
- Spatial resolution: 8.2 cm/pixel.
- Height: 120 meters

Spectral bands

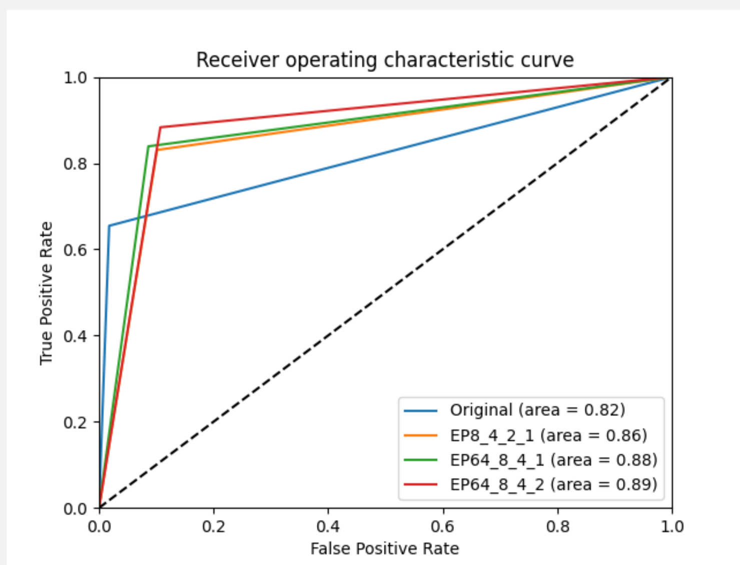
- 475 nm (Blue)
- 560 nm (Green)
- 668 nm (Red)
- 717 nm (Edge)
- 840 nm (NIR)

Accuracy and Performance Results



Anomaly Detection map

ROC curve



Accuracy results

EP Configuration	AUC	% of anomalies detected
No EP	0.818	65.46
EP_8_4_2_1	0.865	83.06
EP_64_8_4_1	0.876	83.90
EP_64_8_4_2	0.888	88.32

Experimental setup

- 12th Gen Intel(R) Core(TM) i7-12700K
  8 performance cores 3.6 GHz, 4 efficient cores. 2.7GHz. 25 MB cache. 64 GB DDR4 RAM. 125-190 W.
- NVIDIA GeForce RTX 3080
  8960 CUDA cores. 1.26 GHz. 12 GB GDDR6X RAM. 350W.

EP of one band execution times

Computation step:	OpenMP	OpenMP + CUDA	Speedup
Opening			
- Max-tree computation:			
- Reorder image and indexes.	0.0852	0.0157	5.4x
- Get parents of each node (union-find).	0.4447	0.3962	1.1x
- Compute node array.	0.1199	0.1177	1.0x
- Compute extinction values.	0.0141	0.0109	1.3x
- EP application at all levels.	0.1937	0.0365	5.3x
Negate image	0.0481	0.0002	235.7x
Closing			
- Max-tree computation:			
- Reorder image and indexes.	0.0826	0.0159	5.2x
- Get parents of each node (union-find).	0.3953	0.3886	1.0x
- Compute node array.	0.1081	0.1054	1.0x
- Compute extinction values.	0.0065	0.0054	1.2x
- EP application at all levels.	0.1875	0.0294	6.4x
Total	1.6858	1.1217	1.5x

Execution times in seconds with gcc compiler O3 optimization level activated.

AD execution times

Computation step:	OpenMP	OpenMP + CUDA	Speedup
EP of all bands	8.4288	5.6087	1.5x
RX detector	16.8466	1.1856	14.2x
Otsu's thresholding	0.0055	0.0046	1.2x
Total	25.2809	6.7989	3.7x

Execution times in seconds with gcc compiler O3 optimization level activated.

References

- Ghamisi, P., Souza, R., Rittner, L., Benediktsson, J. A., Lotufo, R., & Zhu, X. X. (2016, July). Extinction profiles: A novel approach for the analysis of remote sensing data. In 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS) (pp. 5122-5125). IEEE.
- Reed, I. S., & Yu, X. (1990). Adaptive multiple-band CFAR detection of an optical pattern with unknown spectral distribution. IEEE transactions on acoustics, speech, and signal processing, 38(10), 1760-1770.
- Ghamisi, P., Souza, R., Benediktsson, J. A., Zhu, X. X., Rittner, L., & Lotufo, R. A. (2016). Extinction profiles for the classification of remote sensing data. IEEE Transactions on Geoscience and Remote Sensing, 54(10), 5631-5645.

Conclusions

- An OpenMP + CUDA computationally efficient implementation of the EP-based spatial extraction of information for multidimensional images is proposed.
- Thrust library is used in both implementations to speed up sorting operations.
- EPs are combined with the Reed-Xiaoli anomaly detection algorithm to improve the detection of anomalies in fluvial ecosystems.
- The proposed method takes advantage of heterogeneous computing to perform the task in a reduced execution time.
- Experiments were performed over high-dimensionality images of fluvial ecosystems, achieving speedups up to 3.7x.