Using convolutional neural networks to classify UXO with multicomponent electromagnetic induction data

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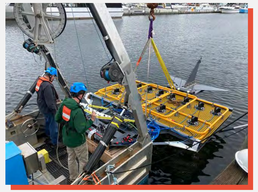
Black Tusk GEOPHYSICS

Project background

- Modern time-domain electromagnetic systems are used to detect and classify UXO in a single pass in marine environments.

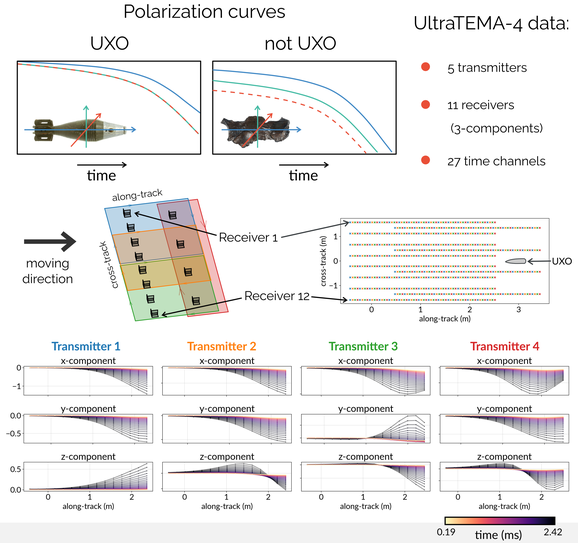


UltraTEMA-4 (marine)

Objective:

- Develop a convolutional neural network for detection and classification of UXOs directly from electromagnetic data.

Electromagnetic data



UltraTEMA-4 data:

- 5 transmitters
- 11 receivers (3-components)
- 27 time channels

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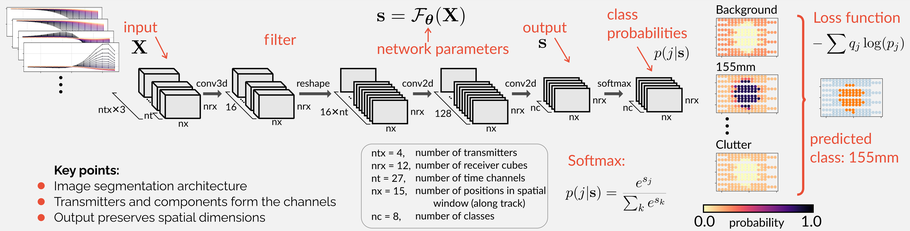
UXO classification
- Standard approach: invert polarizabilities and compare with UXO library
- Our approach: directly classify from EM data using neural networks

Architecture of Convolutional Neural Networks



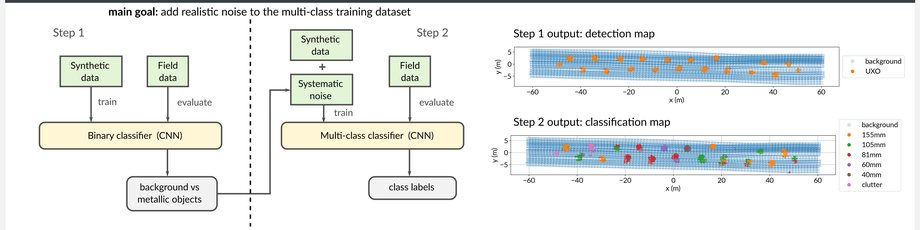
Key points:
- Image segmentation architecture
- Transmitters and components form the channels
- Output preserves spatial dimensions

ntx = 4, number of transmitters
nrx = 12, number of receiver cubes
nt = 27, number of time channels
nx = 15, number of positions in spatial window (along track)
nc = 8, number of classes

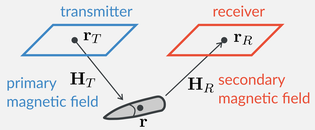
Softmax:

$$p(j|\mathbf{s}) = \frac{e^{s_j}}{\sum_k e^{s_k}}$$

Two step workflow: detection + classification



Generating training dataset



Approximate physics model

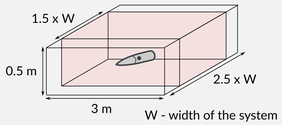
$$d(\mathbf{r}_R, t) = \mathbf{H}_R(\mathbf{r}, \mathbf{r}_R) \cdot \mathbf{P}(t) \cdot \mathbf{H}_T(\mathbf{r}, \mathbf{r}_T)$$

$$\mathbf{P}(t) = \mathbf{A}(\phi, \theta, \psi) \cdot \mathbf{L}(t) \cdot \mathbf{A}^\top(\phi, \theta, \psi) \qquad \mathbf{L}(t) = \begin{pmatrix} L_1 & & \\ & L_2 & \\ & & L_3 \end{pmatrix}$$

Target classes:
- Background
- Small ISO
- Medium ISO
- Large ISO
- Clutter (20 mm, spherical objects)

Number of samples:
- Training: 20k (detection)
- Training: 400k (multi-class)
- Validation: 10k

For each realization, randomly set:
- Target class (L_1, L_2, L_3)
- Location (x, y, z)
- Orientation (ϕ, θ, ψ)
- Noise (system signature)



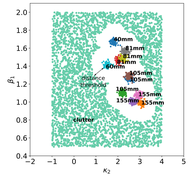
Clutter design

Physics-based parameterization of EM decay:

$$L(t) = kt^{-\beta} \exp(-t/\gamma)$$

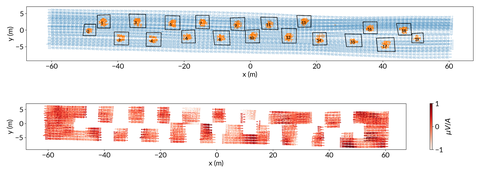
9 parameters in total:

1. Estimate values for UXOs in ordnance library
2. Define a distance threshold
3. Fill the remaining space with clutter objects

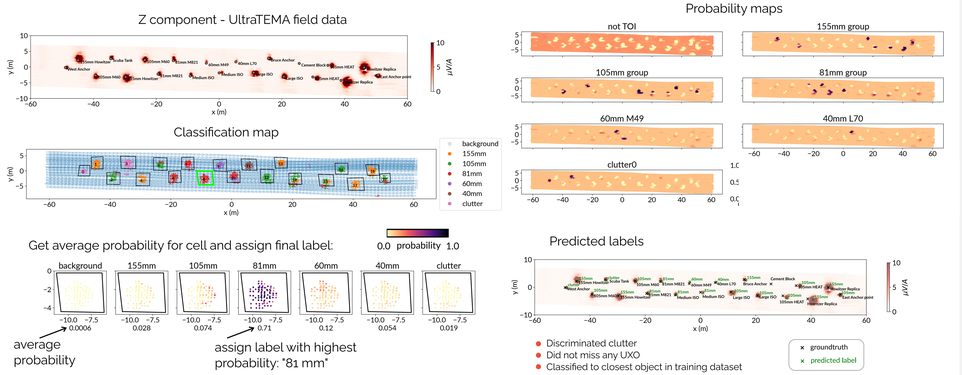


Realistic noise

Adding spatially correlated noise:



Calibration line classification results (Sequim Bay site)



Conclusions

- A CNN with image segmentation architecture was successfully used to classify UXOs from marine EM data.
- Synthetic noise and clutter design are important for good classification.

Future work

- Try
  - Different seawater/sediments EM response removal
  - Training with synthetic modeling of seawater/sediments EM response
- Explore multi-target scenario (two or more objects in a spatial window)