Detection of Unknown Ship Radars

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In collaboration with: RAFAEL
Background

- Many ships transmit radar signal as they sail across ports.
- Ships identification ability is important.
Radar

• A detection system which uses radio waves for:
  – Navigation
  – Tracking Objects & Threats

• Each radar transmitter has its own special characteristics:
  – Frequency & Pulse Width
  – Non-linear effects
Open World Recognition

Desirable Solution

Open World

Traditional solution

Closed World

[Geng et al., 2020]
Open World Recognition – Applications

• A challenging open task in Machine Learning

Computer Vision  Natural Language Processing
Quality Measures

– False positive (FP) = known ship labeled as unknown
– True positive (TP) = unknown ship labeled as unknown

Low FP is more important than high TP
Project Goal

Online recognition of known and unknown ships

A few days later
Dataset

- 500,000 radar signals from 76 ships (classes)
- Real data received from Rafael

Ship 1

Ship 2
Prior Work

- **Classification** using deep learning (ResNet-18)
  - Net inputs – Spectrograms
  - 89.8% accuracy

- **Rejection** algorithm based on Deep Open Classification (DOC):
  - TP = 66%, FP = 35%

Not a full Open-World solution

[Shu et al., 2017]

[Fridchay & Kadar, SIPL Project 2020]
Proposed Solution

- **Classification** of known ships
- **Rejection** of unknown ships
- **Open-world recognition and learning** of unknown ships
Closed World Classification

- Data
  - Pre-processing
  - Neural Network
  - Known/Unknown Classifier
    - Clustering
      - Known Class Label
      - Unknown Class Label
Pre-processing – Bispectrum

- $2^{nd}$ order autocorrelation of the DFT
- Emphasizes $2^{nd}$ order non-linear properties

- Example applications:
  - Distinguishing between musical instruments
  - EEG signals monitoring

[Chen et al., 2008]
Pre-processing – Bispectrum

\[ B(k_1, k_2) = X^f(k_1)X^f(k_2)X^f(k_1 + k_2) \]
Dimensionality Reduction

- $K_1, K_2$ plane reduced to one dimension

Single Interval Bispectrum

[Hao et al., 2020]
Network Inputs

Merged 4 channels: Spectrogram + Bispectrum
Datasets – Closed World

• **Dataset #1** – ‘Standard’
  - 40 training classes

• **Dataset #2** – ‘Hard-To-Separate’
  - 10 training classes
  - Classes share same classic features
## Results – Closed World

<table>
<thead>
<tr>
<th>Input Type</th>
<th>Standard Dataset</th>
<th>Hard-to-Separate Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrogram</td>
<td>89.8%</td>
<td>72.9%</td>
</tr>
<tr>
<td>Bispectrum + Spectrogram</td>
<td>90.1%</td>
<td>75.5%</td>
</tr>
</tbody>
</table>
Rejection Algorithm

Data → Pre-processing → Neural Network → Known/Unknown Classifier

Known Class Label → Clustering → Unknown Class Label
Rejection – Proposed Solution

• Previous project (DOC) algorithm:
  – Set reject threshold for each class **separately**

• **Our solution’s main idea:**
  – Use all neural network output **combined**
  – **Anomaly detection** to recognize unknown ships
Anomaly Detection – Based on k-NN

- For each training sample: Calculate mean distance from k-nearest neighbors

- **Threshold** = top X% of mean distances

[Daniel, Goldberg & Klein, 2021]
Anomaly Detection – Based on k-NN

• For each **test set sample**: Calculate mean distance from k-neighbors from the **train set**

\[
\text{mean dist} > \text{threshold} \Rightarrow \text{Unknown, Else} \Rightarrow \text{Known}
\]
Rejection – Results and Conclusions

• Significantly improved results compared to DOC
• Controllable FP rate
Open World Recognition

Data → Pre-processing → Neural Network → Known/Unknown Classifier → Clustering → Known Class Label

Clustering → Unknown Class Label
Open World Recognition

- **Main idea:**
  Use neural network output vector to cluster unknown samples
Number of Clusters

Used 3 techniques for determining the number of clusters:

- Elbow Method
- Silhouette Analysis
- Davies-Bouldin index

- Choose $k$ by majority vote
Results - Realistic Simulation

Data → Pre-processing → Neural Network → Known/Unknown Classifier → Clustering → Known Class Label → Unknown Class Label
Realistic Simulation – Assumptions

• Radar receiver is **directional**
• We **continuously** receive signals from **the same ship**
• Batch size = 100 samples
• Batch is unknown if: \( \#\text{rejected samples} > \text{const}(= 65) \)
Realistic Simulation – Stage 1

Known Class #1

Successful known detection:

Rejected Data:

- **Mean distances - Known Class**
  - 10% of samples are within a certain range of mean distances.

- **Mean distances - Trained Classes**
  - Distribution of mean distances for trained classes.
Realistic Simulation – Stage 2

Unknown Class #1

Successful unknown detection: Successful clustering (1 class):

![Histogram of Mean Distances - Unknown Class](image1)

![Histogram of Mean Distances - Trained Classes](image2)
Realistic Simulation – Stage 3

Unknown Class #1

Successful unknown detection: 10%

Successful clustering (1 class):
Realistic Simulation – Stage 4

Unknown Class #2

Successful unknown detection: 10%

Successful clustering (2 classes):
Realistic Simulation – Stage 5

Unknown Class #3

Successful unknown detection: 10%

Successful clustering (3 classes):
Realistic Simulation – Stage 6

Unknown Class #4

Successful unknown detection: 10%

Successful clustering (4 classes):
Realistic Simulation – Stage 7

Known Class #2

Successful known detection: Successful clustering (4 classes):
Conclusion

- **Improved** Closed World Classification
- **New and better** Rejection using anomaly detection
- **Novel** Online Learning based on clustering

- **Open-world** recognition for ship radar data
  - Generic solution, suitable for many applications
Thanks!

Yair Moshe  Nimrod Peleg  Ori Bryt

Questions?
References


