Deinterleaving RADAR Pulses

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Overview

- Administrative
  - 3rd year thesis
  - Full time at the L2S
- Communication
  - Publication of a Conference paper: “Deinterleaving and Clustering unknown RADAR pulses” - Manon Mottier; Gilles Chardon; Frédéric Pascal
  - International Conference: IEEE RadarConf 2021, Atlanta, GA, USA
  - International Seminar: Atos Scientific Community

Content

Data description

- Work from simulated labeled data
- Each dataset is composed of RADAR pulses, described by only 4 features:
  - Frequency (F)
  - Pulse Width (PW)
  - Level (L)
  - Time of Arrival (TOA)

Data description

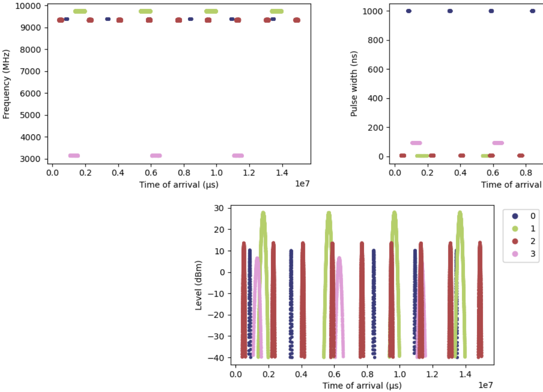


Figure: Example of a **simple** signal containing 4 RADARs.

Methodology

1. **RADAR pulses deinterlacing:**
   - **Clustering**: Cluster each observation of this signal under the constraint of not merging different radars in one cluster
   - **Cluster fusion**: Hierarchical agglomerative clustering combined with optimal transport distances

2. **RADAR Identification**: Extraction of group characteristics and comparisons to a reference database to identify the transmitter

Deinterlacing RADAR pulses

Clustering with HDBSCAN

Methodology:

- Application of clustering algorithm on two features: Frequency and Pulse Width
- Why HDBSCAN ?
  - Unsupervised algorithm that allows us to search for clusters of varying densities
  - Few parameters to optimize
- Over-estimation of the number of clusters
  - Allows to receive RADARs that do not transmit continuously
  - Each cluster must not contain the observations of different RADARs

Deinterlacing RADAR pulses

Output of HDBSCAN

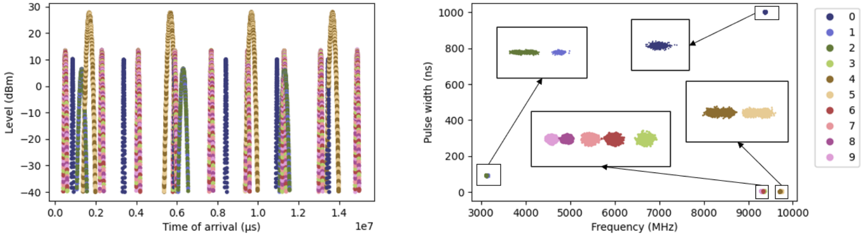


Figure: HDBSCAN Output. Colors represent the different clusters.

Deinterlacing RADAR pulses

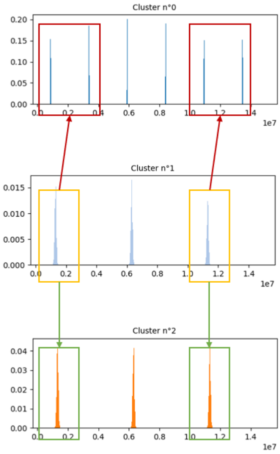
Cluster fusion

Methodology:

1. Dimensionality reduction: each cluster is represented by a histogram of its TOA and LEVEL
2. Compute distances between cluster histograms using optimal transport
3. Aggregation of the 2 closest clusters i.e., the 2 clusters with the lowest transport costs
4. Computation of new costs between old clusters and the new ones
5. Repeat steps 2 to 4 until a single cluster is obtained

Deinterlacing RADAR pulses

Histograms



Deinterlacing RADAR pulses

Optimal Transport explanation

- Transporting distribution to another has a cost:

$$C(\mathbf{P}) = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{nm} P_{nm} = \langle \mathbf{C}, \mathbf{P} \rangle \tag{1}$$

$C(\mathbf{P})$ = Total cost

C_{nm} = cost transporting unit mass from x_n to y_m (transport cost)

P_{nm} =quantity of mass taken from x_n to y_m (transport plan)

- The optimal transport plan is a simple minimization problem:

$$\mathbf{P}^{\star} = \underset{\mathbf{P} \in \mathbf{R}_{+}^{N \times M}}{\operatorname{argmin}} \langle \mathbf{C}, \mathbf{P} \rangle \text{ such that } \mathbf{P1}_M = \mathbf{a}, \mathbf{P}^T \mathbf{1}_N = \mathbf{b}^T. \tag{2}$$

Deinterlacing RADAR pulses

Dendrogram

- Decision model based on several unsupervised metrics to cut the dendrogram:
  - Silhouette score
  - Calinski-Harabasz score
  - Davies-Bouldin score

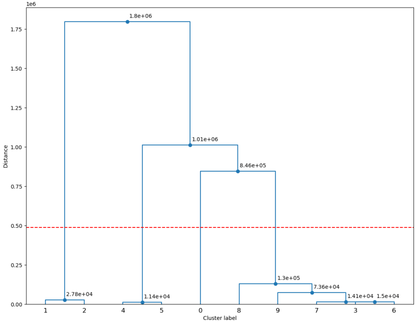
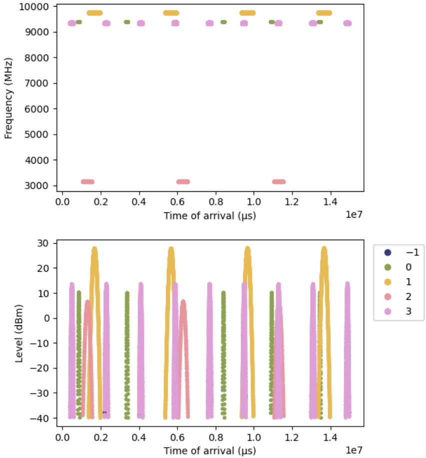


Figure: Cluster aggregations with Optimal Transport Distances.

Deinterlacing RADAR pulses

Final Grouping

- Perfect grouping
- Statistics:
  - Homogeneity $= 1$
  - Completeness $= 1$
  - Unclassified rate $= 2\%$



RADAR Identification

Waveform analysis

Methodology:

1. Construction of a measure that describes each RADAR belonging to a reference database based on its frequencies and pulse width:

$$\mu_j = \sum_{n=1}^{N} \alpha_n \delta_{f_n, pw_n} \tag{3}$$

$N =$ the number of frequencies and pulse width on which the RADAR transmits
$\alpha =$ the weight of the frequency and pulse width
$\delta =$ dirac mass (with $\sum \alpha_n = 1$)

RADAR Identification

Definition domain of the waveforms

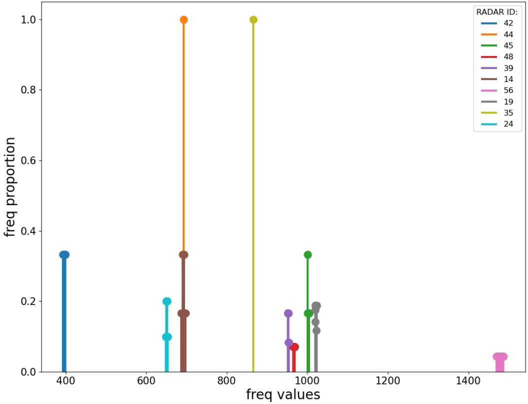


Figure: Referential Database representation withe some emitters from Frequency.

RADAR Identification

Definition domain of all waveforms

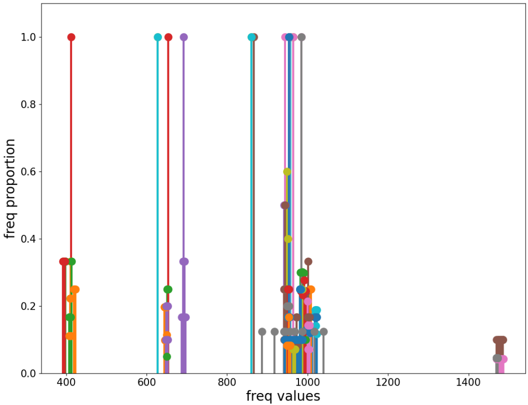


Figure: Referential Database representation with all emitters from Frequency.

RADAR Identification

Definition domain of all waveforms

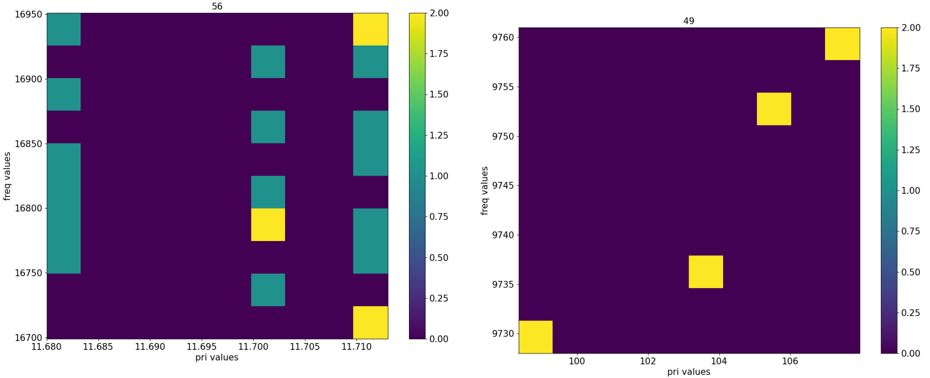


Figure: 2D histograms from PRI and Frequency.

RADAR Identification

Zoom on some waveforms

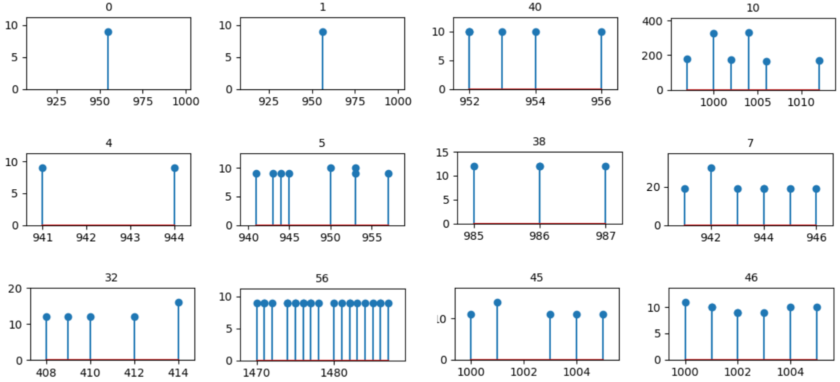


Figure: Zoom on some transmitters from Frequency.

RADAR Identification

Cost matrix between all waveforms

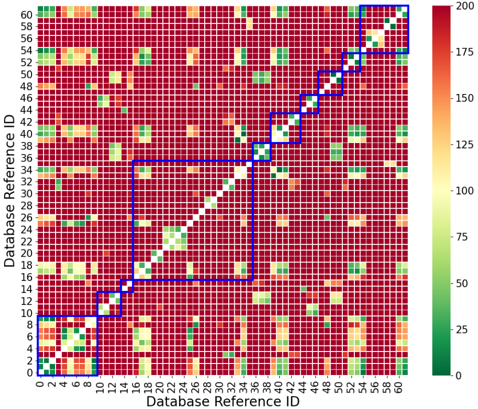


Figure: Cost matrix between the waveform built from Frequency and Pulse Width. Red indicates high transport cost and green indicates low transport cost. The blue shapes mark the different types of transmitters.

RADAR Identification

Cost matrix zoom

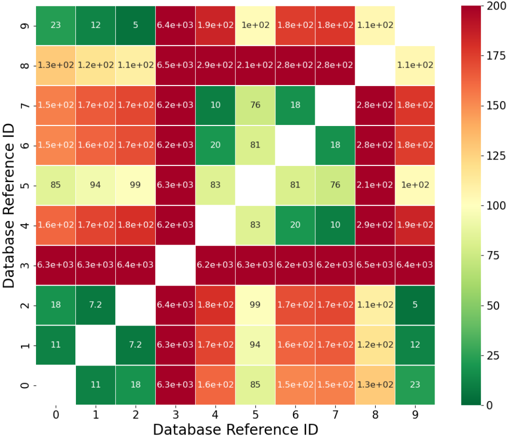


Figure: Cost matrix between one type of transmitter built from Frequency and Pulse Width. Red indicates high transport cost and green indicates low transport cost.

RADAR Identification

Cost matrix zoom

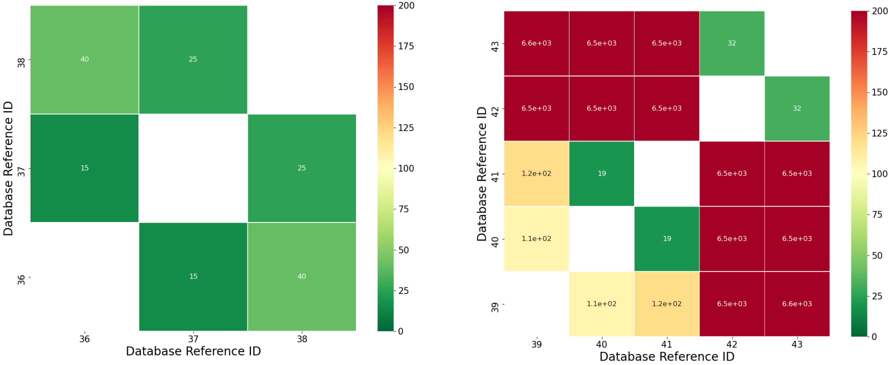


Figure: Cost matrix between one type of transmitter built from Frequency and Pulse Width. Red indicates high transport cost and green indicates low transport cost.

RADAR Identification

Groups analysis

2. Construction of a measure that describes each cluster from the frequency and the pulse width:

$$\gamma = \frac{1}{M} \sum_{m=1}^{M} \delta_{f_m, pw_m} \tag{4}$$

$M =$ the number of pulses in the cluster

3. Identification of the transmitter:

$$j^\star = \operatorname{argmin} d\left(\mu_j, \gamma\right) \tag{5}$$

RADAR Identification
Cost matrix

Figure: Cost matrix between groups and waveforms built from Frequency and Pulse Width. Red indicates high transport cost and green indicates low transport cost.

RADAR Identification

Classification Decision

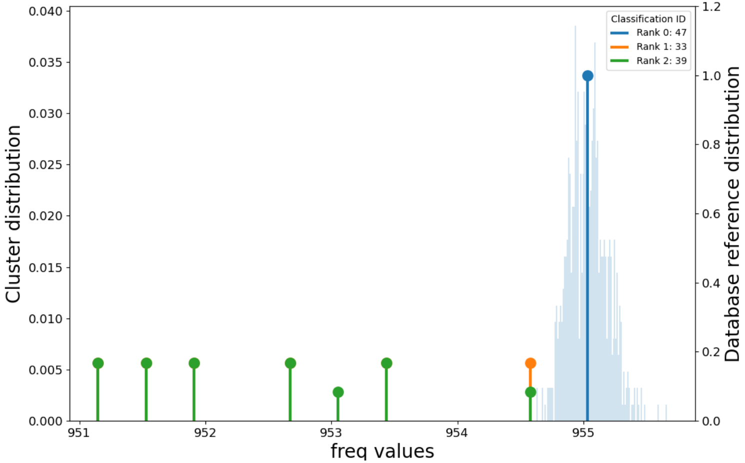
Clusters ID	Rank 1		Rank 2		Rank 3	
	ID	Cost	ID	Cost	ID	Cost
0	47	2.05	33	932.7	39	934.4
1	50	2.0	49	2.0	37	30.7
2	51	1.86	31	162.3	3	177.0
3	17	2.42	53	16.10	52	24.1

Table: Classification decision.

- Correct identification
- Problem with mono frequency RADAR
- Difficulty to identify sub-modes
- Frequency and Pulse width not sufficient

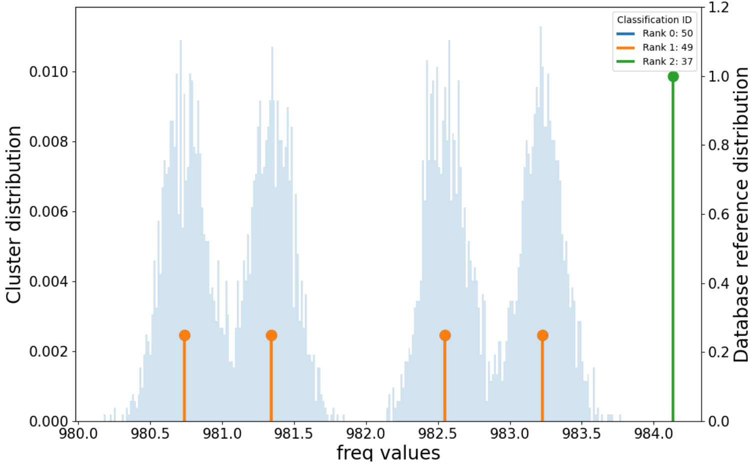
RADAR Identification

Classification Output: Group 0



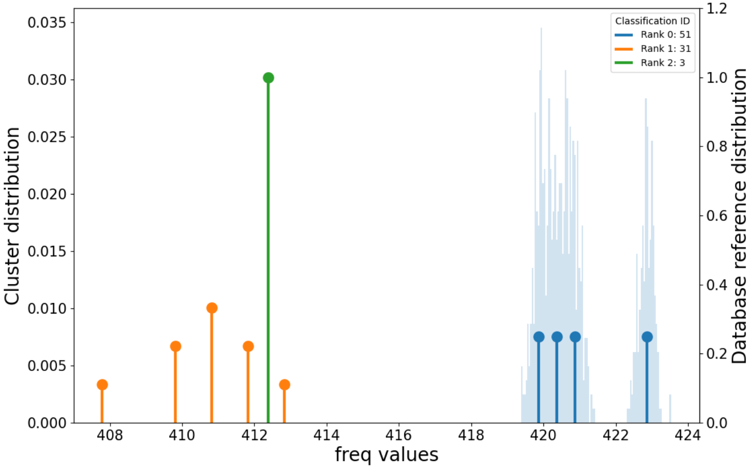
RADAR Identification

Classification Output: Group 1



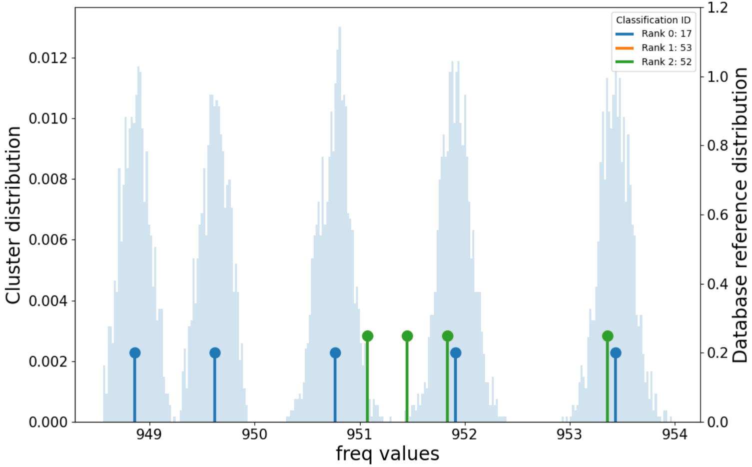
RADAR Identification

Classification Output: Group 2



RADAR Identification

Classification Output: Group 3



Content

Deinterlacing RADAR pulses

Unlabeled data

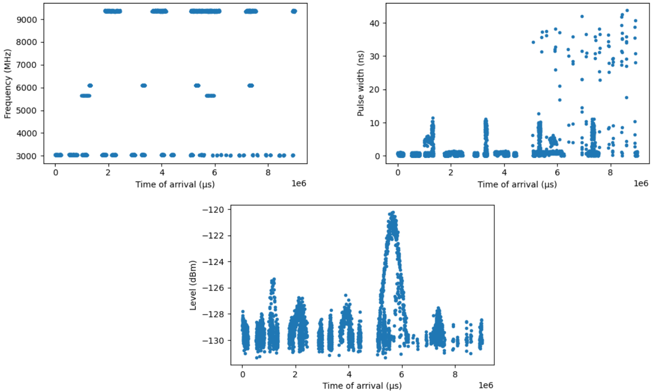


Figure: Unlabeled data with 5 RADARs.

Deinterlacing RADAR pulses

Clustering with HDBSCAN

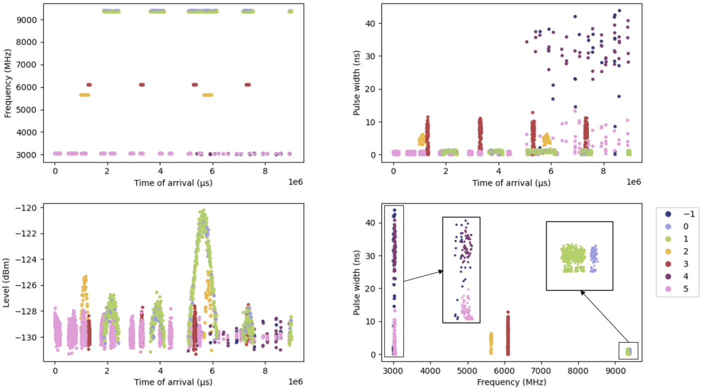


Figure: HDBSCAN Output. Colors represent the different clusters (including outliers' class).

Deinterlacing RADAR pulses

Histograms

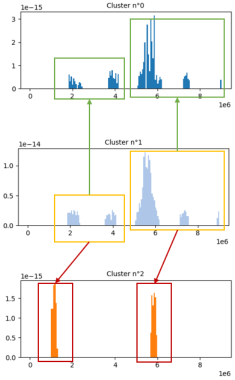
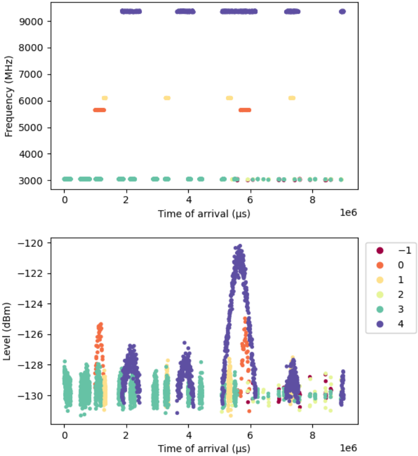


Figure: Histograms of the previous clusters.

Deinterlacing RADAR pulses

Final Grouping

- Pulses of the 2 transmitters around 3GHz are mixed
- Hdbscan can not differentiate them at step 1
- Statistics:
  - Homogeneity $= 0{,}94$
  - Completeness $= 1$
  - Unclassified rate $= 0{,}9\%$



RADAR Identification

Cost matrix

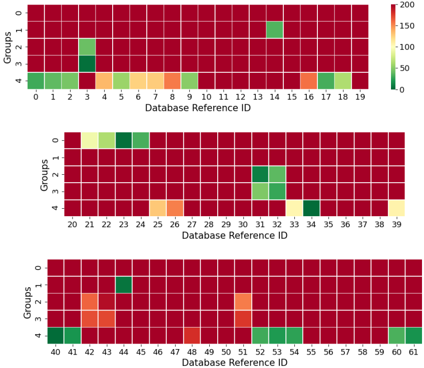


Figure: Cost matrix between groups and waveforms built from Frequency and Pulse Width. Red indicates high transport cost and green indicates low transport cost.

RADAR Identification

Classification Decision

Clusters	Rank 1		Rank 2		Rank 3	
	Id	Cost	Id	Cost	Id	Cost
0	23	3.29	24	32.3	22	63.4
1	44	5.5	14	34.7	23	458.4
2	31	10.6	32	38.2	3	42.0
3	3	3.06	32	27.6	31	47.7
4	40	2.3	34	2.3	61	18.5

Table: Classification results.

RADAR Identification

Classification Output: Group 0

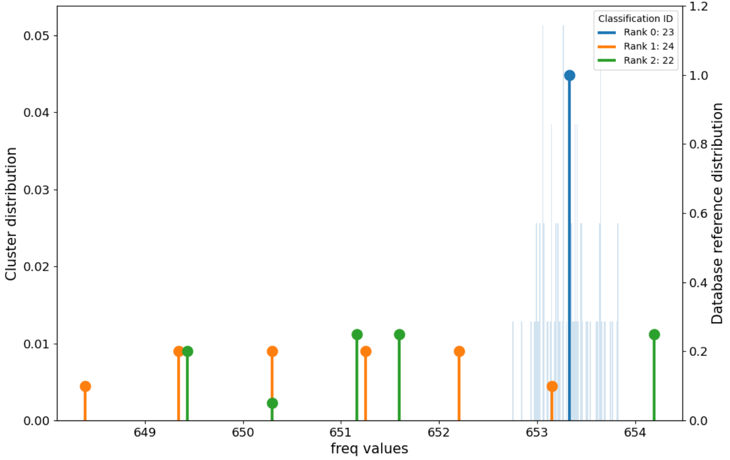


Figure: Freq representation from Group and waveforms.

RADAR Identification

Classification Output: Group 1

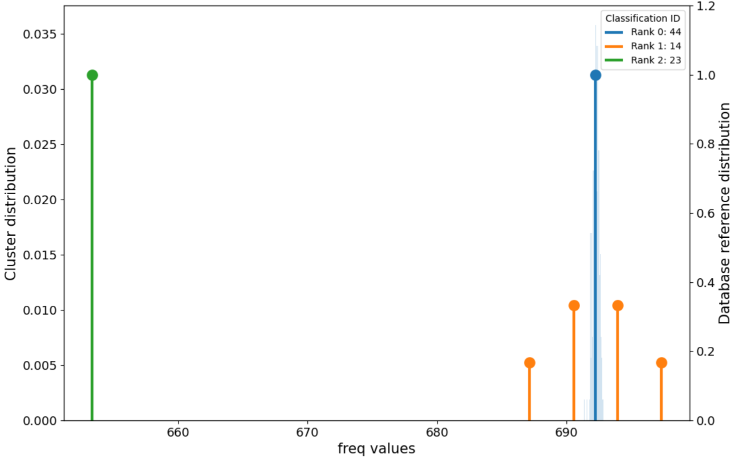


Figure: Freq representation from Group and waveforms.

RADAR Identification

Classification Output: Group 2

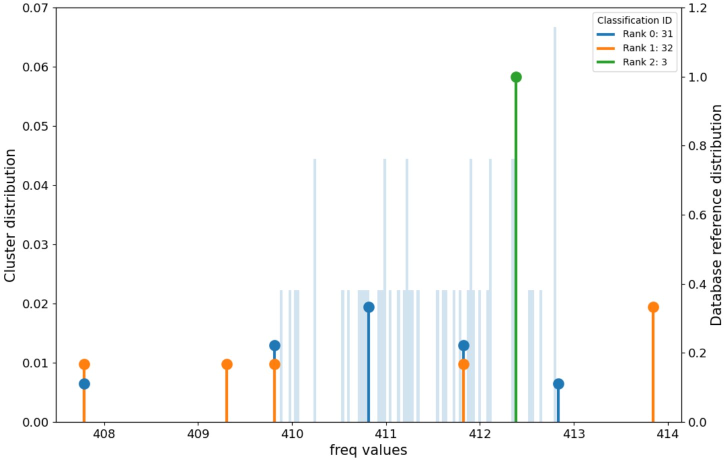


Figure: Freq representation from Group and waveforms.

RADAR Identification

Classification Output: Group 3

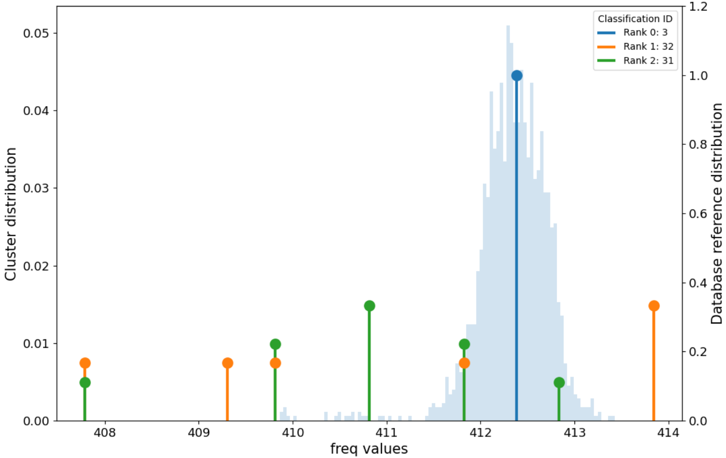


Figure: Freq representation from Group and waveforms.

RADAR Identification

Classification Output: Group 4

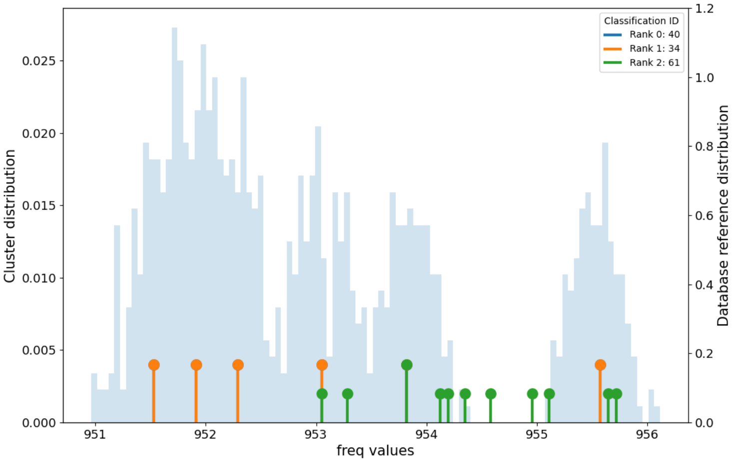


Figure: Freq representation from Group and waveforms.

Content

Discussion

- **Administrative**
  - Defense date
  - Scientific formation
- **Next publication/ communication**
  - EUSIPCO *(European Signal Procecssing Conference)*
    - Belgrade - 22 Aug / 2 Sep, 2022
    - Paper submission deadline: 20 Feb, 2022
  - GRETSI *(Colloque Francophone de Traitement du Signal et des Images)*
    - Nancy - 5 Sep / 9 Sep, 2022
    - Paper submission deadline: Feb, 2022
  - Article in a scientific journal
- **Methodology**

Thank you for your attention

For more information please contact:

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