RADAR Emitter Classification with Optimal Transport Distances

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Introduction

Identifying unknown RADAR emitters from received pulses is an important problem in electronic intelligence. It is a difficult problem, as agile RADAR emitters can have complex characteristics, and measurements are corrupted by various noises (non-Gaussian noise, missing pulses, etc.). We introduce a new classification method based on optimal transport distances between collected RADAR pulses and a priori known emitter classes.

Compared to previously proposed methods, this method does not require a training step, it can deal with a large number of classes, and it is easily interpretable. The method is tested on data obtained by a realistic RADAR scene simulator.

Emitter class description

Database with more than **60 classes** and described by 2 features:

- frequency (f_m)
- pulse width (w_m)

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

$$\mu_j = \sum_{m=1}^{M} \alpha_m \delta_{f_m, pw_m} \tag{1}$$

with M = the number of frequencies and pulse width on which the RADAR transmits, α = the weight of the frequency and pulse width, j = the index of the transmitter in the database, δ = dirac mass (with $\sum \alpha_m = 1$)

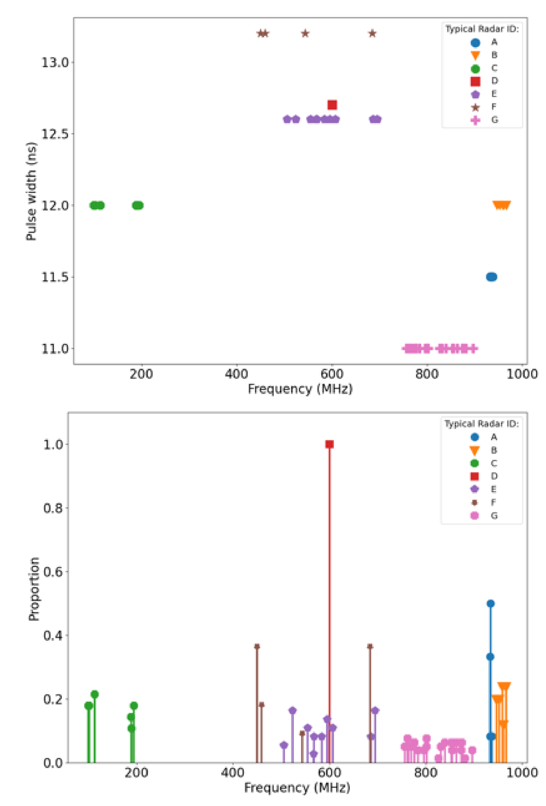

Figure 1: Representation of **simulated** RADARs classes in (f_m, w_m) and (f_m) planes. Each color represents a simulated emitter class.

RADAR pulses description

RADAR pulses are segmented, analyzed then described by 4 features:

- frequency (f_n)
- pulse width (w_n)
- level (g_n)
- time of arrival (t_n)

Model: Construction of a probability distribution from the set of pulses obtained by a previous deinterlacing method based on frequency and pulse width:

$$\nu = \frac{1}{N} \sum_{n=1}^{N} \delta_{f_n, pw_n} \tag{2}$$

with N the number of pulses in the set.

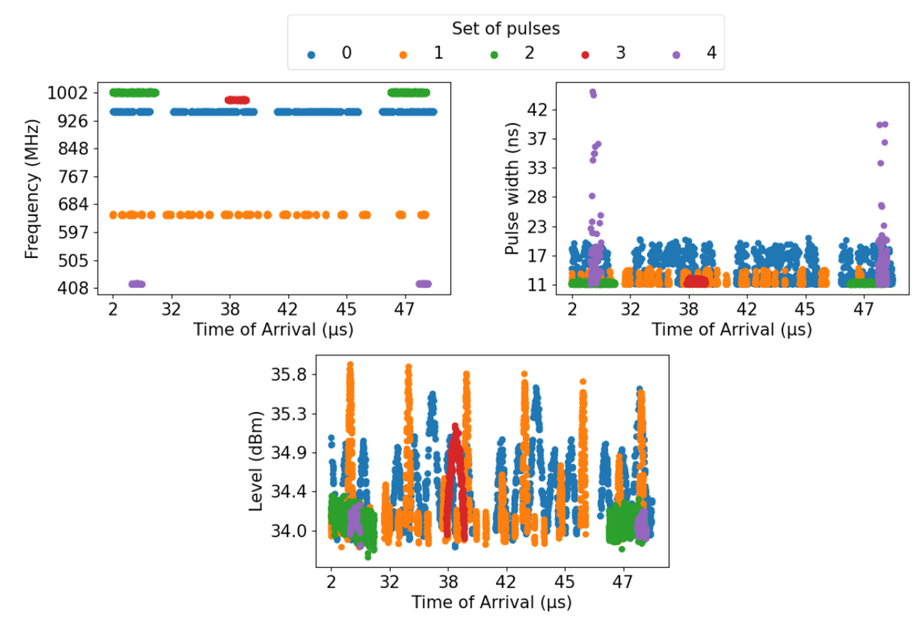

Figure 2: Sets of pulses contained five transmitters represented by a color.

Optimal Transport

Approach: Compare distributions of data and emitters classes to define a distance to quantify their similarity and dissimilarity:

- Data **correspond** to Emitter class 1
  - ✔ **Similar** distribution
  - ✔ **Low** transport cost
- Data **don't correspond** to Emitter class 2
  - ✘ **Different** distribution
  - ✘ **High** transport cost

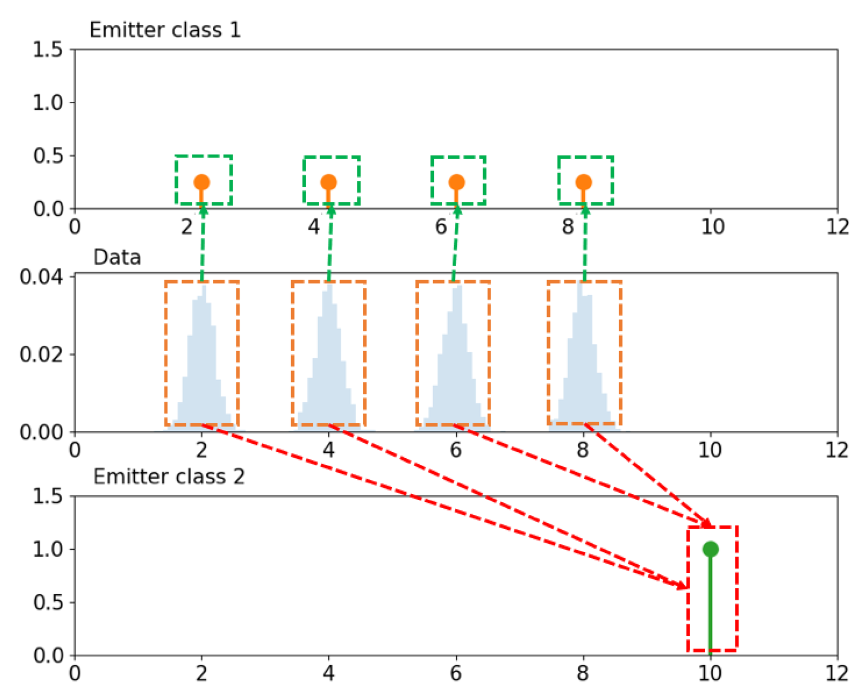

Figure 3: Comparison between a 1 dimensional data with two **simulated** emitters classes.

- Total cost $C(\mathbf{P})$ of a transport plan between two discrete probability distributions $\nu = \sum_{n=1}^{N} a_n \delta_{x_n}$ and $\mu = \sum_{m=1}^{M} b_m \delta_{y_m}$ is:

$$C(\mathbf{P}) = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{nm} P_{nm} = \langle \mathbf{C}, \mathbf{P} \rangle \tag{3}$$

with $\mathbf{a} = (a_1, \dots a_N)^T \in \mathbf{R}_+^N$, $\sum_{n=1}^{N} a_n = 1$, and $\mathbf{b} = (b_1, \dots b_M)^T \in \mathbf{R}_+^M$, $\sum_{m=1}^{M} b_m = 1$.

- Optimal transport plane $d(\nu, \mu) = C(\mathbf{P}^\star)$ is defined as the minimizer of Eq. (3):

$$\mathbf{P}^\star = \underset{\mathbf{P} \in \mathbf{R}_+^{N \times M}}{\text{argmin}} \langle \mathbf{C}, \mathbf{P} \rangle \text{ such that} \quad \mathbf{P}\mathbf{1}_M = \mathbf{a}, \mathbf{P}^T\mathbf{1}_N = \mathbf{b}. \tag{4}$$

with P_{nm} representing the amount of mass taken from x_n to y_m, $C_{nm} = c(x_n, y_m)$ the cost of transporting a unit mass of x_n to y_n and $c(x, y) = \|x - y\|_2$ a cost function.

Conclusion

- Works on moderately complicated cases with few data
- Methodology can handle a large number of classes to identify
- Among 3600 sets of pulses tested, identification with the 1st output almost 95% of the time
- Perspectives:
  - Pulse width spread modelisation
  - Adding a 3rd dimension with the Pulse Repetition Interval

Identification model

Method: Identification of the emitter class by assigning the closest RADAR class in the optimal transport distance sense to each set of pulses:

$$j^\star = \underset{j \in (1, \dots, J)}{\text{argmin}} \; d(\mu_j, \nu). \tag{5}$$

with J the number of emitters classes

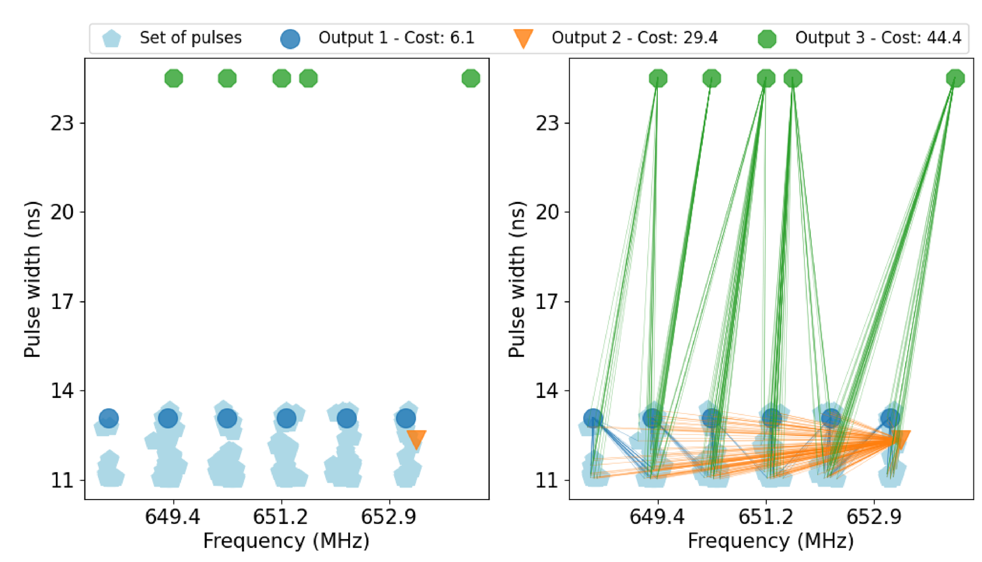

Figure 4: Transport plan between the pulses and the three closest emitter classes identified by the algorithm for set of pulses 1.