Specific Emitter Identification: Analysis on Real Radar Signal Data

Stefano D'Agostino[#1], Goffredo Foglia[*2], and Daniela Pistoia.[*3]

[#] *Naval Academy,*
Viale Italia 72, 57127 Livorno, Italy
[1] Ph. +39 3281561847, email: stefano.dagostino@marina.difesa.it
[*] *Elettronica S.p.A.,*
Via Tiburtina Valeria km 13.7, 00131 Rome, Italy
[2] Ph. +39 064154985, Fax +39 064154941, email: goffredo.foglia@elt.it
[3] Ph. +39 06415810, Fax +39 064154941, email: daniela.pistoia@elt.it

Abstract— **This paper focuses on the Specific Emitter Identification (SEI) technique applied to Electronic Support Measure (ESM) systems. The main idea is to analyze the radar pulses and characterize those by extracting features that should be different for each radar. In the paper, feature extraction algorithms are used to characterize the radar pulses: a measurement campaign has been conducted to acquire real radar pulses from different radar modes and radar signals. The applicability of the feature extraction procedure has been analyzed for different case studies to obtain a complete picture of the results achievable with the different radar signals.**

I. Introduction

The use of ESM sensors [1][2][3] is widely used for emitter detection, classification and identification.

In radar applications, the classification and/or identification functionality is usually performed exploiting the information on the target RCS and scattering distribution along the range, for example using High Range Resolution (HRR) [4][5][6].

On the other hand, the ESM systems can measure several parameters in order to classify the different emitters, exploiting a higher number of discrimination degree: frequency, Pulse Repetition Interval (PRI), Pulse Width (PW), Phase Modulation On Pulse (PMOP) like chirp, barker codes etc. [7][8][9]. The possibility to digitally measure [10] such parameters give to the ESM systems the opportunity to

- resolve targets very close one each other, exploiting digital signal processing techniques, such as traditional deinterleaving [11][12] as well as artificial intelligence signal analysis, thus solving the problem of track-plot association which can be very complex for radar in a dense scenario;
- operate in very dense environments using the higher number of discrimination degree of freedom with respect to traditional radar (frequency, PW, PRI, etc.) [13];
- identify targets on the basis of the classical waveform parameters by means of a-priori information, stored in the emitter library [14].

Moreover the exploitation of Specific Emitter Identification (SEI) techniques [15] [16] can allow to identify in unique way a specific emitter, if already previously received. The basic idea is to collect the waveform from an emitter and then process the pulses to determine unique coefficients. These coefficients refer to different waveform features and should be different for each radar. Those features typically includes intra-pulse features like Amplitude Unintentional Modulation On Pulse (A-UMOP), Phase Unintentional Modulation On Pulse (P-UMOP) [17] or other signal characteristics that could be specific for a given emitter. For example in [17][18] the P-UMOP feature of the received signal is exploited: a second order Power Spectral Density (PSD) function is evaluated (Bi-Spectrum) and further processed for feature extraction, leading to satisfactory results for simulated data. Other features of the real radar systems that can be exploit to identify in a unique way an emitter includes the non-linear distortions of the power amplifier [19]. In [20][21] the authors rely on Scaled Conjugate Gradient and M-estimation algorithms to improved the frequency alignment of the pulses. This technique is compared with the maximum likelihood estimation. In papers [22][23][24] is provided an overview of methods of identification emitter sources based on regression analysis: a formal mathematical approach is used in order to extract, select and classify radar signal features. Finally, techniques like Resemble coefficient extraction and Support Vector Machine have been used on open literature [25] showing the ability to discriminate between emitters with different signal MOP.

In this paper real radar signals have been acquired to apply some feature extraction algorithmic procedures on live radar data. The analyses have been conducted on different radar modes and different radar signal to verify the robustness of the features extraction algorithm with respect to different case studies. The paper is organized as follows: in Section II is presented the signal model, while in Section III are described the results of the features extraction algorithms on the different available real radar signals, including analysis on different radar modes of the same signal. Finally, in Section IV some conclusions and future research tracks are given.

II. Signal Model and SEI Processing

In this paper we focus on the characteristics of the single radar pulse: we assume that two radars emit a pulse train with a certain number of pulses with the same classical parameters (carrier frequency, PW, PRI, MOP, Amplitude etc.). Once the classical parameters have been estimated using and the radar waveform has been extracted from the electromagnetic background (see Fig. 1), the SEI feature extraction processing can start.

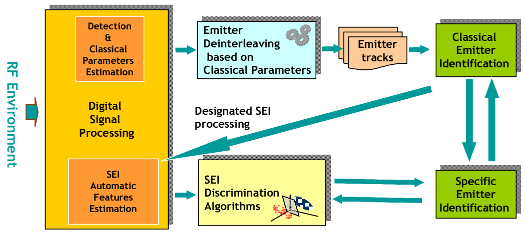

Fig. 1 Block scheme of the classical and SEI processing.

By doing so, the SEI Automatic Features Estimation block operates on each single pulse and so the signal model can be assumed to be

$$x(t) = \left[A + \Delta A(t)\right] e^{j\left[2\pi f_0 t + \vartheta(t) + \Delta\vartheta(t)\right]} \qquad t \in \left[t_0, t_0 + PW\right]$$

where t_0 represent the pulse start time, A represent the signal amplitude, f_0 the radar carrier frequency, $\vartheta(t)$ the PMOP (for example barker, chirp, poly-phase, etc.), $\Delta A(t)$ and $\Delta\vartheta(t)$ represent respectively the A-UMOP and P-UMOP. The aim is to provide a characterization of $\Delta A(t)$ and $\Delta\vartheta(t)$ by the use of adequate algorithmic procedures.

III. Results on Real Signal Data

Measurements on real radar signals has been performed in Elettronica S.p.A. facilities: two different radar signal has been properly down converted and captured and stored using a 8 bit Analog to Digital Converter with sampling frequency equal to 2GHz. More details on the analyzed dataset are reported in Table I and Table II.

TABLE I
DATASET SIGNAL X

Signal X			
	Mode A	Mode B	Mode C
Frequency after down conversion (MHz)	674	600	710
Peak Power (dBm)	63,69	63,06	63,38
Fall Time (ns)	89,82	69,86	59,88
Top Power (dBm)	63,27	62,63	63,01
Rise Time (ns)	139,7	139,72	129,74
Pulse Width (us)	2,614	2,63	2,63
Overshoot (%)	11,76	6,6	6,25

TABLE II
DATASET SIGNAL Y

Signal Y			
	Mode A	Mode B	Mode C
Frequency after down conversion (MHz)	674	600	710
Peak Power (dBm)	63,69	62,88	63,38
Fall Time (ns)	79,83	69,86	59,88
Top Power (dBm)	63,27	62,43	63,01
Rise Time (ns)	229,54	229,54	229,54
Pulse Width (us)	2,53	2,5	2,54
Overshoot (%)	11,76	14,28	6,25

A. *Feature Stability Vs Mode*

The acquired radar signals consist of three different modes, denoted as Mode A, Mode B and Mode C, that mainly differs one each other for the carrier frequency. A first case study is to compare the extracted features for the same emitter signal to understand if such features are invariant with respect to the radar mode. This situation is shown in Fig. 2 for the signal X and in Fig. 3 for the signal Y. More precisely, in the figures are reported the extracted A-UMOP features for all the three different modes for ten different pulses inside the coherent pulsed train waveform. Three features (generically denoted as feature1, feature2 and feature3) have been extracted twice for each pulse in two different time position inside the PW. In the following we will denote as "behaviour1" the features extracted for $t \in \left[t_0, t_1\right]$ and with "behaviour2" the same information extracted for $t \in \left[t_2, t_0 + PW\right]$, with t_1 and t_2 properly chosen. Fig. 2 shows that the Mode A exhibits a very different behaviour with respect to the other two modes. On the contrary, Mode B and Mode C seem indistinguishable only using A-UMOP features. As to the signal Y, shown in Fig. 3, all the three different modes exhibits very different features value one each other. From this analysis is possible to conclude that in general the features are not robust with respect to the radar mode, i.e. when a same emitter change mode, also the feature will change values. This is true for almost all the features analyzed in this paper. The consequence is that the comparison between two similar emitters has to be performed comparing the same radar mode.

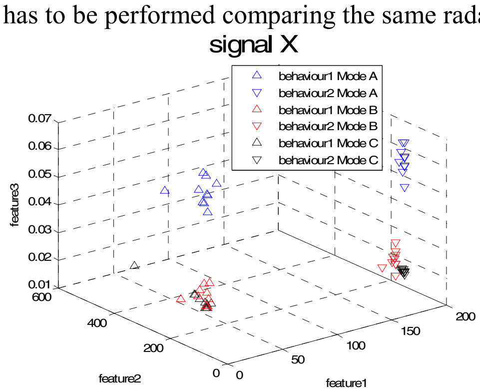

Fig. 2 Features of A-UMOP for Signal X.

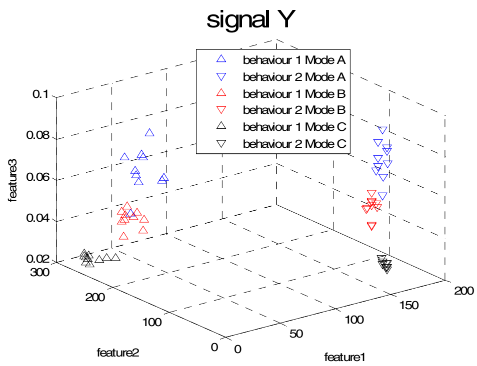

Fig. 3 Features of A-UMOP for Signal Y.

B. Features Discrimination

In this sub-section we will analyze the ability of the features to characterize the emitter in a unique way.The comparison between the signal X and signal Y will be done for each radar mode, as highlighted by the analysis of the previous sub-section.

In Fig. 4, the A-UMOP features are shown for both the signals, with respect to the Mode A: the extracted features of the two different signals are spread and partially overlapped, so that an automatic and robust classification appears to be very difficult.

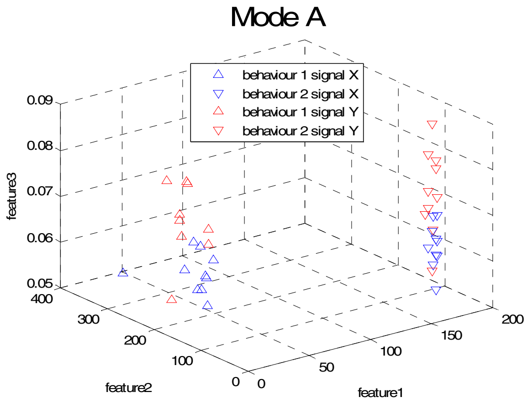

Fig. 4 Features of A-UMOP for Mode A.

In Fig. 5, the A-UMOP features are shown for both the signals, with respect to the Mode B: in this case, the two different signals exhibit different characteristics, and the different values of the A-UMOP extracted features can lead to correct signal discrimination.

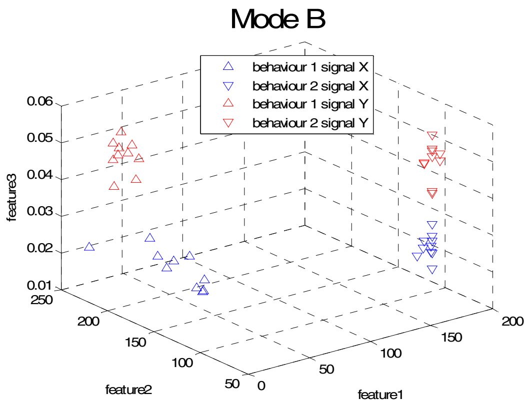

Fig. 5 Features of A-UMOP for Mode B.

In Fig. 6, the A-UMOP features are shown for both the signals, with respect to the Mode C: in this case the features related to the behaviour1 can be used for the two signals discrimination, while the features related to behaviour 2 seems indistinguishable.

Finally, in Fig. 7, 8, and 9, the P-UMOP features are shown for both the signals, and respectively for Mode A, B , and C.

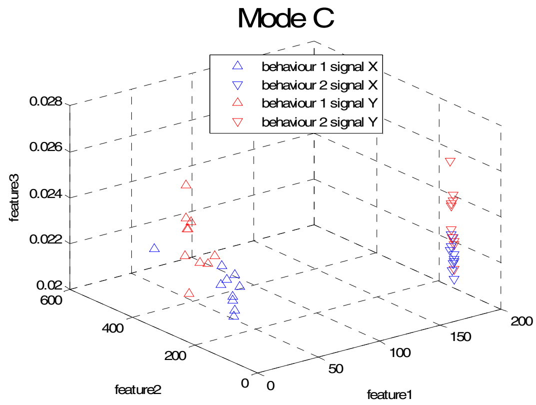

Fig. 6 Features of A-UMOP for Mode C.

It can be noted that the two signals in Mode A gives very different value for the P-UMOP features.

Remarkably, the two signals in Mode A had identical A-UMOP features (see Fig. 4), but is it still possible to discriminate the two signals using P-UMOP features. The situation for the Mode B and Mode C is more confused, but it has to be noted that for those cases the A-UMOP information already have given good results (Fig. 5 and Fig. 6).

Is it possible to conclude that is not a-priori predictable if a feature will be useful to the signal discrimination, and the more the available extracted features, the higher the probability to distinguish the emitters (in accordance to [15]).

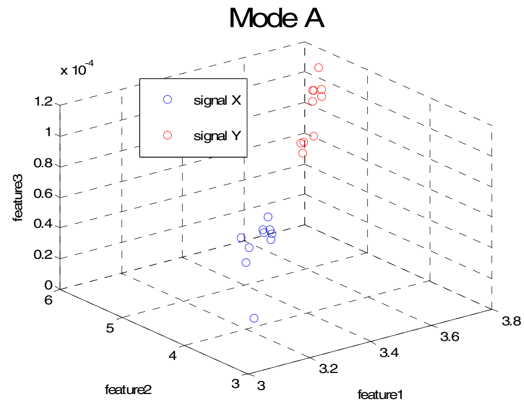

Fig. 7 Features of P-UMOP for Mode A.

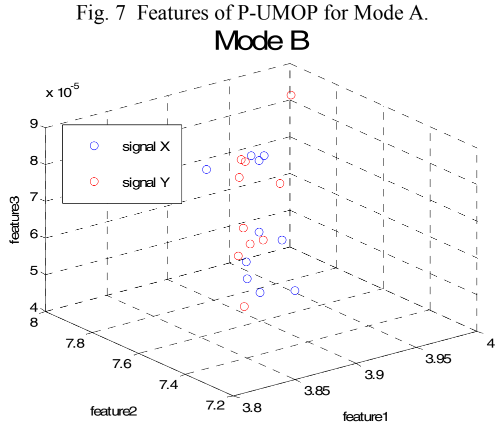

Fig. 8 Features of P-UMOP for Mode B.

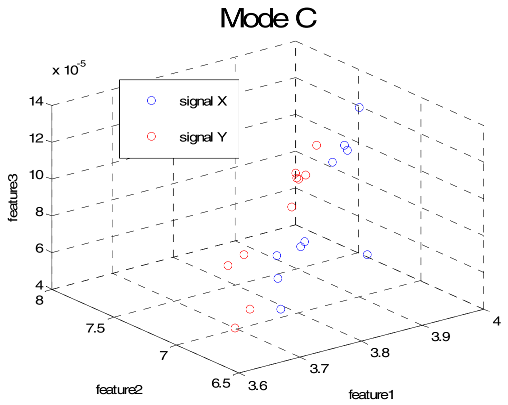

Fig. 9 Features of P-UMOP for Mode C.

IV. CONCLUSIONS

In this paper the problem of SEI for radar emitters has been analyzed, also with the aid of real radar signals.

The used real radar data include several radar operative mode and two different signals. Several feature extraction algorithms have been tested on real data, showing that different radar mode of the same emitter often exhibit different features values: the comparison between two similar emitters has to be performed comparing only the same radar mode. Moreover it has been shown that different signals can be indistinguishable with respect to some features and can differ with respect to other features.

Future research tracks might concern the analysis in presence of other different signals from different emitters, and also the analysis on the same emitter after a long time period (order of some months).

ACKNOWLEDGMENT

The authors wish to acknowledge Giampiero Panci and Stefano Randon for the real signals measurement campaign.

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