Automatic Classification of UAVs with a Conventional Radar-Based Surveillance System

SET-315 Research Symposium on "Detection, Tracking, ID and Defeat of Small UAVs in Complex Environments" (9-10th of October, 2023)

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Mid-Range C-UAV Black Knight

Multi-Band Neutralizer
Jammer & Spoofing

Range-Doppler
Surveillance Radar

Mid/Near Range
EO/IR Systems

C2

PSU
(optional)

Supply

Data, Video and Control

D&T Up to 5Km range for mini-UAV@-3dBsm

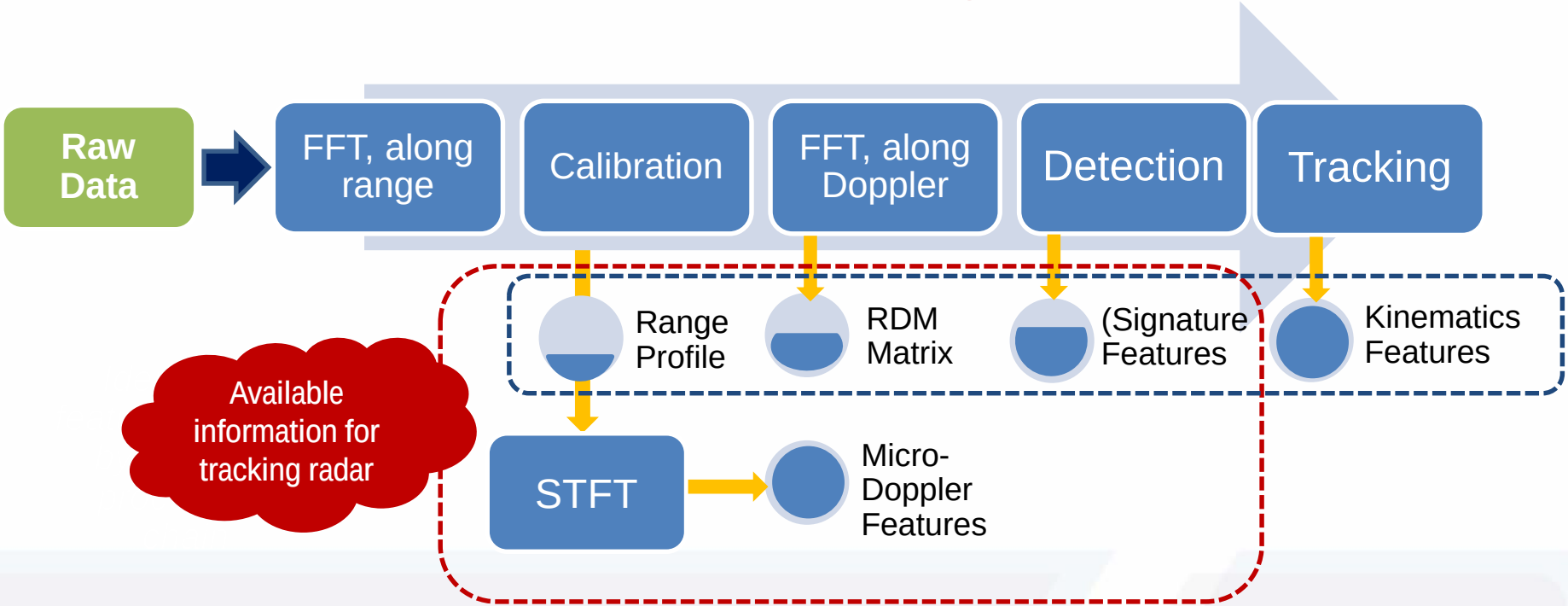
Radar Parameters and Configuration

Operating Frequencies	X Band
Waveform Type	LFMCW
Operative Range	5km (for class I UAVs)
Antenna	5x25° (Fan beam)

Range Resolution	>2m
Azimuth Coverage	360°
Dimensions	55 x 55 x 85cm
Weight	20kg

Configuration	Operative_600m	Operative_2km	Operative_4km
Parameter	Value		
Signal Start Frequency	9.36 GHz	9.36 GHz	9.36 GHz
Band	75 MHz	18.87 MHz	9.75 MHz
Antenna rounds per minute	20	20	20
Max Range	624 m	2100 m	4200 m
Range Resolution	2.00 m	7.95 m	15.90 m
Max Target Speed	96 Km/h	96 Km/h	96 Km/h
Pulse Repetition Frequency	3339 Hz	3339 Hz	3339 Hz
Samples in a Sweep	624	624	624

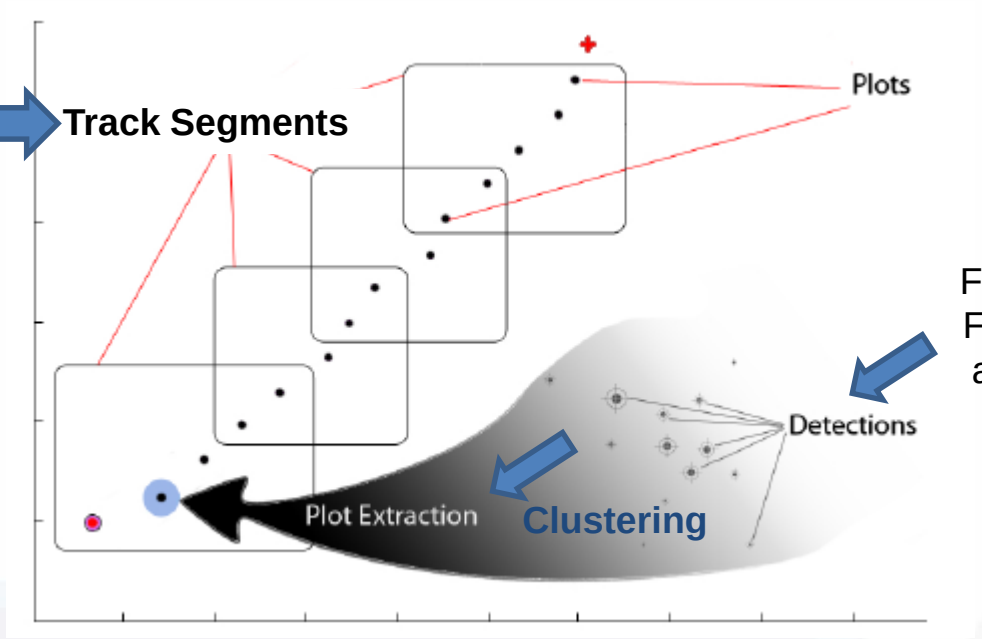
Radar Processing Chain



Detection, Plot, Track

From a **NTREF (4-10)** number of observations

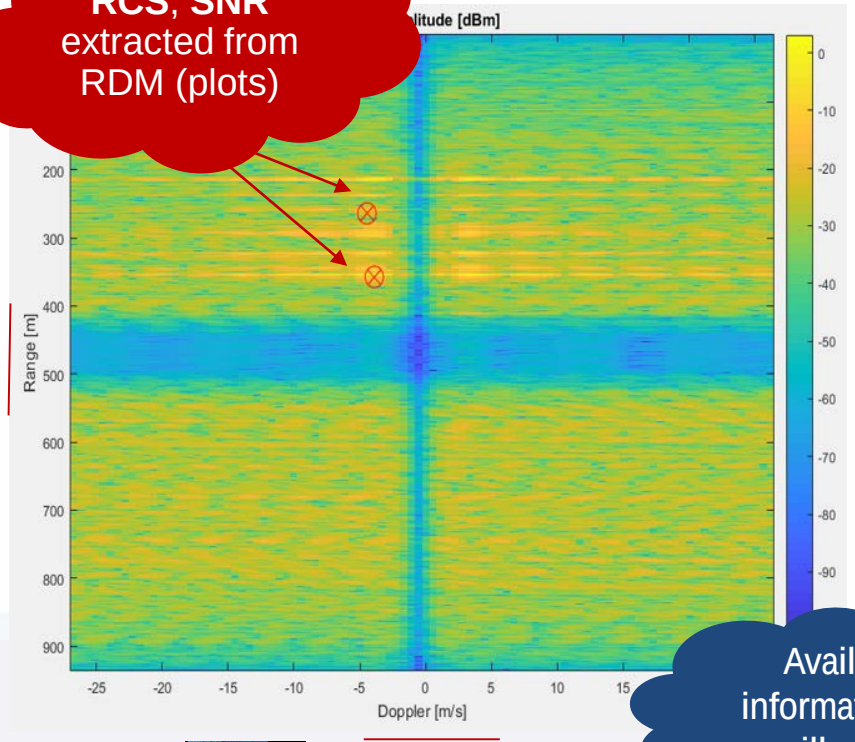
Track Segments



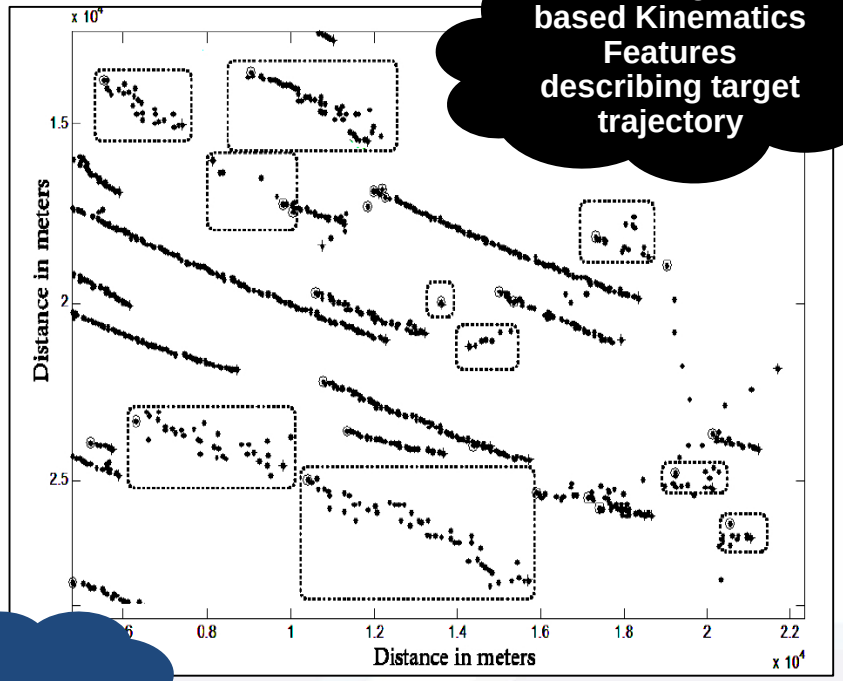
From the **Kalman** Filtering, for each antenna rotation

Feature Definition

RCS, SNR extracted from RDM (plots)



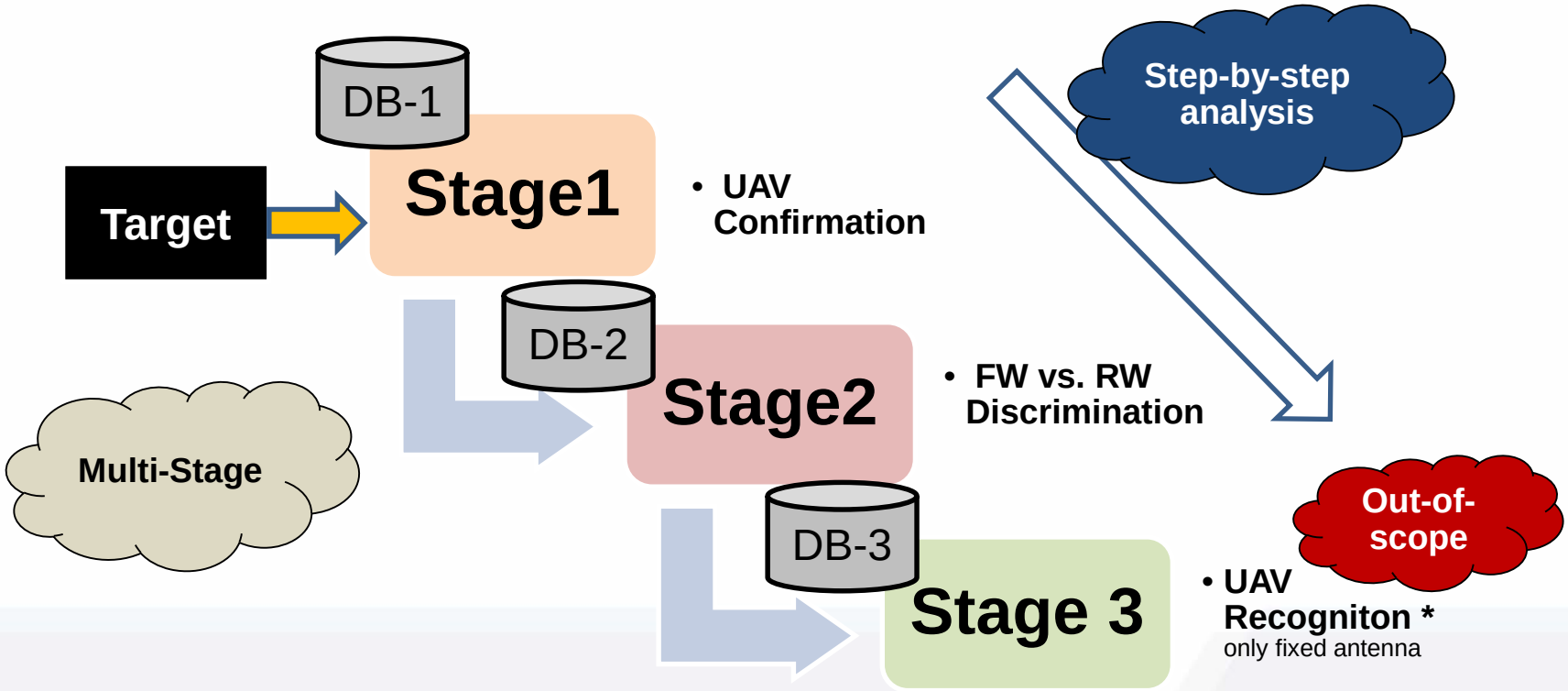
Track-Segment based Kinematics Features describing target trajectory



Available information for surveillance radar

Super Set of **50 features:** 30 are signature-based, 20 kinematic-based

High Level Classifier Architecture



Measurement Campaign (1/3)

	Name	Wing Type	Info	
	IDS FlySmart	Quadricopter	Diameter: 77 cm Blades Length: 36 cm Weight: 2 Kg	engine: 9280 RPM (max) speed: 11 m/s (max) RCS: −14.34 dBm
	IDS Colibrì	Quadricopter	Diameter: 81 cm Blades Length: 41 cm Weight: 5.5 Kg	engine: 7100 RPM (max) RCS: −11.19 dBm (mean)
	IDS Nik	Quadricopter	Blades Length: 31 cm	engine: 8300 RPM (max) RCS: −16.25 dBm (mean)

Measurement Campaign (2/3)

	Name	Wing Type	Info	
	IDS FlyFast	Fixed Wing	Wingspan: 110 cm Length: 70 cm Weight: 0.98 Kg	(max) engine: 18300 RPM (max) speed: 33 m/s (mean) RCS: −19.18 dBm
	IDS FlySecur	Fixed Wing	Wingspan: 200 cm Length: 130 cm Weight: 2.0 Kg	(max) engine: 18000 RPM (max) speed: 30 m/s (mean) RCS: −15.77 dBm
	IDS FlyNovex	Hexacopter	Diameter: 114 cm Blades Length: 28 cm Weight: 6 Kg	(max) engine: 9600 RPM (max) speed: 18 m/s (mean) RCS: −11.17 dBm

Measurement Campaign (3/3)

	Name	Wing Type	Info	
	DJI Phantom 3 Pro	Quadricopter	Diameter: 59 cm Blades Length: 24 cm Weight: 1.3 Kg	(max) engine: 14592 RPM (max) speed: 16 m/s (mean) RCS: −17.69 dBm
	Yuneek Typhoon 4K	Quadricopter	Diameter: 42 cm Weight: 1.7 Kg	(max) speed: 8 m/s
	Invidia Jetson	Quadricopter	Blades Length: 23 cm	(max) engine: 10656 RPM (mean) RCS: −15.92 dBm

DB Samples: TGTs and FA

1° STAGE	NTREF	4	6	8	10
Operative _600m	EE*	8914	5512	3419	2200
	Drone	2463	2007	1658	1364
Operative _2km	EE*	81824	56822	41446	31525
	Drone	3243	2819	2454	2170
Operative _4km	EE*	40833	30128	23423	18837
	Drone	1470	1258	1078	918

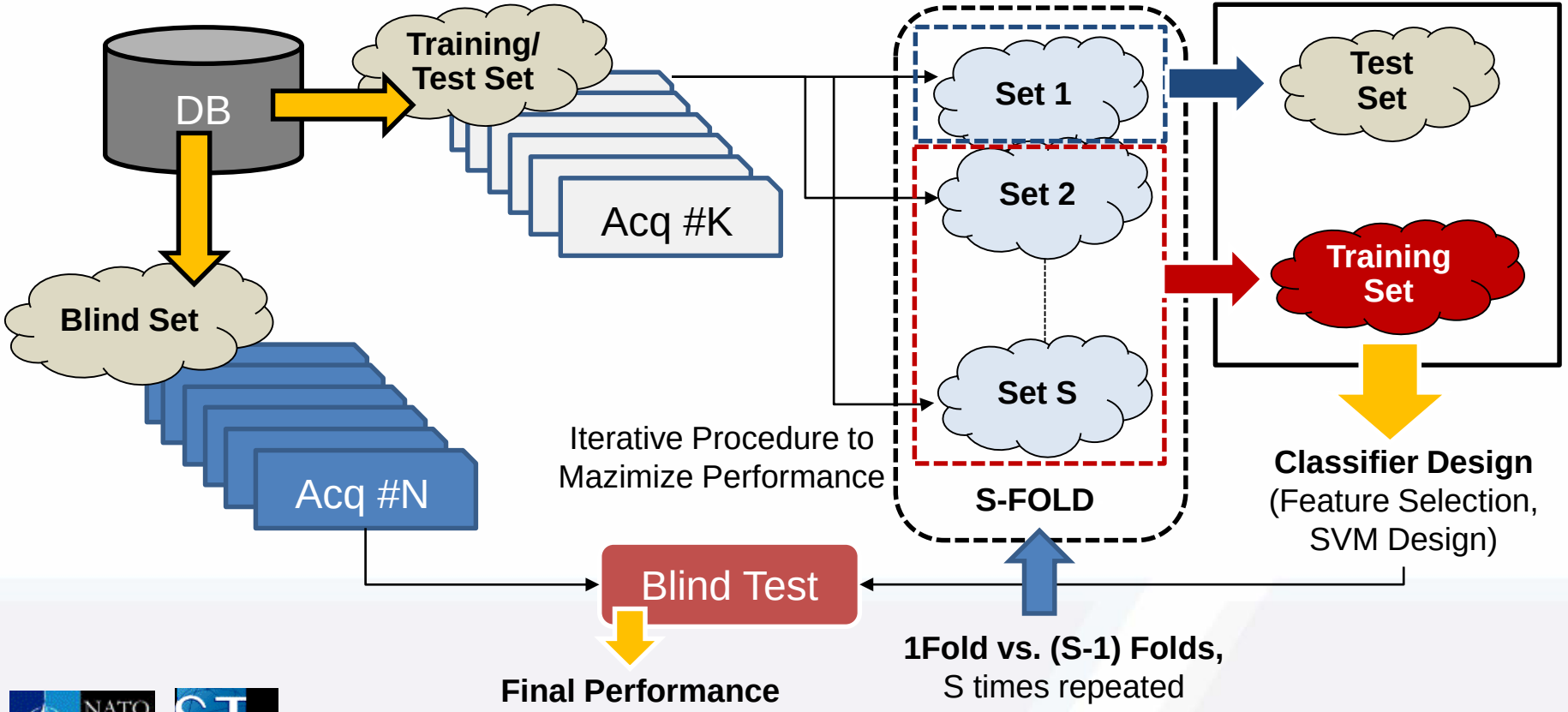
2° STAGE	NTREF	4	6	8	10
Operative _600m	FW	689	539	419	328
	RW	1774	1468	1239	1036
Operative _2km	FW	1496	1275	1097	961
	RW	1747	1544	1357	1209
Operative _4km	FW	398	303	225	153
	RW	1072	955	853	765

(*) **E**verything **E**lse

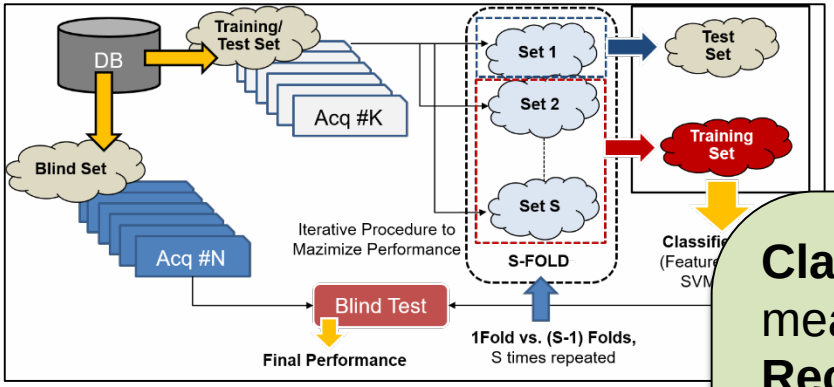
Each sample is a segment of track computed by the radar, formed each NTREF antenna rotations

The number of samples for class provides statistical significance for at least the classification between drone and *Everything Else*, and for the discrimination between fixed wing and rotating wing

Classifier Design & Performance Evaluation



Classifier Design & Performance Evaluation



Classifiers' performance are evaluated by means of **Accuracy,** per-class **Precision and Recall**. Each of those index is measured:

- during training process using s-fold cross validation process
- holding out several acquisitions for a final **blind test**
- By definition of a **Global index (GI)** using the results from training process, blind tests, and new re-partition of the dataset

Drone vs. EE (1° Stage)

Drone/EE	Accuracy (%)		
NTREF	4	6	8
Operative 600m	95.46	95.40	95.62
Operative 2km	98.82	98.79	98.74
Operative 4km	98.32	97.69	97.99
All_Conf	98.29	98.35	98.35

Drone/EE classifier not afflicted by NTREF

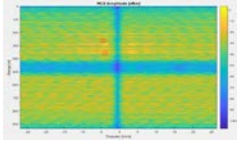
The **mean accuracy** is very **high**. It is measured as average on many subset of the available dataset. It shows that the Drone vs EE classification is very **robust**

Drone/EE	Recall (%)	Precision (%)	Recall (%)	Precision (%)
NTREF=4	Drone	EE	Drone	EE
Operative 600m	87.59	97.60	90.86	96.65
Operative 2km	80.86	99.53	87.32	99.24
Operative 4km	75.48	99.23	79.93	99.02
All_Conf	80.12	99.27	85.66	98.93

Most likely errors fall into missed detection, maybe due to unbalanced dataset

(*) **E**verything **E**lse

Conclusions

	Simpler features, such as **kinematics** and **signature** based ones, can be successfully exploited to define a very **accurate and robust classification** algorithm to discriminate **Drone / EE**, and **FW / RW**
	Using a **surveillance radar**, we reach very high Performance: **Accuracy > 98%** for TGT/EE, and around **92-94**% for FW / RW. **Blind tests** confirm that the classification algorithms are very **robust**.
	**Features** have been defined to require a **low computational load**, and the classifiers have been integrated in the real-time library.
	New plot-based approaches, optimizing w.r.t. other scores, classification of wildlife (birds, animal), classification of swarms of drones, usage of artificial neural networks