



# Estrazione del PRNU tramite Denoiser basato su Reti Neurali Convoluzionali (DRUNet)

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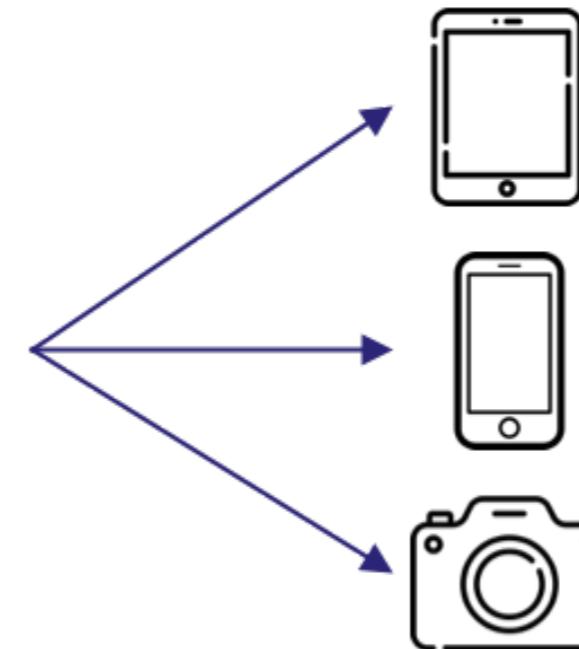
# Introduzione

In questo elaborato è stato preso in esame l'ambito della  
**Multimedia Forensics**



studia le **tracce intrinseche** e **artefatti** caratteristici che vengono lasciati su un qualsiasi media digitale (**immagini** o **video**) durante la loro creazione o altri processi a cui sono sottoposti

## Device Identification:

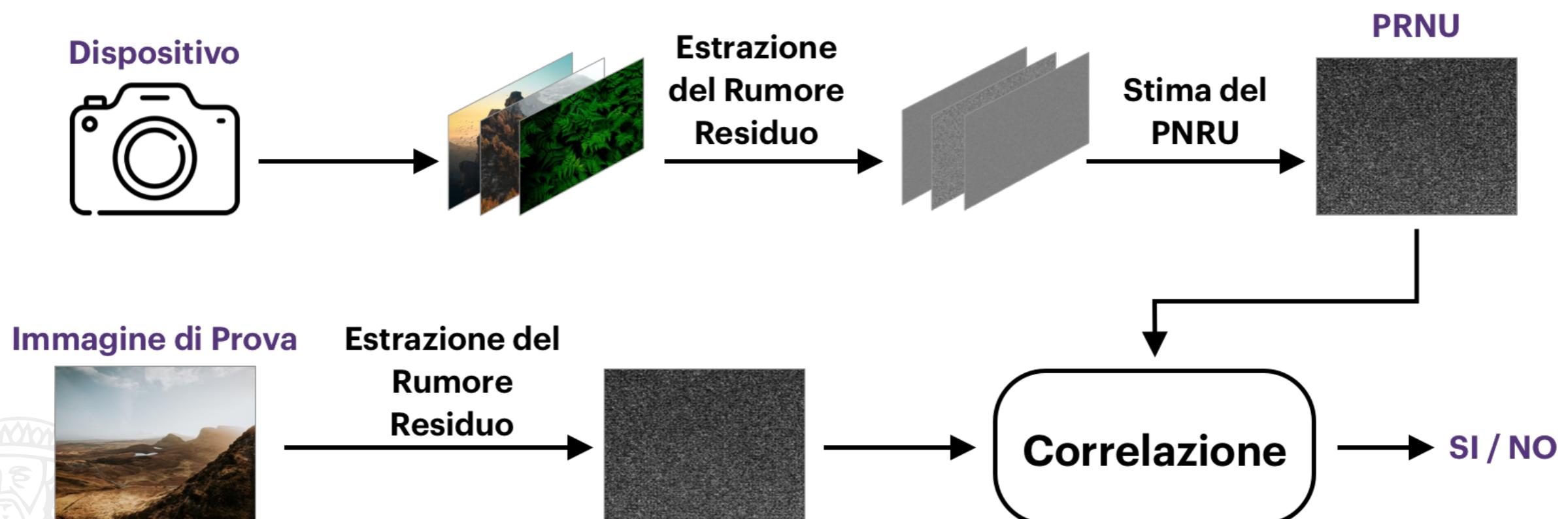


# Introduzione

Viene sfruttato un rumore che viene introdotto dai sensori di ogni fotocamera digitale: il **PRNU** (Photo Response Non Uniformity)



distintivo di ogni **singolo device**



# Attività di Ricerca

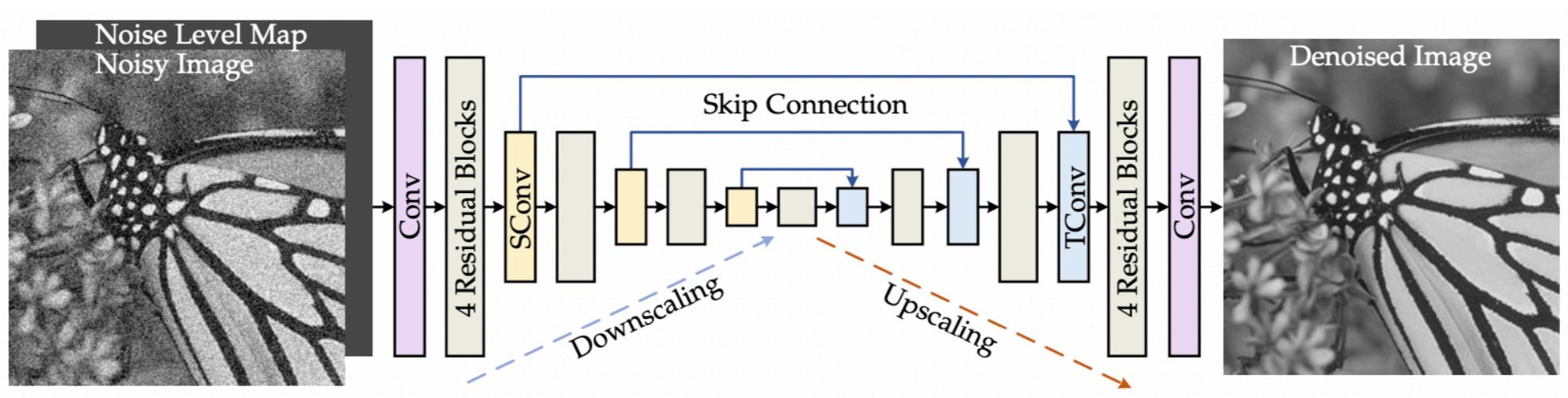
**Obiettivo:** sostituire nel processo di *Device Identification* tramite **PRNU** un **denoiser model-based** con un **denoiser learning-based**

Per la fase di **Denoising** sono state varate 2 possibilità:

- **DRUNet denoiser prior**
- **RIDNet**

# DRUNet

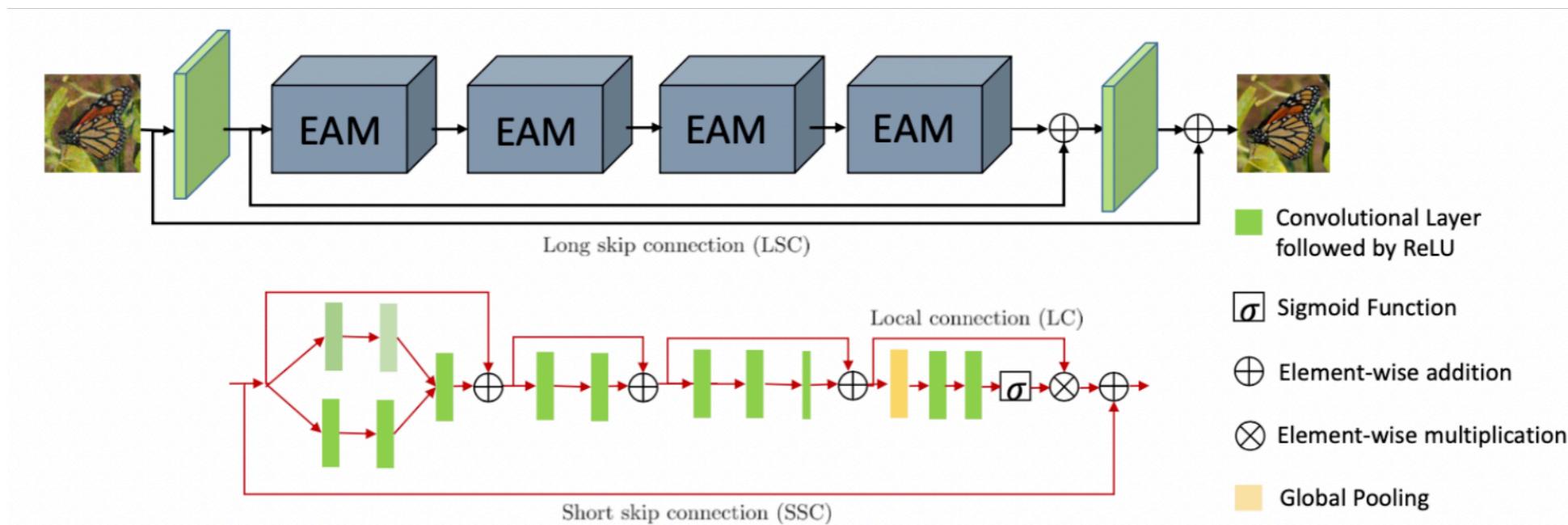
**DRUNet** è una rete in grado di trattare vari livelli di rumore attraverso un unico modello



In questa rete per l'**addestramento supervisionato** si aggiunge del **rumore gaussiano** all'**immagine pulita**

# RIDNet

**RIDNet** è una rete modulare single-stage che sfrutta la *Feature Attention* per il denoising delle immagini



Questa rete è capace di trattare sia **rumore sintetico** sia **rumore reale** presente nelle **immagini**

# Dettagli dell'Implementazione

**Baseline:** Algoritmo per l'estrazione del **PRNU** sviluppato in **Python** da parte di alcuni studenti del Politecnico di Milano



Estrazione del rumore residuo tramite un algoritmo *model-based* (**NoiseExtract**)

## Step implementativi:

1. Sostituzione con un algoritmo learning-based (**DRUNet**)
2. Test con vari **livelli di rumore** ( $\sigma = 15, 50, 100$ )
3. Esperimenti su dataset **reVISION\_dataset\_base**

# Risultati con Dataset Polimi

Tutti i risultati sono stati ottenuti in termini di **AUC** (Area Under Curve), utilizzando come misura di correlazione la **PCE** (Peak to Correlation Energy).

Il dataset è composto da immagine acquisite da **6 dispositivi**, in particolare sono state utilizzate:

- **60 immagini flat** per il calcolo della fingerprint (10 per ogni dispositivo)
- **20 immagini naturali totali** per i test



# PRNU con NoiseExtract (Baseline)

Risultati ottenuti con ***dataset Polimi***:

```
Computing statistics on PCE
AUC on CC 0.98, expected 0.98
AUC on PCE 0.81, expected 0.81
```



**Area Under Curve (AUC)**

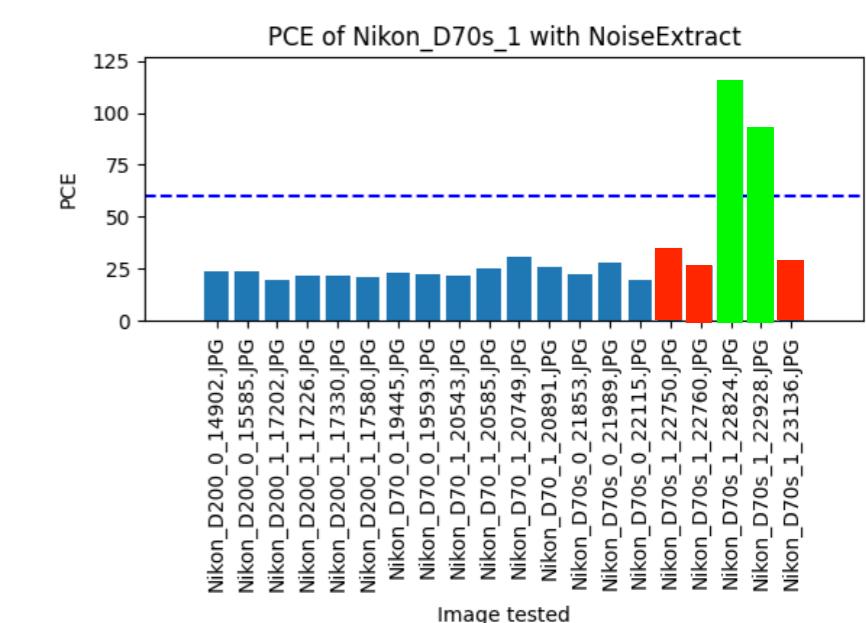
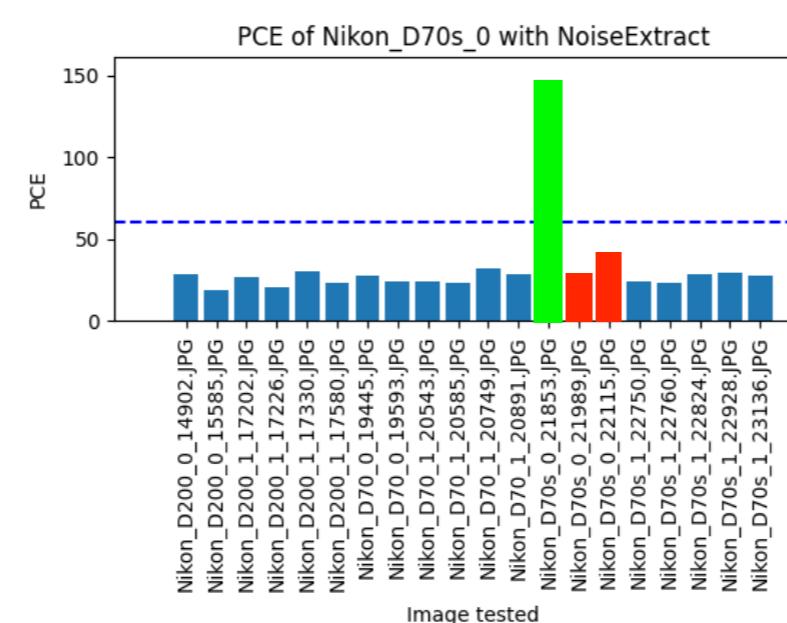
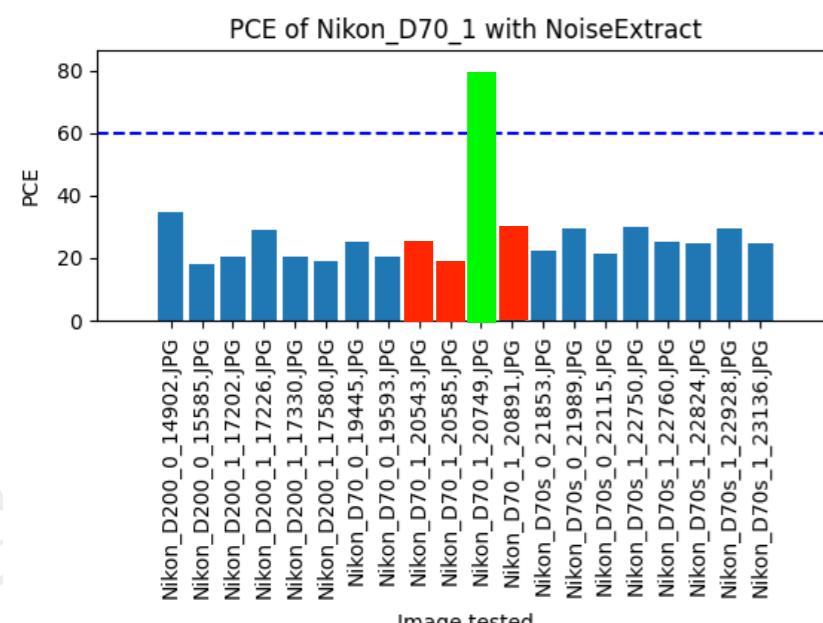
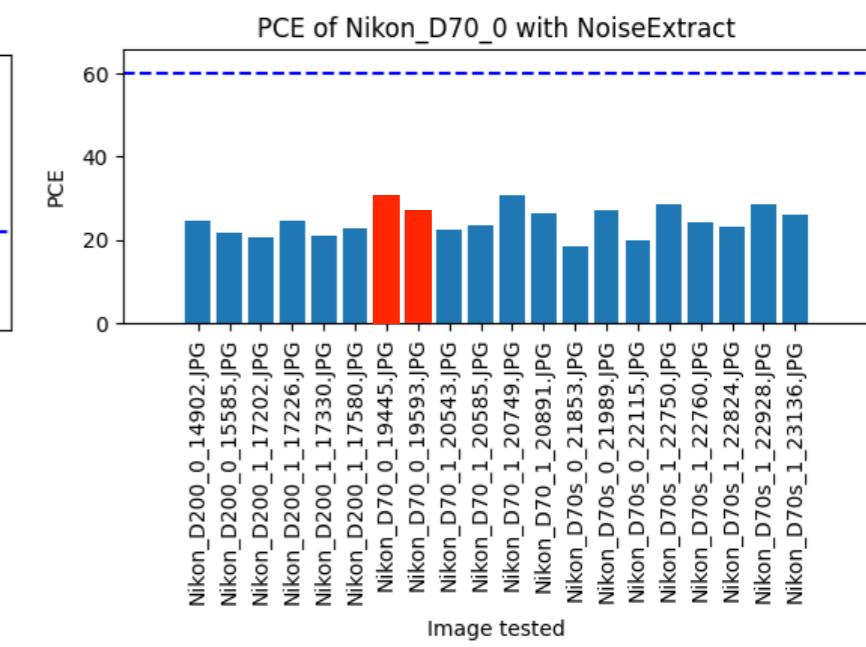
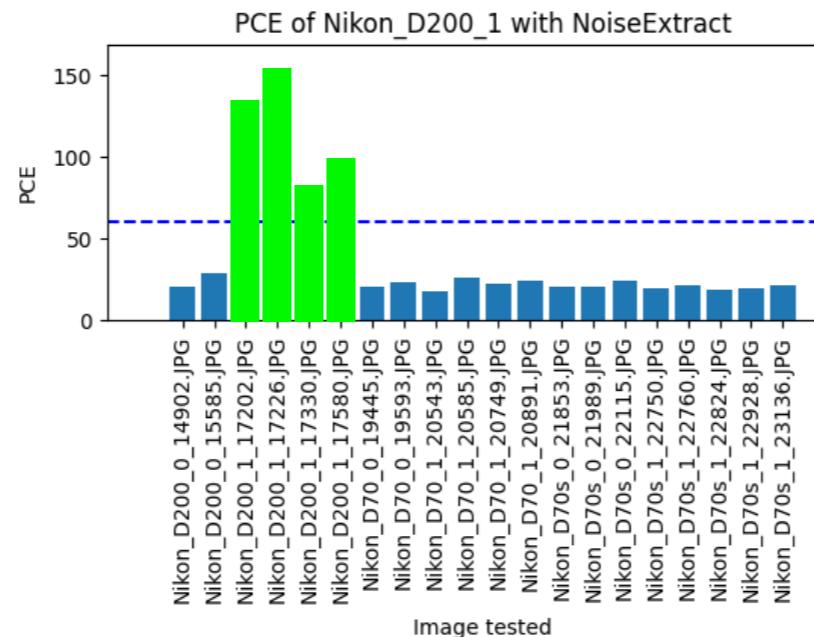
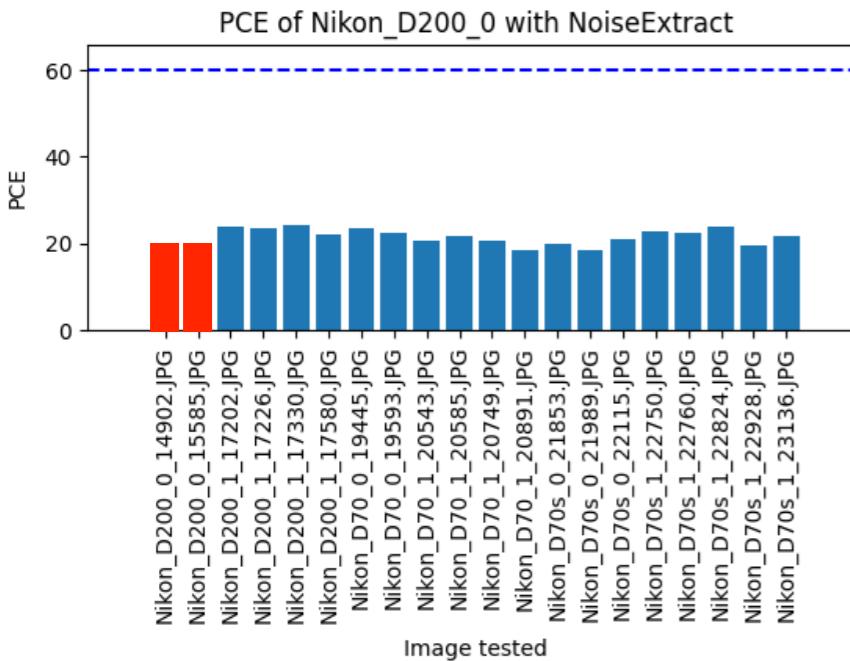
Immagini utilizzate (**6 device**):

- **10 immagini flat** per dispositivo per la fingerprint
- **20 immagini nat** totali per il test

# Iistogrammi con NoiseExtract

Risultati ottenuti con *dataset Polimi*:

**--- Threshold = 60**



# PRNU con DRUNet15

Risultati ottenuti con ***dataset Polimi***:

```
Computing statistics on PCE
AUC on CC 0.77, expected 0.98
AUC on PCE 0.70, expected 0.81
```



**Area Under Curve (AUC)**

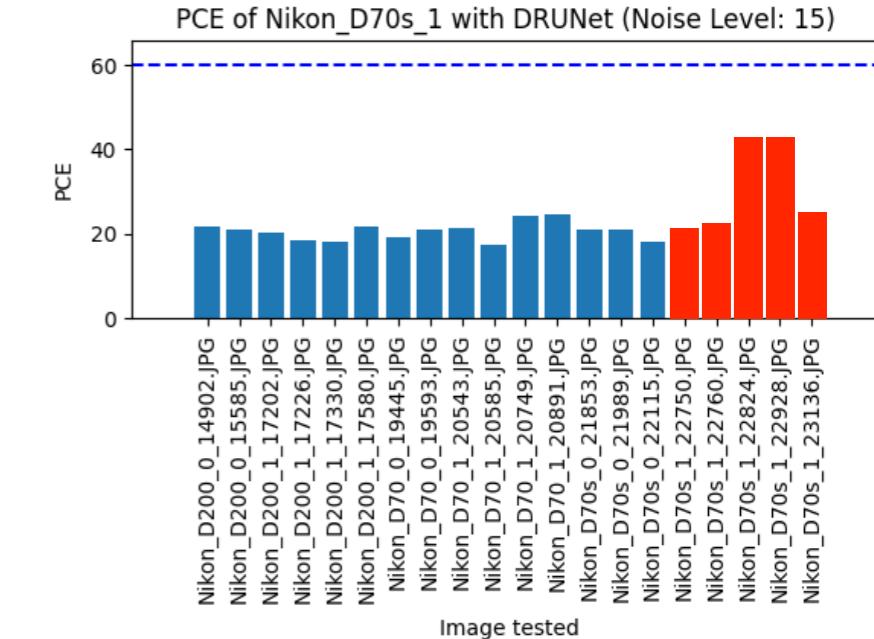
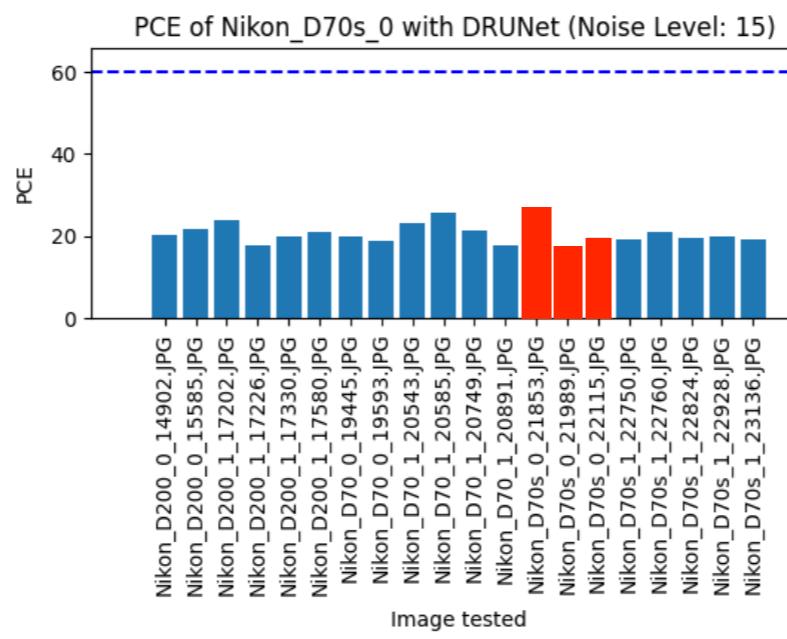
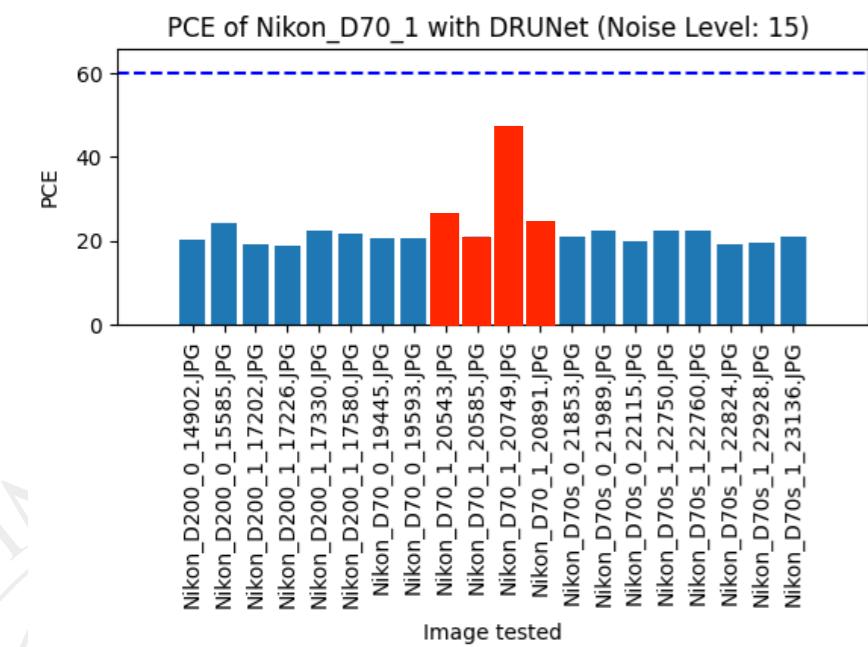
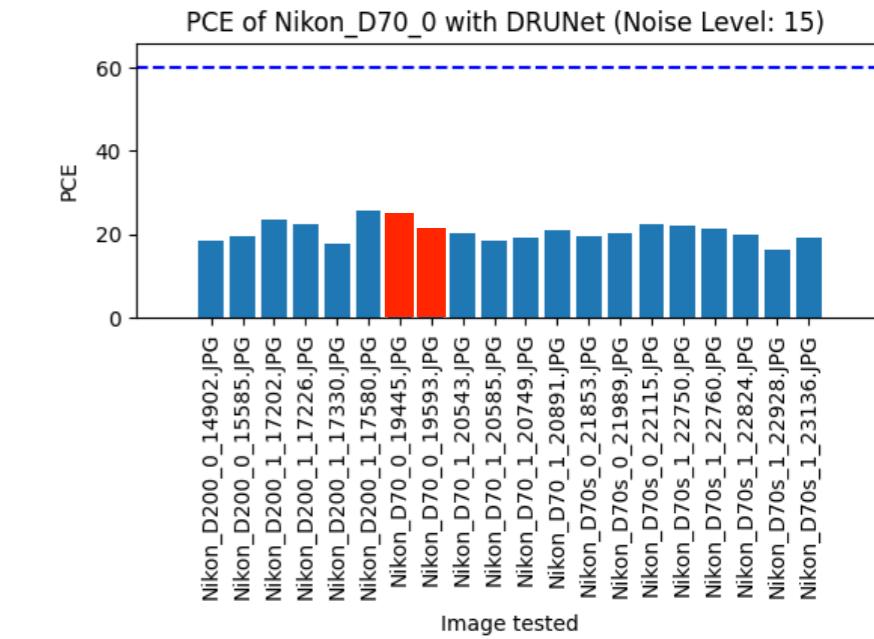
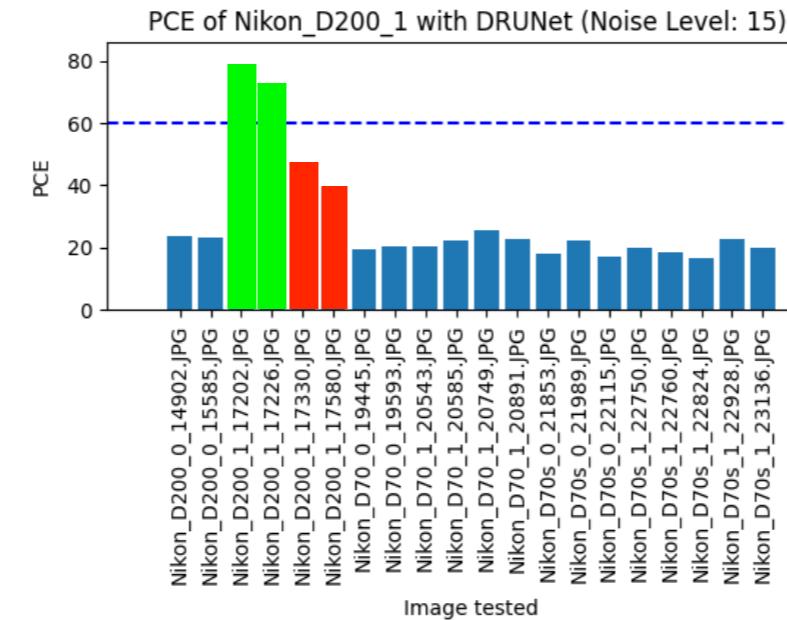
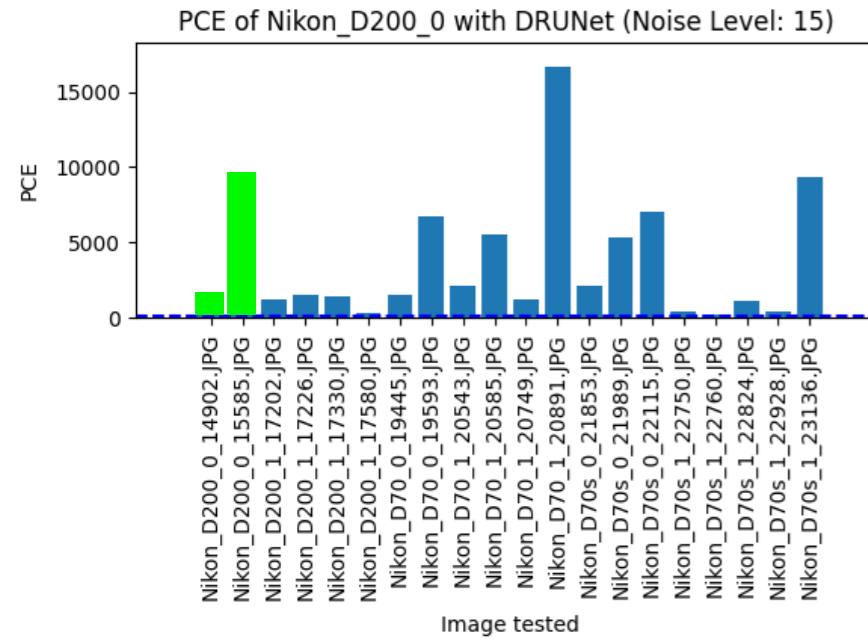
- Immagini utilizzate (**6 device**):
- **10 immagini flat** per dispositivo per la fingerprint
  - **20 immagini nat** totali per il test

**Noise Level = 15**

# Iistogrammi con DRUNet15

Risultati ottenuti con *dataset Polimi*:

**--- Threshold = 60**



# PRNU con DRUNet50

Risultati ottenuti con ***dataset Polimi***:

Computing statistics on PCE  
AUC on CC 0.73, expected 0.98  
AUC on PCE 0.82, expected 0.81



**Area Under Curve (AUC)**

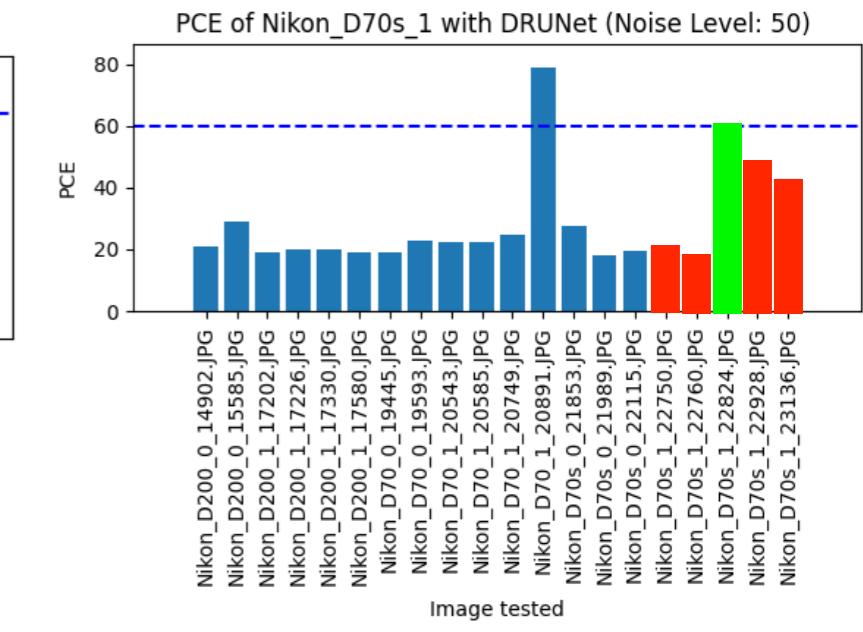
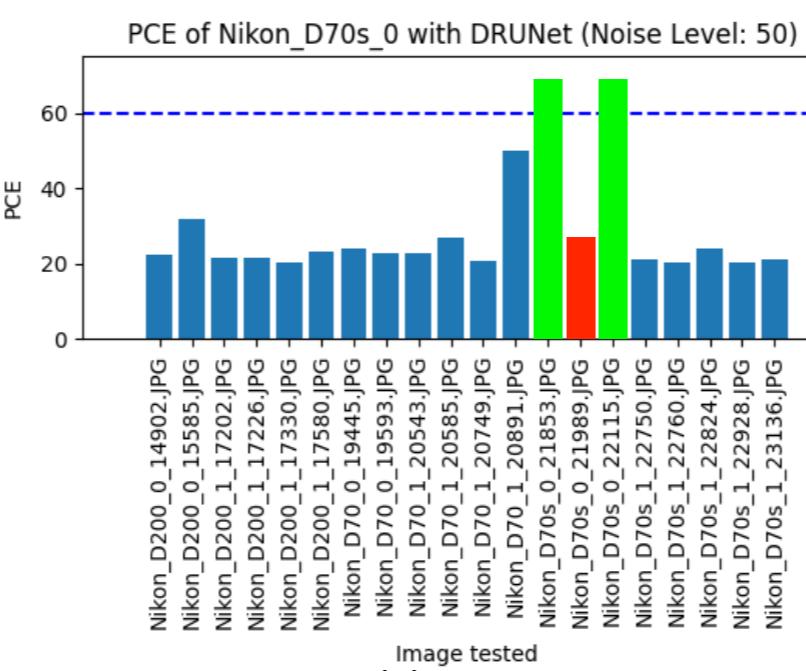
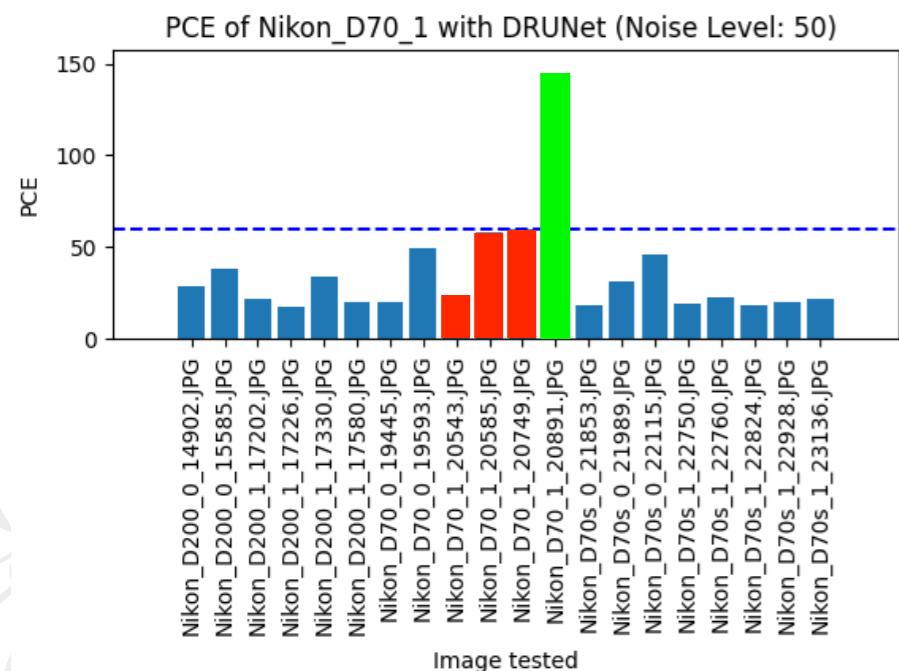
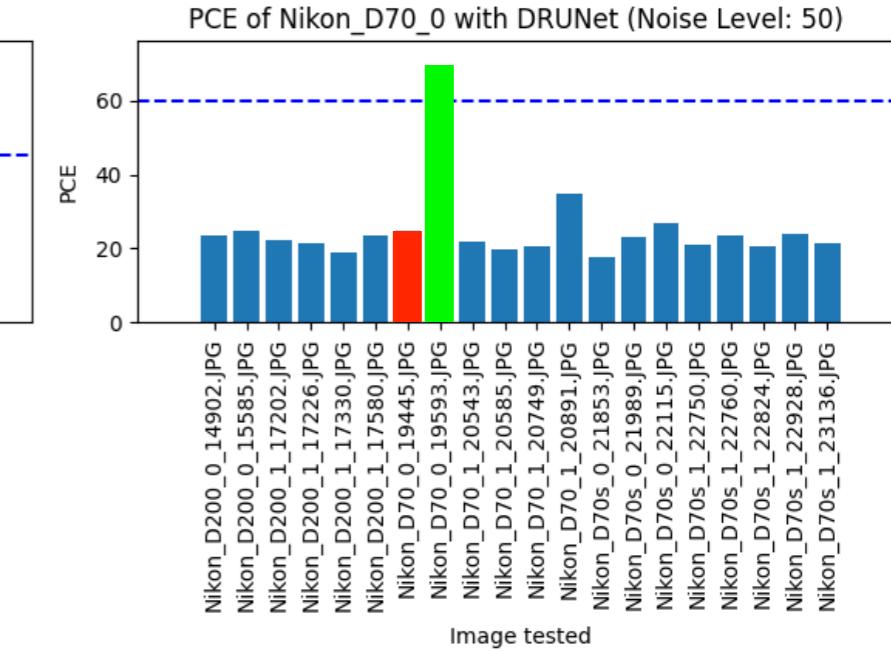
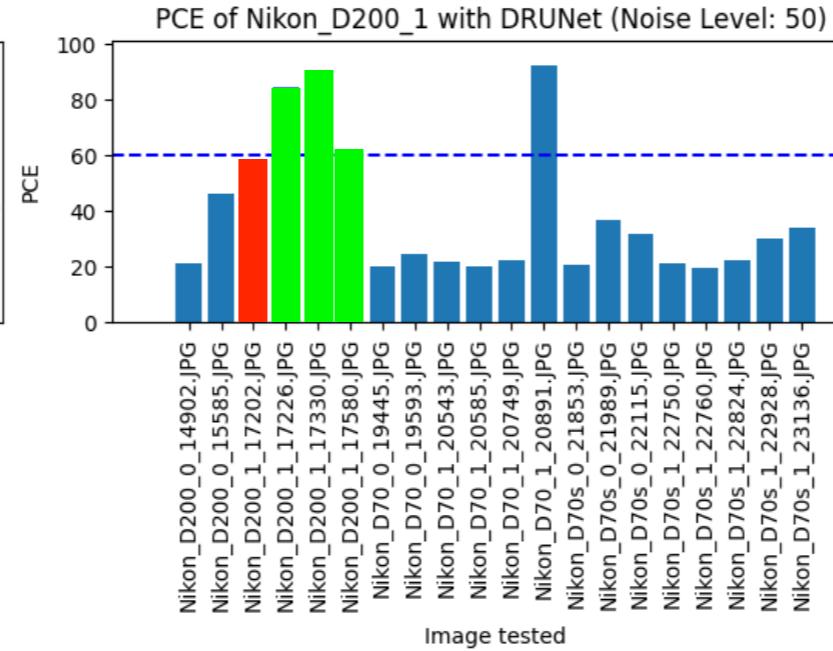
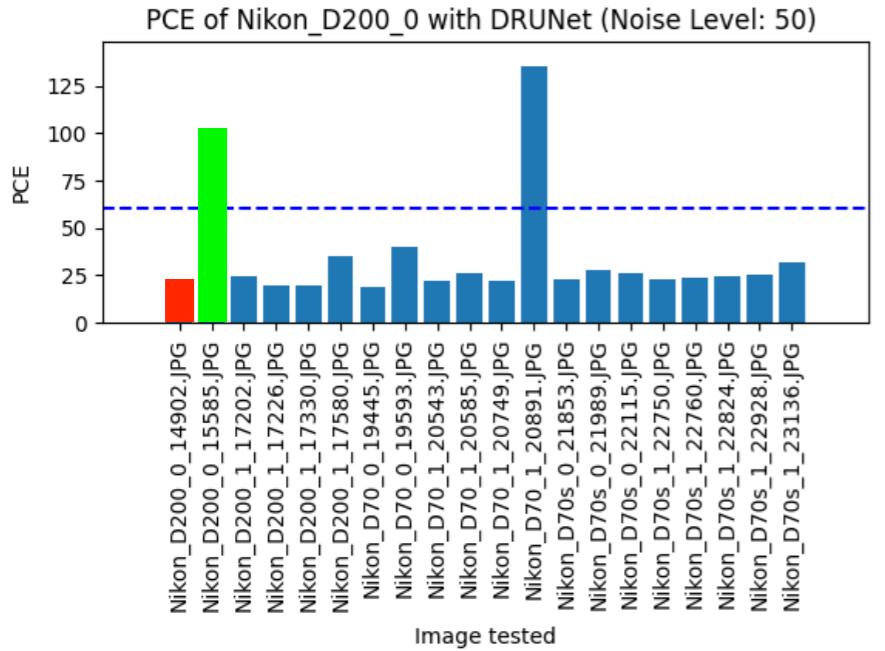
- Immagini utilizzate (**6 device**):
- **10 immagini flat** per dispositivo per la fingerprint
  - **20 immagini nat** totali per il test

**Noise Level = 50**

# Iistogrammi con DRUNet50

Risultati ottenuti con *dataset Polimi*:

**--- Threshold = 60**



# Confronto sul dataset del Polimi

Di seguito è riportata una **tabella comparativa** dei metodi sopra analizzati:

	NoiseExtract	DRUNet15	DRUNet50
AUC	0.81	0.70	0.82

# Risultati con Dataset reVISION\_dataset\_base

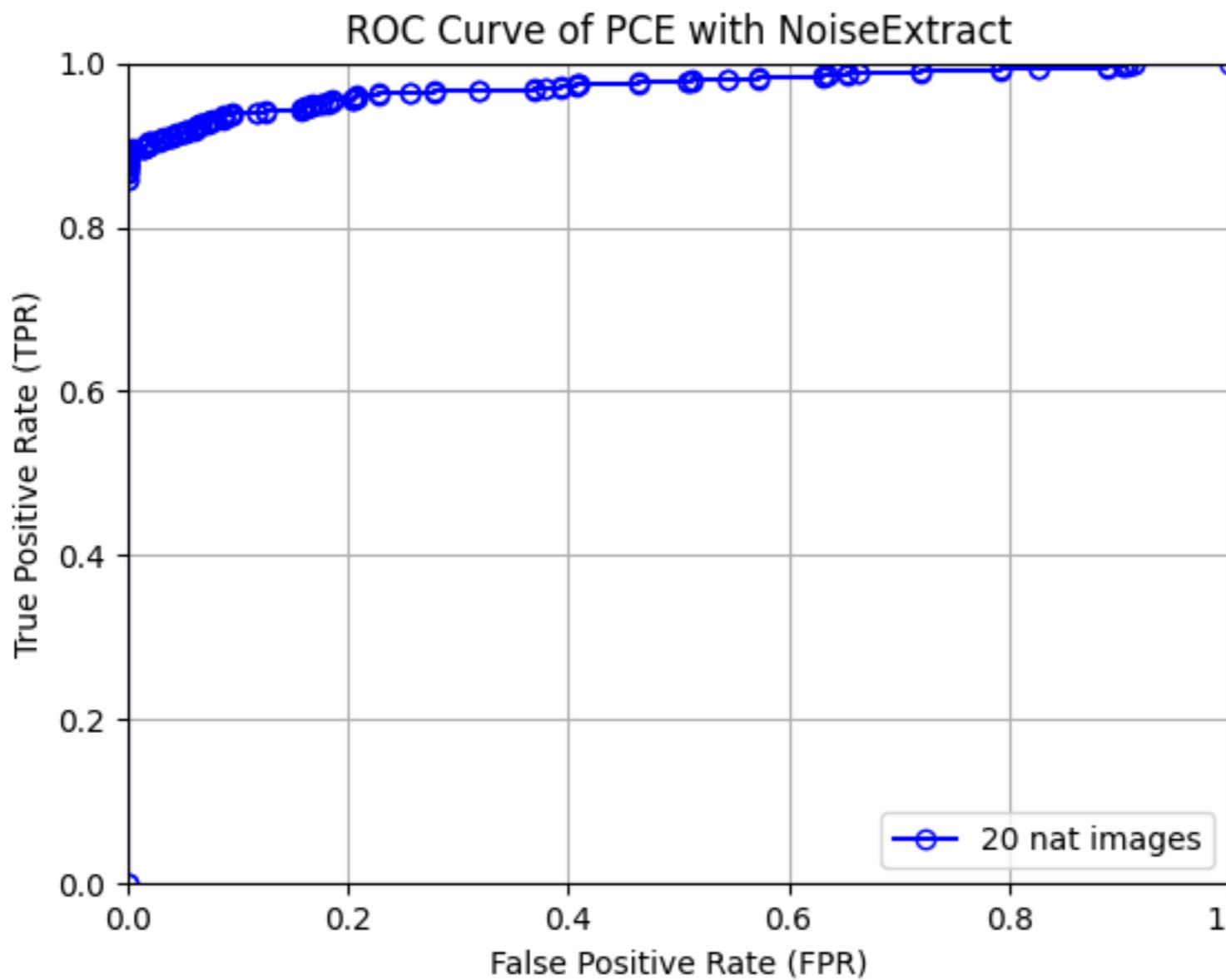
Il dataset è composto da immagine acquisite da **32 dispositivi**, in particolare sono state utilizzate:

- **1600 immagini flat** per il calcolo della fingerprint (50 per ogni dispositivo)
- **640 immagini naturali totali** per i test (20 per ogni dispositivo)

Brand	Dispositivi
Samsung	D01, D08, D11, D22, D26, D27, D31, D35
Apple	D02, D05, D06, D09, D10, D13, D14, D15, D18, D19, D20, D29, D34
Sony	D12
Huawei	D16, D28, D30, D33
Microsoft	D17
Wiko	D21
Asus	D23
Xiaomi	D24
OnePlus	D25, D32

# ROC Curve con NoiseExtract

Risultati ottenuti con *reVISION\_dataset\_base*:



Computing statistics on PCE  
AUC on CC 0.95, expected 0.98  
AUC on PCE 0.97, expected 0.81

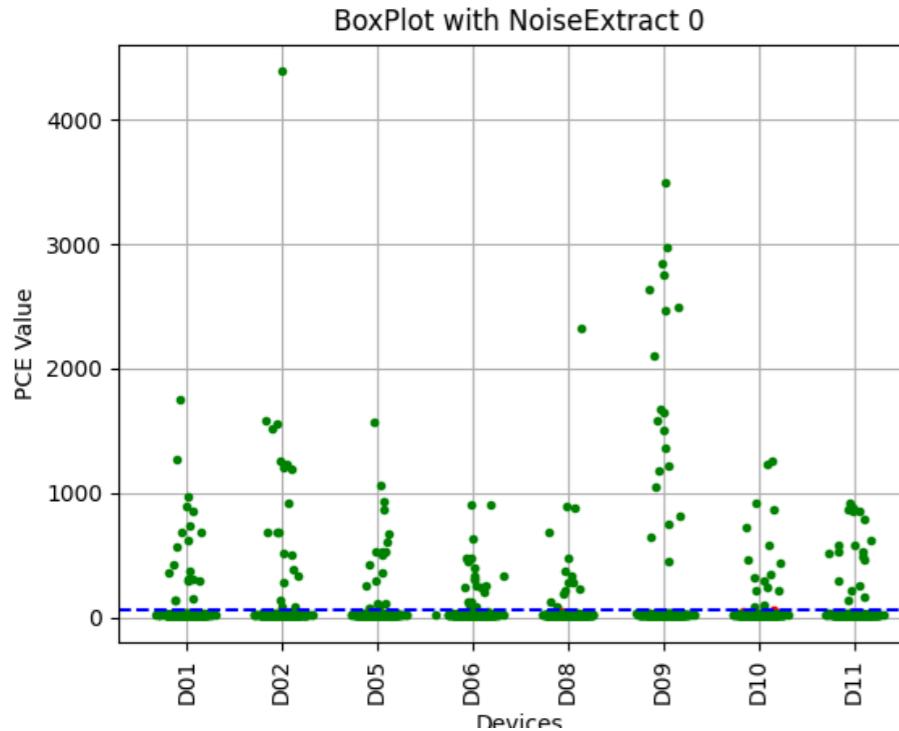
Area Under Curve (AUC)

Immagini utilizzate per ogni dispositivo (32 device):

- **50 immagini flat** per la fingerprint
- **20 immagini nat** per il test

# BoxPlot con NoiseExtract 1/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D01	20	0	620	0	1	0
D02	20	0	620	0	1	0
D05	20	0	620	0	1	0
D06	20	0	620	0	1	0
D08	14	0	620	6	0.7	0
D09	20	0	620	0	1	0
D10	16	0	620	4	0.8	0
D11	20	0	620	0	1	0

--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

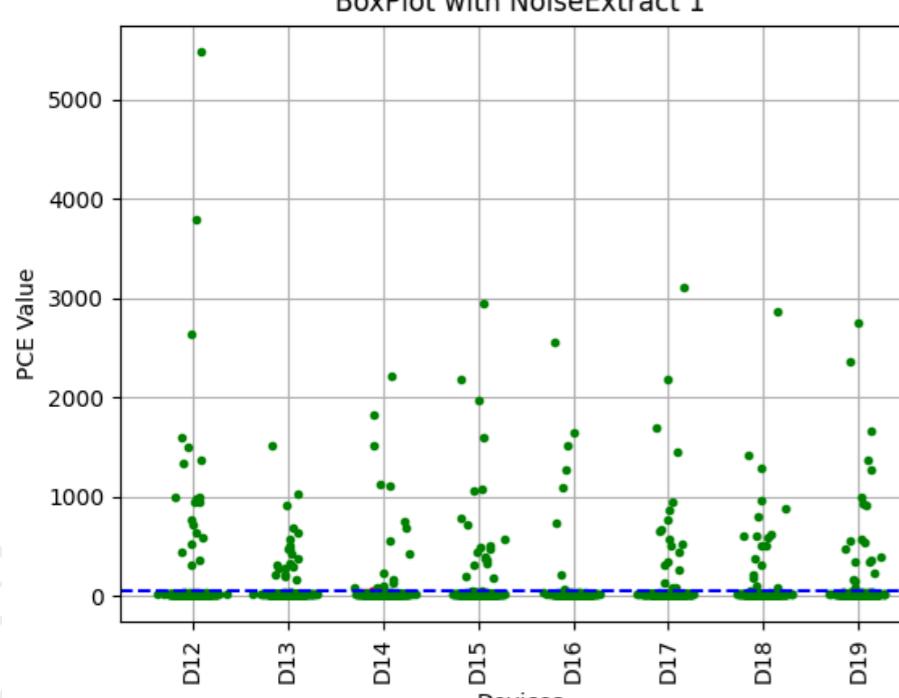
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

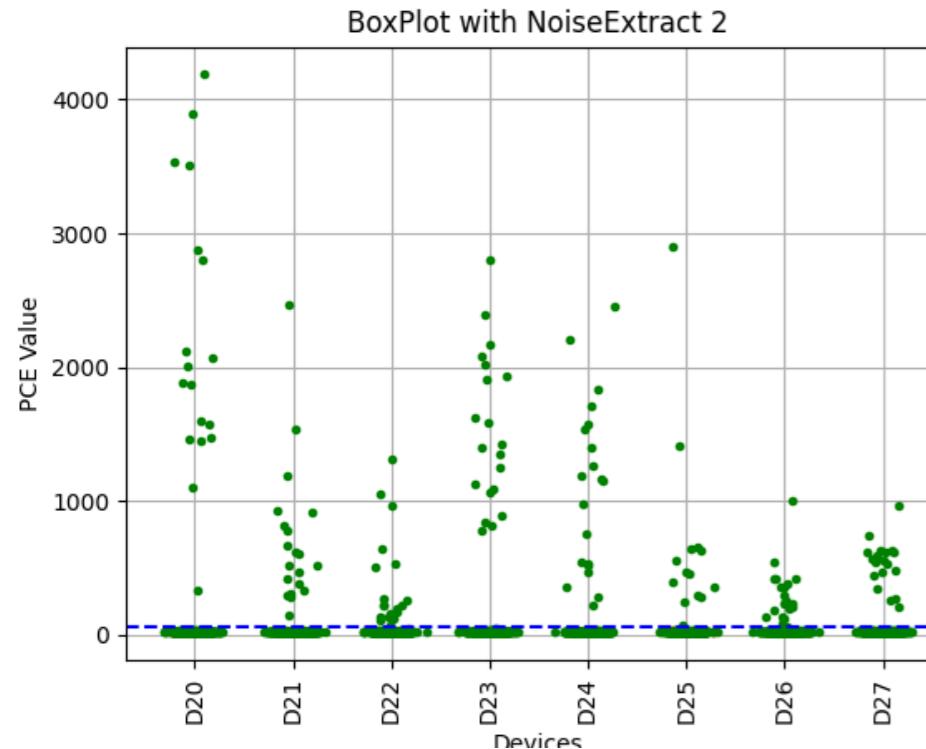
**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$



# BoxPlot con NoiseExtract 2/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D20	18	0	620	2	0.9	0
D21	20	0	620	0	1	0
D22	19	0	620	1	0.95	0
D23	20	0	620	0	1	0
D24	20	0	620	0	1	0
D25	14	0	620	6	0.7	0
D26	20	0	620	0	1	0
D27	20	0	620	0	1	0

--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

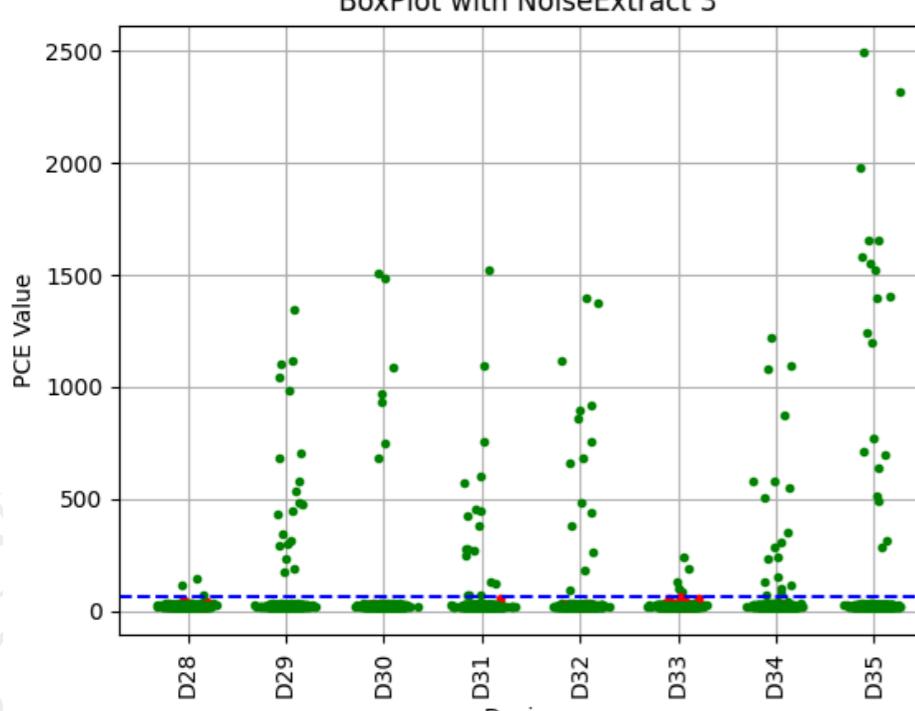
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

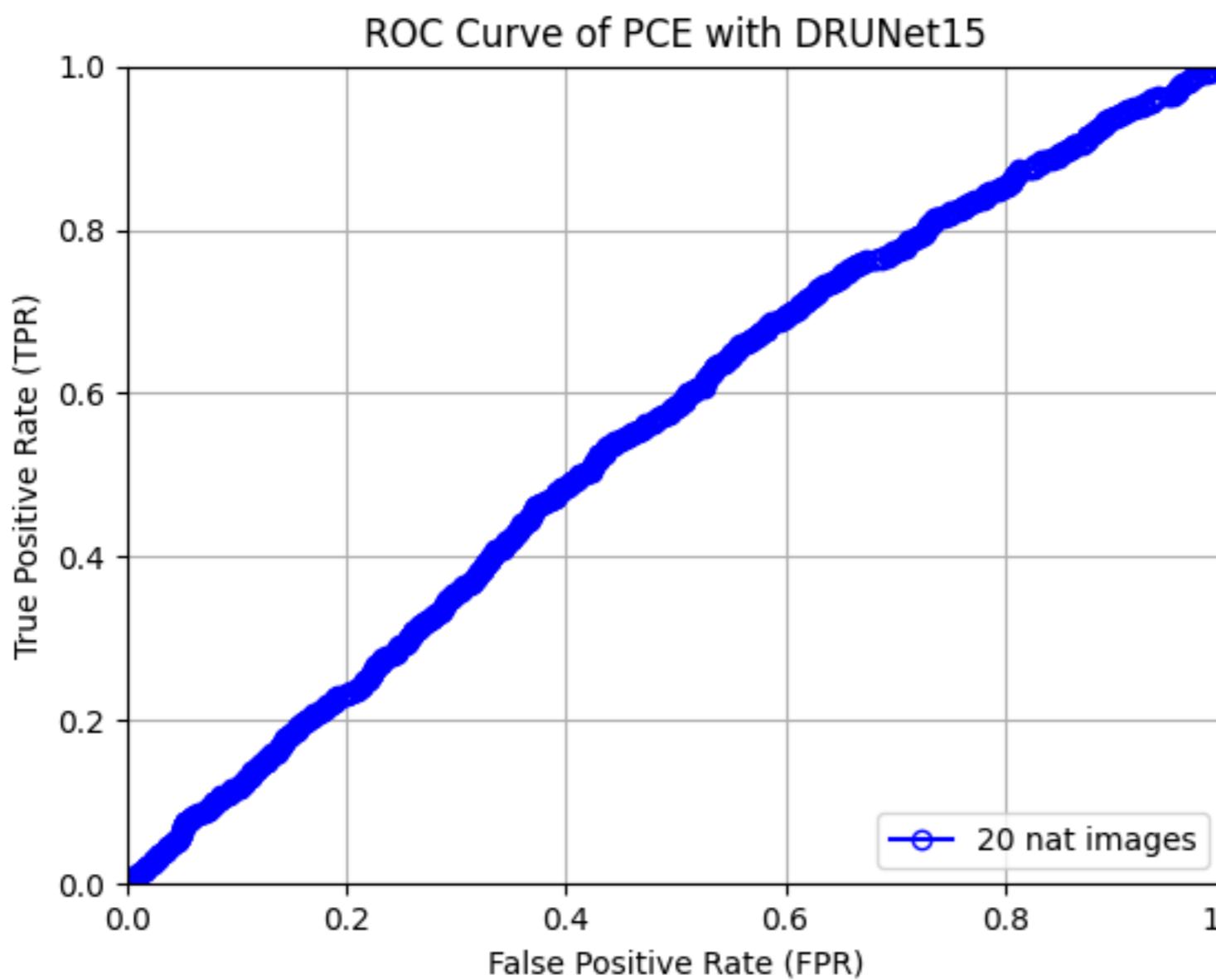
$$FPR = \frac{FP}{FP + TN}$$



Device	TP	FP	TN	FN	TPR	FPR
D28	3	0	620	17	0.15	0
D29	20	0	620	0	1	0
D30	7	0	620	13	0.35	0
D31	18	0	620	2	0.9	0
D32	15	0	620	5	0.75	0
D33	5	0	620	15	0.25	0
D34	19	0	620	1	0.95	0
D35	20	0	620	0	1	0

# ROC Curve con DRUNet15

Risultati ottenuti con *reVISION\_dataset\_base*:



Noise Level = 15

Computing statistics on PCE  
AUC on CC 0.53, expected 0.98  
AUC on PCE 0.56, expected 0.81

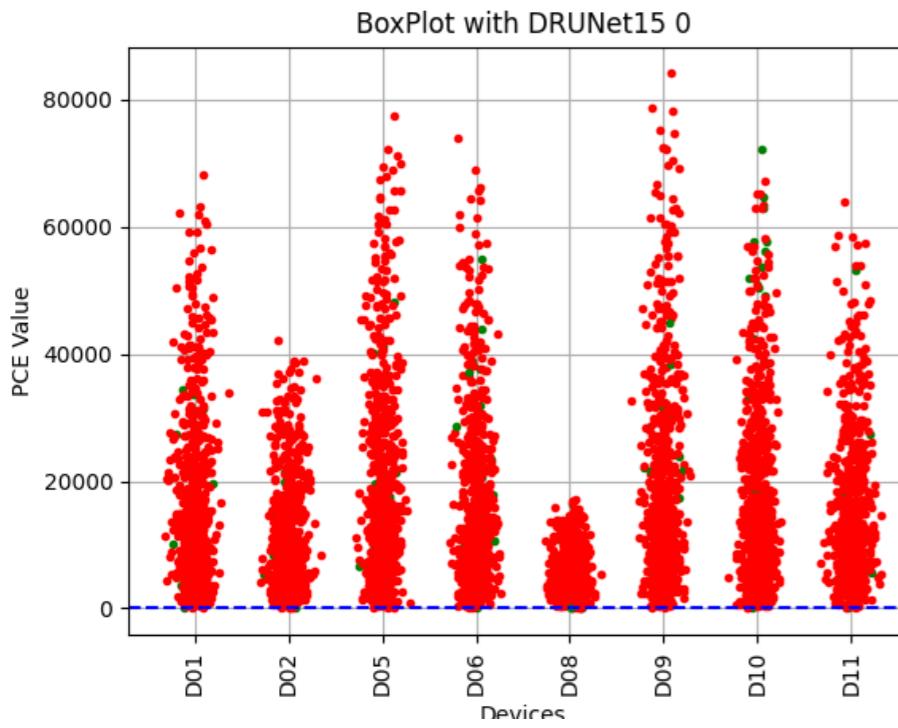
Area Under Curve (AUC)

Immagini utilizzate **per ogni dispositivo** (32 device):

- **50 immagini flat** per la fingerprint
- **20 immagini nat** per il test

# BoxPlot con DRUNet15 1/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D01	20	619	1	0	1	0.99
D02	20	619	1	0	1	0.99
D05	20	620	0	0	1	1
D06	20	619	1	0	1	0.99
D08	20	618	2	0	1	0.99
D09	20	620	0	0	1	1
D10	20	619	1	0	1	0.99
D11	20	619	1	0	1	0.99

--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

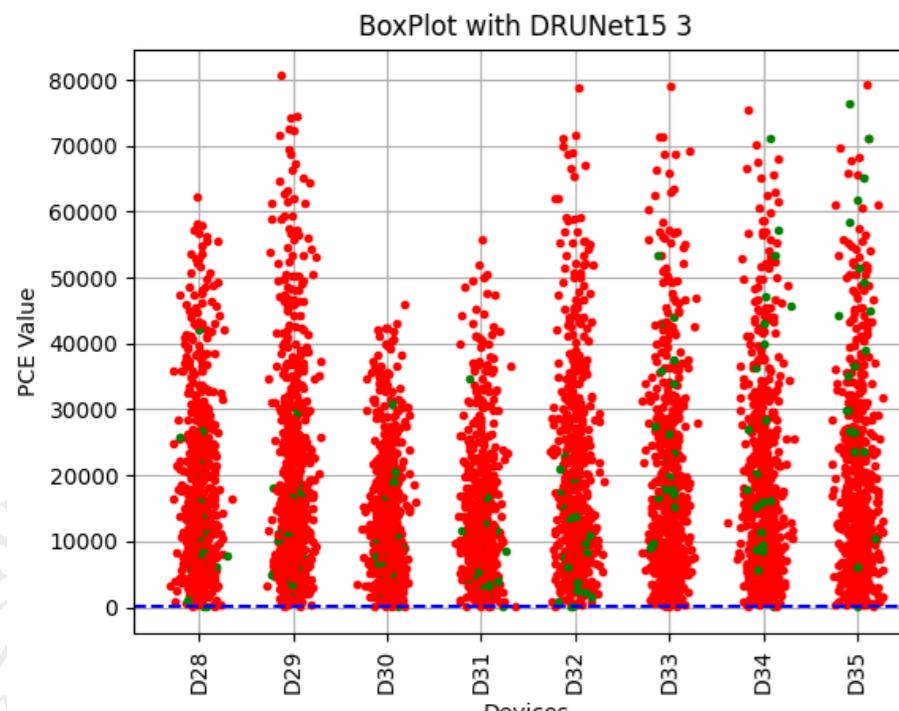
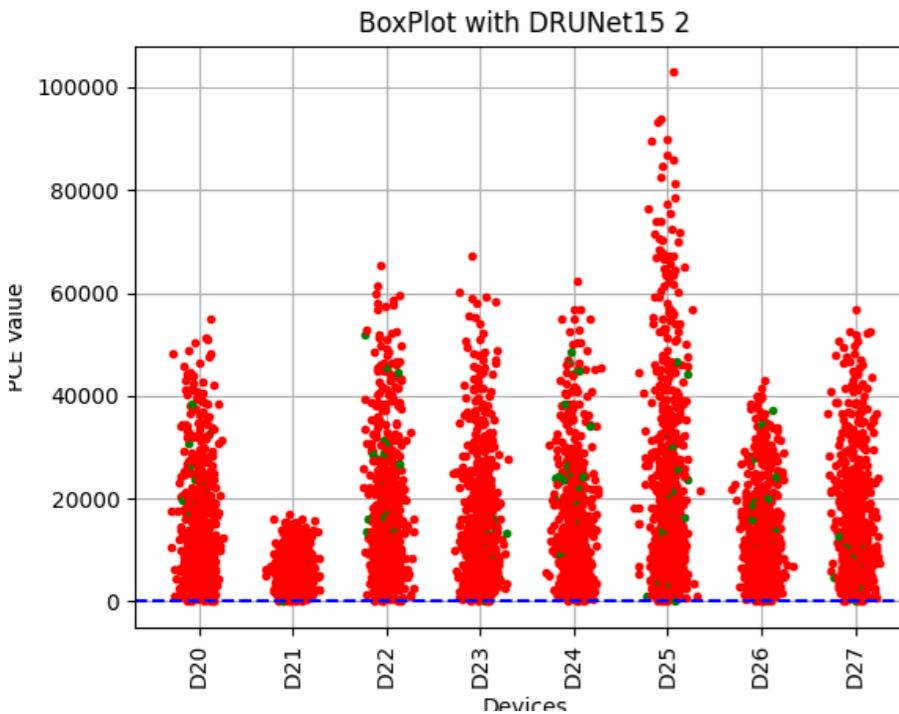
**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$

Device	TP	FP	TN	FN	TPR	FPR
D12	20	620	0	0	1	1
D13	20	620	0	0	1	1
D14	20	620	0	0	1	1
D15	20	619	1	0	1	0.99
D16	20	620	0	0	1	1
D17	19	620	0	1	0.95	1
D18	20	620	0	0	1	1
D19	20	619	1	0	1	0.99

# BoxPlot con DRUNet15 2/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D28	20	619	1	0	1	0.99
D29	20	620	0	0	1	1
D30	20	619	1	0	1	0.99
D31	20	619	1	0	1	0.99
D32	20	620	0	0	1	1
D33	20	619	1	0	1	0.99
D34	20	619	1	0	1	0.99
D35	20	619	1	0	1	0.99

--- Threshold = 60

PCE > 60:

- True Positive (TP)
- False Positive (FP)

PCE < 60:

- True Negative (TN)
- False Negative (FN)

True Positive Rate (TPR):

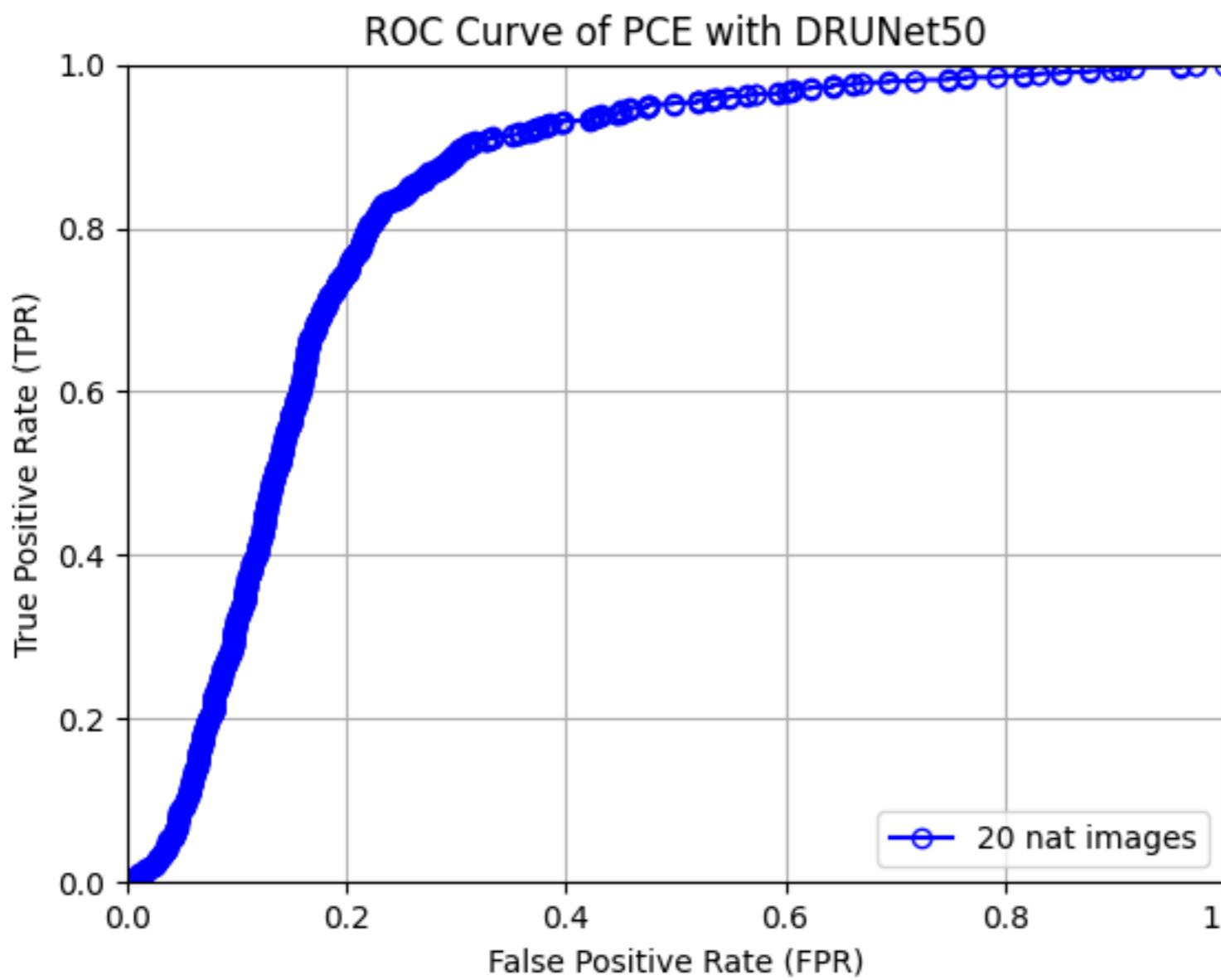
$$TPR = \frac{TP}{TP + FN}$$

False Positive Rate (FPR):

$$FPR = \frac{FP}{FP + TN}$$

# ROC Curve con DRUNet50

Risultati ottenuti con *reVISION\_dataset\_base*:



Noise Level = 50

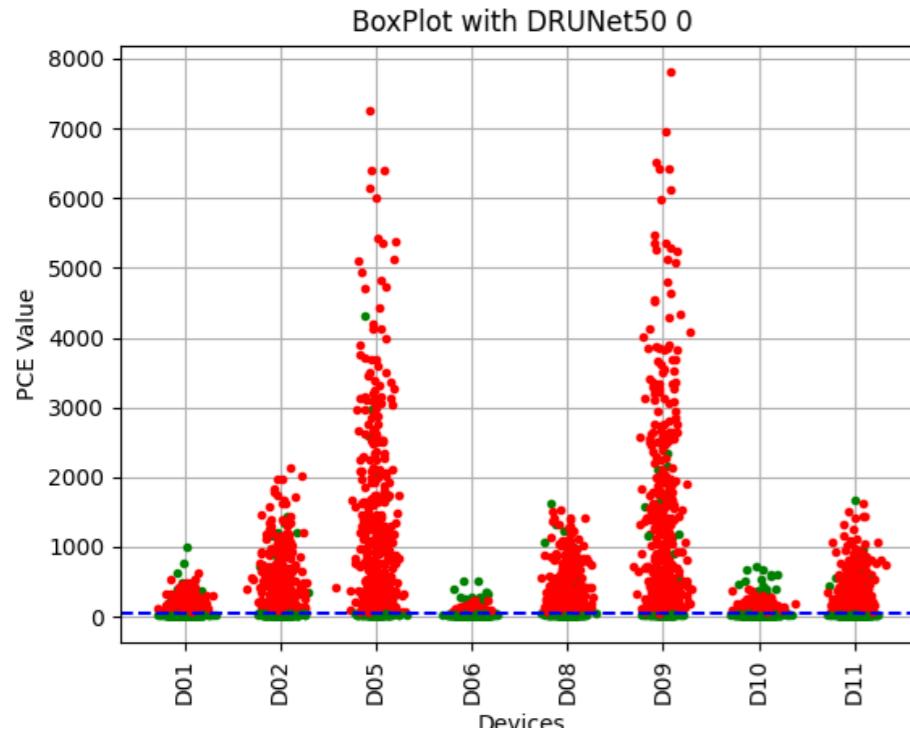
Computing statistics on PCE  
AUC on CC 0.73, expected 0.98  
AUC on PCE 0.83, expected 0.81

Area Under Curve (AUC)

- Immagini utilizzate **per ogni dispositivo** (32 device):
- **50 immagini flat** per la fingerprint
  - **20 immagini nat** per il test

# BoxPlot con DRUNet50 1/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D01	20	206	414	0	1	0.33
D02	20	404	216	0	1	0.65
D05	20	499	121	0	1	0.8
D06	19	80	540	1	0.95	0.12
D08	20	428	192	0	1	0.69
D09	20	515	105	0	1	0.83
D10	20	164	456	0	1	0.26
D11	20	307	313	0	1	0.49

--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

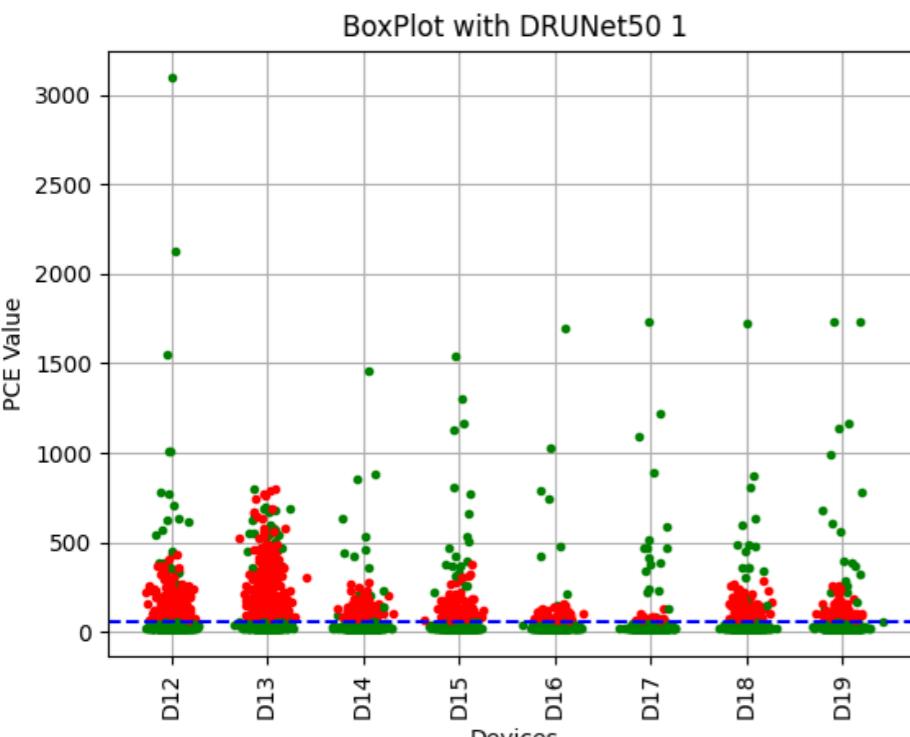
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

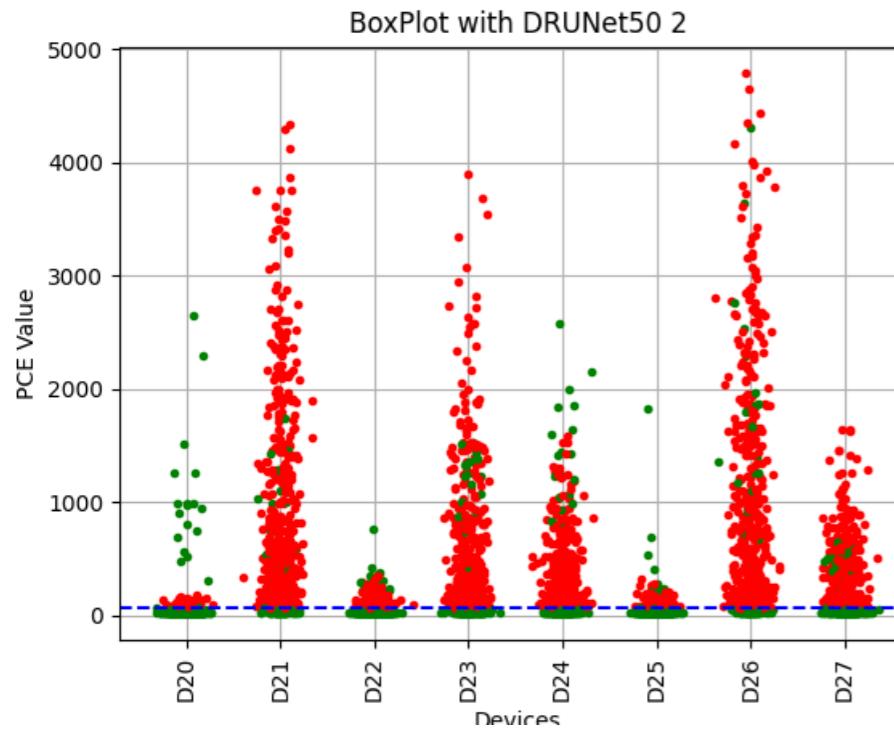
$$FPR = \frac{FP}{FP + TN}$$



Device	TP	FP	TN	FN	TPR	FPR
D12	20	207	413	0	1	0.33
D13	20	273	347	0	1	0.44
D14	17	107	513	3	0.85	0.17
D15	20	124	496	0	1	0.2
D16	9	67	533	11	0.45	0.1
D17	19	23	597	1	0.95	0.03
D18	19	142	478	1	0.95	0.22
D19	20	99	521	0	1	0.15

# BoxPlot con DRUNet50 2/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D20	18	70	550	2	0.9	0.11
D21	20	514	106	0	1	0.82
D22	20	142	478	1	0.95	0.22
D23	20	420	200	0	1	0.67
D24	20	392	228	0	1	0.63
D25	16	109	511	4	0.8	0.17
D26	20	522	98	0	1	0.84
D27	20	361	259	0	1	0.58

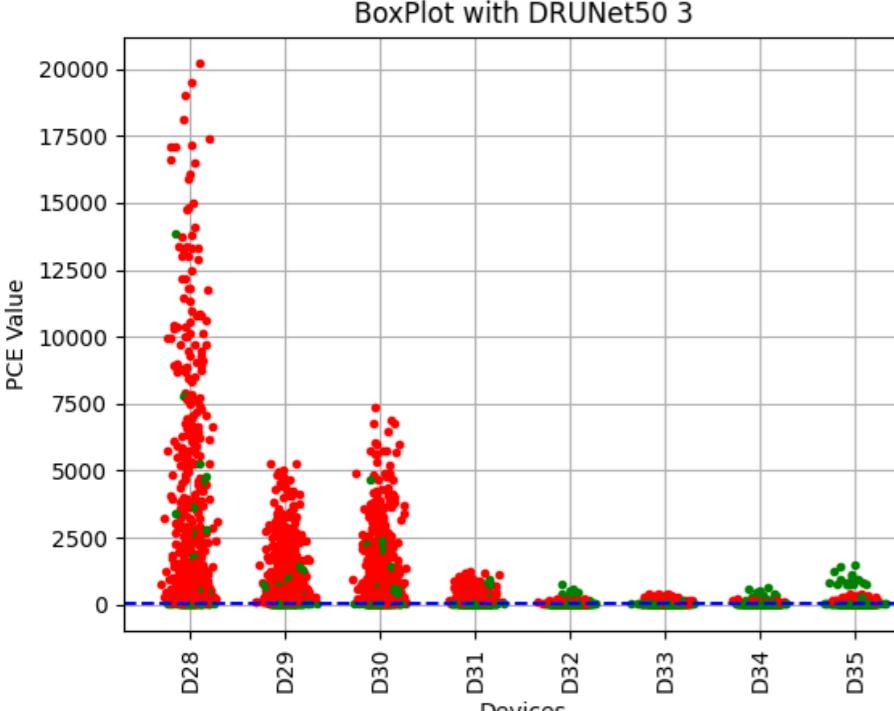
--- Threshold = 60

PCE > 60:

- True Positive (TP)
- False Positive (FP)

PCE < 60:

- True Negative (TN)
- False Negative (FN)



Device	TP	FP	TN	FN	TPR	FPR
D28	17	572	48	3	0.85	0.92
D29	20	536	84	0	1	0.86
D30	20	530	90	0	1	0.85
D31	18	309	311	1	0.95	0.49
D32	14	79	541	6	0.7	0.12
D33	14	164	456	6	0.7	0.26
D34	20	71	549	0	1	0.11
D35	20	200	420	0	1	0.32

True Positive Rate (TPR):

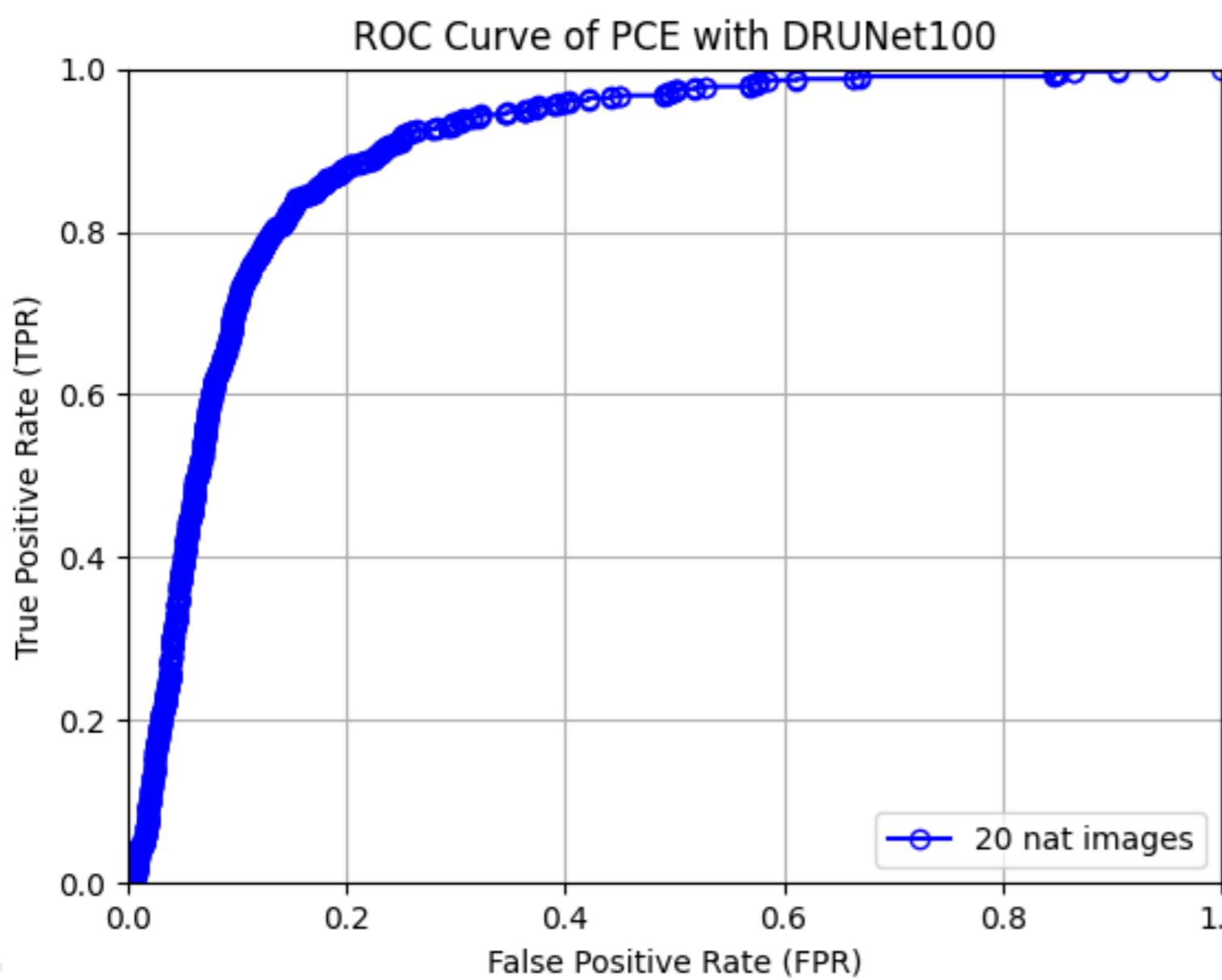
$$TPR = \frac{TP}{TP + FN}$$

False Positive Rate (FPR):

$$FPR = \frac{FP}{FP + TN}$$

# ROC Curve con DRUNet100

Risultati ottenuti con *reVISION\_dataset\_base*:



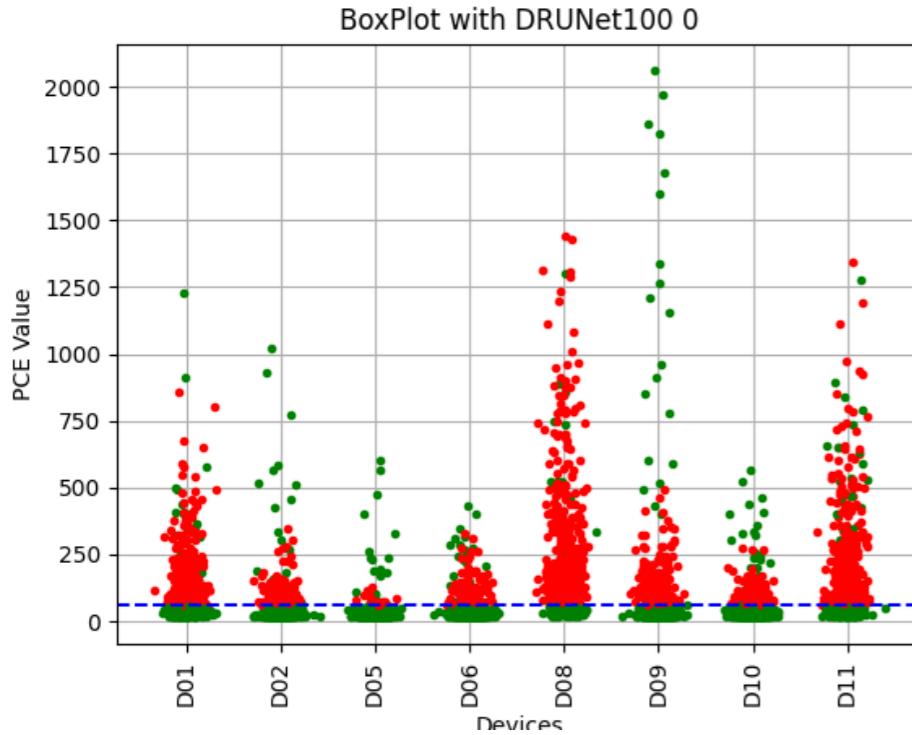
Noise Level = 100

Computing statistics on PCE  
 AUC on CC 0.75, expected 0.98  
 AUC on PCE 0.90, expected 0.81

- Immagini utilizzate **per ogni dispositivo** (32 device):
- **50 immagini flat** per la fingerprint
  - **20 immagini nat** per il test
  - **Tempo** per il **calcolo della fingerprint** (per **ogni dispositivo**) → **4,5 min.**
  - **Tempo di elaborazione** per **ogni immagine** → **5 sec.**

# BoxPlot con DRUNet100 1/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D01	20	262	358	0	1	0.42
D02	19	15	505	1	0.95	0.18
D05	18	20	600	2	0.9	0.03
D06	19	113	507	1	0.95	0.18
D08	20	450	170	0	1	0.72
D09	20	176	444	0	1	0.28
D10	20	95	525	0	1	0.15
D11	20	333	287	0	1	0.53

--- Threshold = 60

**PCE > 60:**

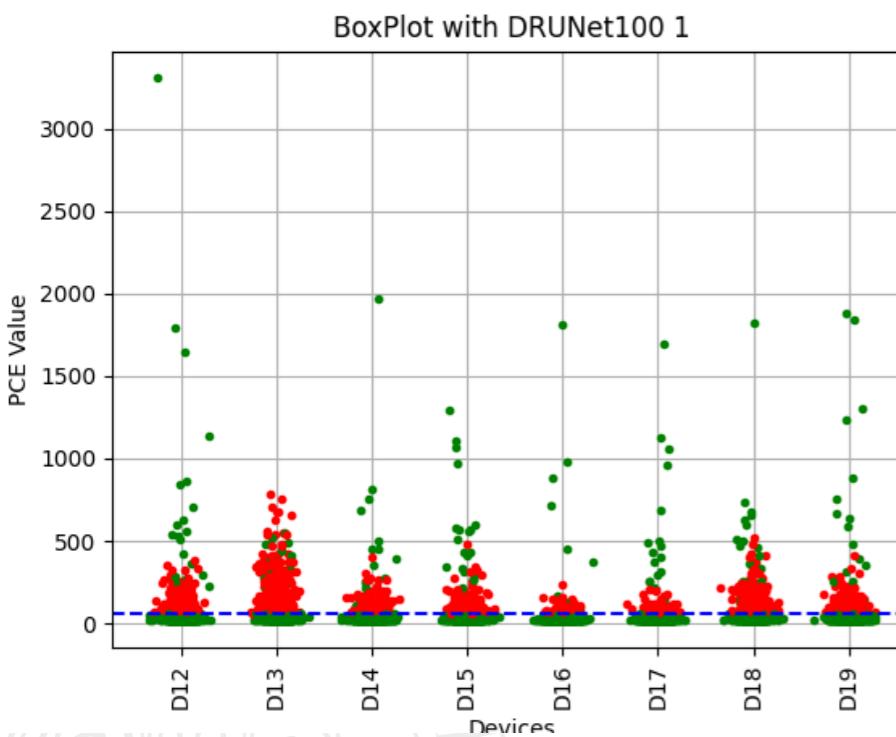
- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$



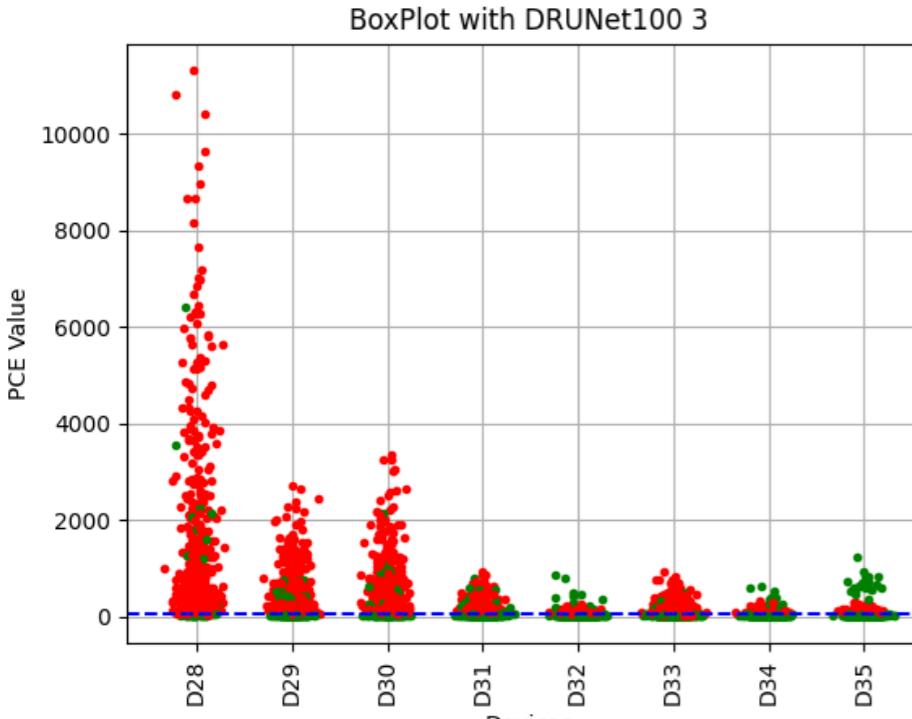
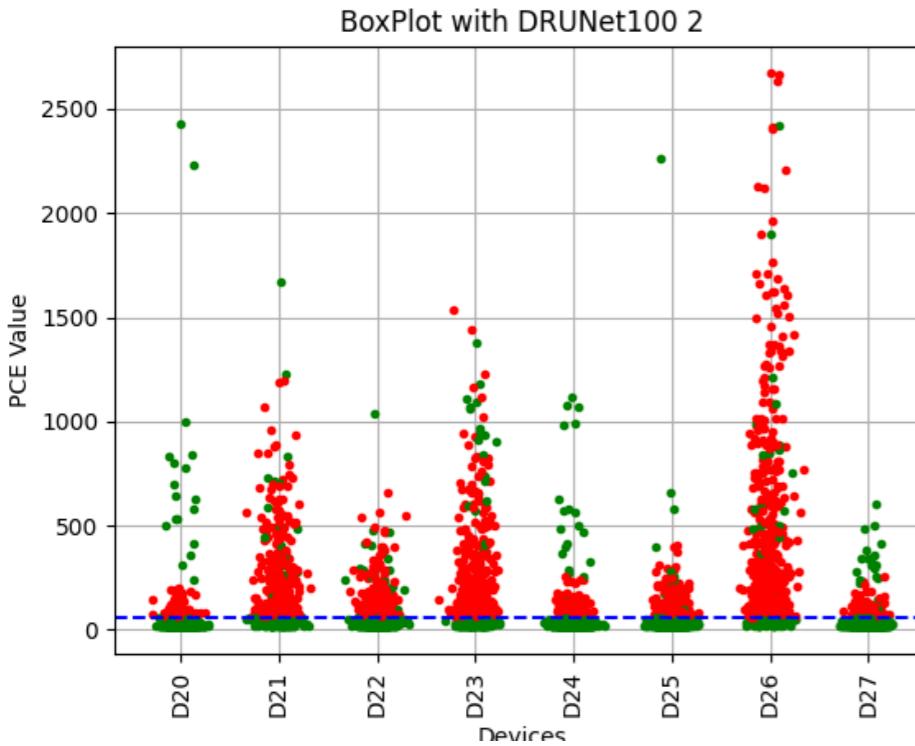
Device	TP	FP	TN	FN	TPR	FPR
D12	20	167	453	0	1	0.26
D13	20	241	379	0	1	0.38
D14	19	120	500	1	0.95	0.19
D15	20	129	491	0	1	0.20
D16	11	53	567	9	0.55	0.08
D17	19	81	539	1	0.95	0.13
D18	20	191	429	0	1	0.30
D19	20	128	492	0	1	0.20

**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$

# BoxPlot con DRUNet100 2/2

Risultati ottenuti con *reVISION\_dataset\_base*:



Device	TP	FP	TN	FN	TPR	FPR
D28	19	579	41	1	0.95	0.93
D29	20	474	146	0	1	0.76
D30	19	494	126	1	0.95	0.79
D31	20	309	311	0	1	0.49
D32	16	100	520	4	0.8	0.16
D33	13	304	316	7	0.65	0.49
D34	20	109	511	0	1	0.17
D35	20	158	462	0	1	0.25

--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

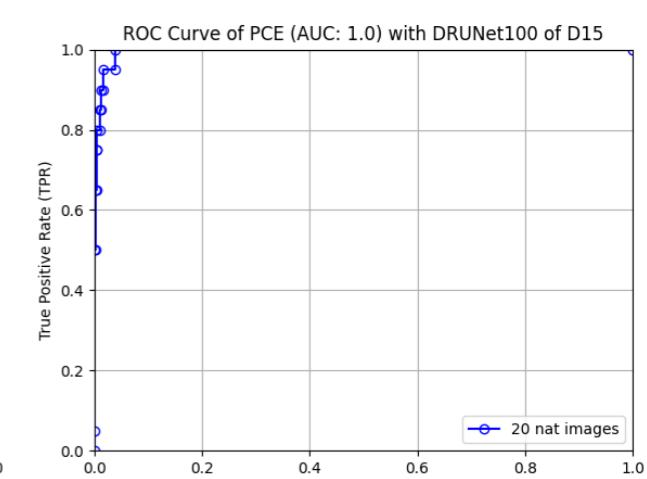
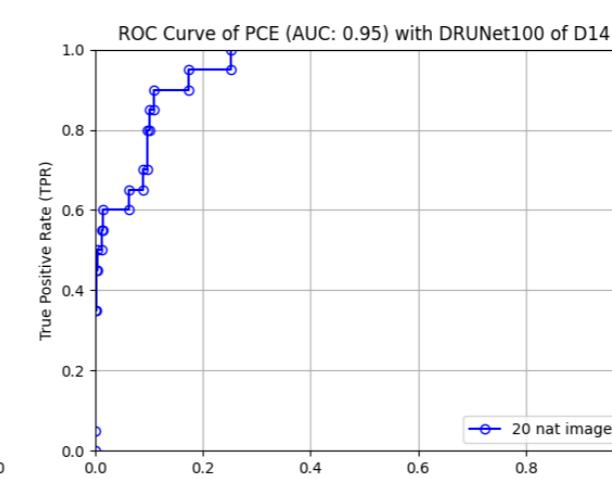
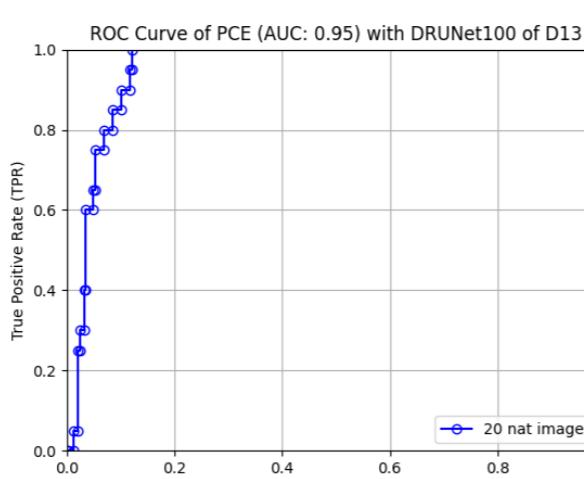
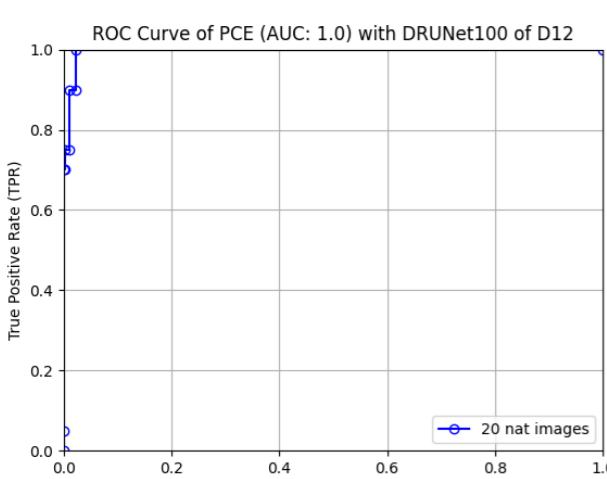
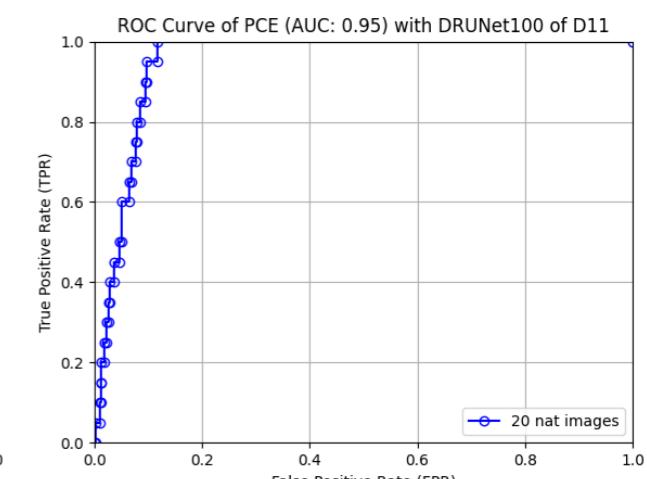
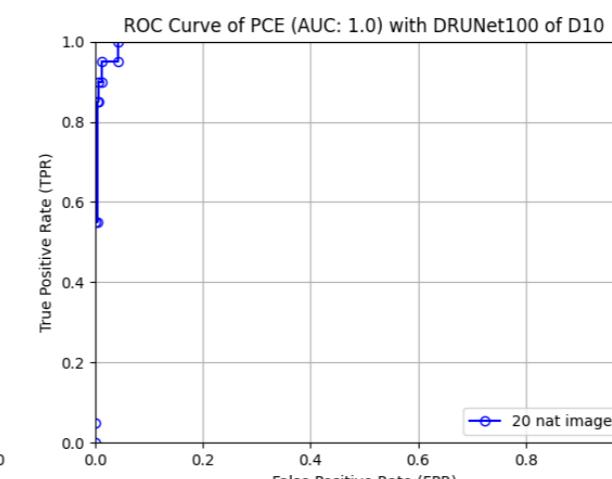
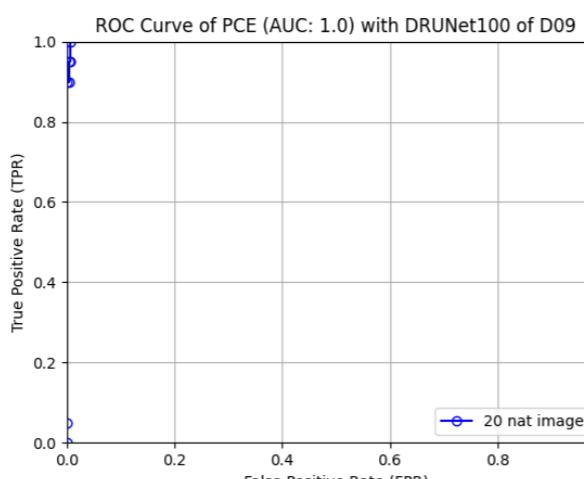
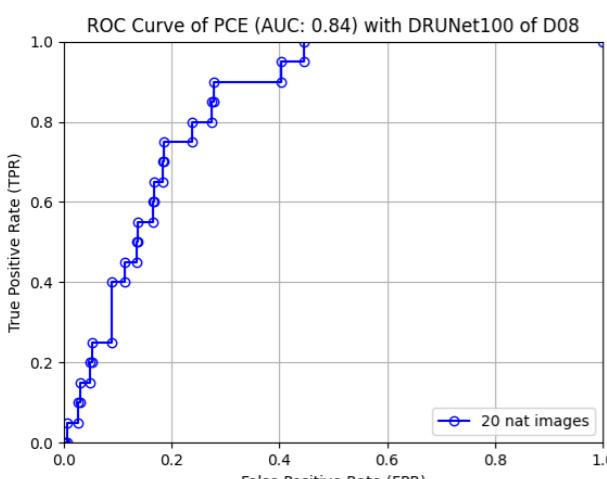
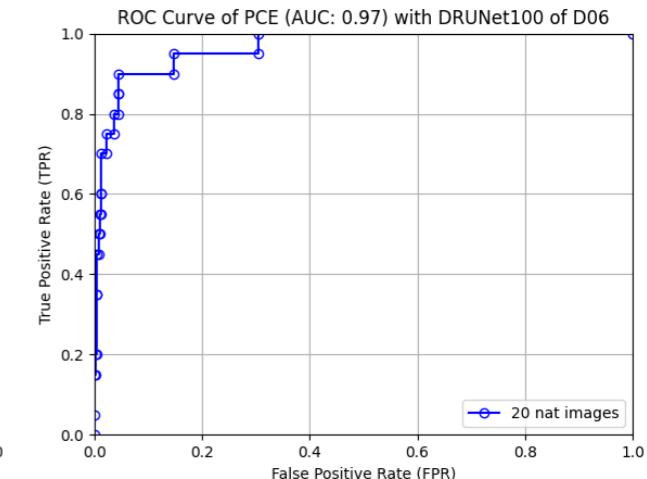
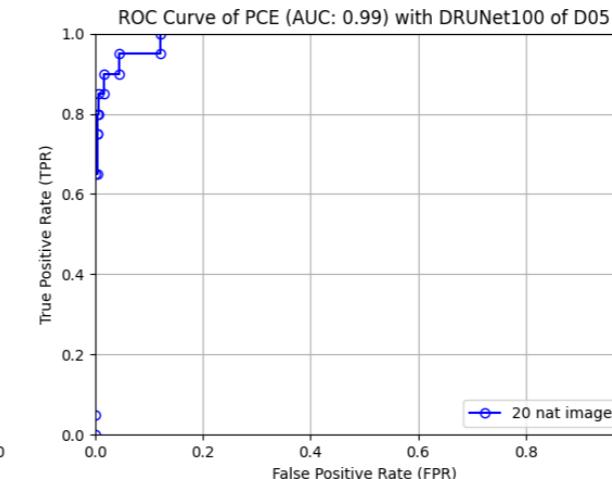
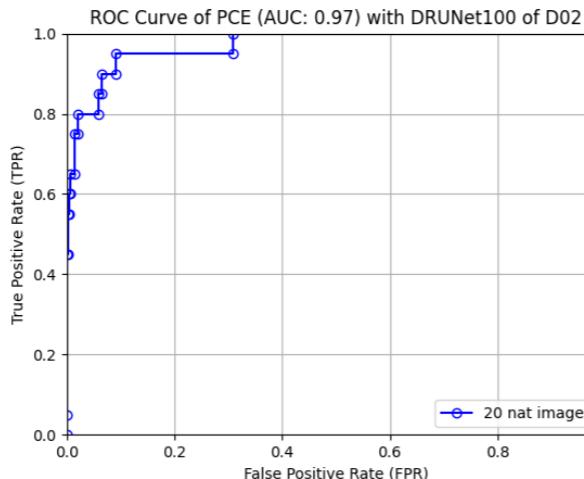
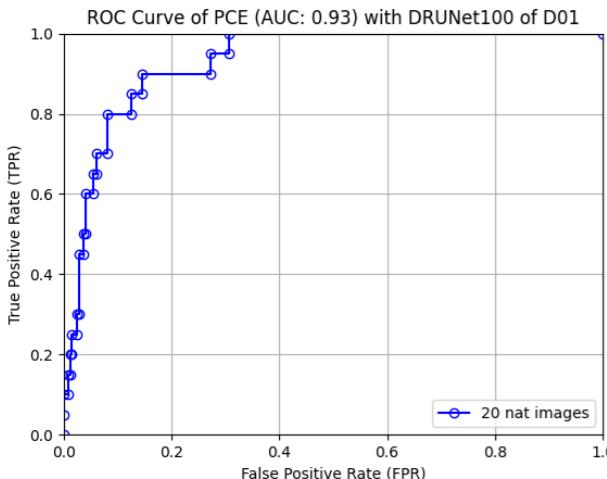
$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$

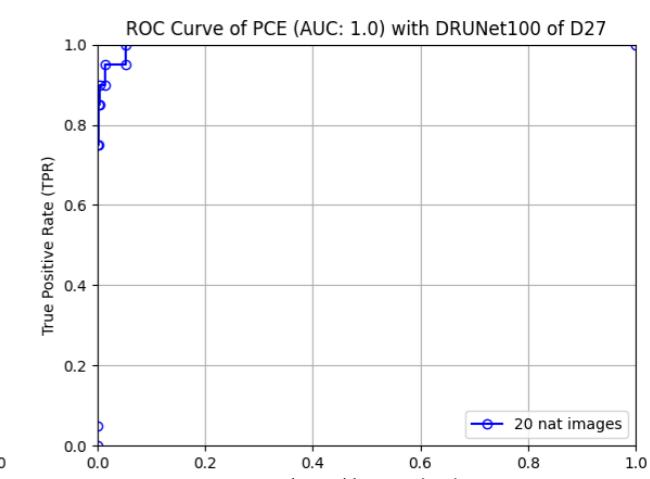
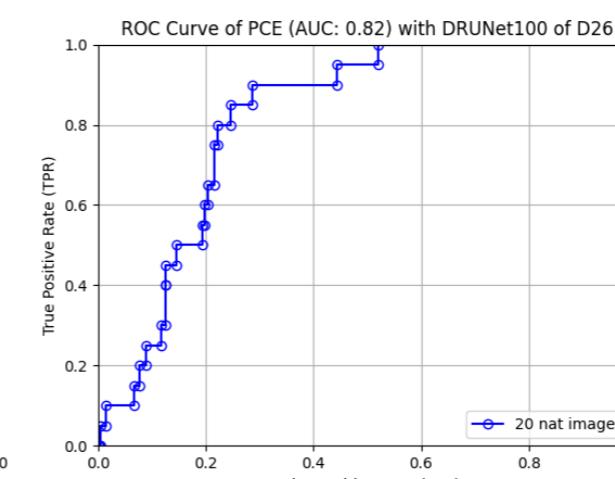
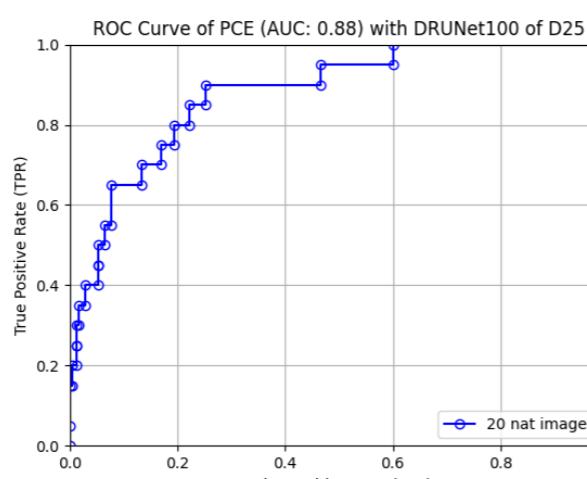
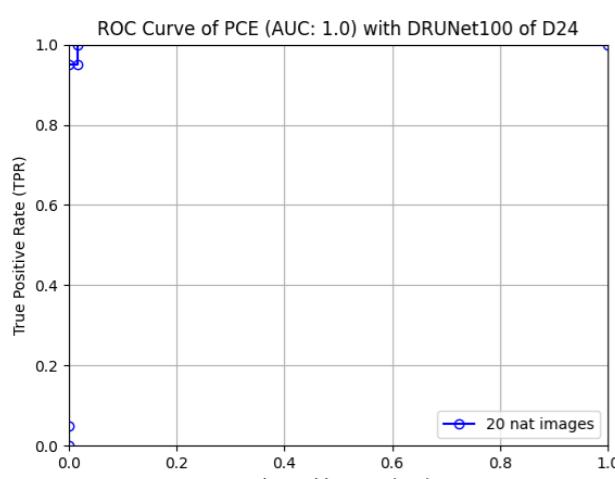
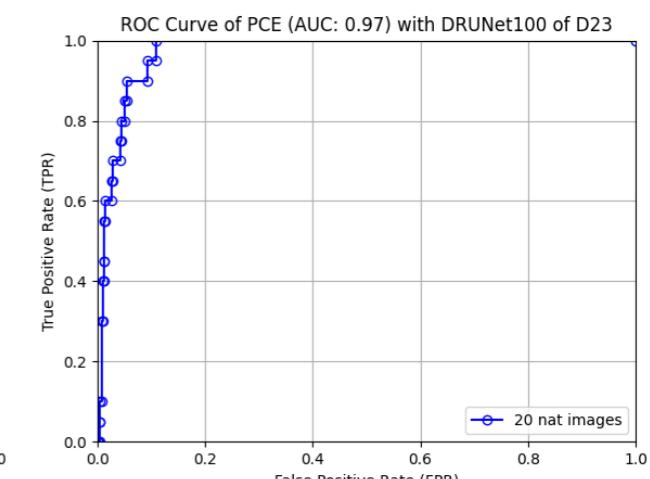
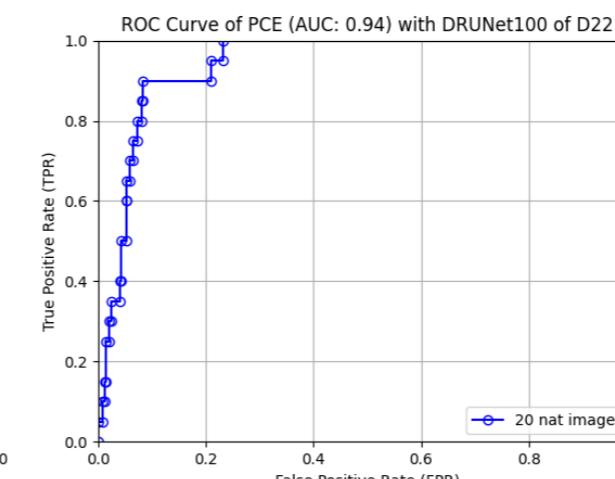
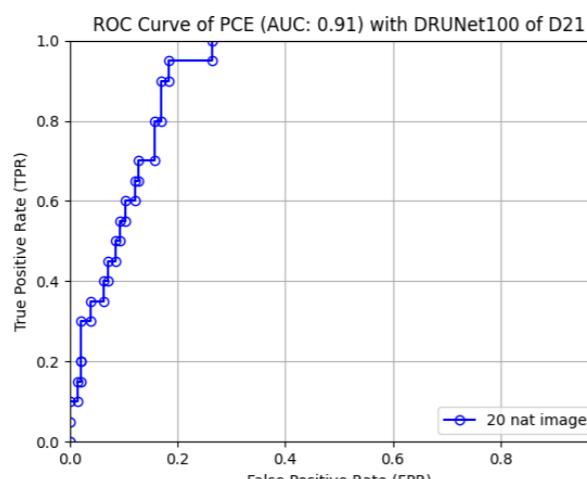
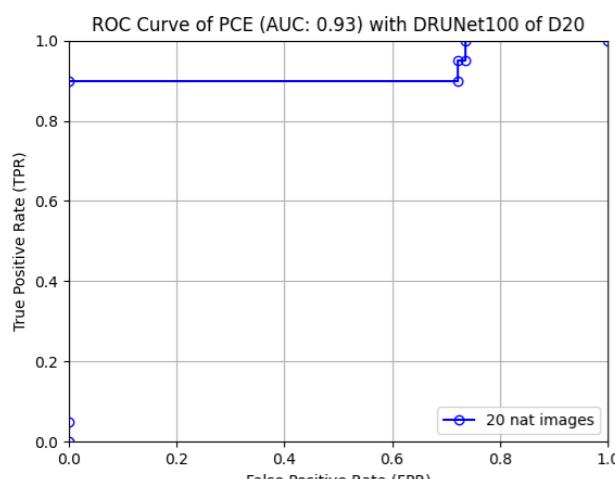
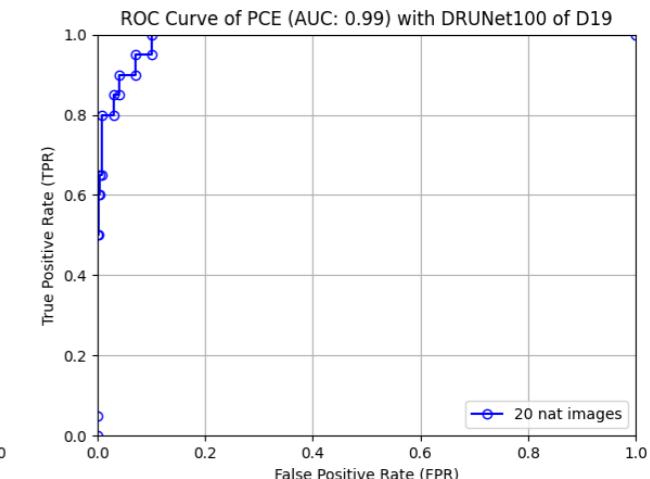
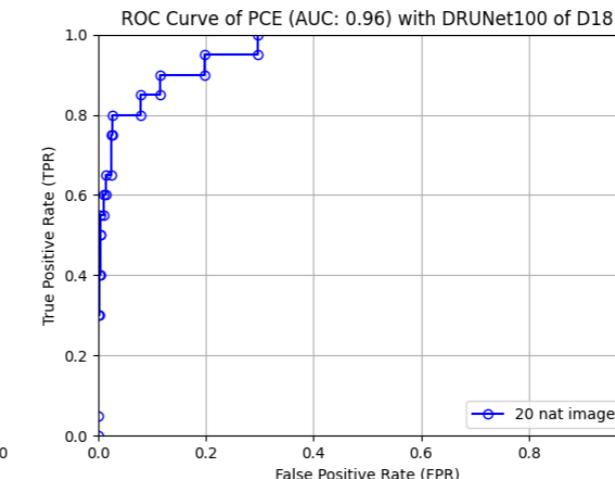
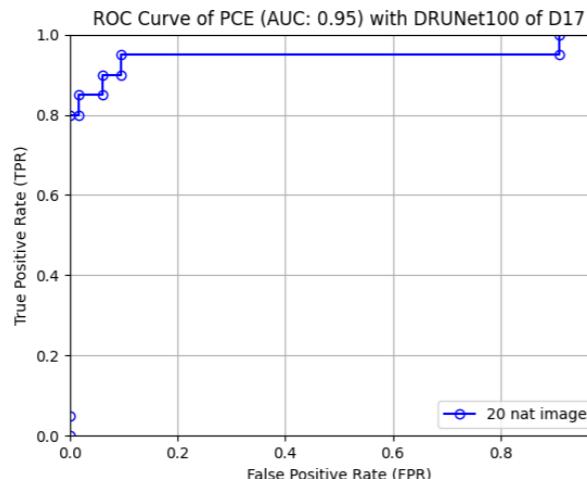
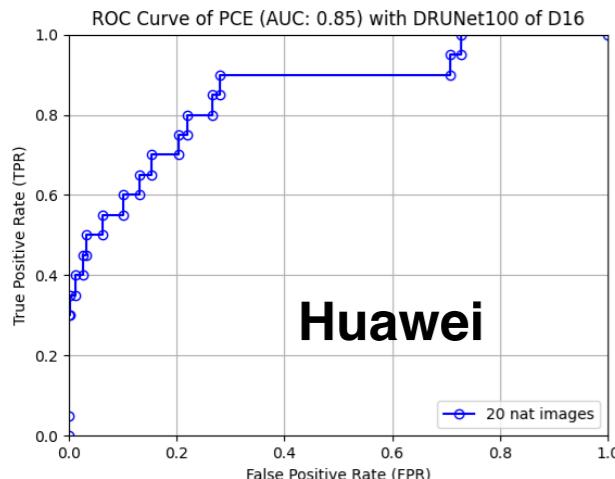
# ROC Curve con DRUNet100 per Singolo Device 1/3

Risultati ottenuti con *reVISION\_dataset\_base*:



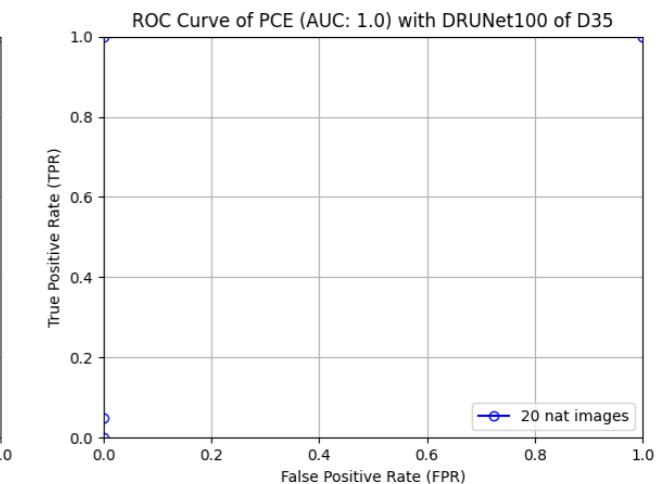
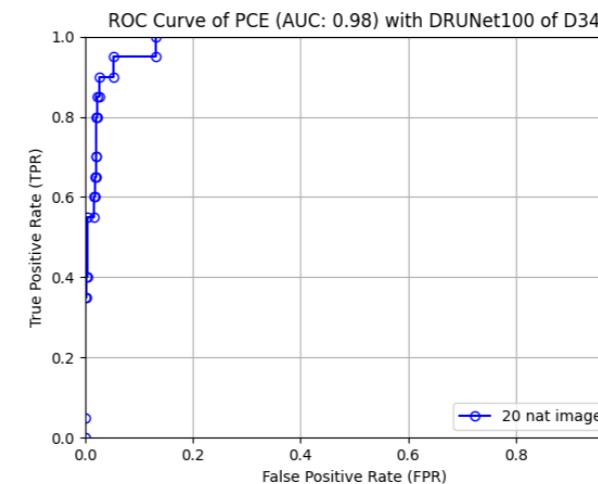
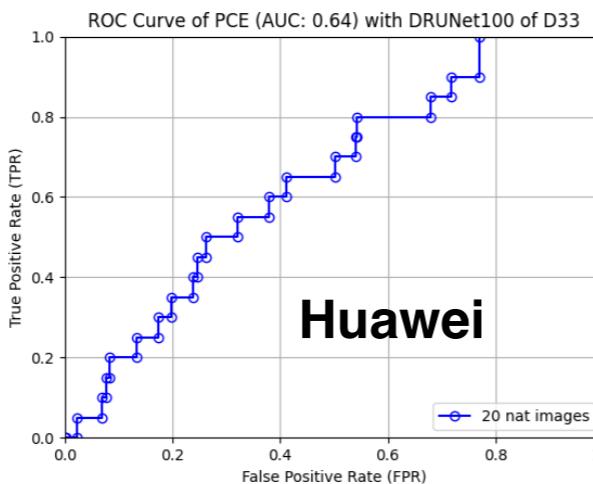
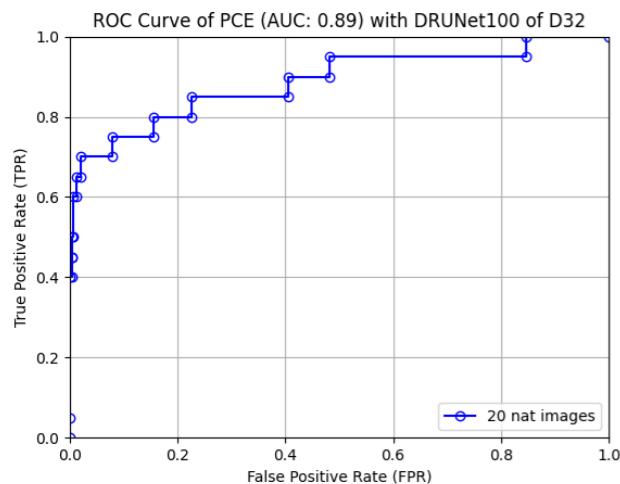
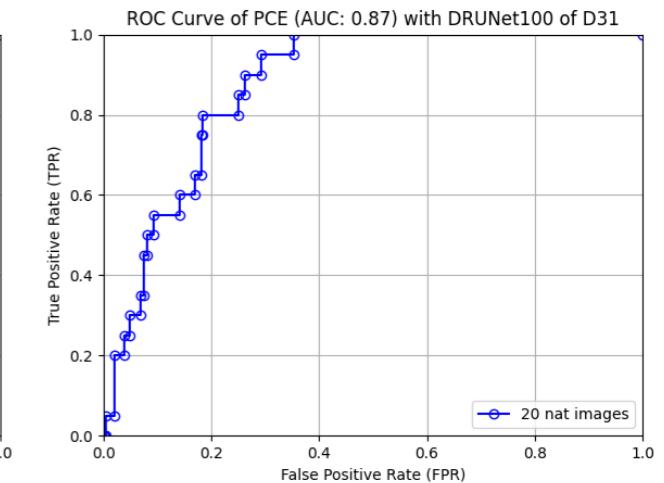
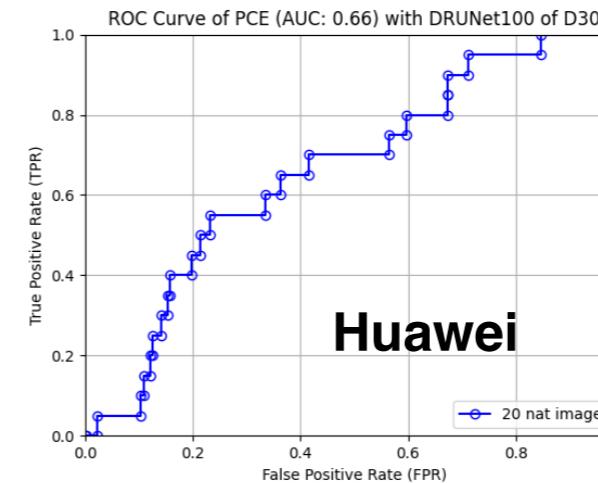
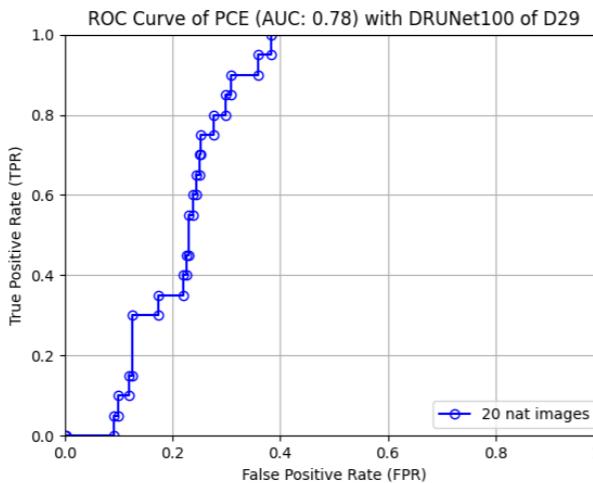
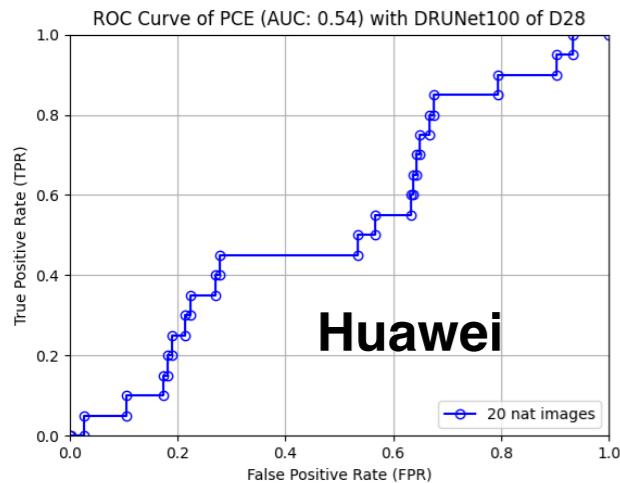
# ROC Curve con DRUNet100 per Singolo Device 2/3

Risultati ottenuti con *reVISION\_dataset\_base*:



# ROC Curve con DRUNet100 per Singolo Device 3/3

Risultati ottenuti con *reVISION\_dataset\_base*:



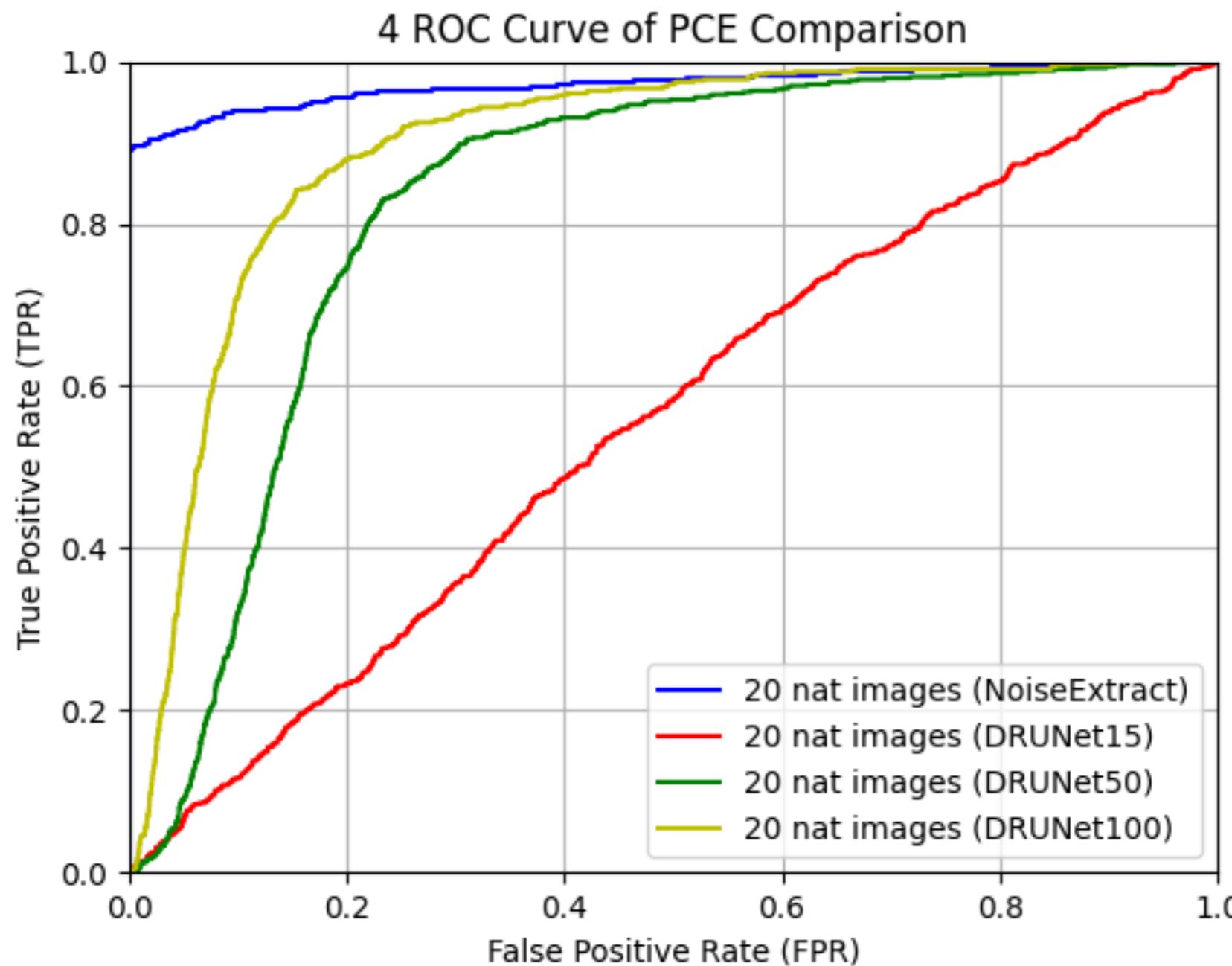
## Confronto sul dataset reVISION\_dataset\_base

Di seguito è riportata una **tabella comparativa** dei metodi sopra analizzati:

	NoiseExtract	DRUNet15	DRUNet50	DRUNet100
AUC	0.97	0.56	0.83	0.90

# Confronto delle 4 ROC Curve

Risultati ottenuti con *reVISION\_dataset\_base*:



# Ablation Studies su DRUNet50

Per quanto riguarda il modello con **DRUNet50**, abbiamo **rimosso delle operazioni** per osservare come si comportava il sistema complessivo in termini di prestazioni.

In particolare abbiamo rimosso:

- **Solo l'operazione di Zero Mean**
- **Solo l'operazione di Wiener DFT**
- **Entrambe le operazioni di Zero Mean e di Wiener DFT**

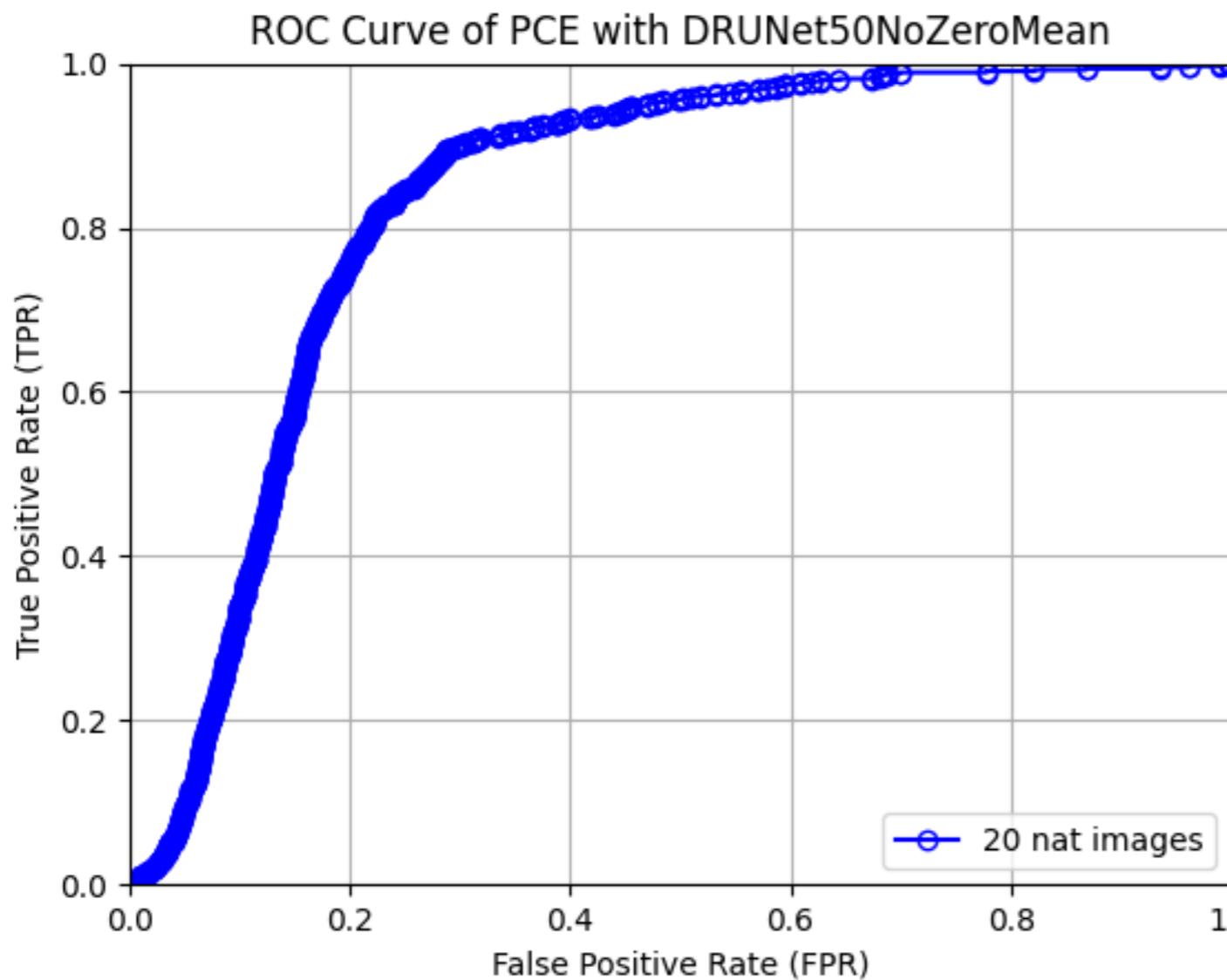
Gli esperimenti sono sempre stati effettuati sul dataset

***reVISION\_dataset\_base***

# ROC Curve con DRUNet50NoZeroMean

In questo caso abbiamo rimosso:

- L'operazione di **Zero Mean**



Noise Level = 50

Computing statistics on PCE  
AUC on CC 0.73, expected 0.98  
AUC on PCE 0.83, expected 0.81

Area Under Curve (AUC)

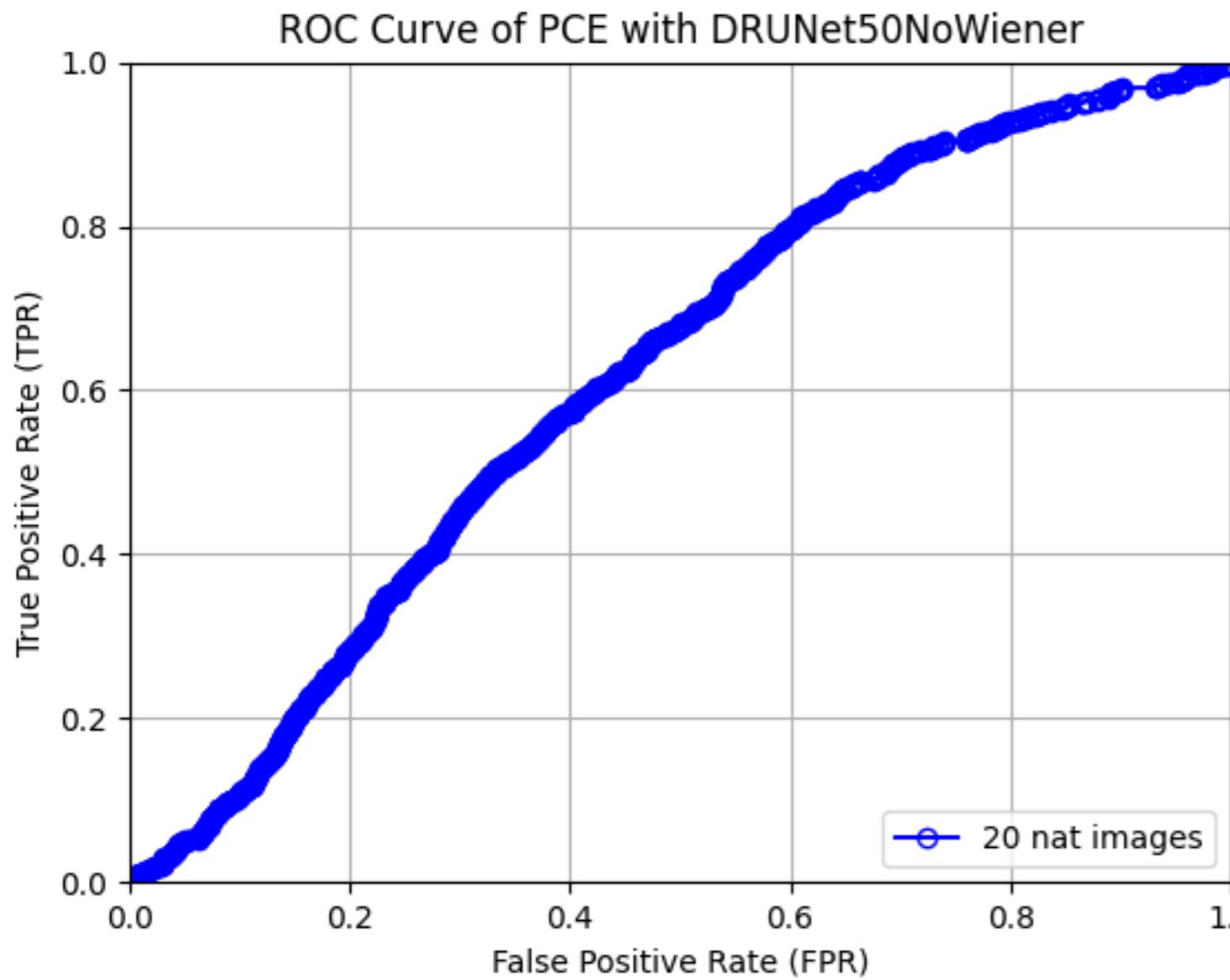
Immagini utilizzate **per ogni dispositivo** (32 device):

- **50 immagini flat** per la fingerprint
- **20 immagini nat** per il test

# ROC Curve con DRUNet50NoWiener

In questo caso abbiamo rimosso:

- L'operazione di **Wiener DFT**



Noise Level = 50

Computing statistics on PCE  
AUC on CC 0.60, expected 0.98  
AUC on PCE 0.62, expected 0.81

Area Under Curve (AUC)

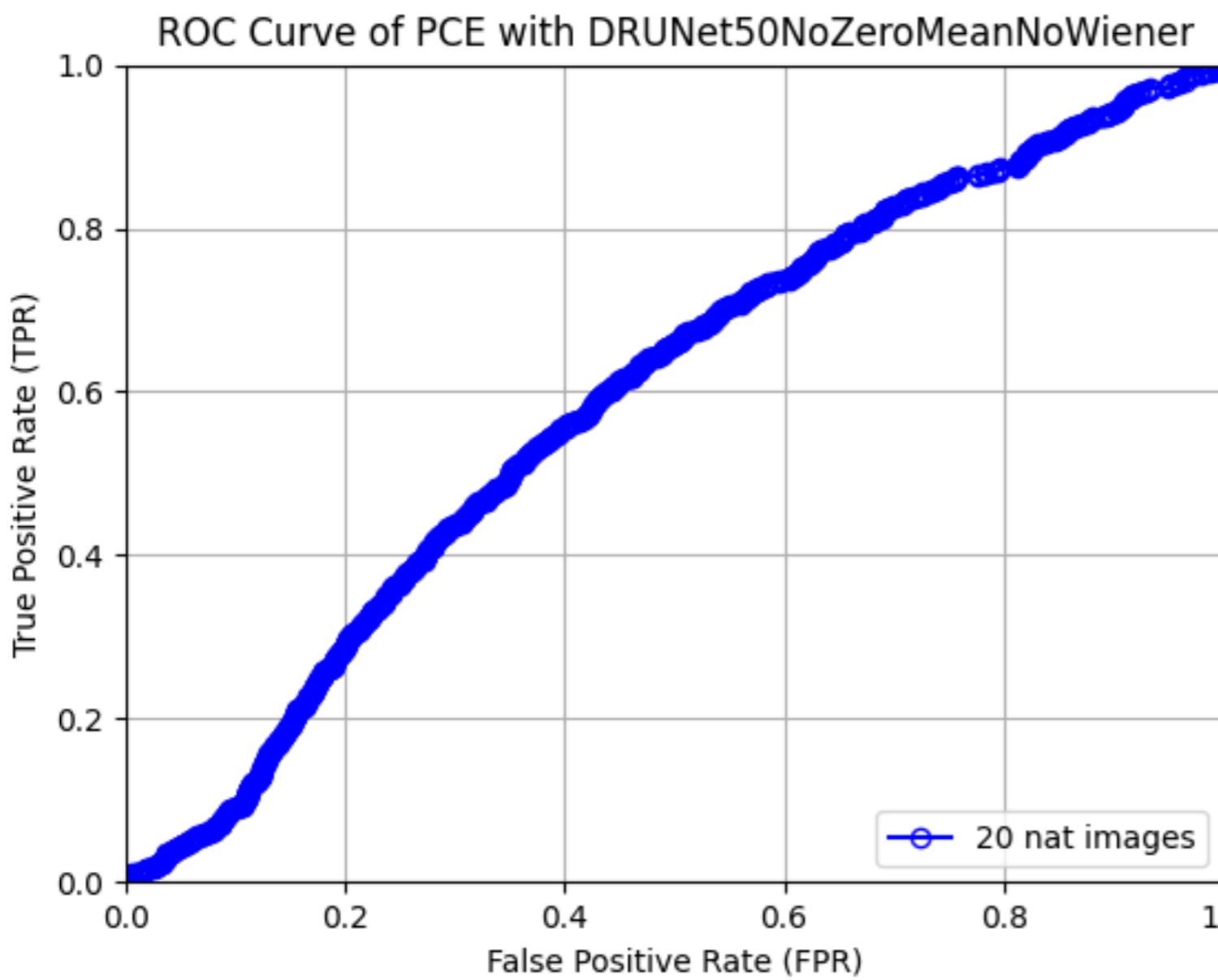
Immagini utilizzate **per ogni dispositivo** (32 device):

- **50 immagini flat** per la fingerprint
- **20 immagini nat** per il test

# ROC Curve con DRUNet50NoZeroMeanNoWiener

In questo caso abbiamo rimosso:

- L'operazione di **Zero Mean** e di **Wiener DFT**



Noise Level = 50

Computing statistics on PCE  
AUC on CC 0.51, expected 0.98  
AUC on PCE 0.59, expected 0.81

Area Under Curve (AUC)

Immagini utilizzate **per ogni dispositivo** (32 device):

- **50 immagini flat** per la fingerprint
- **20 immagini nat** per il test

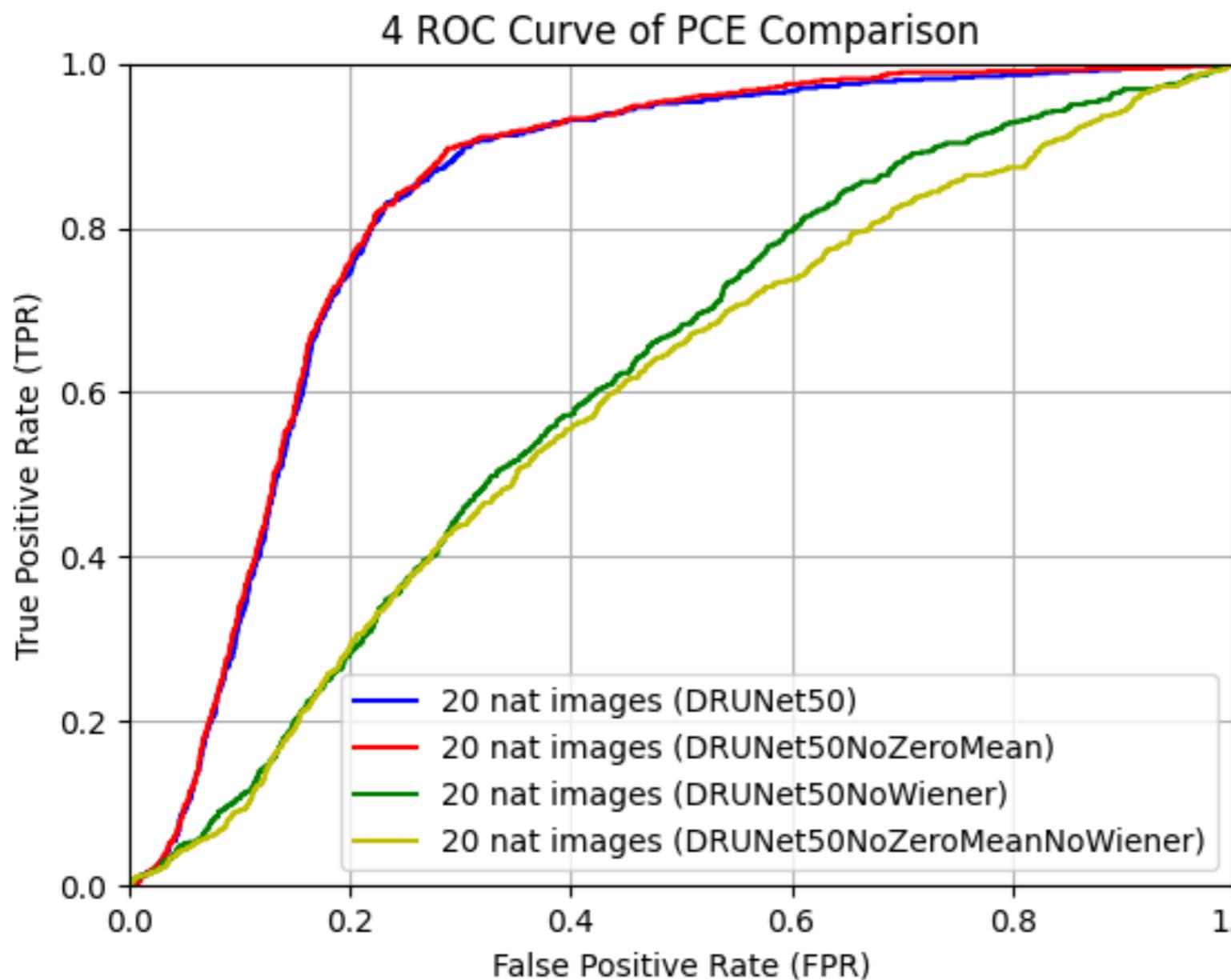
# Confronto Risultati dell'Ablation Studies

Di seguito è riportata una **tabella comparativa** dei risultati ottenuti tramite gli *Ablation Studies*:

	<b>DRUNet50</b>	<b>DRUNet50NoZeroMean</b>	<b>DRUNet50NoWiener</b>	<b>DRUNet50NoZeroMeanNoWiener</b>
<b>AUC</b>	0.83	0.83	0.62	0.59

# Confronto delle 4 ROC Curve

Confrontiamo le **3 ROC degli Ablation Studies** con la **ROC di DRUNet50**:



Si può notare come la rimozione dell'**operazione di Zero Mean** non incida sulle prestazioni del sistema complessivo.

La rimozione dell'**operazione di Wiener DFT** comporta invece una drastica riduzione dell'**AUC** sulla PCE.

# Conclusioni

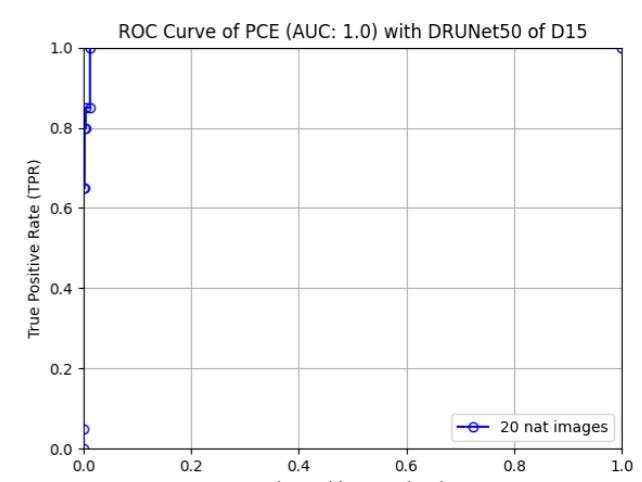
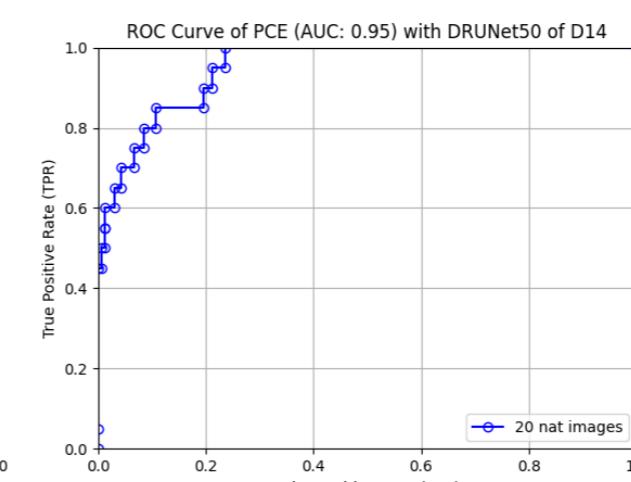
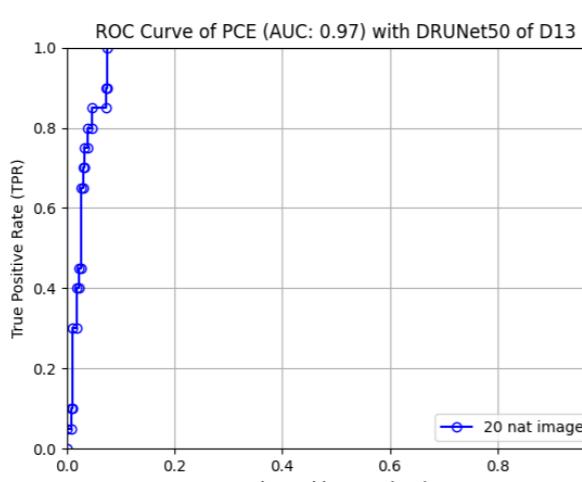
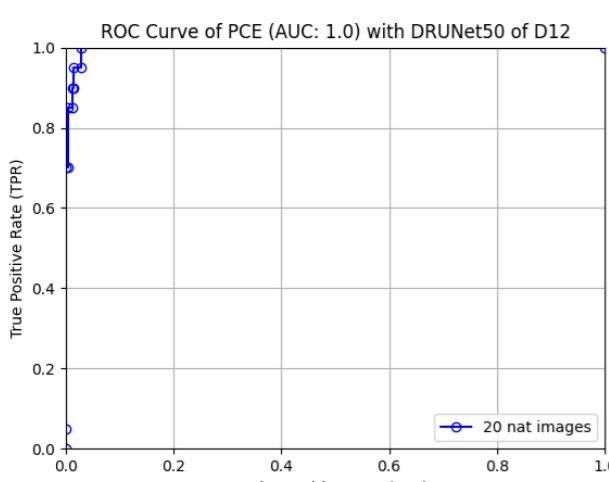
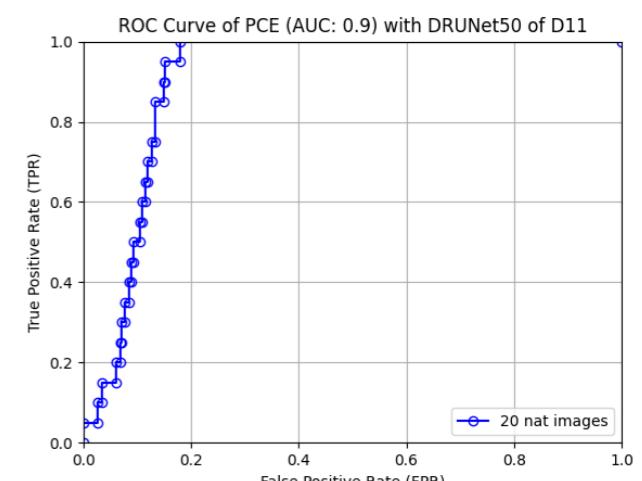
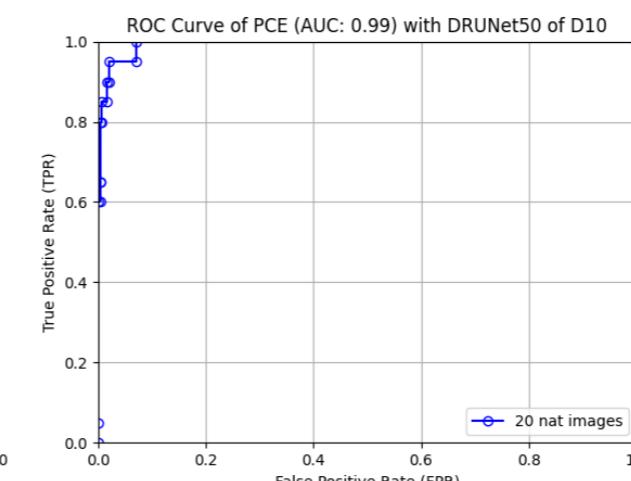
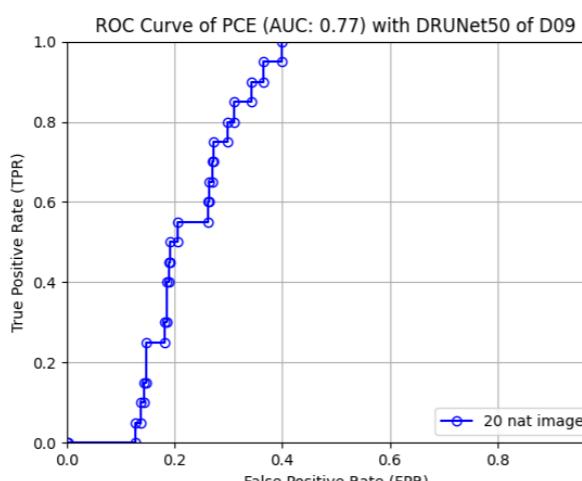
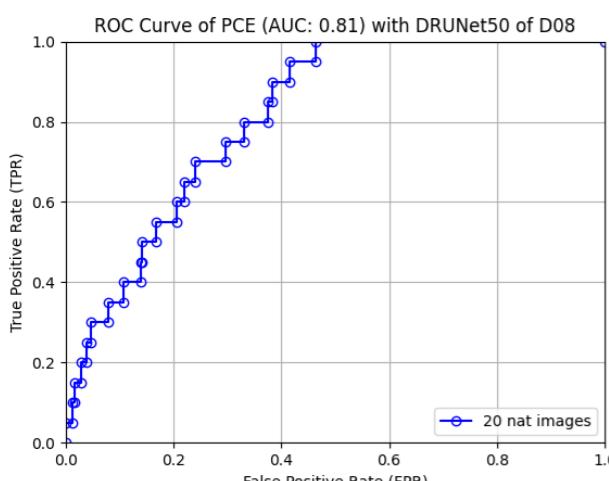
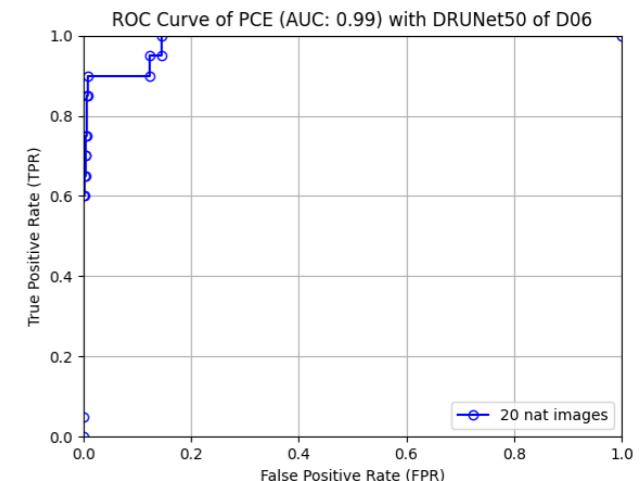
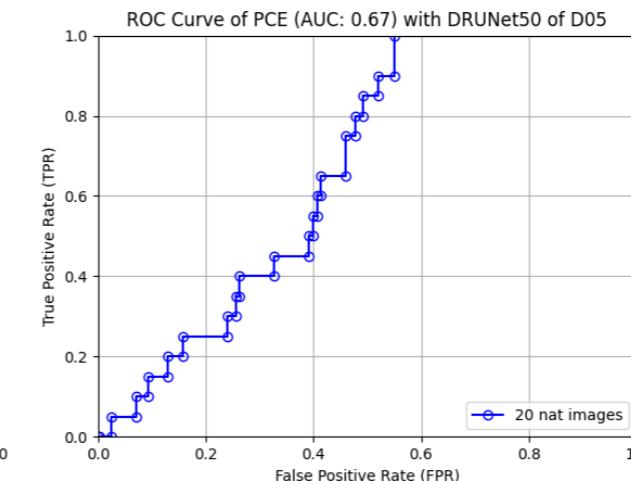
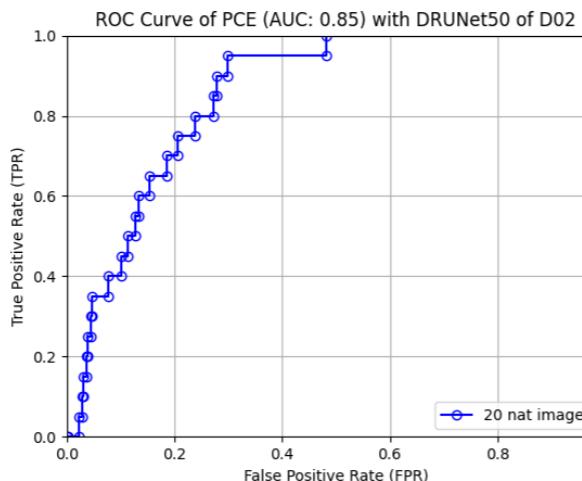
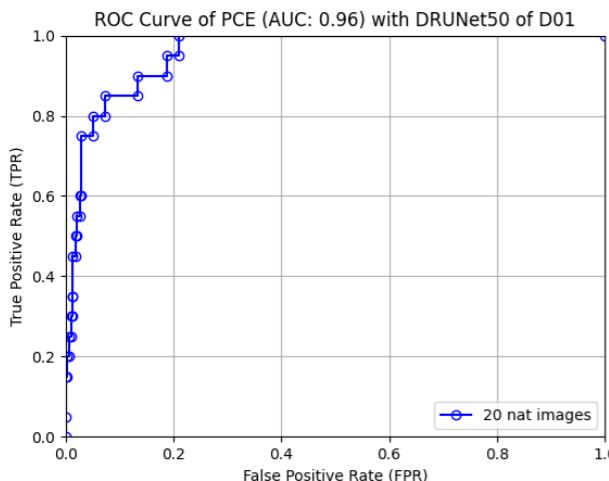
- Si è adattato un metodo ***learning-based*** come **DRUNet** all'algoritmo dell'estrazione del **PRNU** del Politecnico di Milano che utilizzava invece un algoritmo ***model-based***
- Si sono ottenute **buone prestazioni** su tutti i **device** del dataset, ad **eccezione** dei modelli **Huawei**.
- Gli **Ablation Studies** hanno evidenziato come la rimozione dell'**operazione di Zero Mean** non influisca sulle prestazioni, al contrario invece della rimozione dell'**operazione di Wiener DFT**.



# Appendici

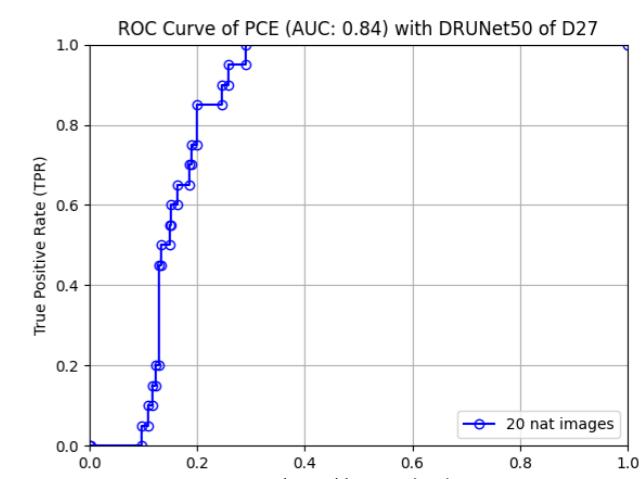
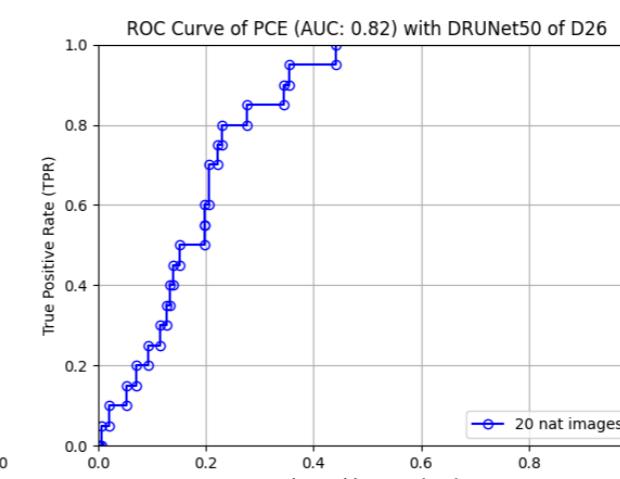
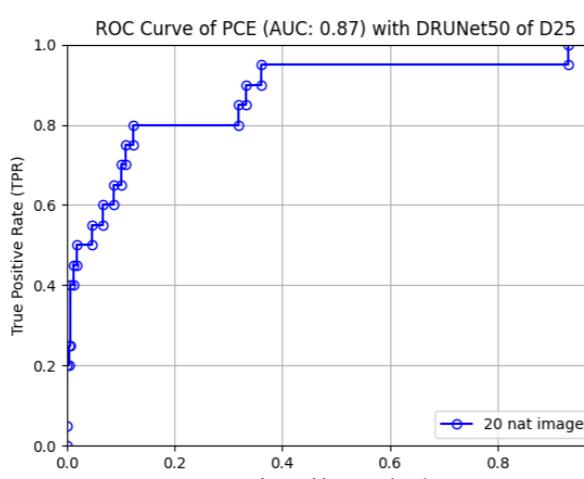
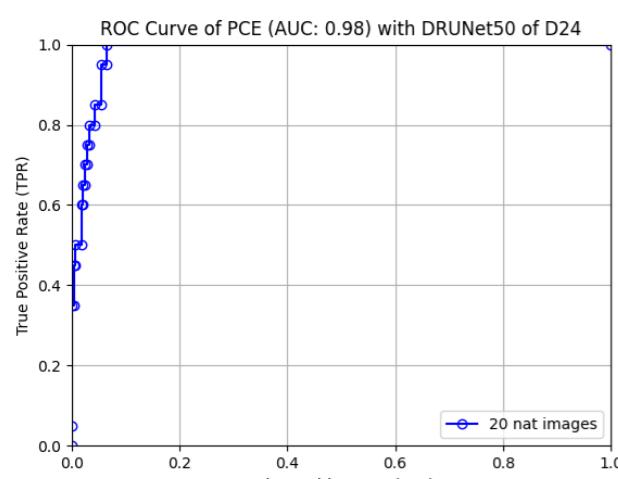
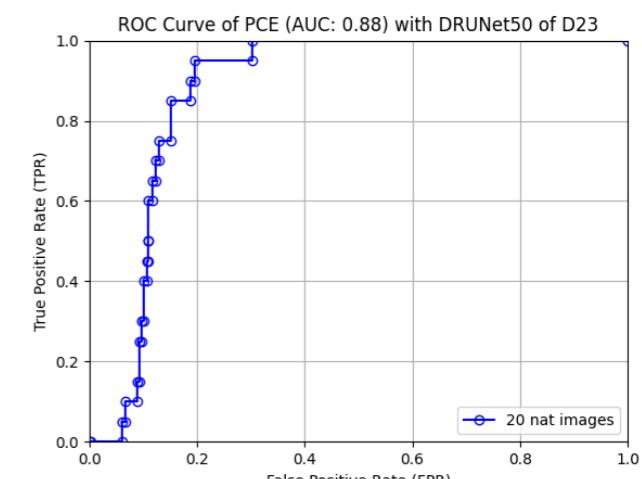
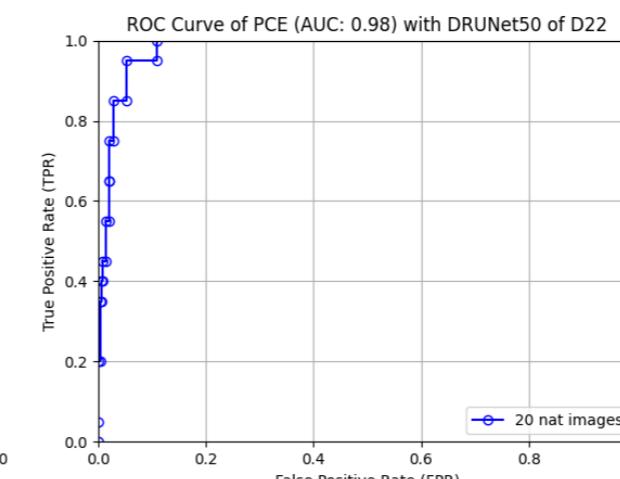
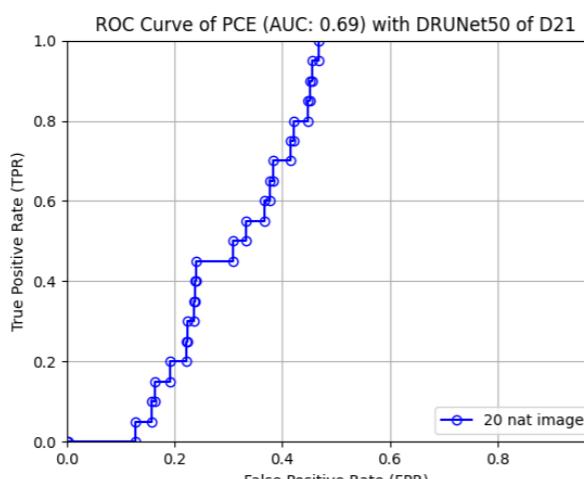
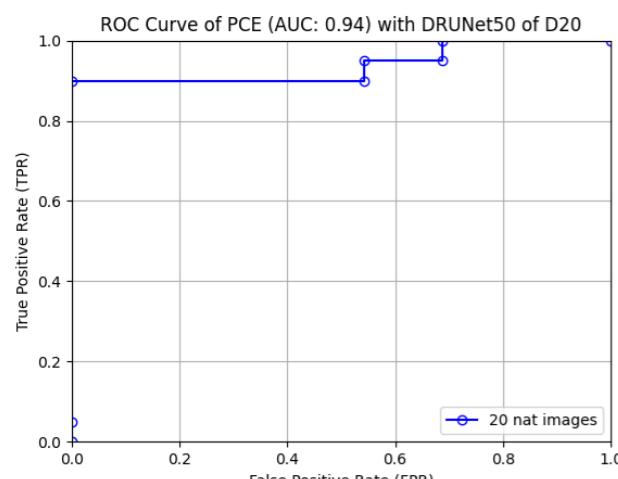
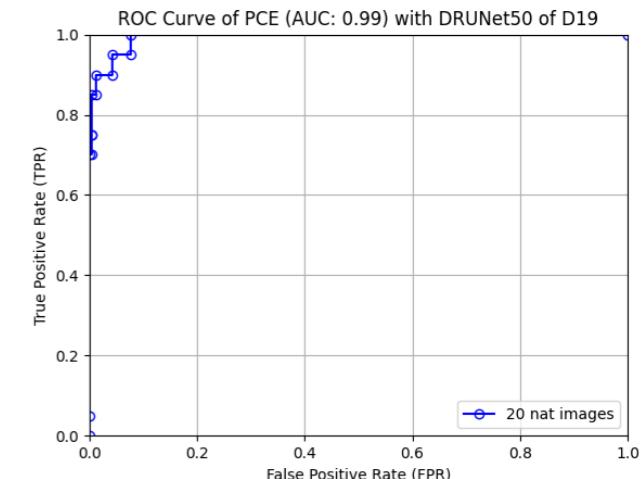
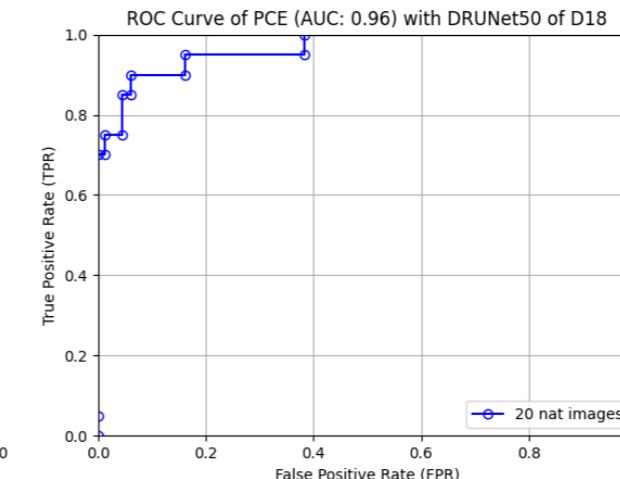
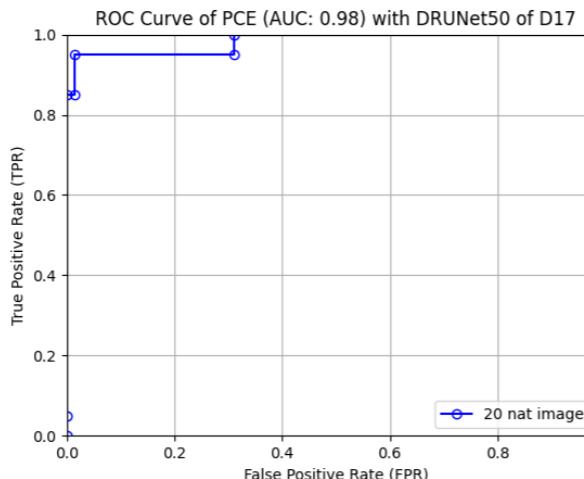
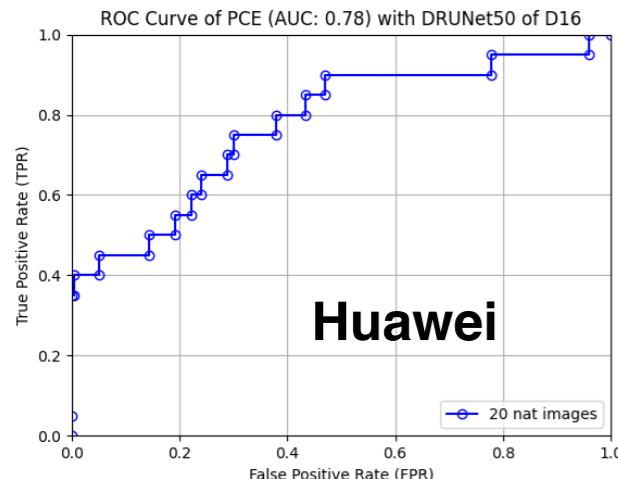
# ROC Curve con DRUNet50 per Singolo Device 1/3

Risultati ottenuti con *reVISION\_dataset\_base*:



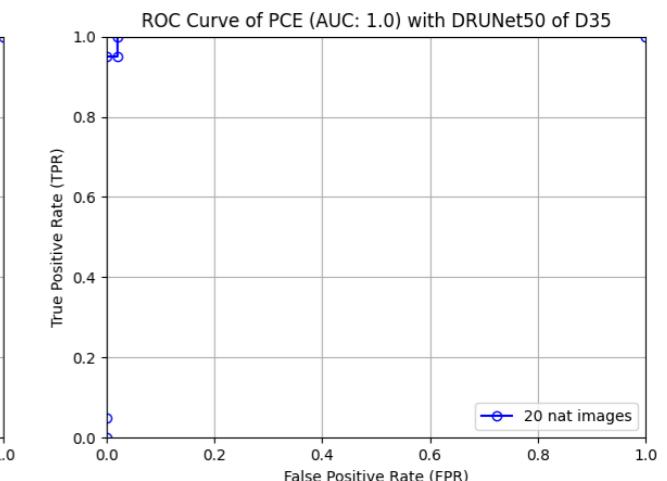
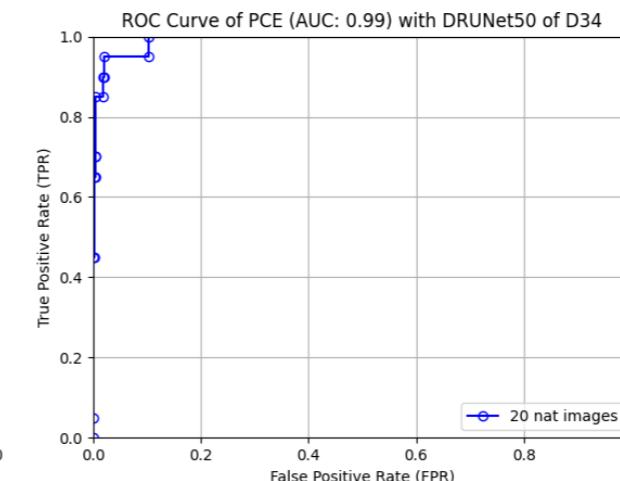
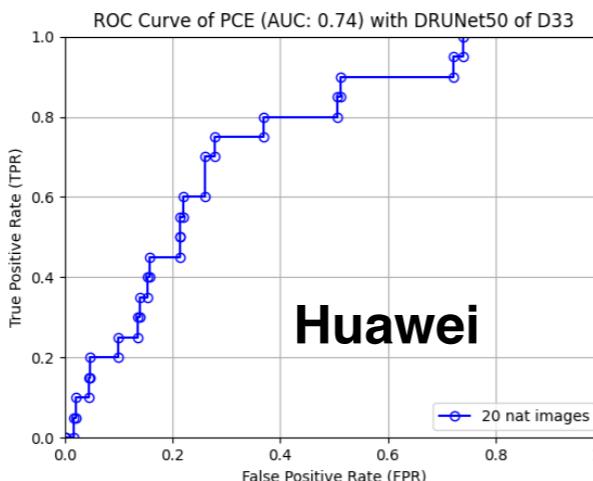
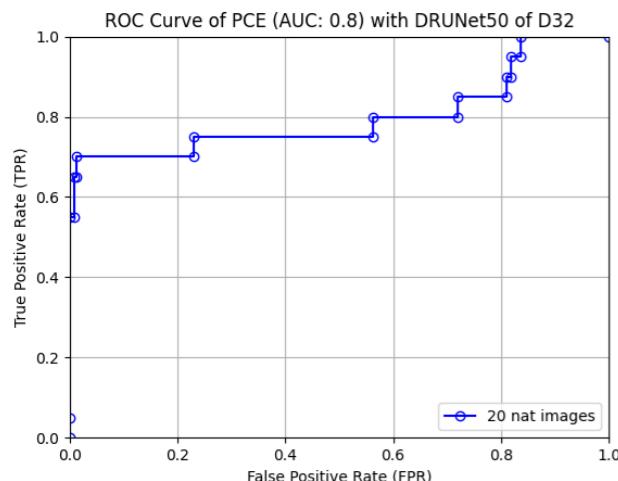
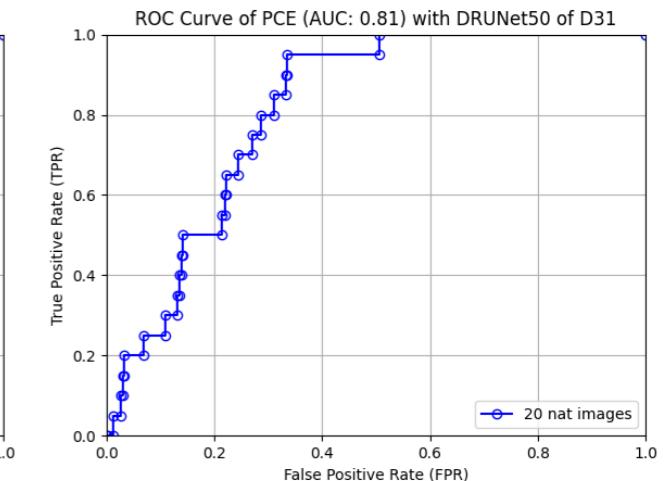
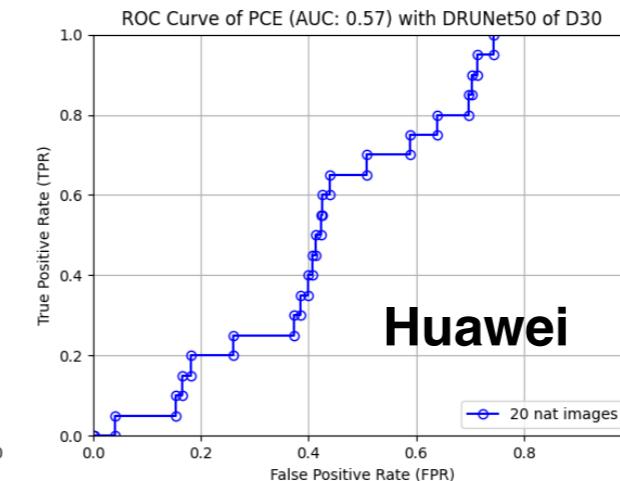
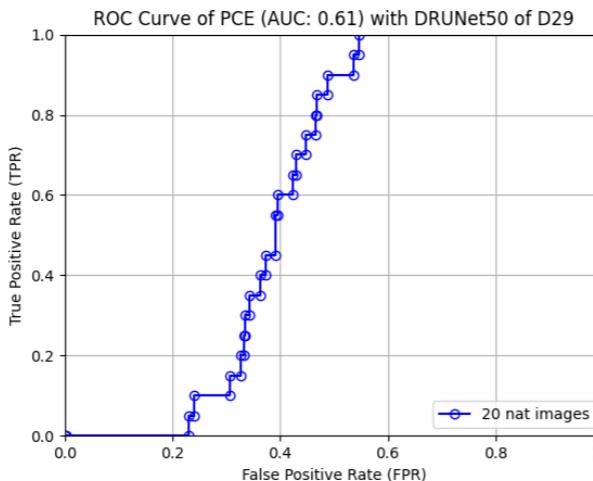
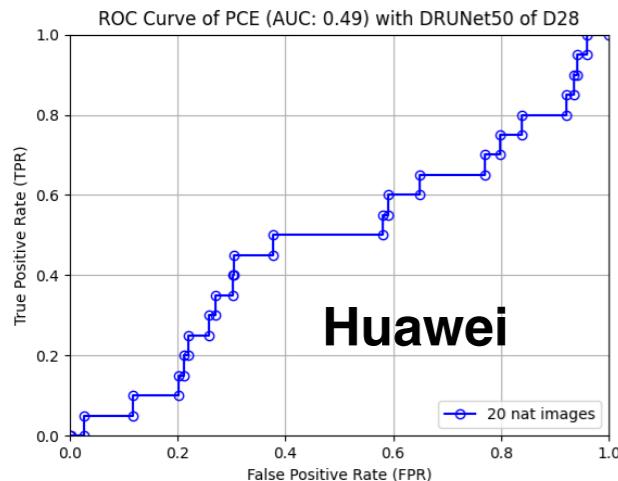
# ROC Curve con DRUNet50 per Singolo Device 2/3

Risultati ottenuti con *reVISION\_dataset\_base*:

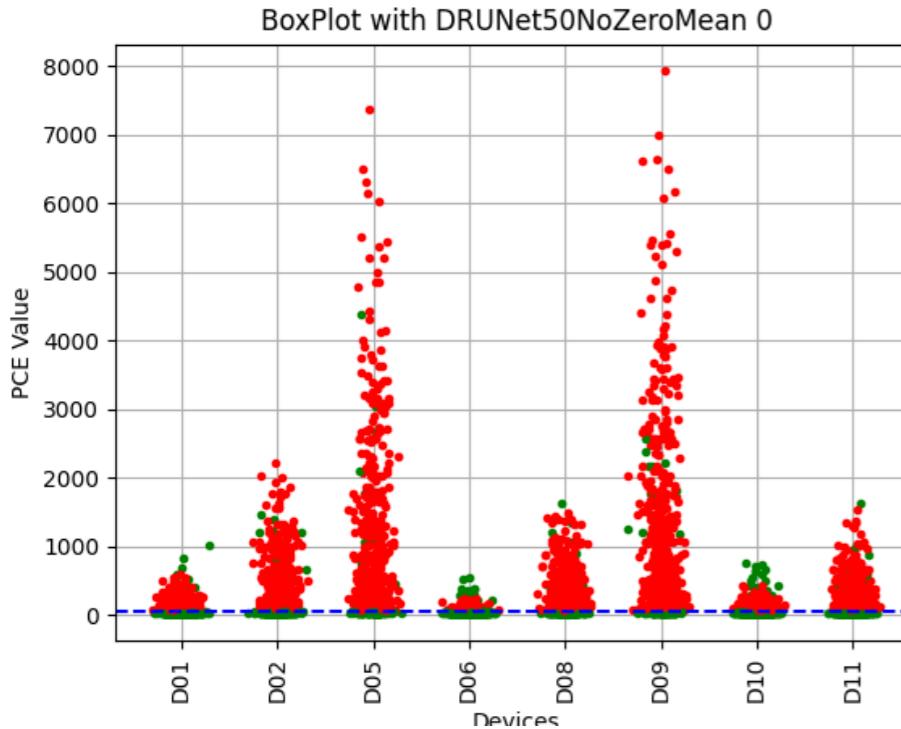


# ROC Curve con DRUNet50 per Singolo Device 3/3

Risultati ottenuti con *reVISION\_dataset\_base*:



# BoxPlot con DRUNet50NoZeroMean 1/2



Device	TP	FP	TN	FN	TPR	FPR
D01	20	214	406	0	1	0.345161
D02	20	420	200	0	1	0.677419
D05	20	504	116	0	1	0.812903
D06	19	79	541	1	0.95	0.127419
D08	20	433	187	0	1	0.698387
D09	20	519	101	0	1	0.837097
D10	20	174	446	0	1	0.280645
D11	20	307	313	0	1	0.495161

**--- Threshold = 60**

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

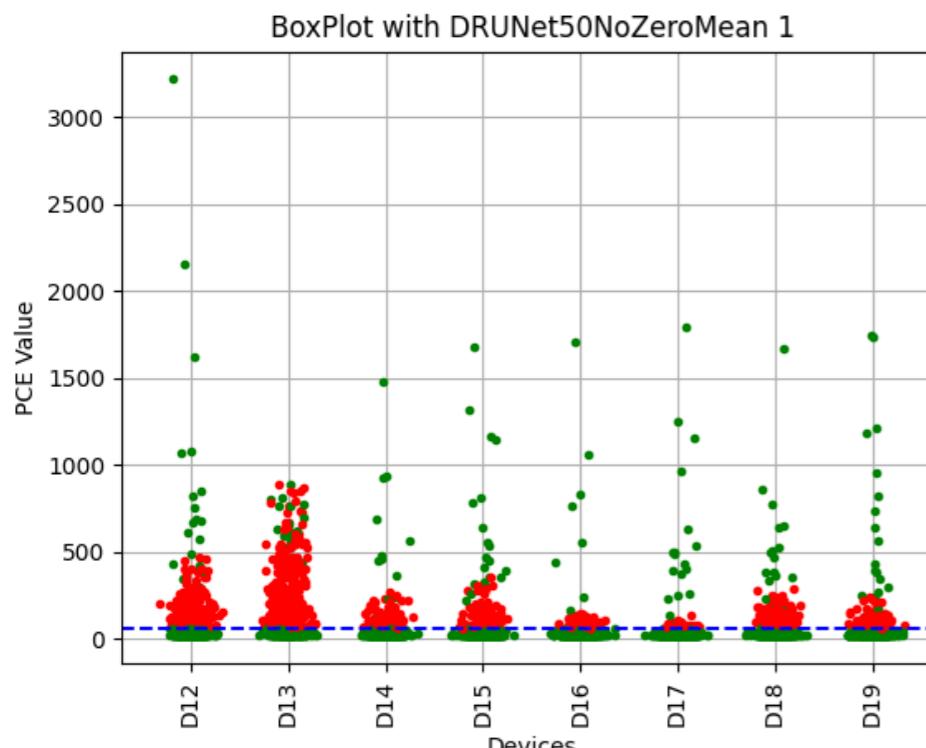
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

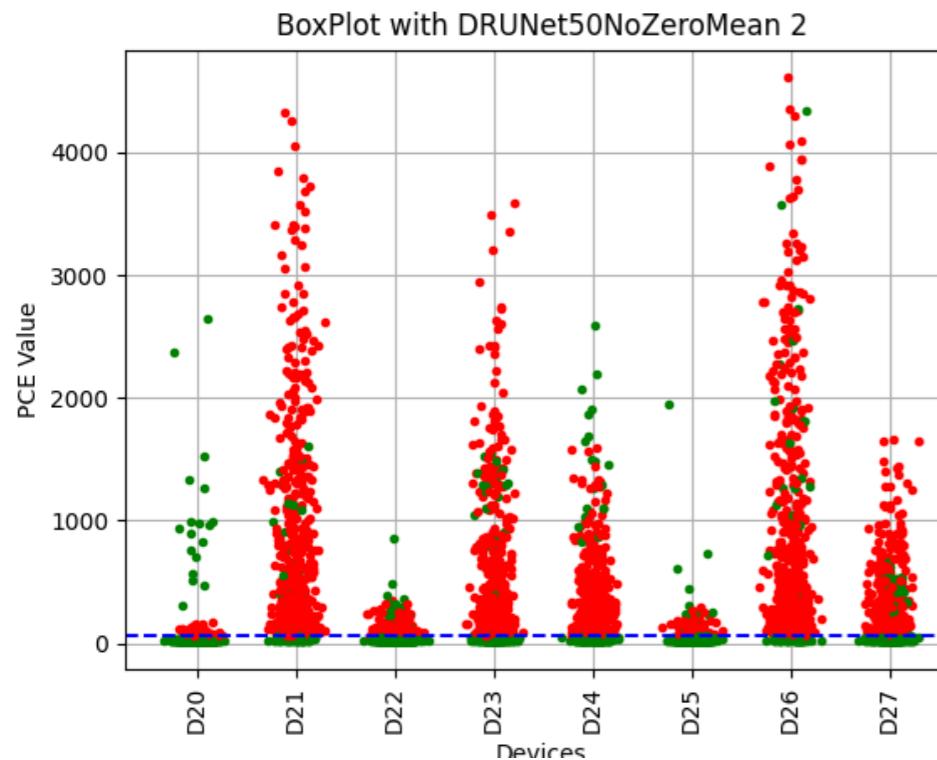
**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$



Device	TP	FP	TN	FN	TPR	FPR
D12	20	222	398	0	1	0.358065
D13	20	308	312	0	1	0.496774
D14	17	107	513	3	0.85	0.172581
D15	20	117	503	0	1	0.18871
D16	9	68	552	11	0.45	0.109677
D17	19	25	595	1	0.95	0.0403226
D18	19	145	475	1	0.95	0.233871
D19	20	91	529	0	1	0.146774

# BoxPlot con DRUNet50NoZeroMean 2/2



Device	TP	FP	TN	FN	TPR	FPR
D20	18	71	549	2	0.9	0.114516
D21	20	526	94	0	1	0.848387
D22	20	141	479	0	1	0.227419
D23	20	411	209	0	1	0.662903
D24	20	413	207	0	1	0.666129
D25	16	103	517	4	0.8	0.166129
D26	20	531	89	0	1	0.856452
D27	20	376	244	0	1	0.606452

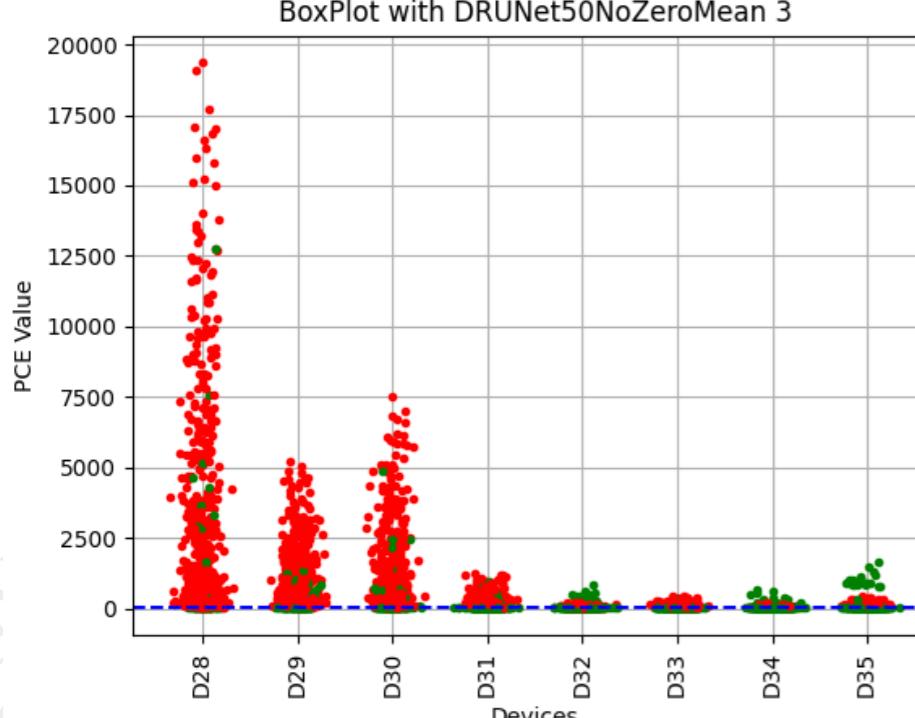
--- Threshold = 60

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)



Device	TP	FP	TN	FN	TPR	FPR
D28	16	572	48	4	0.8	0.922581
D29	20	539	81	0	1	0.869355
D30	20	528	92	0	1	0.851613
D31	20	315	305	0	1	0.508065
D32	14	83	537	6	0.7	0.133871
D33	15	171	449	5	0.75	0.275806
D34	20	66	554	0	1	0.106452
D35	20	210	410	0	1	0.33871

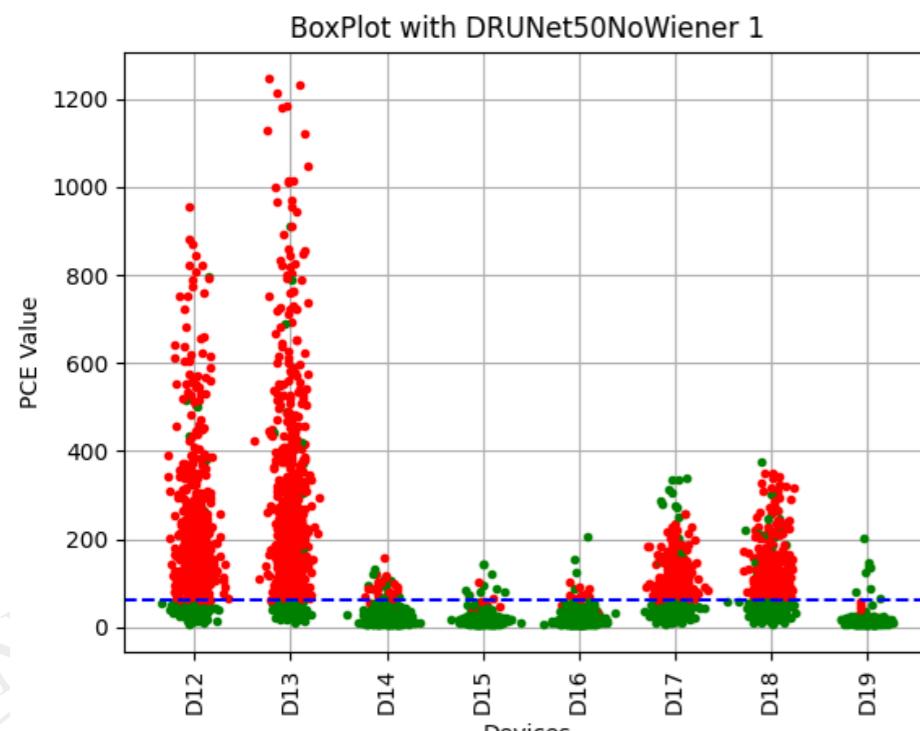
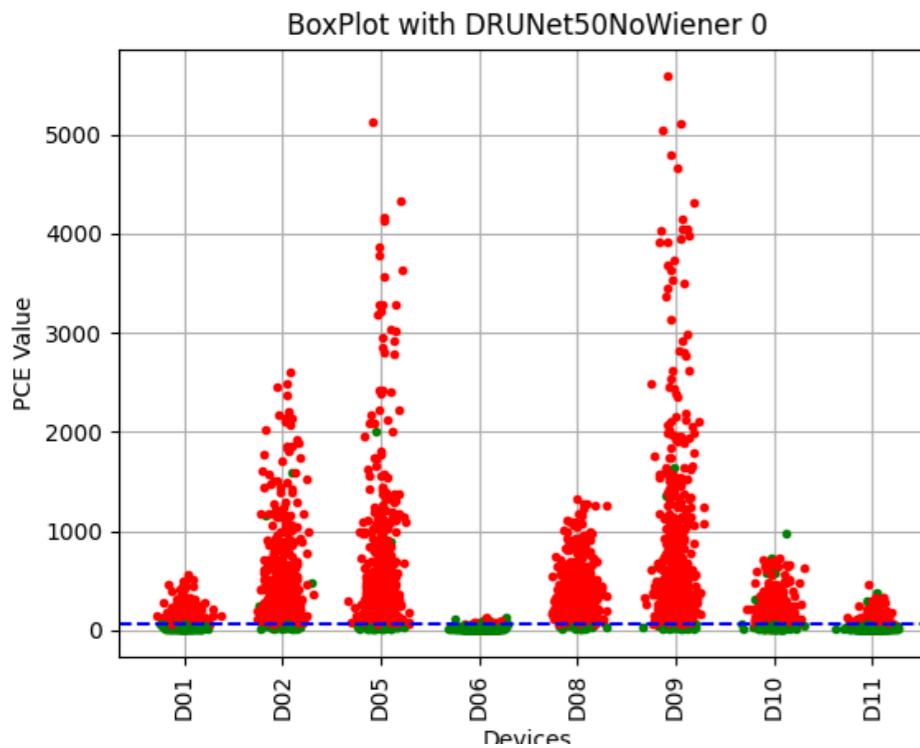
**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$

# BoxPlot con DRUNet50NoWiener 1/2



Device	TP	FP	TN	FN	TPR	FPR
D12	20	490	130	0	1	0.790323
D13	20	548	72	0	1	0.883871
D14	11	22	598	9	0.55	0.0354839
D15	9	3	617	11	0.45	0.00483871
D16	4	9	611	16	0.2	0.0145161
D17	19	351	269	1	0.95	0.566129
D18	17	396	224	3	0.85	0.63871
D19	8	0	620	12	0.4	0

**--- Threshold = 60**

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

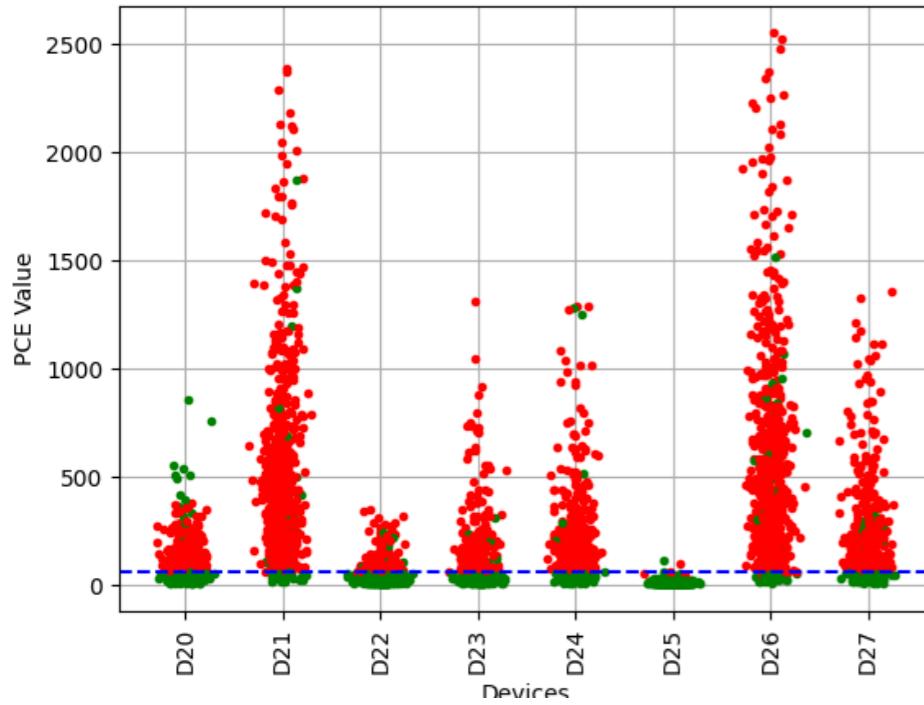
$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$

# BoxPlot con DRUNet50NoWiener 2/2

BoxPlot with DRUNet50NoWiener 2



**--- Threshold = 60**

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

- True Negative (TN)
- False Negative (FN)

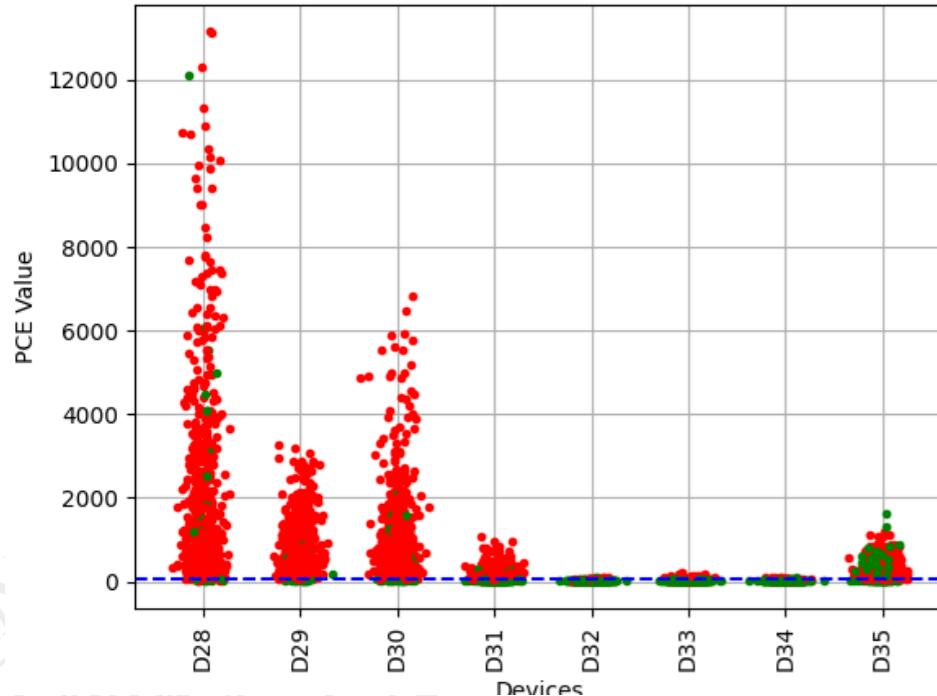
**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

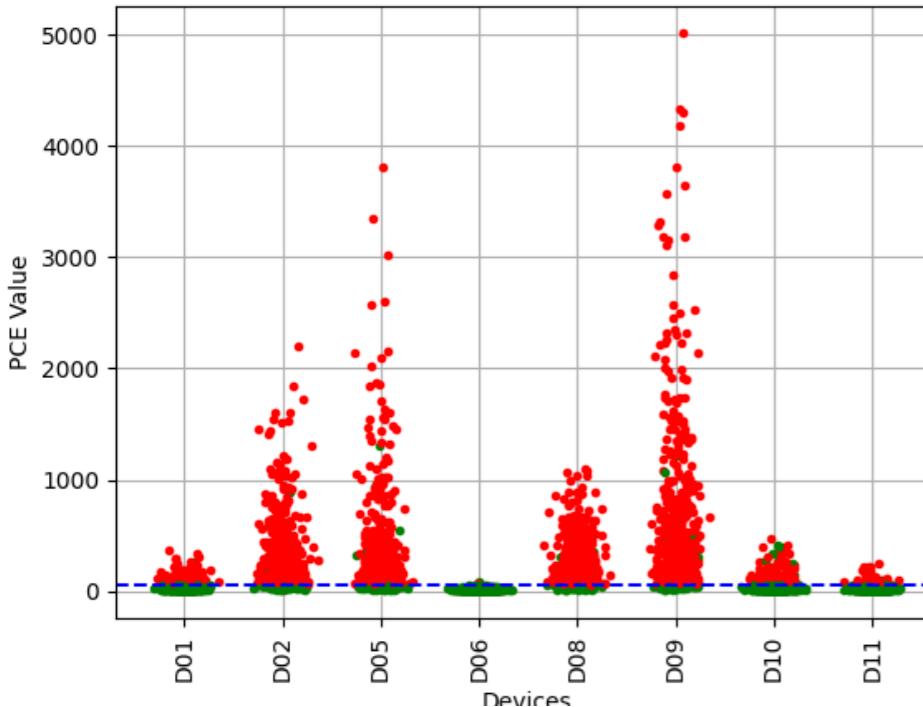
$$FPR = \frac{FP}{FP + TN}$$

BoxPlot with DRUNet50NoWiener 3



# BoxPlot con DRUNet50NoZeroMeanNoWiener 1/2

BoxPlot with DRUNet50NoZeroMeanNoWiener 0



Device	TP	FP	TN	FN	TPR	FPR
D01	4	139	481	16	0.2	0.224194
D02	18	510	110	2	0.9	0.822581
D05	20	488	132	0	1	0.787097
D06	1	1	619	19	0.05	0.0016129
D08	19	532	88	1	0.95	0.858065
D09	20	554	66	0	1	0.893548
D10	13	148	472	7	0.65	0.23871
D11	5	43	577	15	0.25	0.0693548

**--- Threshold = 60**

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

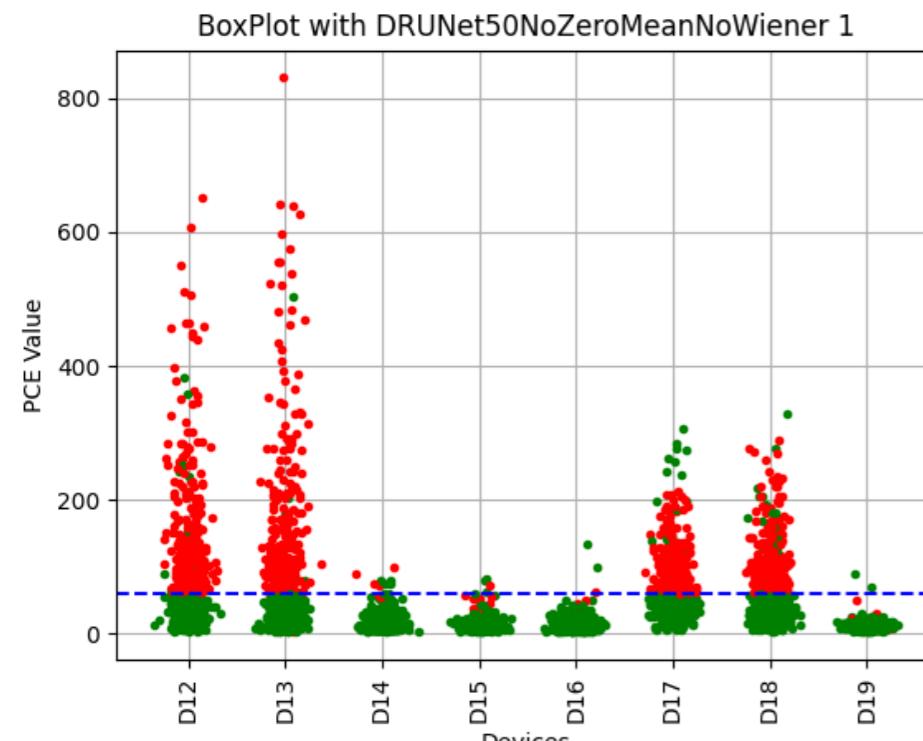
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

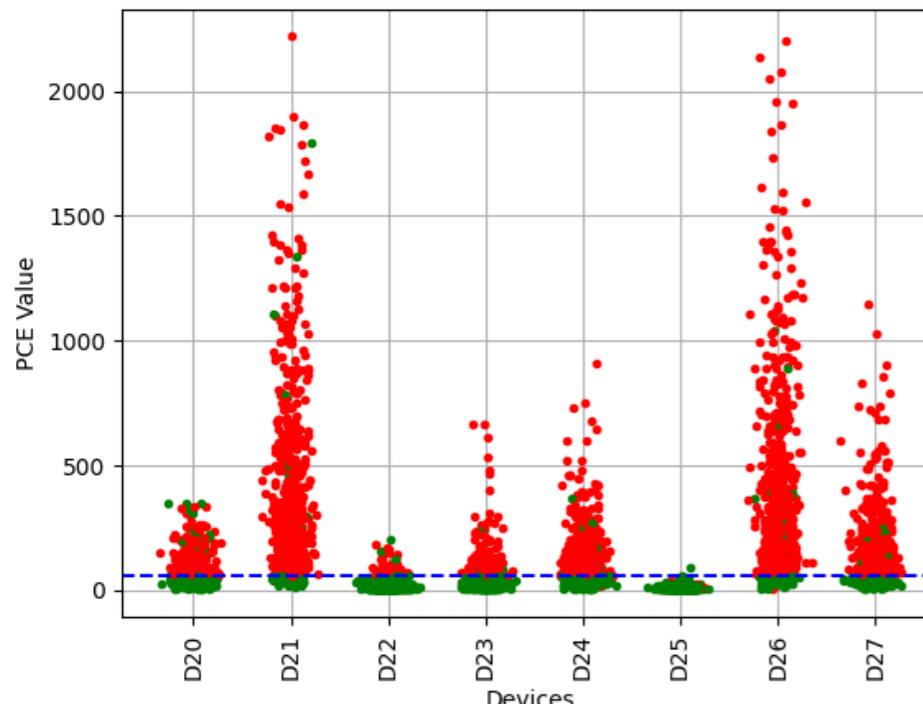
$$FPR = \frac{FP}{FP + TN}$$



Device	TP	FP	TN	FN	TPR	FPR
D12	17	272	348	3	0.85	0.43871
D13	9	257	363	11	0.45	0.414516
D14	5	4	616	15	0.25	0.00645161
D15	4	1	619	16	0.2	0.0016129
D16	2	1	619	18	0.1	0.0016129
D17	19	260	360	1	0.95	0.419355
D18	16	232	388	4	0.8	0.374194
D19	2	0	620	18	0.1	0

# BoxPlot con DRUNet50NoZeroMeanNoWiener 2/2

BoxPlot with DRUNet50NoZeroMeanNoWiener 2



Device	TP	FP	TN	FN	TPR	FPR
D20	18	255	365	2	0.9	0.41129
D21	19	567	53	1	0.95	0.914516
D22	5	40	580	15	0.25	0.0645161
D23	7	119	501	13	0.35	0.191935
D24	14	359	261	6	0.7	0.579032
D25	1	0	620	19	0.05	0
D26	19	559	61	1	0.95	0.901613
D27	18	420	200	2	0.9	0.677419

**--- Threshold = 60**

**PCE > 60:**

- True Positive (TP)
- False Positive (FP)

**PCE < 60:**

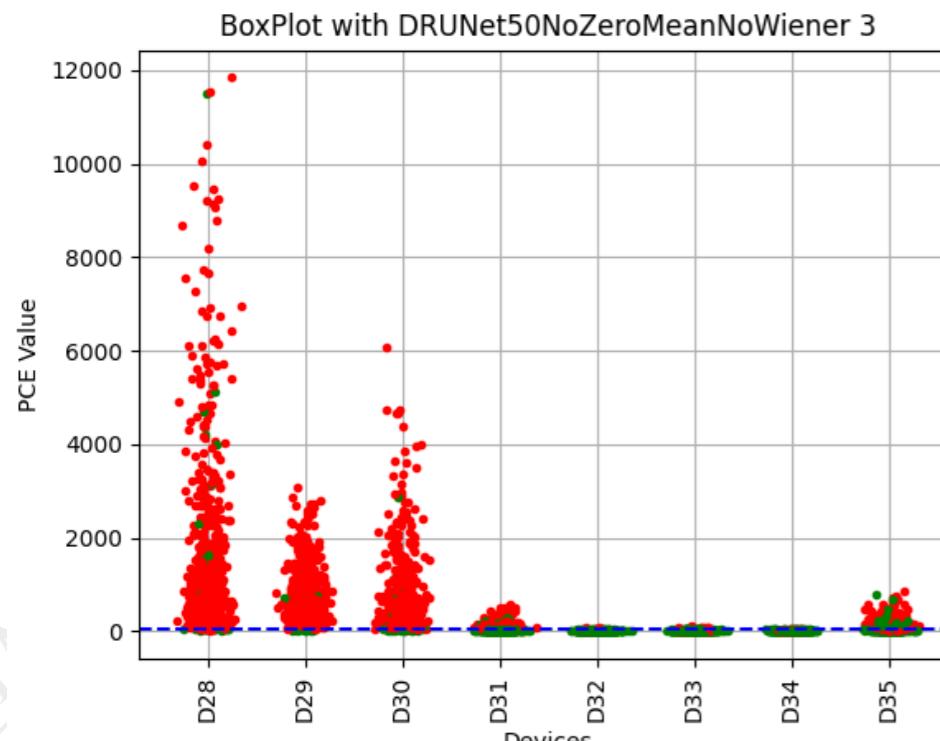
- True Negative (TN)
- False Negative (FN)

**True Positive Rate (TPR):**

$$TPR = \frac{TP}{TP + FN}$$

**False Positive Rate (FPR):**

$$FPR = \frac{FP}{FP + TN}$$



Device	TP	FP	TN	FN	TPR	FPR
D28	17	601	19	3	0.85	0.969355
D29	20	593	27	0	1	0.956452
D30	20	574	46	0	1	0.925806
D31	13	194	426	7	0.65	0.312903
D32	0	4	616	20	0	0.00645161
D33	0	11	609	20	0	0.0177419
D34	0	2	618	20	0	0.00322581
D35	16	344	276	4	0.8	0.554839



# Confronto delle Tabelle 1/4

**DRUNet50**

Device	TP	FP	TN	FN	TPR	FPR
D01	20	206	414	0	1	0.33
D02	20	404	216	0	1	0.65
D05	20	499	121	0	1	0.8
D06	19	80	540	1	0.95	0.12
D08	20	428	192	0	1	0.69
D09	20	515	105	0	1	0.83
D10	20	164	456	0	1	0.26
D11	20	307	313	0	1	0.49

**DRUNet50NoZeroMean**

Device	TP	FP	TN	FN	TPR	FPR
D01	20	214	406	0	1	0.345161
D02	20	420	200	0	1	0.677419
D05	20	504	116	0	1	0.812903
D06	19	79	541	1	0.95	0.127419
D08	20	433	187	0	1	0.698387
D09	20	519	101	0	1	0.837097
D10	20	174	446	0	1	0.280645
D11	20	307	313	0	1	0.495161

**DRUNet50NoWiener**

Device	TP	FP	TN	FN	TPR	FPR
D01	13	305	315	7	0.65	0.491935
D02	19	554	66	1	0.95	0.893548
D05	20	532	88	0	1	0.858065
D06	6	11	609	14	0.3	0.0177419
D08	19	574	46	1	0.95	0.925806
D09	20	564	56	0	1	0.909677
D10	19	414	206	1	0.95	0.667742
D11	10	102	518	10	0.5	0.164516

**DRUNet50NoZeroMeanNoWiener**

Device	TP	FP	TN	FN	TPR	FPR
D01	4	139	481	16	0.2	0.224194
D02	18	510	110	2	0.9	0.822581
D05	20	488	132	0	1	0.787097
D06	1	1	619	19	0.05	0.0016129
D08	19	532	88	1	0.95	0.858065
D09	20	554	66	0	1	0.893548
D10	13	148	472	7	0.65	0.23871
D11	5	43	577	15	0.25	0.0693548



# Confronto delle Tabelle 2/4

## DRUNet50

Device	TP	FP	TN	FN	TPR	FPR
D12	20	207	413	0	1	0.33
D13	20	273	347	0	1	0.44
D14	17	107	513	3	0.85	0.17
D15	20	124	496	0	1	0.2
D16	9	67	533	11	0.45	0.1
D17	19	23	597	1	0.95	0.03
D18	19	142	478	1	0.95	0.22
D19	20	99	521	0	1	0.15

## DRUNet50NoZeroMean

Device	TP	FP	TN	FN	TPR	FPR
D12	20	222	398	0	1	0.358065
D13	20	308	312	0	1	0.496774
D14	17	107	513	3	0.85	0.172581
D15	20	117	503	0	1	0.18871
D16	9	68	552	11	0.45	0.109677
D17	19	25	595	1	0.95	0.0403226
D18	19	145	475	1	0.95	0.233871
D19	20	91	529	0	1	0.146774

## DRUNet50NoWiener

Device	TP	FP	TN	FN	TPR	FPR
D12	20	490	130	0	1	0.790323
D13	20	548	72	0	1	0.883871
D14	11	22	598	9	0.55	0.0354839
D15	9	3	617	11	0.45	0.00483871
D16	4	9	611	16	0.2	0.0145161
D17	19	351	269	1	0.95	0.566129
D18	17	396	224	3	0.85	0.63871
D19	8	0	620	12	0.4	0

## DRUNet50NoZeroMeanNoWiener

Device	TP	FP	TN	FN	TPR	FPR
D12	17	272	348	3	0.85	0.43871
D13	9	257	363	11	0.45	0.414516
D14	5	4	616	15	0.25	0.00645161
D15	4	1	619	16	0.2	0.0016129
D16	2	1	619	18	0.1	0.0016129
D17	19	260	360	1	0.95	0.419355
D18	16	232	388	4	0.8	0.374194
D19	2	0	620	18	0.1	0



# Confronto delle Tabelle 3/4

**DRUNet50**

Device	TP	FP	TN	FN	TPR	FPR
D20	18	70	550	2	0.9	0.11
D21	20	514	106	0	1	0.82
D22	20	142	478	1	0.95	0.22
D23	20	420	200	0	1	0.67
D24	20	392	228	0	1	0.63
D25	16	109	511	4	0.8	0.17
D26	20	522	98	0	1	0.84
D27	20	361	259	0	1	0.58

**DRUNet50NoZeroMean**

Device	TP	FP	TN	FN	TPR	FPR
D20	18	71	549	2	0.9	0.114516
D21	20	526	94	0	1	0.848387
D22	20	141	479	0	1	0.227419
D23	20	411	209	0	1	0.662903
D24	20	413	207	0	1	0.666129
D25	16	103	517	4	0.8	0.166129
D26	20	531	89	0	1	0.856452
D27	20	376	244	0	1	0.606452

**DRUNet50NoWiener**

Device	TP	FP	TN	FN	TPR	FPR
D20	18	351	269	2	0.9	0.566129
D21	19	579	41	1	0.95	0.933871
D22	7	168	452	13	0.35	0.270968
D23	16	246	374	4	0.8	0.396774
D24	19	464	156	1	0.95	0.748387
D25	1	2	618	19	0.05	0.00322581
D26	19	584	36	1	0.95	0.941935
D27	18	473	147	2	0.9	0.762903

**DRUNet50NoZeroMeanNoWiener**

Device	TP	FP	TN	FN	TPR	FPR
D20	18	255	365	2	0.9	0.41129
D21	19	567	53	1	0.95	0.914516
D22	5	40	580	15	0.25	0.0645161
D23	7	119	501	13	0.35	0.191935
D24	14	359	261	6	0.7	0.579032
D25	1	0	620	19	0.05	0
D26	19	559	61	1	0.95	0.901613
D27	18	420	200	2	0.9	0.677419



# Confronto delle Tabelle 4/4

## DRUNet50

Device	TP	FP	TN	FN	TPR	FPR
D28	17	572	48	3	0.85	0.92
D29	20	536	84	0	1	0.86
D30	20	530	90	0	1	0.85
D31	18	309	311	1	0.95	0.49
D32	14	79	541	6	0.7	0.12
D33	14	164	456	6	0.7	0.26
D34	20	71	549	0	1	0.11
D35	20	200	420	0	1	0.32

## DRUNet50NoZeroMean

Device	TP	FP	TN	FN	TPR	FPR
D28	16	572	48	4	0.8	0.922581
D29	20	539	81	0	1	0.869355
D30	20	528	92	0	1	0.851613
D31	20	315	305	0	1	0.508065
D32	14	83	537	6	0.7	0.133871
D33	15	171	449	5	0.75	0.275806
D34	20	66	554	0	1	0.106452
D35	20	210	410	0	1	0.33871

## DRUNet50NoWiener

Device	TP	FP	TN	FN	TPR	FPR
D28	17	601	19	3	0.85	0.969355
D29	20	594	26	0	1	0.958065
D30	20	584	36	0	1	0.941935
D31	16	377	243	4	0.8	0.608065
D32	1	13	607	19	0.05	0.0209677
D33	2	45	575	18	0.1	0.0725806
D34	3	17	603	17	0.15	0.0274194
D35	20	530	90	0	1	0.854839

## DRUNet50NoZeroMeanNoWiener

Device	TP	FP	TN	FN	TPR	FPR
D28	17	601	19	3	0.85	0.969355
D29	20	593	27	0	1	0.956452
D30	20	574	46	0	1	0.925806
D31	13	194	426	7	0.65	0.312903
D32	0	4	616	20	0	0.00645161
D33	0	11	609	20	0	0.0177419
D34	0	2	618	20	0	0.00322581
D35	16	344	276	4	0.8	0.554839