A COOPERATIVE TIME-FREQUENCY APPROACH TO DETECT, RECOGNIZE AND TRACK DRONES WITH AUDIO SENSOR NETWORKS

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PRESENTATION #21

AGENDA

- SCENARIO
- THE APPROACH
- LEVEL I - DETECTION
- LEVEL II - RECOGNITION
- LEVEL III – TRACKING
- CONCLUSIONS

A FEW WORDS ON THE SPEAKER

Claudio Santo Malavenda: PhD, MBA. He covered several roles in STMicroelectronics, Selex ES (actual Leonardo) and Elettronica dealing with Project and Contract management. His works activity deals first series products management and marketing, Wireless Sensor Network, C4I systems for fire control in network centric environment and Cyber Electromagnetic Activities.
He actually supports companies as a freelance with innovative projects for process optimization and innovative product release.

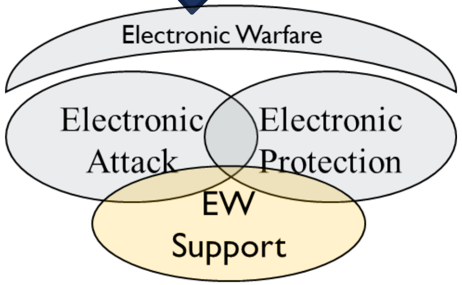
SCENARIO – TECHNOLOGY POSITIONING

Mechanical Wave - audio
(not electromagnetic wave)

During this RESEARCH

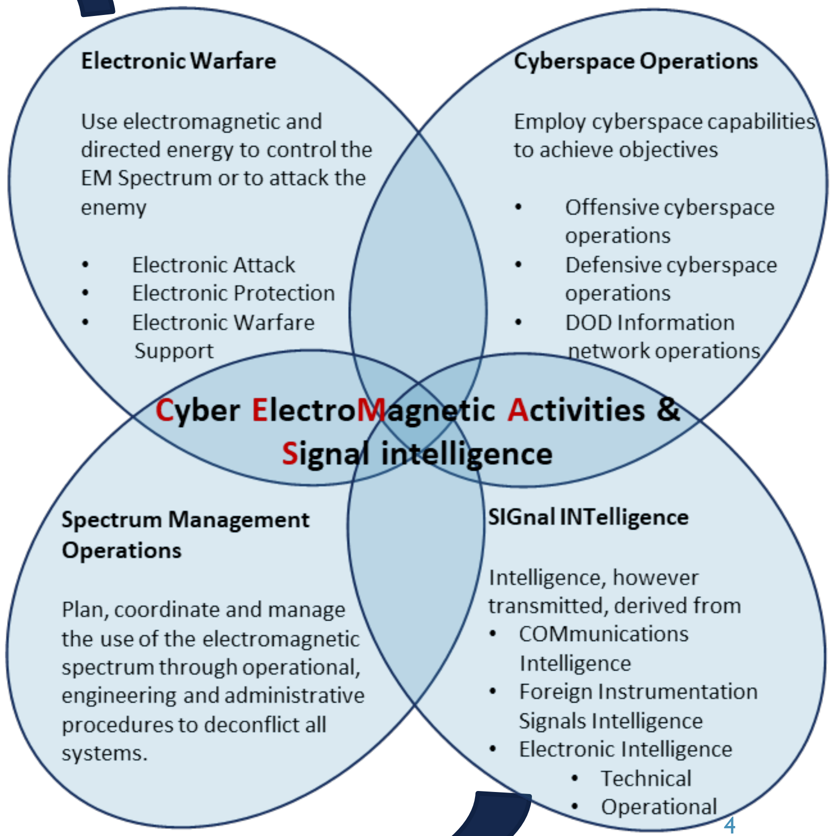
OPELINT is concerned with operationally relevant information such as the **location, movement**, employment, tactics, and activity of foreign noncommunications emitters and their associated weapon systems

TECHELINT is concerned with the technical aspects of foreign noncommunications emitters such as **signal characteristics**, modes, functions, associations, capabilities, limitations, vulnerabilities, and technology levels

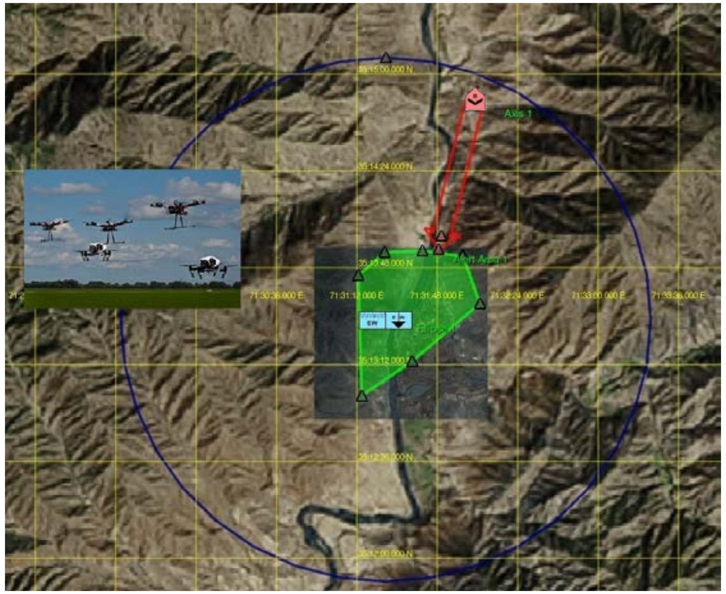


When USED

Actions tasked by, or under direct control of, an operational commander to search for, **intercept, identify, and locate or localize sources** of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations



SCENARIO



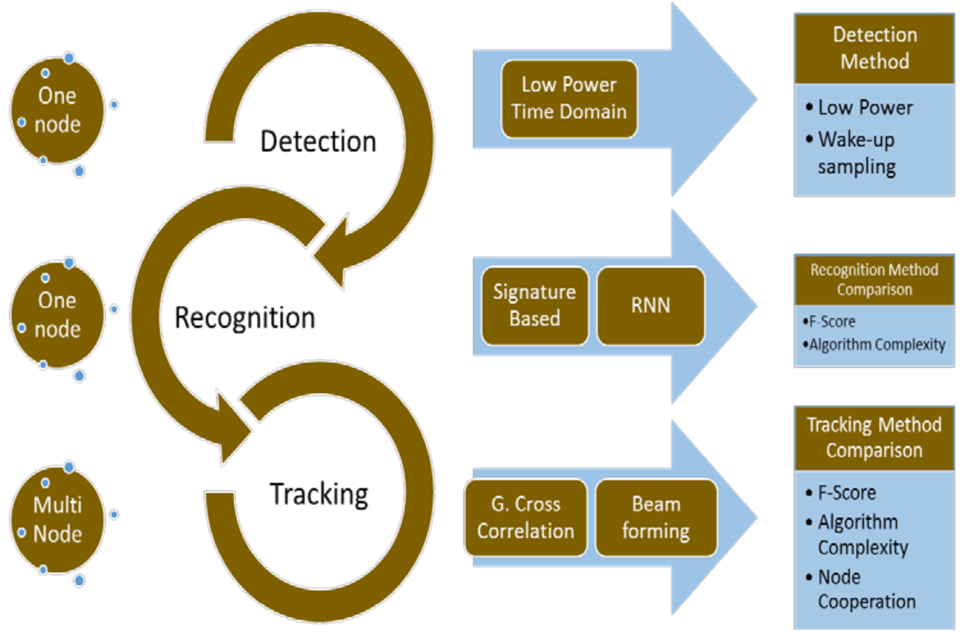
A large number of cheap audio sensors, each one capable to recognize the drone’s audio signature and, when a match is found, locate the malicious source, by collaborating with other nodes.

The focus of the research is to detect, recognize and track with audio array a single drone or a small swarm of drones, i.e. assimilable to a single large unit, in an open field scenario.

Symmetric warfare defence:
Drones: smaller, cheaper and capable to cooperate.
Dually, the target defence is then implemented in small, cheap and collaborating nodes

Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Civil Category (UK CAA)	Example Platform
Class I <150 kg	MICRO < 2 kg	Tactical Platoon, Section, Individual (single operator)	Up to 200ft AGL	5 km (Line of Sight (LOS))	Weight Classification Group (WCG) 1 Small Unmanned Aircraft (<20 kg)	Black Widow
	MINI 2-20[13] kg	Tactical Sub-Unit (manual launch)	Up to 3000ft AGL	25 km (LOS)		Scan Eagle, Skylark, Raven, DH3
	SMALL > 20 kg	Tactical Unit (employs launch system)	Up to 5000ft AGL	50 km (LOS)	WCG 2 Light Unmanned Aircraft (20><150 kg)	Luna, Hermes 90
Class II 150–600kg	TACTICAL	Tactical Formation	Up to 10,000ft AGL	200 km (LOS)	WCG 3 UAV (>150 kg)	Sperwer, Iview 250, Aerostar, Watchkeeper
Class III >600 kg	Medium Altitude, Long Endurance (MALE)[14]	Operational/ Theatre	Up to 45,000ft AGL	Unlimited (BLOS)		Reaper, Heron, Hermes 900
	High Altitude, Long Endurance (HALE)	Strategic/ National	Up to 65,000ft AGL	Unlimited (BLOS)		Global Hawk
	Strike/ Combat	Strategic/ National	Up to 65,000ft AGL	Unlimited (BLOS)		

THE APPROACH



DETECTION

this phase detects an anomaly in the audio spectrum

RECOGNITION

this phase assumes that we have an anomaly approaching and discriminates if it is assimilable to a drone

TRACKING

this phase assumes there is at least a drone in the detection area and tries to track its movement

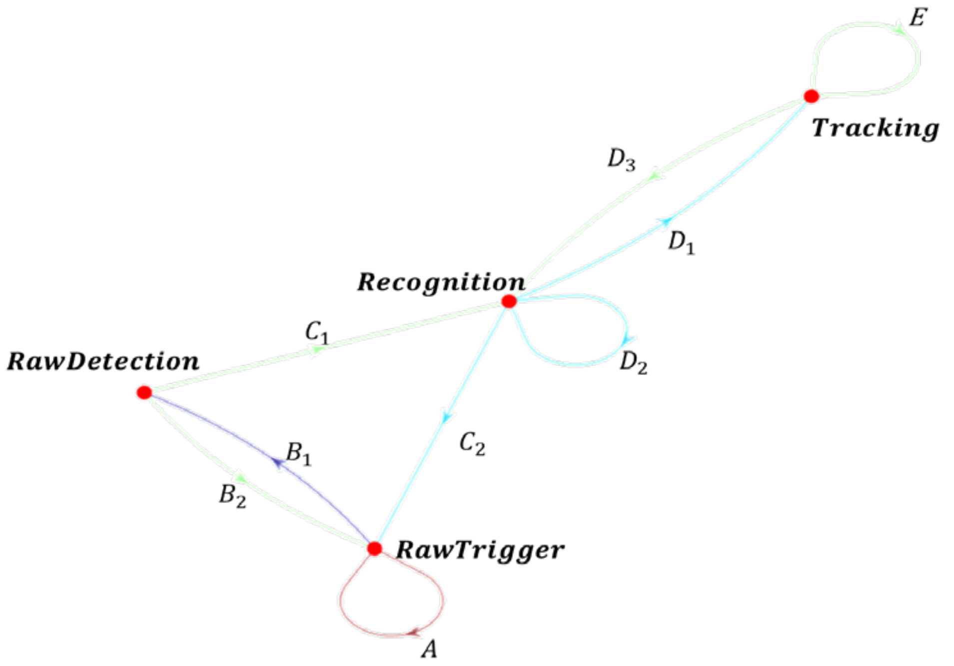
The research is still ongoing: focus on the methodology, raw sensing and recognition phases

THE APPROACH - MODELLING

A first level of modelling this approach is possible through the Markov chains

Associating each model phase to a state and evaluating the probability to change the state.

$$\begin{cases} \boldsymbol{A}\ \ the\ probability\ to\ detect\ no-alarm\ in\ Raw\ Trigger \\ \boldsymbol{B}_1\ \ the\ probability\ to\ detect\ an\ aomaly\ in\ Raw\ Trigger \\ \boldsymbol{B}_2\ \ the\ probability\ to\ false\ detection\ from\ Raw\ Trigger \\ \boldsymbol{C}_1\ \ probability\ to\ detect\ an\ aomaly\ in\ Raw\ Detetcion \\ \boldsymbol{C}_2\ probability\ to\ NOT\ recognize\ a\ drone\ in\ 'Recognition' \\ \boldsymbol{D}_1\ the\ probability\ to\ recognize\ a\ drone\ in\ \ 'Recognition' \\ \boldsymbol{D}_2\ \ \begin{matrix} the\ probability\ to\ keep\ recognizing\ a\ drone \\ with\ no\ other\ collaborating\ nodes\ available \end{matrix} \\ \boldsymbol{D}_3\ \ probability\ to\ lost\ tracking \\ \boldsymbol{E}\ the\ probability\ to\ keep\ the\ tracking \end{cases}$$

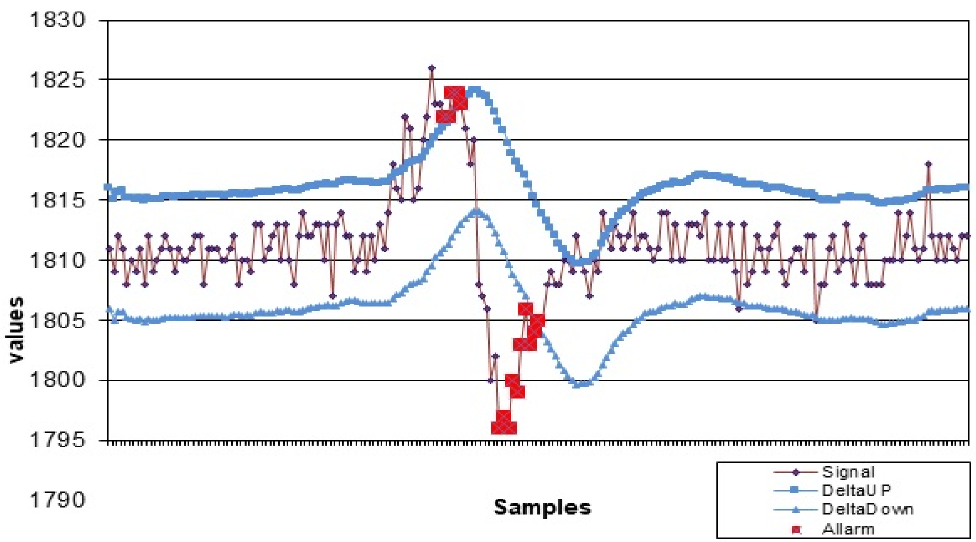


LEVEL 1 – DETECTION (1/2)

- Raw sensing with trigger counter

```
for i = (K+1):signal-length
    for j= (i-K):i
        delta=delta+y(j);
    end
    delta=delta/K;
    threshup(i)=y(i)+delta;
    threshdown(i)=y(i)-delta;
    if (y(i)>threshup(i))||(y(i)<threshdown(i))
        countA=countA+1;
        if countA>A
            allarm
        end
    else
        countA=0;
    end
end
```

- Low computation / Low energy (suitable for embedded device)
- Non dynamic Parameter [**k**, Δ, **a**]



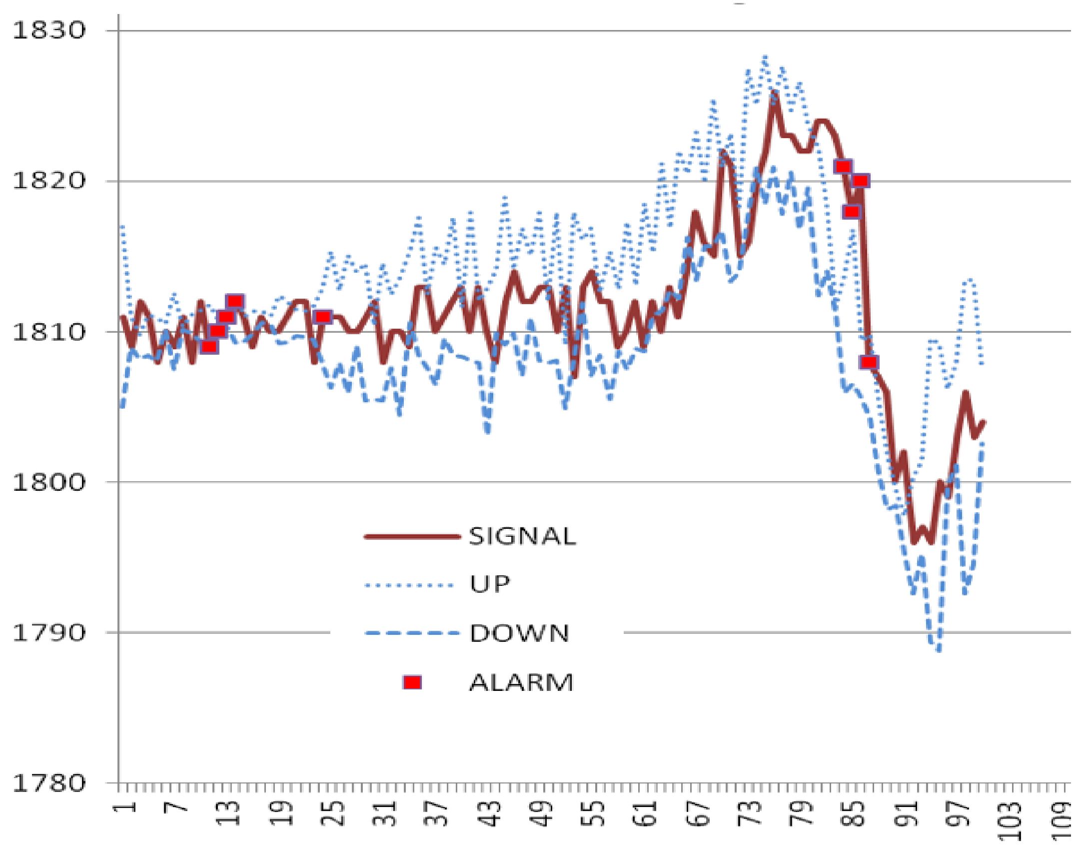
LEVEL 1 – DETECTION (2/2)

- Particle Swarm Optimization (PSO)
  - continuous updating of parameters [**k**, Δ, **a**]

  - Higher computational need
    - At each cycle it optimizes a fitness function

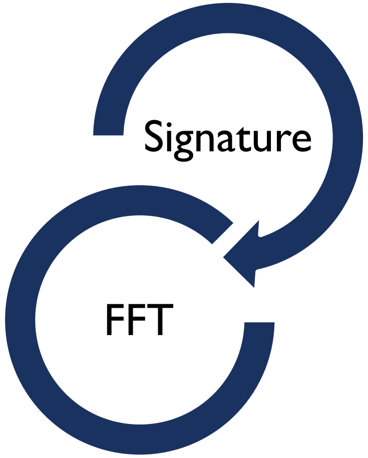
  Calculating the optimum values for the algorithm with:

  - $$\vec{p_i} = \begin{cases} p_l^k = MIN\left[F(k_{(i-k_i)}); \dots ; F(k_i)\right] \\ p_l^\Delta = MIN\left[F(\Delta_{(i-k_i)}); \dots ; F(\Delta_i)\right] \end{cases}$$



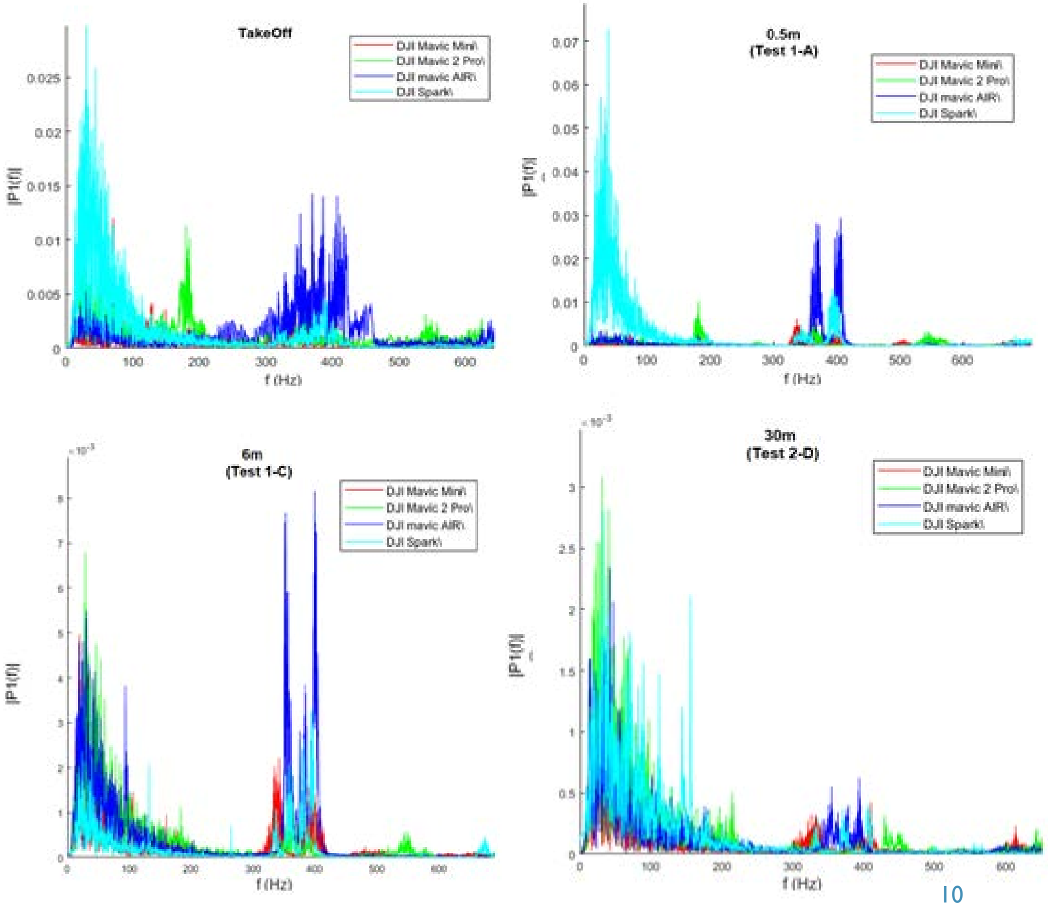
LEVEL 2 – RECOGNITION (1/2)

- SIGNATURE-BASED
  - Produce signature with algebraic calculation from FFT
  - **Tested with audio track from**
    - **Mavic mini**
    - **Mavic 2 Pro**
    - **Mavic AIR**
    - **DJI Spark**



MATCH PRE-RECORDED

SIGNATURE WITH CURRENT FFT



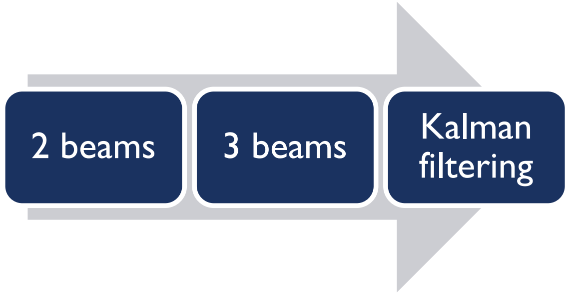
- RNN

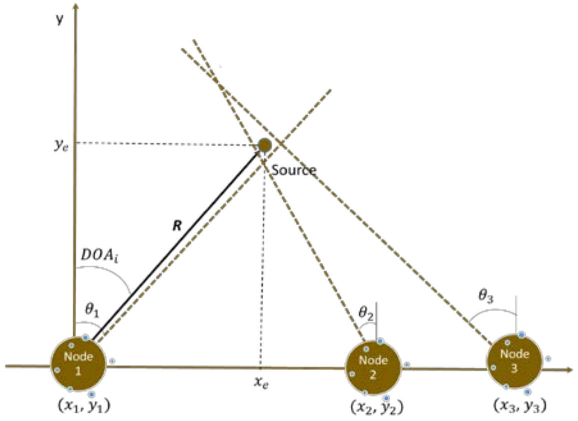
  produce signature with a neural network

Offline stage: use record to produce signature
Online stage: use signature to detect incoming audio

LEVEL 3 – LOCALIZATION

- MULTI SENSOR: NODES COOPERATE
  - G-Cross reference
    - 2 BEMS / 2 Nodes cooperating
    - 3 BEAMS / 3 Nodes Cooperates
  - Beamforming

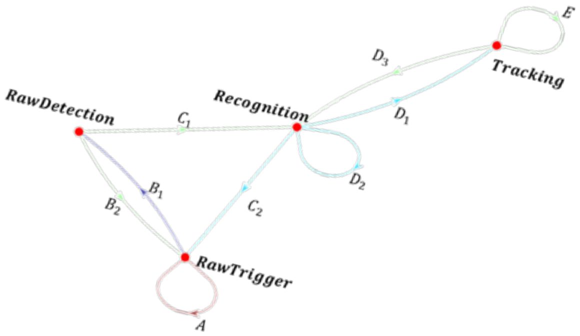




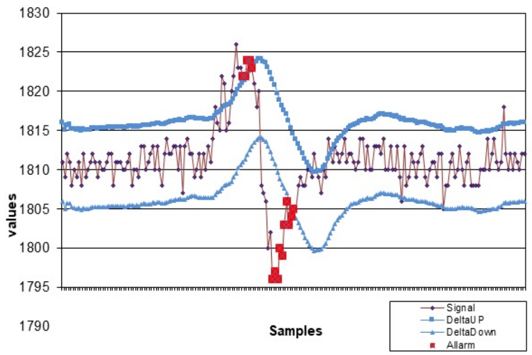
Reference system for cross-correlation multibeam

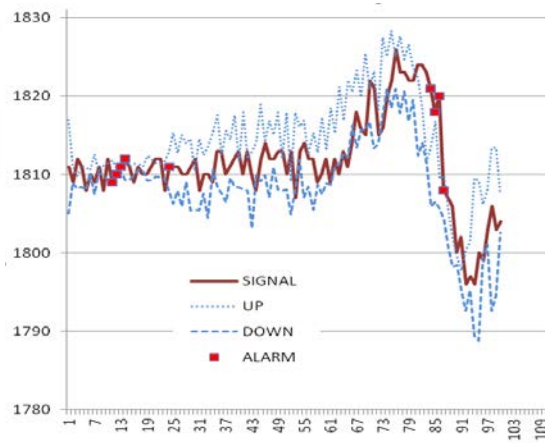
SIMULATION RESULTS (1/2)

- Markov Modelling phase
  - According to empirical values it is possible to assume that all nodes will stay most of the time in the Raw Trigger phase, i.e. the most energy saving modes for the detecting node



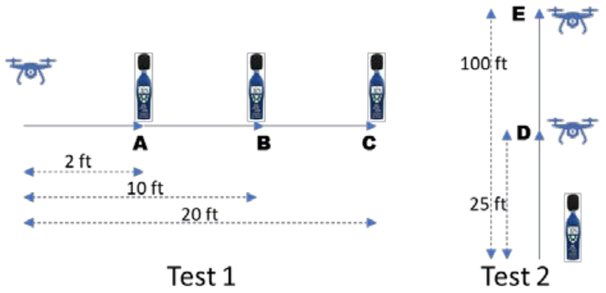
- LEVEL I detection
  - According to MATLAB simulation of this phase
    - Trigger counter method
      - Most suitable to detect a particular audio profile (fixed parameters)
      - Generates more false alarm
      - Has a low computational need
    - Trigger follower method
      - Has a higher adaptability to detect audio anomalies
      - Uses a larger amount of computational energy
      - Generates a lower amount of false alarm
      - Random contributes in calculation of velocities produce non-deterministic alarms



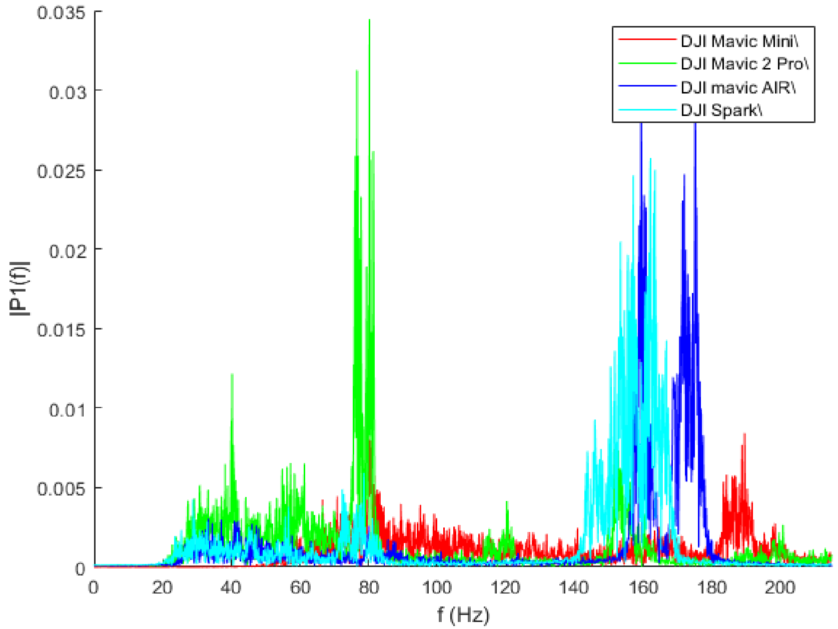


SIMULATION RESULTS (2/2)

- LEVEL II recognition



  - Tested five recording points for each drone
  - It is possible to discriminate drones with their energy content in the [20Hz, 200Hz] window.
  - This value matches typical rpm values and input voltage of brushless motors used in commercial drones.
  - It could also be possible to build a 'library' of detectable drones matching those values with expected audio fundamentals



Fundamental Signature

CONCLUSION

- Symmetric warfare defence for Electronic Warfare (mechanical wave case)
  - Defense method dual to the attack one: small, cheap and capable to cooperate
- A multi level algorithm can keep low the amount of energy used in battery powered nodes (for long time surveillance) and use most sophisticated techniques only when necessary
- Suitable for several HW targets from small embedded sensors to more advanced ones

- Low frequencies can lead the characterization of different drones
- Literature on commercial drones can be used to build up a raw library of expected fundamental signature according to a specific type of drone

- Smart sensor networks can be used as a enabling technology for audio localization

QUESTIONS